U.S. Department
of Transportation

Federal Highway
Administration

Publication No. FHWA-RD-89-013
May 1990

Present Practices of Highway Transportation of Hazardous Materials

Research, Development, and Technology
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FOREWORD

This report presents the results of a research study undertaken to review present practices for safe transportation of hazardous materials on public highways. The report contains a review of the responsibilities and current practices of Federal, State, and local agencies related to highway transportation of hazardous materials and a review of current guidelines for selecting preferred hazardous materials transportation routes.

The study included extensive analyses of existing accident and incident data bases to develop new knowledge for use by highway agencies in safe management of hazardous materials transportation. In particular, default values for truck accident rate and probability of release given an accident have been developed for use in routing studies. Highway agencies are encouraged to develop default values applicable to their local area using the procedures outlined in the report.

This report is being distributed to each Region, Division, and State highway agency.

R. J. Betsold
Director, Office of Safety and Traffic
Operations Research and Development

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD-89-013	2. Government Accession No.	3. Recipient's Catalog No. PB91-124016
4. Title and Subtitle PRESENT PRACTICES OF HIGHWAY TRANSPORTATION OF HAZARDOUS MATERIALS		5. Report Date May 1990
		6. Performing Organization Code
7. Author(s) D. W. Harwood and E. R. Russell		8. Performing Organization Report No. 8669-S
9. Performing Organization Name and Address Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110		10. Work Unit No. (TRAIS) 3A4E2012
		11. Contract or Grant No. DTFH61-86-C-00039
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296		13. Type of Report and Period Covered Final Report August 1986-November 1989
		14. Sponsoring Agency Code
15. Supplementary Notes FHWA Contract Manager: J. G. Viner, HSR-30		

16. Abstract

This report summarizes the state of the art of safe management of hazardous materials transportation by highway. The report includes a review of literature related to hazardous materials transportation safety; a review of the responsibilities and current practices of Federal, State, and local agencies; a critique of current sources of accident, incident, and exposure data; an analysis of existing accident, incident, and exposure data bases; a review of current methodologies for establishing safe routes for hazardous materials transportation; recommendations for improving the current FHWA routing guidelines; and recommendations for future research related to highway transportation of hazardous materials.

17. Key Words Hazardous Materials Transportation Truck Safety Risk Assessment Routing Guidelines	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	263	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

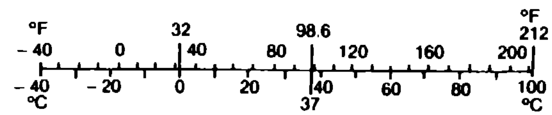
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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LIST OF ABBREVIATIONS

The text of this report uses a number of abbreviations for agencies, legislation, and government programs. While each abbreviation is defined where it is first used, the following table is provided for the convenience of readers.

AASHTO	American Association of State Highway and Transportation Officials
ABAG	Association of Bay Area Governments
BMCS	FHWA Bureau of Motor Carrier Safety (now OMC)
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
CHEMTREC	Chemical Transportation Emergency Center
CHP	California Highway Patrol
CTS	Commodity Transportation Survey
DOD	United States Department of Defense
DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
FARS	NHTSA Fatal Accident Reporting System
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration (part of USDOT)
FRA	Federal Railroad Administration (part of USDOT)
HMIR	RSPA Hazardous Materials Incident Reporting System
HMTA	Hazardous Materials Transportation Act (1974)
ICC	Interstate Commerce Commission
IDOT	Illinois Department of Transportation
MCSAP	Motor Carrier Safety Assistance Program
MTB	RSPA Materials Transportation Bureau (now OHMT)
NASS	NHTSA National Accident Sampling System
NHTSA	National Highway Traffic Safety Administration (part of USDOT)
NOACA	Northeast Ohio Areawide Coordinating Agency
NRC	Nuclear Regulatory Commission
NTSB	National Transportation Safety Board
OHMT	RSPA Office of Hazardous Materials Transportation
OMC	FHWA Office of Motor Carriers
OTA	Office of Technology Assessment (part of the U.S. Congress)
OTO	FHWA Office of Traffic Operations
RCRA	Resource Conservation and Recovery Act
RSPA	Research and Special Programs Administration (part of USDOT)
SARA	Superfund Amendments and Reauthorization Act (1986)
SHMED	State Hazardous Materials Enforcement Development Program
STAA	Surface Transportation Assistance Act (1982)
STCC	Standard Transportation Commodity Code
TIUS	Truck Inventory and Use Survey
TRB	Transportation Research Board
USDOT	United States Department of Transportation

I. INTRODUCTION

This report reviews the state of the art and presents the results of analyses of a broad range of issues related to highway transportation of hazardous materials. The objectives and scope of this research and the organization of this report are described below.

A. Research Overview

The objectives of this research study were:

1. To analyze existing exposure, accident, incident, and risk data pertaining to highway transportation of hazardous materials.

2. To synthesize present knowledge and practices related to highway safety, design, traffic operation, and incident management relating to hazardous materials (hazmat) shipments.

3. To identify research needed to develop potential new countermeasures and improvements in existing techniques and procedures with regard to hazardous materials problems which, at the national level, are the responsibility of the Federal Highway Administration (FHWA).

The study was limited to those aspects of hazardous materials transportation which are related to the responsibilities of FHWA, State, and/or local highway agencies.

Several major technical tasks were performed during the research including:

- A review of published and unpublished literature relevant to highway transportation of hazardous materials.
- An analysis of existing data bases containing accident, incident, and exposure data related to highway transportation of hazardous materials. The data bases that have been analyzed include the DOT Research and Special Programs Administration (RSPA) Hazardous Materials Incident Reporting System; the FHWA Office of Motor Carriers (OMC) Accident Reports; the Missouri Statewide Traffic Accident Reporting System; and the 1982 Truck Inventory and Use Survey (TIUS).
- A review of the current practices of State and local agencies related to highway transportation of hazardous materials.
- A review of the Federal responsibilities related to highway transportation of hazardous materials.

- A review of existing risk assessment methods for establishment of hazardous materials shipment routes and the development of recommendations for improving those methods.

- The development of improved truck accident data for use in risk assessment from data for the State highway systems in California, Illinois, and Michigan.

A review panel made up of representatives from highway agencies at the Federal, State, and local levels and representatives of the hazardous materials trucking industry played an important part in the study. The review panel assisted the research team in establishing the direction for the study, suggested topics to be investigated in the study, and assisted in developing and ranking of recommended topics for future research.

B. Scope and Organization of This Report

This report is organized into seven main sections and one appendix, in addition to this Introduction. Each section is briefly discussed below.

Section II provides a review and critique of literature related to highway transportation of hazardous materials.

Section III reviews the responsibilities and current practices of Federal, State, and local agencies related to highway transportation of hazardous materials. This review is based on the literature and visits by the project staff for agencies in six States and three local agencies.

Section IV reviews the available sources of accident, incident, and exposure data related to highway transportation of hazardous materials.

Section V presents the results of analyses of existing accident, incident, and exposure data bases.

Section VI reviews the current state of the art of risk assessment for establishing routes for highway transportation of hazardous materials. This section focuses on a critique and recommended improvements to FHWA routing guidelines.[10]

Section VII presents recommendations for future research related to highway transportation of hazardous materials.

Section VIII presents the conclusions and recommendations of the study.

Appendix A of the report describes the development of default values of truck accident rate and release probabilities for different highway types for use in risk assessment and routing evaluations for highway transportation of hazardous materials.

Appendix B presents two numerical examples of the application of the revised procedures for hazardous materials transportation routing analyses recommended in this report.

II. LITERATURE REVIEW

This section of the report provides a review and critique of the literature related to hazardous materials (hazmat) transportation by highway. The topics covered include highway safety and highway design issues in hazmat transportation.

Another aspect of the state of the art of hazardous materials transportation by highway -- the responsibilities and current practices of Federal, State, and local agencies -- is reviewed in section III of this report.

A. Highway Safety Issues in Hazmat Transportation

Highway safety issues in hazmat transportation are addressed in the following discussion including the magnitude of the hazmat transportation safety problem, the results of research concerning truck safety that are potentially applicable to hazmat transportation, and the analysis methods currently in use for hazmat transportation risk assessment.

1. Magnitude of the Problem

This section of the report reviews existing data on the magnitude of the safety problem associated with highway transportation of hazardous materials. The discussion addresses the quantities and types of hazardous materials transported, the frequency of accidents and incidents involving hazardous materials, and the consequences of those accidents and incidents. Accidents and incidents in hazardous materials transportation need to be carefully distinguished. Traffic accidents are occurrences to vehicles on public highways involving collisions between vehicles, collisions between vehicles and other objects, a vehicle running off the road, or a vehicle overturning in the road. Traffic accidents involving trucks transporting hazardous materials do not necessarily result in a release of those materials. Hazardous materials incidents are occurrences in which a hazardous material being transported is unintentionally released. Hazardous materials incidents result both from traffic accidents and from other causes. Thus, some accidents are not incidents, some incidents are not accidents, and some occurrences are both accidents and incidents.

The discussion focuses primarily on those sources in the literature that can be used to assess the magnitude of the hazardous materials transportation problem at the national level. However, several useful studies have also been conducted at the State level including work in Arizona (references 88, 91, and 92), California (reference 17), New Jersey (references 78 and 109), Virginia (references 13 and 90), and Washington (references 117 and 118).

a. Quantity and type of hazardous materials transported: The total quantity of hazardous materials shipped each year in the United States is uncertain because no complete data on hazmat shipments exist at either the national, State, or local levels. Various estimates have been made based on the incomplete data that are available. The National Transportation Safety

Board (NTSB) stated in 1981 that the U.S. Department of Transportation (USDOT) estimated that:[76]

- At least 4 billion tons (3.6×10^{12} kg) of hazardous materials are shipped each year.
- At least 218 million ton-miles (3.18×10^{11} kg-km) of hazardous materials are shipped every year.
- At least 250,000 shipments of hazardous materials (bulk and nonbulk) are made every day.
- About 10,700 shippers and 11,700 carriers are involved in hazmat transportation.
- At least 400,000 trucks regularly transport hazardous materials.
- Between 5 percent and 15 percent of all trucks on the road at any given time carry hazardous materials

Recent estimates by the Office of Technology Assessment (OTA) provide more detail on the estimate of the quantities of hazardous materials shipped in 1982.[1,85] These data, shown on table 1, estimate that 60 percent of all hazardous materials by weight are transported by highway although, because of the relatively long distances involved in rail, water, and air shipments, the highway mode accounts for only 12 percent of the ton-miles of hazardous materials shipped. The totals estimated by OTA for tons and ton-miles of hazardous materials shipped are substantially lower than the DOT estimates shown above, reflecting the uncertainty in the available data. The most complete available data on the truck fleet involved in hazmat transportation and the types of products they carry are provided by the Truck Inventory and Use Survey (TIUS) conducted at 5-year intervals by the Bureau of the Census. The most recent TIUS for which data are available was conducted in 1982.[14] Table 2 presents a breakdown of the 1982 TIUS data developed in the OTS study.[1,85]

Table 1. Estimated transportation of hazardous materials by mode in 1982.[1,85]

Mode	Number of vehicles or vessels used for hazmat transportation	Tons of cargo transported	Ton-miles (millions)
Truck	337,000 dry freight or flatbed 130,000 cargo tanks	927,000,000 (59.8%)	93,600 (11.9%)
Rail	115,600 tank cars	73,000,000 (4.7%)	53,000 (6.7%)[a]
Waterborne	4,909 tanker barges	549,000,000 (35.4%)	636,500 (81.2%)
Air	3,772 commercial planes	285,000 (0.01%)	459 (0.06%)
	Total	1,549,285,000	783,559

[a] Based on 1983 data.

Table 2. Summary of truck fleet carrying hazardous materials.[1,85]

Category	Number of trucks (thousands)	Truck-miles (millions)
Total hazmat truck fleet	466.6	16,236
Percent of miles truck was involved in carrying hazardous materials:		
Below 25%	243.8	10,282
25%-49%	117.0	2,971
50%-74%	20.5	776
75%-100%	80.3	2,191
Not reported	5.0	15
Body type:		
Van	140.8	7,016
Tank (liquid)	130.3	4,317
All other (28 categories)	195.5	4,903
Principal product:		
Mixed cargos	113.5	5,716
Petroleum	136.6	3,491
Chemicals	60.3	2,069
All other (24 categories)	156.2	4,960
Gross weight (lb):		
10,000 or less (2 categories)	122.5	1,818
19,501-33,000 (2 categories)	90.8	1,578
40,001-50,000	36.1	1,479
50,001-60,000	34.4	1,983
60,001-80,000	110.9	8,083
All other (8 categories)	71.9	1,295
Range of operation:		
Within 50 miles	269.7	4,888
50-200 miles	90.9	4,075
Over 200 miles	73.1	6,749
Off-road	32.3	525
Not reported	0.6	
Operator class:		
Business use	275.8	6,200
Motor carrier	153.3	8,391
Owner/operator	21.1	1,423
All other (5 categories)	16.4	222

b. <u>Frequency of incidents involving hazardous materials</u>: Figure 1 illustrates the frequency of hazardous materials incidents by transportation mode for the period 1976-1984, as determined by OTA, from the Research and Special Programs Administration (RSPA) Hazardous Materials Incident Reporting system (HMIR).[1,85]

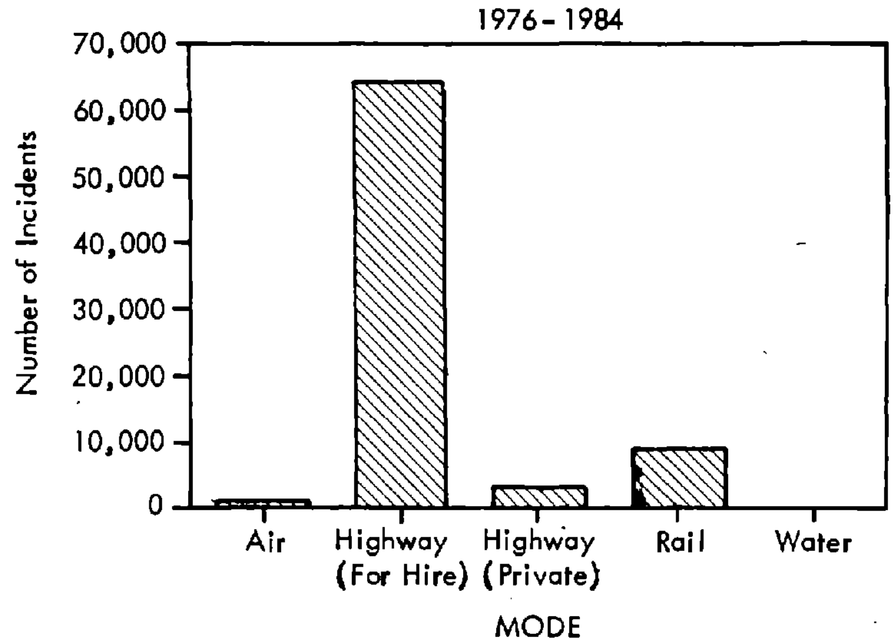


Figure 1. Frequency of hazmat incidents by transportation mode, 1976-1984.[1]

This data base includes incidents in which a hazardous material was unintentionally released while being transported, while being loaded or unloaded, or while in temporary storage incidental to these operations. The figure shows that the vast majority of reported hazmat incidents involve highway transportation, as opposed to the air, rail, and water modes. The highway incidents include both releases due to traffic accidents and releases due to other causes such as valve or container leaks. The RSPA data make a distinction between highway incidents involving "for hire" trucks where the shipper and the carrier are separate entities, and incidents involving "private" carriers, where the truck is owned by the shipper of the cargo. "For hire" trucks travel substantially more miles per year than "private" trucks and carry a wider variety of cargos.

Figures 2 and 3 show the trends over time in the frequencies of highway incidents involving a hazmat release in the "for hire" and "private" categories, respectively.[1] These data include both incidents that occur on the highway and incidents that occur in truck terminal or yard areas.

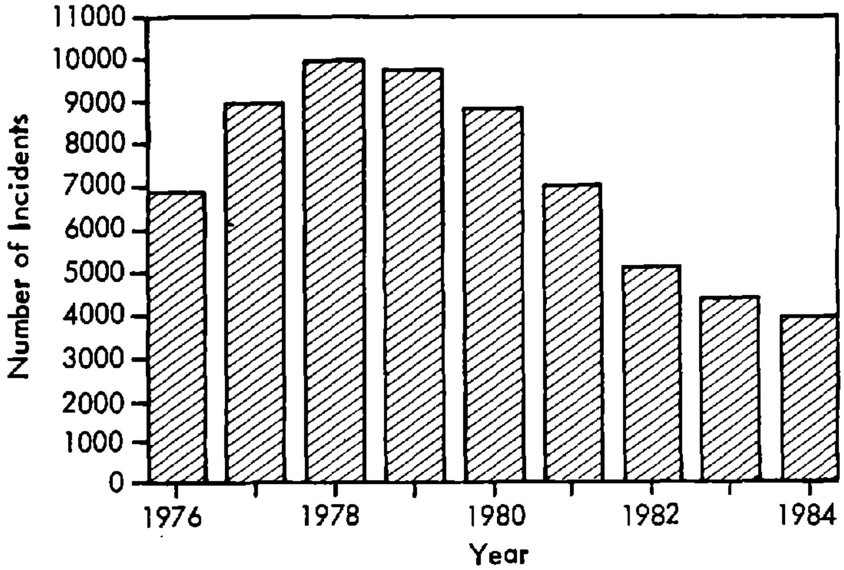


Figure 2. Frequency of hazmat incidents in highway (for-hire) mode by year.[1]

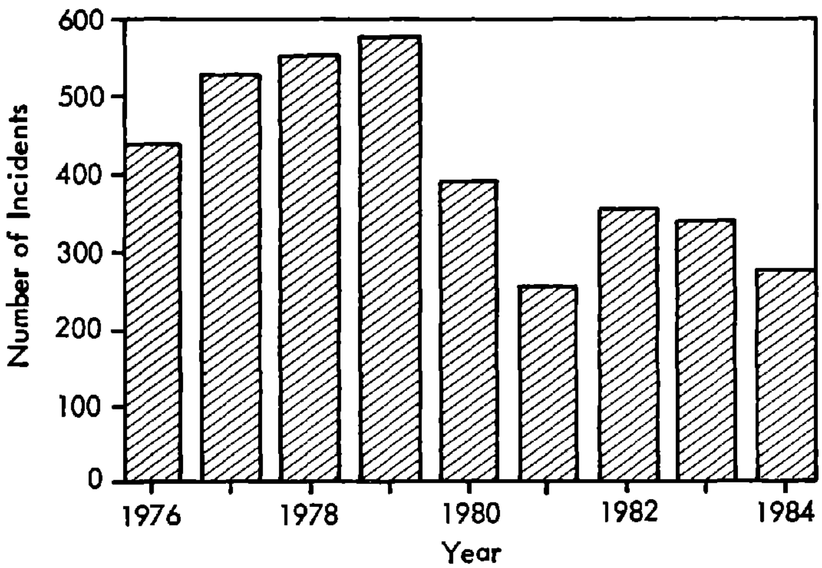


Figure 3. Frequency of hazmat incidents in highway (private) mode by year.[1]

The reported frequencies of highway-related hazmat incidents reached a peak about 1978 or 1979 and have declined since. This decline in reported incident frequency could be the result of a decrease over time in truck accident rates or in the quantities of hazardous materials shipped. However, it should also be noted that there was a change in the hazmat incident reporting requirements in 1981, so that small-quantity spills of electric battery acid and paint no longer need to be reported.

Previous analyses of the RSPA HMIR data, including the OTA study, have been broad in scope, covering all modes of transportation. Section V of this report focuses solely on the highway mode and solely on incidents that occur during actual transportation on the highway. Incidents occurring during loading or unloading in yard or terminal areas have been exluced from the analyses in section V because they are not relevant to highway routing issues.

2. Truck Safety

Virtually all highway shipments of hazardous materials are carried by truck, and there are more than 400,000 trucks that regularly transport hazardous materials.[76] Thus, the safety of hazmat transportation by highway is a larage-scale truck safety management problem.

Two fundamental objectives in safety management of hazmat trucking are: (1) to minimize the risk of personal injury and property damage due to traffic accidents; and (2) to minimize the risk of personal injury and property damage due to other causes (e.g., valve and container leaks). The management of the risk of traffic accidents is similar for hazmat trucking and for trucking in general, because the same types of trucks are used for transporting both hazardous and nonhazardous cargos. However, the consequences of accidents involving trucks transporting hazardous materials are potentially much greater than for other types of trucks. In addition, the management of risks due to causes other than traffic accidents is of unique interest in hazmat transportation, since such incidents can also have severe consequences.

Key truck safety issues in hazmat transportation that confront both highway agencies and carriers include what truck configurations and what highway routes should be used for particular hazmat shipments and for hazmat transportation in general. However, reliable data for making such determinations are rare. There has been virtually no research into the safety characteristics (accident rates, accident severities, accident types, etc.) of trucks involved directly in hazmat transportation.

There is a substantial body of research dealing with truck safety in general, that is potentially applicable to hazmat trucking. However, the available reseach results must be interpreted very cautiously, because of limitations on the type of data available for truck safety research. A review of the effects of data limitations on truck safety research is a useful first step, because these same types of data limitations will constrain the analyses performed in the present study. This review is presented in the following section followed by a summary of relevant research findings concerning truck safety.

a. Structural problems in truck safety research: The investigations of most critical truck safety questions require both accident and exposure data. Accident data consist of reports of traffic accidents obtained either from police reports, or from independent follow-up investigations. Each record in an accident data base documents the characteristics of a particular accident or a particular accident-involved vehicle.

Exposure data provide a measure of the opportunities or accidents to occur. Typical exposure measures in truck safety studies are vehicle-miles of truck travel or ton-miles of cargo shipped.

A major weakness in most truck safety research is that exposure data that correspond well to the available accident data are seldom available. Suppose, for example, that one obtained police-reported accident data for truck accidents on all highways in a particular State broken down by highway type, truck type (single-unit trucks/single-trailer combination trucks/double-trailer combination trucks/etc.), and cargo area configuration (van/flatbed/tanker/etc.). In order to determine accident rates by these variables, one would need exposure data broken down by the same factors. There are no existing truck exposure data of this type in any State, and data of this type would be very hard to collect in any reasonable fashion over an entire State, given the likely variations of truck flows within cells of these variables due to such factors as: location on highway system, direction of travel, season of year, day/night, etc.

Because of the cost and difficulty of collecting corresponding exposure data, researchers usually find it necessary to make exposure estimates from data sources that are independent of, and not intended for use with, the available accident data. This correspondence between the independent data sets is often poor and limits the accuracy of the results.

Another structural problem in truck safety research is the inability to consider the effects of all relevant independent variables. Table 3, adapted from a recent FHWA study, provides a partial list of the broad range of factors thought to influence truck safety.[67] As a practical matter, no study can hope to account for the effects of more than a few of these variables. The available studies in the literature must be judged not just on whether they consider the effects of the variables of primary interest in the study, but whether they adequately control for the potential effects of other factors that could potentially confound the study result. No study is perfect in this respect, but some are much better than others. The following review of the truck safety literature relies on the studies assessed as best controlling or accounting for the effects of multiple related factors.

b. Findings of truck safety research: This section of the report summarizes the findings of truck safety research as background to the current study of safety in trucking of hazardous materials. By way of introduction, it is useful to examine the long-term trends in truck accident rates. Figure 4 illustrates these trends, as recently estimated by the Transportation Research Board (TRB) based on data reported to the National Safety Council.[112]

Table 3. Factors considered to affect truck accidents.

TRUCK TYPE OR CONFIGURATION	HIGHWAY
Number of trailers	Function
Number of axles on tractor/trailer(s)	Access control
Cab type	Number of lanes
Cargo area configuration	Lane width
	Shoulder width
TRUCK SIZE AND WEIGHT	Shoulder surface
Width of trailer	Median width
Length, overall	Horizontal alignment
Length, trailer(s)	Vertical alignment
Empty/loaded	Surface condition (wet/dry/etc.)
Weight, gross	Pavement condition
Weight, trailer	Pavement type
TRUCK OPERATIONS	TRAFFIC
Cargo type	Volume (ADT)
Operator type	Volume (day/night)
Trip type	Percent trucks
TRUCK DRIVER	ENVIRONMENT
Age	Visibility
Experience with rig	Weather
Hours of service	Light
Driver condition	
	TEMPORAL
LOCATION	Month/season of year
State	Day of week
Urban/rural	Time of day

The data show that trucking has generally become safer over the years, with accident involvement rates for both intercity common (for hire) carriers and private carriers decreasing steadily since the 1950s. More recent trends in both the fatal and overall truck accident involvement rates are illustrated in figure 5. It is interesting to note that truck accident rates have decreased substantially over the period 1979-1982, just as hazmat incident frequencies decreased over that period. (However, truck accident rates have begun to rise again from 1983 through 1987.)

Trucks generally have lower total accident involvement rates than passenger cars, but higher fatal accident involvement rates. Figure 6 illustrates the results of a TRB analysis of the ratio of combination truck (tractor-trailer) accident involvement rate to all-vehicle accident involvement rates based on National Highway Traffic Safety Administration (NHTSA) data for the period 1975-1983.[112] Total accident rates for combination trucks are generally about half of all-vehicle accident rates. However, fatal accident rates for combination trucks are generally 1.4 to 1.6 times those for all vehicles, and this ratio has been increasing in recent years.

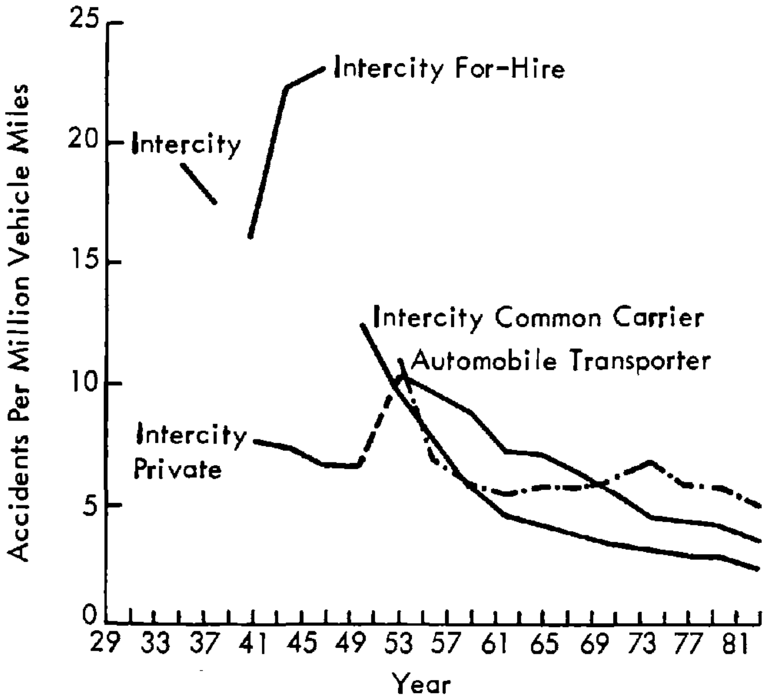


Figure 4. Long-term trends in truck accident rates.[112]

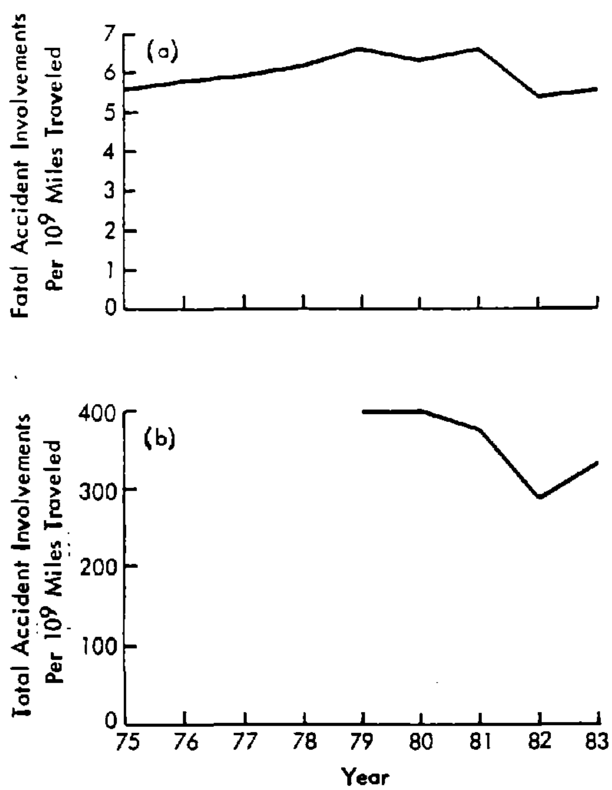


Figure 5. Recent trends in total and fatal truck accident involvement rates.[112]

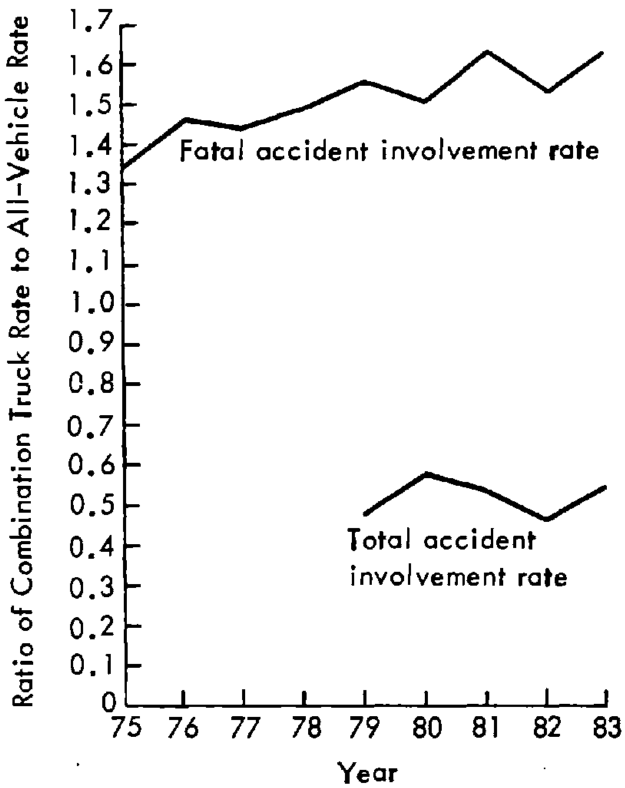


Figure 6. Ratio of combination truck accident involvement rate to all-vehicle accident involvement rate for total accidents and fatal accidents.[112]

A 1981 NHTSA analysis suggests similar conclusions to those indicated by Figure 6.[71] Comparisons among overall accident rates of all large trucks (over 10,000 lb or 4,500 kg gross weight), combination trucks, single-unit trucks, and passenger cars are presented in table 4. These estimates were developed by NHTSA from accident data for seven States, accident data from the National Accident Sampling System (NASS), and available exposure data. Table 5 presents analogous data for fatal accidents, based on data from the Fatal Accident Reporting System (FARS). The data in tables 4 and 5 imply that large trucks have lower total accident involvement rates than passenger cars, but higher fatal accident involvement rates. Single-unit trucks have consistently lower accident involvement rates than combination trucks, at all severity levels. However, the data suggest that fatal accident rates for combination trucks are approximately 2.5 times higher than for passenger cars, a greater difference than found by most previous investigations.

Table 4. Accident and accident-involved vehicle rates by type of vehicle.[28,71]

Vehicle type	1977 number of registered vehicles[a]	1977 travel[a] (10^6 veh-mi)	Veh-mi of travel per vehicle	1978 estimate[b] of all accidents	All accidents per 10^6 veh-mi	1978 estimate[b] of all accident-involved vehicles	Accident-involved vehicles per 10^6 veh-mi	Accident-involved vehicles per 1,000 registered vehicles
Total large trucks	5,370,500	95,805	17,839	432,000	4.51	454,000	4.74	85
Combination trucks	922,800	46,489	50,378	276,000	5.94	281,000	6.04	305
Single-unit trucks	4,447,700	49,316	11,088	173,000	3.51	173,000	3.51	39
Passenger cars	120,985,820[c]	1,120,900[c]	9,265	5,793,000[d]	5.17	9,247,000[d]	8.25	76

[a] Data from FHWA Cost Allocation Study (1982).
[b] The estimation methodology is documented by Najjar.[71] Estimates are rounded to the nearest thousand.
[c] 1979-1980 annual average data from FHWA, Highway Statistics Division.
[d] 1979-1980 annual average data from National Accident Sampling System (NASS).

Table 5. Fatal accident and accident-involved vehicle rates by type of vehicle.[28,71]

Vehicle type	1977 travel[a] (10^6 veh-mi)	1978 FARS fatal accidents[b]	Fatal accidents per 10^8 veh-mi	1978 FARS fatal accident-involved vehicles[b]	Fatal accident-involved vehicles per 10^8 veh-mi
Total large trucks	95,805	5,066	5.3	5,393	5.6
Combination trucks	46,489	4,005	8.6	4,239	9.1
Single-unit trucks	49,316	1,126	2.3	1,154	2.3
Passenger cars	1,141,800[c]	32,028	2.8	40,750	3.6

[a] Data from FHWA Cost Allocation Study (1982).
[b] Excludes single-unit trucks with unknown gross vehicle weight.
[c] 1978 data from FHWA, Highway Statistics Division.

The severity distribution of large truck accidents, in contrast to traffic accidents as a whole, is illustrated in table 6 for a 2-year period (1979-1980).[28] The table shows that large truck accidents are more likely to involve fatalities, but less likely to involve injuries, than traffic accidents as a whole.

Table 6. Percent distribution of accidents by severity.[28] (1979-1980 annual average)

Accident severity	All traffic accidents	All large-truck accidents	All nonlarge-truck accidents
Fatal[a]	0.7	1.4	0.6
Injury[b]	33.3	25.7	33.7
Property damage only[b]	60.5	68.9	60.0
Unknown[b]	5.7	3.7	5.8

[a] Fatal Accident Reporting System (FARS).
[b] National Accident Sampling System (NASS).

There are countless driver, vehicle, and roadway factors that influence truck accident rates. Out of this multitude of factors, there are three primary vehicle and roadway factors whose effects on truck accident rates are important for effective management of hazmat transportation by highway. These are:

- Highway type.
- Truck configuration.
- Cargo area configuration.

Definitions of these factors and research findings concerning their effect on truck safety are discussed below. The remaining factors, while not directly relevant to hazmat transportation safety, must be considered to the extent that their effects are related to or confounded with the three critical factors.

(1) Highway type: The type of highway on which vehicles operate is known to have a strong effect on accident rates for all vehicle types including trucks. Four factors related to the geometric design of the highway and its surrounding environment are generally used to define highway type. These are:

- Type of development (urban/rural).
- Access control (freeway/nonfreeway).
- Number of lanes.
- Presence or absence of median (divided/undivided).

The effect of highway type on truck accident rates is a critical factor in comparing the risk of hazmat releases due to traffic accidents between alternative routes. It would be desirable to know typical truck accident rates, preferably broken down by truck type and cargo area configuration, for the following highway types at a minimum:

- Rural freeway.
- Rural multilane nonfreeway.
- Rural two-lane highway.
- Urban freeway.
- Urban arterial street.

Unfortunately, there are very few studies that have examined truck accident rates at this level of detail.

A recent California Department of Transportation (Caltrans) study examined truck accident involvement rates by highway type and truck configuration.[43] The results of this study are presented in table 7. The primary purpose of the study was to determine the effect of truck configuration on accident rates, with particular attention given to single-unit trucks, single-trailer combination trucks, and double-trailer combination trucks. This comparison was made for four specific highway types: rural freeways, rural nonfreeways (including both two-lane and four-lane sections), urban freeways, and urban nonfreeways. The study results indicate that accident rates, both for trucks and for other types of vehicles, are generally lower on freeways than on nonfreeways and are generally higher on urban highways than on rural highways. The accident rates for urban nonfreeways appear particularly high in table 7, but this finding is based on a single site and, thus, should be considered less reliable than the other study findings. It should be noted that this study was based on a limited number of sites that are not necessarily statistically representative of all California highways, much less the Nation as a whole, and the study had no control for the effects of cargo area configuration, which probably varies more widely in California than any other State. The results of this study are considered further in the next section of the report which addresses the effect of truck configuration.

Table 7. Truck accident involvement rates by highway type and truck configuration.[43] (selected California sites, 1979-1983)

	Rural freeway	Rural nonfreeway	Urban freeway	Urban nonfreeway
Number of sites	9	3	5	1
Cumulative length (mi)	316.77	214.49	170.57	14.19
Exposure (10^6 veh-mi)				
All vehicles	11,190	2,929	38,038	442
All trucks	2,959	493	2,460	48
Single-unit trucks	641	130	1,359	29
Single-trailer combination trucks	1,806	204	845	16
Double-trailer combination trucks	512	159	256	3
Total Accident Rate (per 10^6 veh-mi)				
All vehicles	1.02	1.68	1.36	8.96
All trucks	0.90	1.49	1.48	1.64
Single-unit trucks	0.56	0.68	1.01	1.04
Single-trailer combination trucks	0.94	1.91	2.18	2.03
Double-trailer combination trucks	1.18	1.63	1.63	5.33
Fatal Accident Rate (per 10^6 veh-mi)				
All vehicles	0.03	0.07	0.01	0.07
All trucks	0.03	0.08	0.01	0.06
Single-unit trucks	0.01	0.01	0.01	0.04
Single-trailer combination trucks	0.03	0.14	0.02	0.06
Double-trailer combination trucks	0.04	0.06	0.04	0.03
Fatal Plus Injury Accident Rate (per 10^6 veh-mi)				
All vehicles	0.46	0.83	0.56	3.36
All trucks	0.40	0.57	0.46	0.78
Single-unit trucks	0.23	0.27	0.34	0.38
Single-trailer combination trucks	0.42	0.76	0.64	1.14
Double-trailer combination trucks	0.49	0.57	0.48	2.67

A 1987 study determined fatal accident involvement rates by highway type for combination trucks using nationwide accident data from a University of Michigan data base compiled from Fatal Accident Reporting System (FARS) and FHWA Office of Motor Carriers (OMC) data and nationwide exposure data compiled by FHWA.[18] The results of this study, presented in table 8, are quite consistent with the Caltrans results for fatal accidents presented in table 7.

Table 8. Fatal accident involvement rates of combination trucks by highway type.[18]
(Nationwide data, 1980-1982)

Highway type	Number of fatal accident involvements	Travel by combination trucks (10^6 veh-mi)	Fatal accident involvement rate (per 10^6 veh-mi)
Urban Interstate	917	25,551	0.036
Urban noninterstate	1,979	27,164	0.073
Rural Interstate	1,750	60,554	0.029
Rural noninterstate	5,678	66,078	0.086
Unknown	276	-	
All	10,600	179,347	0.059

Previous investigators performing hazmat transportation risk assessments have been frustrated by the lack of definitive information on truck accident rates by highway type. Most investigators have recommended the use of actual accident data for the highway routes in question, whenever possible.[10,64] This recommendation is sound if the analysis segments are long enough to ensure that the sample sizes of accidents used are sufficient to provide an accurate measure of the traffic safety differences between the routing alternatives in question. Section VI of this report presents a procedure based on a test of the Chi-squared statistic to determine whether the site-specific accident experience for a particular highway segment is sufficiently different from the expected accident experience to warrant use of the site-specific accident data.

Because of the lack of truck accident data for hazmat risk assessments, a study for the Environmental Protection Agency (EPA) developed average truck accident involvement rates for three highway types: freeways; rural nonfreeways; and urban arterials.[2,3] These rates, illustrated in table 9, were based on data for 194 5-mile highway segments in California, Texas, and New Jersey. These segments were located adjacent to truck volume counting locations and were not necessarily representative of the highway system as a whole in those States. However, the results in table 9 do provide a reasonable illustration of the differences in truck safety between highway types. Section VI and appendix A of this report present improved truck accident data for use as default values in hazmat routing analyses. These improved data are based on accident data and estimated truck volumes of the entire State highway systems in California, Illinois, and Michigan.

Table 9. Estimated truck accident rates.[2,3]
(Selected sites in California, Texas, and New Jersey)

Highway type	Truck accident rate (accidents per 10^6 veh-mi)
Interstate (freeway)	0.65
U.S. and State highways (rural nonfreeways)	2.26
Interrupted flow due to intersections (urban arterials)	3.65

The available findings concerning the effect of highway type on truck safety have important implications for hazmat transportation. First, freeways should be generally preferred to nonfreeways as hazmat transportation routes. Not only do freeways have lower accident rates than nonfreeways, but they are also usually located farther from residential and other development than nonfreeways and provide a more manageable location to contain and clean up any spills that do occur. Possible exception may be elevated freeways, depressed freeways, bridges, and tunnels. Second, urban highways typically have higher truck accident rates than rural highways, with urban arterial streets having the highest truck accident travel rates of any highway type. However, it must be recognized that if additional distance is required to use freeway routes or avoid urban areas, the exposure to accidents (vehicle-miles of travel) is increased. Thus, there is a tradeoff between accident rate and distance traveled that needs to be considered formally to select a minimum risk route whenever the route with the lowest accident rate is not the shortest route.

(2) Truck configuration: The effect of truck configuration on safety is also a concern in the management of hazmat transportation safety. Research results concerning truck configuration should be of interest to carriers in the selection of the type of trucks to be used for particular types of shipments. Truck configuration is not generally considered in hazmat routing studies, because it is assumed that the same types of trucks would be used on all of the routing alternatives considered and previous research is not sufficient to provide valid estimates of how differences in accident involvement rates of truck types vary between highway types.

There are three truck configurations of primary interest in hazmat transportation. These are:

- Single-unit trucks.

- Single-trailer combination trucks.

- Double-trailer combination trucks.

Single-unit trucks are smaller than combination trucks and have a cargo compartment mounted on a rigid frame that is integral with the truck cab. Single-unit trucks are used primarily for local pickup and delivery operations and for short-haul intercity trucking. Combination trucks have separate tractor and trailer units joined together with a trailer hitch. By far the vast majority of intercity trucking -- for both hazardous and nonhazardous cargos -- is performed with single-trailer combination trucks, consisting of a tractor pulling a single semitrailer. Double-trailer combinations, consisting of a tractor pulling a semitrailer followed by a full trailer, have long been used in the western States and are now becoming common nationally with the enactment of the 1982 Surface Transportation Assistance Act (STAA).

Previous research generally indicates that single-unit trucks have substantially lower accident involvement rates than combination trucking, perhaps by as much as 50 percent. This conclusion is supported by both the NHTSA findings presented in tables 4 and 5 and the Caltrans findings in table 7.[43,71] This finding does not necessarily indicate that single-unit trucks are preferable for hazmat shipments, however. Single-unit trucks are smaller than combination trucks and carry less cargo, so more trips are required to carry the same cargo. If a combination truck can carry twice as much cargo as a single-unit truck, then the expected number of accidents for the combination trucks will be the same even if their accident rate is twice as high as the single-unit trucks.

Substantial research attention has recently focused on the safety differences between single- and double-trailer combinations, because of interest in the effects of the 1982 STAA, which authorized the use of doubles on routes designated by the Secretary of Transportation, even in States (primarily in the East) where doubles were previously prohibited. The Transportation Research Board (TRB) performed a study mandated by Congress to assess the safety differences between twin-trailer trucks, consisting of two 28-ft (8.5 m) trailers, in comparison to existing (non-STAA) 45-ft (13.7 m) semitrailers.[112]

The TRB study reviewed a broad range of previous studies that addressed the safety effects of the tractor-semitrailer and twin-trailer configurations and identified three studies whose results were considered most credible. These studies were those in references 22, 40, and 43. These studies estimated that the accident involvement rates for twins were, respectively, 2 percent less, 6 percent more, and 12 percent more than the rates for tractor-semitrailers.[22,40,43] Furthermore, the use of twins was estimated to result in a 9 percent reduction in the vehicle-miles required to transport a given tonnage of cargo. Thus, even if the accident rate for twins were slightly higher than the accident rate for tractor-semitrailers, the reduced vehicle-miles of travel would result in no net increase in accident frequencies from the use of twins.

These three studies were selected by the TRB study panel as most credible because they incorporated the best experimental controls to isolate the effect of truck type and reduce the potential influence of extraneous variables. The studies in references 22 and 40 were limited to the evaluation of van semitrailers and van twins, so the effect of differences in cargo area configurations was excluded.

The first of these three studies combined data from the FHWA Motor Carrier Accident data base for 1977 with exposure data from the 1977 Truck Inventory and Use Survey; reasonable similarity among the roadway types, temporal distribution of operations, commodity types and densities, and carrier operating practices was achieved by limiting comparisons to intercity operations of van trailers by ICC-authorized carriers.[22]

The second study used a unique approach to match accident and exposure data for tractor-semitrailers and twin trailers.[40] This study, conducted by a major nationwide trucking firm, assembled accident data for trips between pairs of terminals for which the company used both tractor-semitrailers and twin trailers. Thus, the accident data set for both kinds of trucks applied to trips on the same days, over identical routes, under identical conditions. This approach provides a nearly perfect match between the accident and exposure data, and indicates a key advantage of private carrier data bases over government data bases in performing truck accident studies for vehicle-related issues.

The third of these studies, by Caltrans, the results of which are summarized in table 7, achieved good experimental control by using only selected road segments on which a reasonably good match between accident and exposure data could be made in most cases.[43] This limitation was an attempt to circumvent the problem of uncertainty in statewide travel estimates made in an earlier study of California data.[122] The estimate quoted above of a 12 percent higher accident involvement rate for twins, as compared to tractor-semitrailers, is based on the reanalysis in the TRB study of the Caltrans data summarized in table 7; this reanalysis gave equal weight to each site so that the sites with the largest percentage of twin trailer and tractor-semitrailer exposure would not dominate the analysis results. One remaining concern about the Caltrans study is that it made no distinction between the various cargo area configurations (vans/flatbeds/tankers/etc.) of tractor-semitrailers and twin trailers, which vary widely in California and include truck configurations that are not found in other States.

Although these studies reviewed above are among the best in their experimental design and control of extraneous factors, there remain a substantial number of factors that influence truck safety that were not (and probably could not have been) addressed. For example, none of the studies considered driver factors. In addition, research suggests that empty trucks may have slightly higher accident rates than loaded trucks, primarily because of poor braking performance. Nearly all of the truck studies that have been applied to hazmat transportation include accident data for empty trucks, which may make them less than completely appropriate for analysis of hazmat transportation in loaded trucks. Numerous additional examples of uncontrolled extraneous variables could be cited.

The differences in accident rates between single-trailer and double-trailer combination trucks, at least for trucks with van semi-trailers, are not sufficiently large to warrant a major distinction between them. However, the distribution of accident types for single-trailer and double-trailer combination trucks are quite distinct, as shown in a recent analysis of FHWA data for ICC-authorized carriers, presented in table 10.[18] Double-trailer combination trucks tend to have a greater proportion of overturning accidents than single-trailer combination trucks, while single-trailer trucks tend to have a greater proportion of collision accidents. This finding suggests that single-trailer combination trucks may be preferred for hazmat shipments since overturning accidents are much more likely to result in a hazmat release than are collision accidents as demonstrated in section V of this report.

Table 10. Distribution of accident types for single- and double-trailer combination trucks.[18]
(FHWA data for ICC-authorized carriers, 1984)

	Truck configuration			
	Single-trailer combination truck		Double-trailer combination truck	
Accident type	Number of accidents	Percent of accidents	Number of accidents	Percent of accidents
NONCOLLISION ACCIDENTS				
Ran off road	1,616	6.4	117	8.5
Jackknife	1,749	6.9	138	10.1
Overturn	1,942	7.7	262	19.1
Separation of units	130	0.5	16	1.2
Fire	172	0.7	5	0.4
Cargo loss or spillage	132	0.5	2	0.1
Cargo shift	97	0.4	2	0.1
Other noncollision	47	0.2	1	0.1
COLLISION ACCIDENTS	19,346	76.7	827	60.4
Total	25,231	100.0	1,370	100.0

(3) Cargo area configuration: Trucks vary in the configuration of the trailer or container where the cargo is placed. Common cargo area configurations include enclosed vans, flatbeds or platforms, and tanks. The cargo area configuration of the truck used for a particular shipment is largely controlled by the type of cargo being transported. However, cargo area configuration is of interest in the assessment of hazmat transportation safety, because hazmat transportation typically involves a different mix of cargo area configurations than trucking in general -- more tanks and fewer vans, for example.

The results of a 1971 study, which are presented in table 11, illustrate the effect of cargo area configuration on relative truck accident involvement rates (expressed as the ratio of percent of accident involvement to percent of miles traveled).[104] This study found particularly high accident involvement rates for dump trucks and transit mix (concrete) trucks. However, the types of trucks normally used in intercity trucking -- vans, refrigerators, and tankers -- had relatively similar rates. This study had good experimental control for the effects of highway type since it was based on toll road data. However, the authors cautioned that the available exposure data were limited and their estimates might not be reliable. In addition, the authors recognized that the differences among the cargo area configurations could reflect differing operational practices not accounted for in the study.

A more recent study that included consideration of the effects of cargo area configuration was based on accident data for 1977 drawn from the FHWA Motor Carrier Accident data base and exposure data from the 1977 Truck Inventory and Use Survey (TIUS) conducted by the U.S. Bureau of the Census.[21] The study was limited to trucks operated by ICC-authorized carriers not carrying farm products. The results of the study are presented in table 12. It should be noted that the reported accident rates vary greatly, and not always in consistent patterns. Several of the results in the table are specifically noted as being less reliable, because they are based on limited numbers of accident involvements. However, if one examines the data for the types of trucks most commonly used in intercity trucking -- single-trailer combinations with three-axle tractors in over-the-road operation -- the differences in accident involvement rates among vans, flatbeds, and tankers are not large.

The conclusion that vans, flatbeds, and tankers have relatively similar overall accident rates does not imply that these configurations do not have different safety characteristics that need to be considered in management of hazmat transportation. It only means that the safety differences between these configurations tend to balance out over their entire operating environment. Each truck configuration may experience safety problems associated with particular highway geometric features. Safety problems of this type are addressed in the next section of this report.

B. Highway Design Issues in Hazmat Transportation

This section provides a review of literature related to highway design issues in hazmat transportation. Two types of highway design issues are reviewed: geometric design features associated with truck accidents and protective systems that can be designed into highways to mitigate the consequences of hazmat releases. Thus, the geometric design issues reviewed here address both highway design issues related to causal factors in hazmat releases and highway design issues related to mitigation of the consequences of hazmat releases.

Table 11. Relative involvement ratios for trucks by cargo area configuration.[104]

Cargo area configuration	Relative involvement ratio: % accidents/ % vehicles	% accidents/ % miles
Van	0.84	0.70
Refrigeration truck	1.20	0.99
Dump truck	1.60	2.20
Tank truck	0.77	0.83
Transit mix truck	1.20	3.30

Table 12. Comparison of truck accident involvement rates.[21]

Model year	No. of tractor axles	Accident involvement rate (per 10^6 veh-mi): Single-unit truck	Single-trailer truck: Van	Flatbed	Tanker	Double-trailer truck: Van	Flatbed	Tanker
Over-the-road trucking								
New	2	0.53	0.73	0.45	0.37	1.58	2.94*	1.34
	3	0.17	0.95	1.09	1.03	0.27	1.27*	0.56*
*								
Old	2	0.48	0.66	0.64	0.79	1.14	-	1.84
	3	0.16	1.05	1.69	0.97	0.28	3.48	0.41*
Local trucking								
New	2	1.81	2.00	0.99*	0.42**	1.76*	-	-
	3	0.38	5.73	1.08	2.58	-	-	-
Old	2	2.05	1.70	0.51	0.97*	0.73	-	1.16*
*								
	3	0.37	2.01	0.84	1.42	0.53*	0.80	-

* Less than 15 accident involvements.
** Less than 5 accident involvements.

1. Geometric Design Features Associated With Truck Accidents

A general overview of truck safety issues relevant to hazmat transportation was provided earlier in this report. The following discussion examines specific highway design features associated with truck accident, including:

- Horizontal curves.
- Grades.
- Crest vertical curves.
- Passing zones.
- Railroad grade crossings.
- Interchange ramps.
- Shoulders.

These geometric design elements are highlighted because they may merit special consideration in hazmat routing studies.

Horizontal curves, both on highway sections and on ramps, are common sites for large truck accidents. An NHTSA analysis of 1979 Fatal Accident Reporting System (FARS) data, for accidents involving combination trucks in which the truck driver was killed, found that 45 percent of the single-vehicle accidents occurred on curved sections of roadway as compared to only 16 percent of the multiple-vehicle accidents.[11] Thus, single-vehicle accidents involving trucks are a particular problem on horizontal curves. Roadside design improvements to reduce the consequences of running off the road are important in reducing the consequences of such accidents.

Large trucks tend to have special safety problems on grades. On upgrades, they often travel slowly and are subject to being rear ended by overtaking vehicles. On downgrades, large trucks are susceptible to runaway accidents or overtaking and rear ending of slower vehicles. A 1971 study analyzed truck accidents on grades of the Ohio and Pennsylvania turnpikes and found large trucks overinvolved as the struck vehicle in multiple-vehicle accidents on upgrades.[104] Passenger cars were overinvolved as the struck vehicle on downgrades. To alleviate safety problems of these types, highway agencies typically provide truck climbing lanes on upgrades and runaway truck escape ramps on downgrades.

The differences in highway sight distance requirements for passenger cars and trucks were examined in a 1979 study.[42] With respect to stopping sight distance at crest vertical curves, the author concluded that the increased eye height of truck drivers compensates for inferior truck braking for the average of all truck sizes, but not necessarily for larger and heavier trucks having particularly long braking distances. In addition, increased eye height provides no compensating advantage to truck drivers at horizontal sight restrictions. At sag vertical curves, sight distance is determined by headlight range, and it was found that the truck driver has no unusual visibility disadvantage. Trucks generally require 50 percent more distance to pass other vehicles than do nontrucks. The author concluded that this increased passing distance was not adequately compensated for by the truck drivers' 17 percent to 27 percent passing sight distance advantage and found that passing zones adequate for passenger cars may be inadequate for trucks.

A 1981 study by the National Transportation Safety Board (NTSB) highlighted railroad grade crossings as a particular concern.[77] From 1975 through 1979, there was an annual average of 62 train accidents in the United States involving trucks transporting bulk hazardous materials; these accidents resulted in an annual average of 7 fatalities, 41 injuries, and $1.6 million in property damage. There may also be as many as 750 near-collisions per year of trains with trucks transporting bulk hazardous materials. NTSB found a particular problem at rail-highway grade crossings without active warning devices, especially those near bulk hazardous materials storage, depot, or terminal facilities.

Large trucks appear to experience particular problems at interchange ramps. An NHTSA evaluation of FARS data found that off-ramps at freeway interchanges have the highest ratio (5:100) of overturned trucks to all other trucks involved in fatal accidents.[74] A recent study evaluated truck accident patterns on ramps and found five specific geometric design and traffic control problems that produced truck accident patterns at specific locations.[31] These were:

- Side friction factors generated by ramp curves that were excessive given the roll stability limits of many trucks.
- Truckers assuming that the ramp advisory speed does not apply to all curves on the ramp.
- Deceleration lane lengths that were deficient for trucks, resulting in excessive speeds at the entrance of sharply curved ramps.
- Lightly loaded truck tires that were sensitive to pavement texture in avoiding hydroplaning on high-speed ramps.
- Curbs placed on the outer side of curved ramps pose a peculiar obstacle that may trip and overturn articulated truck combinations.

Each of these situations could potentially lead to a truck accident involving a hazmat release. Particular concern is addressed to truck rollover thresholds, illustrated for several types of loaded trucks in figure 7. The thresholds are expressed as lateral accelerations (g's) required to initiate a rollover; a larger value implies a truck configuration that is less likely to roll over. Design policies for horizontal curves are generally based on avoiding lateral acceleration levels that produce discomfort for automobile drivers; however, many turning maneuvers that are reasonably comfortable for automobile

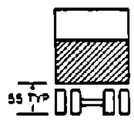
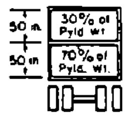
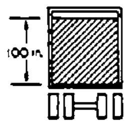
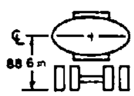
CASE	CONFIGURATION		WEIGHT (lbs) GVW	PAYLOAD CG HEIGHT (in)	ROLLOVER THRESHOLD (G's)
A.		Full Gross, Medium-Density Freight (34 lb/ft³)	80,000	83.5	.34
B.		"Typical" LTL Freight Load	73,000	95.0	.28
C.		Full Gross, Full Cube, Homogeneous Freight (18.7 lb/ft³)	80,000	105.0	.24
D.		Full Gross Gasoline Tanker	80,000	88.6	.32
E.		Cryogenic Tanker (He_2 and H_2)	80,000	100.	.26

Figure 7. Loading data and resulting rollover thresholds for typical tractor-semitrailer trucks at full load.[31]

drivers could produce lateral accelerations that exceed the rollover thresholds indicated in figure 7. The rollover thresholds of trucks may be increased through vehicle redesign. For example, a recent study in Michigan has suggested the redesign of gasoline tankers to produce a truck with both a larger capacity and a lower center of gravity for greater stability.[29] Greater stability also results from increasing the track width (i.e., axle length). The data on rollover thresholds presented in figure 7 are for trucks with a cargo area width of 96 in (2.4 m). As a result of the 1982 STAA, 102-in (2.6 m) cargo area widths are becoming more common. Another study by the same author as reference 29 has found that the increase in width from 96 to 102 in (2.4 to 2.6 m) results in a 15 percent to 18 percent increase in rollover threshold if both the tractor and trailer are widened and the spacing between the springs of the truck suspension is increased.[30]

Finally, an analysis of the FHWA Motor Carrier Accident data base found a truck accident pattern associated with stopping on shoulders.[32] The study considered all accidents of regulated interstate carriers reported to FHWA between 1967 and 1975. A vehicle stopped on the shoulder of the highway was involved in 3 percent of the accidents studied; of the vehicles stopped on shoulders, 43 percent were trucks, a proportion undoubtedly greater than the proportion of trucks in the traffic stream. Rear-end collisions constituted 90 percent of the on-sholder accidents and these collisions resulted in more than an average number of fatalities and injuries per accident. On-shoulder accidents occurring during darkness constituted 62 percent of accidents, and in 53 percent of the accidents the primary cause was identified as drivers dozing at the wheel.

2. Protective Systems to Mitigate Consequences of Hazmat Releases

Another aspect of highway design that enters into the management of hazmat transportation is the incorporation of protective systems in highway designs to mitigate the consequences of hazmat releases. There is virtually no published literature related to protective systems, but this concept is being studied in a current FHWA research contract entitled "Guidelines for Protective Systems for Spills of Hazardous Materials on Highway Systems."[100]

This study is intended to develop guidelines for physical designs to mitigate catastrophic consequences of hazardous materials spills on the roadway and roadside. A catastrophic event is considered to be any hazmat accident or incident that may have life-threatening consequences for motorists or the adjacent population, or cause long-term environmental damage.

The simplest response in areas where a hazmat release could have catastrophic consequences is to prevent hazmat-carrying vehicles from using that particular highway section and reroute them elsewhere. However, this may not always be practical or feasible. Protective systems should be considered in such places.

The research approach being used is to develop generalized scenarios of catastrophic incidents that could potentially occur and then to determine what protective systems could mitigate the consequences of those incidents. Table 13 presents a list of 11 scenarios that have received detailed evaluation, ranked by their catastrophic potential.

Potential protective systems to mitigate these scenarios were identified and evaluated by a project advisory panel of State highway agency personnel from 27 States plus other experts in the field. Six hazardous materials were considered in the evaluation of these scenarios: chlorine, propane, anhydrous ammonia, gasoline, nitric acid, and phosphorous compound. Chlorine was perceived to have the greatest catastrophic potential of any of these materials, while no distinction in catastrophic potential was found between the other five.

The potential for catastrophic consequences for various types of highway facilities was evaluated by the panel. Table 14 presents the rankings of the catastrophic potential of hazmat releases for the facility types ranked as having the greatest potential risks. The table shows that the greatest catastrophic potential was identified for elevated highway facilities where material released can go down to the development below. Slightly less concern was expressed for depressed highway facilities with overpasses or air-rights structures above. Still less catastrophic potential was identified for materials that are transported laterally (e.g., fires or gases that endanger

Table 13. Generalized scenarios being used to evaluate protective systems for hazmat releases.[100]

Rank	General scenario description
1	Poisonous, toxic, flammable, or explosive material endangers large numbers of trapped motorists, e.g., between interchanges, in cut sections, or in traffic jams downwind of poisonous or toxic gas release.
2	Chemical spills of poisonous or explosive materials that could enter underground transit stations or tunnels through sidewalk vents, etc. (Includes entry of lighter-than-air toxic or poisonous gases into adjacent or overhead transit stations.)
3	Hazardous materials accidents causing release of toxic, flammable, or explosive materials in tunnels.
4	Gasoline, LNG, propane (flammables, explosive gases), etc., accidents, and releases on elevated facilities, including ramps thereto, with people at risk below or in adjacent buildings.
5	Release of poisonous toxic or explosive gases in populated areas in general and/or in locations and situations where special populations and/or institutions, such as schools, hospitals, hotels, nursing homes, apartment complexes, etc., are at risk.
6	Releases from accidents between hazardous materials containers on highways and passenger trains or trains carrying hazardous cargo either at rail-highway crossings at grade or in situations with shared rights-of-way, such as freeways with transit in the median.
7	Explosive materials on facilities in populated areas and particularly in situations and areas where catastrophic consequences could occur to highway structures or apartments--adjacent or on air rights. Includes situation with adjacent petrochemical plant that could result in conflagration.
8	Sufficient quantities of poisonous materials such as herbicides or dangerous biological/agents (or any material causing long-term or permanent damage) being released into a potable water supply, particularly reservoirs and susceptible aquifers and/or watersheds.
9	Rural, hilly, or mountainous areas with cities or towns at bottom of long or steep grades where brake failure of hazardous materials carriers could cause catastrophic consequences to the populated area.
10	Spills of nuclear wastes or other nuclear materials, particularly in populated areas, areas affecting water supply, or areas particularly difficult to respond to and/or clean up.
11	Carriers of toxic flammable or explosive materials leaking material during transit in heavily populated or congested areas.

Table 14. Ranking of catastrophic potential of generalized highway facility types.[100]

Rank	Approx. score	General highway facility
1	5.6+	Elevated facilities with development below
2	5.5	Depressed facilities with development over
3	5.0 to 5.4	Any facility adjacent to vulnerable population in order of: a. nursing home or hospital b. schools c. apartments d. shopping centers e. hotel f. factory g. hazmat storage facilities
4	4.0	Drainage into sewage system

Note: Scores on a scale from 1 (least catastrophic potential) to 7 (highest catastrophic potential).

high-rise apartments, schools, hospitals, etc., adjacent to the roadway). The least catastrophic potential was foreseen for materials escaping into a sewer system.

A separate round of evaluations was made for environmental concerns, as opposed to the immediate effects of a release. A direct spill into a potable water supply was rated as having the highest catastrophic potential of any environmental factor.

The project advisory panel generated 98 specific ideas for protective systems relevant to the 11 scenarios in table 13. These ideas for protective systems were evaluated to determine which were the most feasible, implementable, and practical. Table 15 identifies and classifies the most promising protective systems. Only two types of protective systems with the capability to prevent catastrophic consequences were identified; these are vehicle containment and/or control systems. All of the other protective systems are those with the potential to mitigate, but not prevent, the consequences of hazmat releases. Some of the most promising protective systems are discussed below.

An important aspect of highway design to mitigate the consequences of hazmat releases can be provided by operational flexibility that allows emergency response personnel and equipment to reach an accident site quickly and that allows traffic to be rerouted away from a spill. Examples of designs with operational flexibility of this type are traversable medians, median crossovers at regular intervals, and wide shoulders.

Table 15. Potentially effective physical protective systems for hazmat releases on highways.[100]

Category	System
	Mitigating Systems
A. Detection and warning	Built-in PA systems Emergency call boxes Gas detectors/alarms Monitoring for quick response Communication and detection systems
B. Systems to facilitate escape and response	Crossovers Transversable medians Median openings Highway exit/entrance redesign for emergency response vehicles Emergency exits with heavy doors (tunnels) Arrows pointing to nearest exit (tunnels)
C. Systems to mitigate fire/ explosion consequences	Foam blanketing systems Large sprinkler systems Effective vent systems Availability of hydrants
D. Systems to mitigate spills consequences	Pea-style vents to trap gases Effective vent systems (closed area) Robust drainage with holding reservoirs Avoid use of open rails on structures Large sumps Grease trap sedimentation basins Floating surface barriers Drainage gutters directed toward collection points Retention basins that automatically close Clay blankets or barrier members
E. Specialized situations	Fresh air vents at elevated levels (subways) Coamings over street-level intake vents (subways) Air intakes away from roads (tunnels, subways) Massive barriers with energy absorbing materials (runaway trucks)
	Preventive Systems
A. Containment	High performance barrier systems
B. Control	Truck escape ramps Upgrade truck runoffs Wide shoulders

On high-volume freeways with frequent hazmat shipments, permanently installed response capabilities, such as fixed-site foam blanketing systems, could be considered.

To mitigate the consequences of poisonous or explosive materials entering underground transit stations or tunnels, some of the measures mentioned below could be effective:

- Vents designed in free-trap style so that the release gases get trapped in the first section.

- Vents equipped with electronically controlled sealed doors that could be closed in case of a spill.

- Built-in automatic foam generators and sensors.

- Coverings over street-level intake vents with drainage away from vents.

For overhead stations, a possible protective system would be the ability to crash-stop ventilation and provide positive internal air pressure to prevent intrusion of toxic gases.

An emergency arising out of an accident inside a tunnel involving a vehicle carrying hazardous materials may be handled in the following ways:

- By providing sprinkler and vent systems.

- By installing foam systems at periodic intervals.

- By convoying hazmat-carrying vehicles, while closing the tunnel to general traffic, if possible.

Accidents of hazmat vehicles on elevated facilities, on ramps, or in mountainous areas can be quite catastrophic to people living below or in adjacent buildings. Such accidents must be prevented as far as possible. Practical approaches to mitigating the consequences of such accidents could include the following steps:

- Where justified by a high risk, longitudinal traffic barriers or guardrails capable of restraining an 80,000-lb (36,000 kg) tank truck or tractor-trailer impacting at 15 degrees and 50 mi/h (80 km/h) can be provided.[48] The use of such barriers may be justified by the risk of catastrophic consequences, regardless of low risk of accident occurrence. On bridges that span a potable water supply source, this type of barrier may be essential to keep the truck and its cargo on the structure, and prevent the hazardous material from entering the water.

- Design drainage systems on bridges to prevent hazardous materials from reaching the water supply.

- Shoulders should be wide enough and roadside slopes flat enough to allow effective emergency response in case of truck overturns and rollovers so that spills may be contained.

- Runaway or escape ramps are desirable in vulnerable mountainous areas. These are constructed of materials such as deep, loose gravel which allow trucks to be brought to a controlled stop.

For handling potentially catastrophic incidents arising out of release of toxic or explosive gases in populated areas, it would be desirable to locate the roadway and/or adjacent development so that the prevailing winds maximize dispersion of hazardous, gaseous releases away from adjacent populations.

Protection of water supply sources from accidental hazmat spills can be carried out in several ways, as described below. Storm-water drainage from bridges and roadways should not be allowed to flow directly into the body of water; instead, drainage can be directed to a retention basin. Retention basins are required only if rain occurs at the time of the incident, or if the drainage system discharges into the water supply source. Contaminations should be separated from water before it leaves this basin. Retention basins can separate only those compounds that are insoluble in water. Two types of basins can be constructed according to projected need. They are:

- A submerged wall basin.

- A basin connected to the separator in series.

Retention basins are not effective when the hazardous material is soluble in water. In such a case, some sort of chemical treatment is required prior to release of the contaminated water flow into the environment. Another effective way to protect water supply sources from contamination is to install drainage systems with holding reservoirs that can be isolated from regular storm drains should a hazmat spill occur.

Very few of these protective systems for hazmat spills have been implemented because of their high cost. Perhaps the only protective system in the United States intended specifically to protect public water supplies from hazmat spills is found on a 300-ft (90 m) bridge constructed by the North Carolina Department of Transportation.[80] The bridge was constructed as a cored-slab, flat-deck concrete structure without weep holes so that runoff from the bridge cannot flow directly into the river below. Instead, the runoff is piped to two retention basins whose outflow is controlled by sluice gates that can be closed manually in the event of a hazmat spill. The use of storage tanks to contain runoff from a 6-mi (10 km) section of new highway adjacent to a water supply reservoir was considered by the Rhode Island Department of Transportation, but the project was not built because of the high cost of protecting the reservoir ($20 to $30 million).[119]

A comprehensive final report on protective systems and a manual intended for use by highway agencies is expected to be completed by September 1989.

III. RESPONSIBILITIES AND CURRENT PRACTICES OF FEDERAL, STATE, AND LOCAL AGENCIES

One major aspect of the state-of-the-art review performed in this study was a review of the responsibilities and current practices of Federal, State, and local agencies related to highway transportation of hazardous materials. The results of this review are presented in this section of the report. For the convenience of readers, a list of the many abbreviations used in this section is found at the beginning of this volume.

A. Overview of Responsibilities and Current Practices

This section of the report focuses on the review of the responsibilities and current practices of Federal, State, and local agencies related to highway transportation of hazardous materials. The report emphasizes the role of highway agencies at all three levels of government in meeting these responsibilities, but the roles of other agencies are included in the review as well. There are two reasons for including other types of agencies in addition to highway agencies. First, many responsibilities that are assigned to highway agencies in some States are met by nonhighway agencies in other States. Second, highway agencies must work cooperatively with other agencies in many areas where the primary responsibility falls outside the highway agency. In short, the presentation of how Federal, State, and local governments meet their hazardous materials transportation safety responsibilities would be incomplete without considering all types of agencies.

The review is based primarily on published literature and on visits to agencies in six States and three local communities made as part of the study. The States visited were California, Illinois, New Jersey, Virginia, Wisconsin, and Washington. The project staff met with the State highway agencies and other State agencies with hazmat transportation safety responsibilities. The States selected for participation in this study are among the leaders in the hazmat transportation safety field, and the information they provided should be regarded as the state-of-the-art practices. However, it should be recognized that not all States are so far advanced, and many need major improvements in the way they address hazmat transportation safety issues. It is hoped that this material on current practices will provide an example for all States to illustrate how these responsibilities can be met.

The local agencies visited were Contra Costa County, California; Henrico County, Virginia; and Dane County, Wisconsin. These visits, and discussion with officials at the State level, provided a general overview of local agency responsibilities and practices in several States. However, it should be recognized that the variety in the agency size, responsibilities, and expertise is much greater for local agencies than for State agencies. Thus, these limited contacts with local agencies have only scratched the surface of documenting how hazardous materials transportation responsibilities are being met at the local level.

The review of Federal responsibilities related to highway transportation of hazardous materials included visits with officials of two agencies of the U.S. Department of Transportation -- the Research and Special Programs Administration and the Federal Highway Administration. These two agencies have the primary responsibility at the Federal level for safety issues of hazardous materials transportation by highway. Information concerning the responsibilities of other Federal agencies was obtained from published literature and through the Federal, State, and local agency contacts made during the study.

Finally, the study was fortunate to have access to the results of three State questionnaire surveys in the preparation of this report. These were:

- An American Association of State Highway and Transportation Officials (AASHTO) survey of State practices for control and cleanup of hazardous materials spills.[5]

- An AASHTO survey of State routing and signing practices related to highway transportation of hazardous materials.[6]

- A survey of State hazardous materials programs conducted by the Virginia Transportation Research Council for the TRB Committee on Planning and Administration of Transportation Safety Programs.[12]

Each of these surveys solicited responses from all 50 States and received responses from at least 40 States.

Section III-B describes the general responsibilities of Federal, State, and local agencies related to highway transportation of hazardous materials. This section identifies the types of agencies involved in hazardous materials transportation and discusses the responsibilities and functions of each.

Section III-C reviews the current practices of Federal, State, and local agencies in 16 specific areas of responsibility in hazmat transportation safety. The scope of the review includes all of the types of agencies identified in section III-B, but the review focuses on the role of highway agencies.

Section III-D summarizes the conclusions of this review of Federal, State, and local responsibilities and current practices.

B. General Responsibilities of Federal, State, and Local Agencies

1. Federal Agencies

a. U.S. Department of Transportation: The lead Federal agency in hazardous materials transportation in all modes is the U.S. Department of Transportation (USDOT). Specific authority in regulation of hazmat transportation is granted to the Secretary of Transportation by the Hazardous Materials Transportation Act (HMTA) of 1974.

Within the USDOT, the primary responsibility for hazardous materials transportation issues is assigned to the Office of Hazardous Materials Transportation (OHMT) of the Research and Special Programs Administration (RSPA). RSPA has the responsibility to develop, issue, and interpret regulations for all modes of hazmat transportation except bulk marine transportation and exercises enforcement authority for intermodal hazmat shipments.[62] RSPA has an overall coordinating role in hazmat transportation safety that includes coordination with its sister agencies within the USDOT and other Federal, State, and local agencies. In particular, RSPA investigations can preempt State or local regulations found to be inconsistent with Federal regulations. RSPA also sponsors research and encourages training programs to improve the ability of State and local agencies to respond to hazmat transportation emergencies and operates the Hazardous Materials Incident Reporting system, to which hazmat releases in interstate commerce must be reported.

The individual modal administrations within the USDOT exercise enforcement authority within the mode of transportation over which they have jurisdiction. In the highway mode, this authority is exercised by the Federal Highway Administration (FHWA). The FHWA Office of Motor Carriers (OMC) develops, issues, and interprets the Federal motor carrier safety regulations which apply to all trucks operating in interstate commerce, including trucks carrying hazardous materials. OMC also performs inspection and enforcement functions related to hazardous materials transportation by highway and the manufacture and use of containers used in bulk transportation of hazardous materials by highway.[62] OMC inspections may be conducted in the field or at carrier terminals. OMC also operates the Federal motor carrier accident reporting system to which serious accidents involving regulated interstate motor carriers must be reported. A Hazardous Materials Division has recently been formed within OMC to coordinate FHWA activities related to hazmat transportation.

The FHWA Office of Traffic Operations has the responsibility to develop uniform highway signs for use in identifying preferred and prohibited routes for hazardous materials shipments.

The FHWA Office of Research, Development, and Technology performs research related to the safety of hazardous materials shipments by highway, including the present study.

b. Federal Emergency Management Agency: The Federal Emergency Management Agency (FEMA) is responsible for coordinating Federal response to emergencies and disasters of all types, including hazmat transportation incidents. FEMA provides support and guidance planning to State and local agencies for dealing with hazardous materials emergencies and is active in developing and sponsoring training programs for emergency responders.

c. U.S. Environmental Protection Agency: The U.S. Environmental Protection Agency (EPA) is responsible for mitigating the consequences of any hazardous materials spill affecting land, water, or air. EPA requires reports of hazmat spills on the highway and tracks these spills to ensure that they are properly cleaned up. EPA has responsibility for providing technical information on environmental and health risks to emergency responders and to State and local governments. EPA has regulatory responsibility under the Resource Conservation and Recovery Act (RCRA) in the area of hazardous waste to ensure that waste is transported safely and is ultimately treated or disposed of properly. However, EPA transportation regulations by law must be consistent with USDOT regulations. Under the 1986 Superfund Amendments and Reauthorization Act (SARA) Title III, EPA has required each State to establish an Emergency Response Commission to coordinate response to hazardous materials emergencies, and some new funds for emergency response training are available under SARA.

d. Nuclear Regulatory Commission: The Nuclear Regulatory Commission (NRC) has responsibility to promote safety in handling and transporting radioactive materials. This authority is derived from the Atomic Energy Act of 1954. The NRC is responsible for the development of safety standards for packaging of higher level radioactive materials and the development of shipment security requirements. Through a memorandum of understanding between the USDOT and the NRC, each agency has agreed to adopt and enforce the regulations developed by the other.[62]

e. U.S. Department of Energy: The U.S. Department of Energy (DOE) is a frequent shipper of radioactive materials and radioactive waste. DOE complies with applicable USDOT and NRC regulations. As a Federal agency, DOE is not subject to State and local regulations, but DOE does attempt to comply with such regulations. DOE has no regulatory authority over the transportation of radioactive materials by others.

f. U.S. Department of Defense: The U.S. Department of Defense (DOD) is a frequent shipper of radioactive and other hazardous materials related to military programs. DOD complies with applicable USDOT and NRC regulations. As a Federal agency, DOD is not subject to State and local regulations, but DOD does attempt to comply with such regulations. DOD has no regulatory authority over the transportation of radioactive or other hazardous materials by others.

g. National Transportation Safety Board: The National Transportation Safety Board (NTSB) is responsible for investigating major transportation accidents, including highway accidents involving hazardous materials. NTSB has also performed special studies of Federal and State enforcement efforts in hazardous materials transportation by truck and of railroad/highway grade crossing accidents involving trucks transporting bulk hazardous materials.[76,77]

h. U.S. Department of Commerce: The U.S. Department of Commerce Bureau of the Census conducts its Census of Transportation at 5-year intervals. Included within the Census of Transportation is the Truck Inventory and Use Survey which, for a sample of trucks in each State, provides data on vehicle-miles of travel, the types of materials transported, and the general percentage of truck usage devoted to hazardous materials transportation. This data base is one of the few sources of hazmat exposure data at the national level.

i. U.S. Customs Service: The U.S. Customs Service enforces the Nation's trade and tariff policies and intercepts hazardous materials entering the United States illegally.

j. U.S. Department of Justice: The U.S. Department of Justice prosecutes violations of Federal laws including statutes relating to dumping or cleanup of hazardous materials.

2. State Agencies

This section describes the general responsibilities of State agencies in highway transportation of hazardous materials.

a. State highway agencies: State highway agencies have a key role in hazardous materials transportation because they operate the highway system over which most intercity shipments of hazardous materials move. The hazmat responsibilities of State highway agencies vary widely, but there are some State highway agencies involved in virtually every aspect of hazmat transportation. State highway agencies nearly always have a lead role in the signing of hazmat route preferences or prohibitions, because they have the responsibility for placing signs; however, only a very few States have implemented signed hazmat routes. Other areas of hazmat responsibility in which some State highway agencies have a lead role with their State include general regulation of hazmat transportation; routing of hazmat shipments; regulation and routing of explosives and radioactive shipments; enforcement of hazmat transportation regulations; hazmat accident and incident reporting; incident traffic management; and incident site cleanup.

b. State police agencies: State police agencies have a central role in hazmat transportation safety in most States because they usually have the enforcement responsibility for hazmat transportation regulations and are usually among the key responders to the scene of hazmat incidents. In many States, the senior State police officer present at an incident site is the on-scene commander. In some States, police agencies have broader hazmat transportation responsibilities including the adoption of regulations and the exercise of routing authority.

c. State emergency management agencies: State emergency management agencies have the responsibility for coordinating emergency response to hazmat incidents. This responsibility often includes preparedness for hazmat transportation emergencies; operating a 24-hour toll-free number for reporting of hazmat incidents and other emergencies; coordinating emergency response by other State and local agencies; providing training courses; and acting as a clearinghouse for hazardous materials information. State emergency management agencies seldom have a lead role in hazardous materials transportation issues, but serve as a coordinating agency to ensure that other State and local agencies are working together.

d. State environmental agencies: State environmental agencies have the responsibility to protect the environment by ensuring that any hazardous materials spilled on or along the highway are properly cleaned up. Even if another agency does the cleanup, the State environmental agency ensures that the cleanup is complete. Many State environmental agencies operate a hazmat incident reporting system to ensure that hazmat spills requiring cleanup are identified. In some States, the environmental agency may fulfill the responsibilities of the U.S. Environmental Protection Agency under a Federal-State agreement. This may include the exercise of the U.S. EPA's responsibility for safe transport of hazardous waste. In one State that was visited in the present study, the State hazmat transportation regulations are developed and adopted by the State environmental agency, which also has authority to conduct safety audits at carrier terminals.

e. State health agencies: The State health agency in some States has responsibilities very similar to the responsibilities of State environmental agencies discussed above. In fact, several States have a combined environmental and health agency that exercises these functions. In addition, State health agencies may include a radiation safety office that is responsible for planning and emergency response for highway shipment of radioactive materials.

f. State nuclear safety agencies: Some States have a separate nuclear safety agency that plays a key role in regulation of radioactive shipments. For example, the radioactive materials transportation program of the Illinois Department of Nuclear Safety is nationally recognized in this area.

g. State utilities commissions: In at least one State, the utilities commission plays a key role in establishing and enforcing hazmat transportation regulations. The Washington Utilities and Transportation Commission shares regulatory and enforcement authority with the Washington State Police; the enforcement activities of the commission focus on safety audits at carrier terminals, while the police perform the field enforcement function. Utilities commissions in some States have long had regulatory authority over the trucking industry, and commission involvement in hazmat transportation is an outgrowth of this authority.

h. State bridge, tunnel, and toll road authorities: Many bridges, tunnels, and toll roads are administered by public agencies independent of the State highway agency. These agencies establish hazmat transportation regulations for their facilities. These are usually similar to the regulations adopted by other State agencies. Virginia has recently completed a study of appropriate hazmat transportation regulations for bridges and tunnels.[49,54]

3. Local Agencies

This section describes the general responsibilities of local agencies in highway transportation of hazardous materials.

a. Local highway agencies: Local highway agencies are typically less involved in hazmat transportation than State highway agencies. Many cities and counties are not very active in hazmat transportation and, in those that are active, the responsibility for hazmat transportation usually lies outside the highway agency.

Where cities have established preferred or prohibited routes for hazmat shipments, the local highway agency is usually actively involved in the choice of the routes and the posting of signs. Local highway agencies provide support in other areas including providing traffic control devices, closing streets, and establishing detour routes at hazmat incident sites.

b. Local fire departments: Local fire departments usually have the primary local responsibility for emergency response to hazmat incidents. According to the laws or regulations of many States, the local fire chief is the on-scene commander at an incident site. Local fire departments need both trained personnel and specialized equipment to meet this responsibility.

c. Local police agencies: Local police agencies are often the first on the scene at hazmat incidents on local streets and highways, and police officers remain at the scene for traffic control and crowd control after other responders arrive. Police agencies may also become involved in establishing hazmat route preferences and prohibitions and in initiating reports of hazmat accidents and incidents to State agencies. In most States, local police agencies have the authority to enforce State hazmat transportation regulations, but few local police agencies have either the resources or the expertise to perform this function.

d. Local emergency management agencies: Local emergency management agencies, particularly at the county level, have a key role in coordinating emergency response to hazmat incidents on the highway and in maintaining liaison with interested Federal and State agencies. Local emergency management agencies may also coordinate training of emergency response personnel and cleanup of the hazmat spills.

e. Local health agencies: Local health agencies often have a role in assisting in emergency response and monitoring cleanup of hazmat spills. In some States, city or county health departments may serve as the representative of the State health or environmental agency in such matters.

f. Local planning agencies: Local planning agencies often have an important role in the routing of hazmat shipments. In particular, metropolitan planning organizations such as the North Texas Council of Governments in Dallas-Fort Worth (see references 57, 81, and 82) and the Association of Bay Area Governments in the San Francisco Bay area (see references 8, 9, and 53) have been very active in metropolitan areawide hazmat routing studies.

4. Summary of Responsibilities

This section summarizes the responsibilities of Federal, State, and local agencies in highway transportation of hazardous materials. Two charts are presented.

Figure 8 presents a chart of the responsibilities of a broad range of types of agencies in Federal, State, and local government. Specific agencies at the Federal level are identified in the chart; State and local agencies are described in generic terms, since each State and locality has a different organizational structure. For each of 16 areas of responsibility in hazardous materials transportation safety, the chart identifies agencies with lead roles, support roles, or occasional roles. The 16 areas of responsibility identified in figure 8 include 13 specific hazardous materials issues and three general functions that should be present in any large agency (personnel training, research, and information exchange). The three latter responsibilities are rated in relation to whether these functions are currently being exercised in the hazmat area.

A blank entry in figure 8 indicates that an agency has no direct role in that particular area of responsibility. The role identified for each type of agency is its role within its own level of government -- Federal, State, or local. For example, the primary Federal agency within a particular area of responsibility is defined as having a lead role, even if the overall level of responsibility at the Federal level in that area is small. At the State and local levels, several types of agencies may be indicated as having a lead role in a particular area of responsibility, because organizational practices vary widely between States and localities. In general, any type of State or local agency that has a lead role or shares a lead role in some circumstances is identified in the chart as having a lead role.

Figure 9 is a similar chart that identifies the role of highway agencies at the Federal, State, and local levels in the same 16 areas of responsibility in hazardous materials transportation safety. At the Federal level, the chart presents the overall role of the U.S. Department of Transportation in each area of responsibility. At the State level, the chart presents the role of the State highway agencies in each of the six specific States visited in the present study. A key finding drawn from the chart in figure 9 is that the State highway agency has either a lead or a key support role in <u>every</u> area of responsibility for hazmat transportation in at least <u>some</u> States. On the other hand, local highway agencies tend to be less involved in hazmat transportation with local fire, police, emergency management, and planning agencies having a more dominant role.

The charts presented in figures 8 and 9 illustrate the broad range of agencies that have a role in highway transportation of hazardous materials. Altogether, the charts identify 10 specific Federal agencies, including the USDOT; 8 types of State agencies; and 6 types of local agencies that

AGENCY \ AREAS OF RESPONSIBILITY	General Regulation of Hazmat Transportation	Routing of Hazmat Shipments	Regulation and Routing of Explosive Shipments	Regulation and Routing of Radioactive Shipments	Regulation and Routing of Hazardous Waste Shipments	Signing of Hazmat Routes	Enforcement of Hazmat Transportation Regulations	Hazmat Incident Detection	Emergency Response	Incident Traffic Management	Incident Site Cleanup	Hazmat Incident and Accident Reporting	Monitoring Hazmat Flows	Personnel Training	Research	Information Exchange
FEDERAL AGENCIES																
RSPA Office of Hazardous Materials Transportation	●	●	●	●	●		●		◒			●	◒	◒	●	●
FHWA Office of Motor Carrier Safety	◒	◒					◒					◒				◒
FHWA Office of Traffic Operations						●										◒
FHWA Offices of Research, Development and Technology		◒													◒	◒
Federal Emergency Management Agency								●	●	●				●		●
U.S. Environmental Protection Agency					◒						●	◒		●	◒	◒
Nuclear Regulatory Commission				◒												◒
U.S. Department of Energy				◒											◒	◒
U.S. Department of Defense				◒											◒	◒
National Transportation Safety Board												◒				◒
U.S. Department of Commerce													●			
U.S. Customs Service							◒									◒
U.S. Department of Justice							◒									◒
STATE AGENCIES																
State Highway Agencies	●	●	●	●	◒	●	●	◒	◒	●	●	●	◒	●	◒	◒
State Police Agencies	●	●	●	●	●		●	●	●	●	●			●		◒
State Emergency Management Agencies								●	●				◒	●	◒	◒
State Environmental Agencies	●		●	●	●			●	●		●	●				◒
State Health Agencies				●							●	●				◒
State Nuclear Safety Agencies				●					◒		◒					◒
State Utilities Commissions	◒						◒					●				◒
State Bridge, Tunnel, and Toll Road Agencies	◒	◒	◒	◒	◒	◒		◒	◒	◒	◒	◒				◒
LOCAL AGENCIES																
Local Highway Agencies		●				●		◒	◒	●	◒					◒
Local Fire Departments		◒							●	●	●	◒		●		◒
Local Police Agencies		●					●	●	◒	●		◒				◒
Local Emergency Management Agencies	○		○	○	○			●	●		●	◒		●		◒
Local Health Agencies								●	◒		●					◒
Local Planning Agencies	○	●	○	○	○											◒

● LEAD ROLE ◒ SUPPORT ROLE ○ OCCASIONAL ROLE

Figure 8. Responsibilities of Federal, State, and local agencies in hazardous materials transportation by highway.

AREAS OF RESPONSIBILITY / AGENCY	General Regulation of Hazmat Transportation	Routing of Hazmat Shipments	Regulation and Routing of Explosive Shipments	Regulation and Routing of Radioactive Shipments	Regulation and Routing of Hazardous Waste Shipments	Signing of Hazmat Routes	Enforcement of Hazmat Transportation Regulations	Hazmat Incident Detection	Emergency Response	Incident Traffic Management	Incident Site Cleanup	Hazmat Incident and Accident Reporting	Monitoring Hazmat Flows	Personnel Training	Research	Information Exchange
FEDERAL HIGHWAY AGENCIES																
Federal Highway Administration	◒	◒				●	◒					◒			◒	◒
STATE HIGHWAY AGENCIES																
California	◒	◒	◒	◒	◒	●	○	◒	◒	●	●	◒		◒	◒	◒
Illinois	●		●	◒	◒		●	◒	◒	●		●		●		●
New Jersey	●		●	◒	◒		◒	○		●		◒	●	◒	●	◒
Virginia		○						○		●	◒	◒		◒	●	◒
Washington		●				●		○		●	◒	◒	◒	◒		◒
Wisconsin	●		●	◒	◒		●	○	●	●		◒		◒		◒
LOCAL HIGHWAY AGENCIES		●				●		◒	◒	●	◒					◒

● LEAD ROLE ◒ SUPPORT ROLE ○ OCCASIONAL ROLE

Figure 9. Responsibilities of Federal, State, and local highway agencies in hazardous materials transportation by highway.

that may have a role in hazmat transportation by highway. The charts also illustrate that highway agencies, particularly at the State level, have a key role in highway transportation of hazardous materials.

The next section discusses the current practices of Federal, State, and local agencies in each of the 16 areas of responsibility summarized in figures 8 and 9.

C. Current Practices of Federal, State, and Local Agencies

This section of the report presents the current practices of Federal, State, and local agencies in a variety of aspects of hazmat transportation safety. This section is an overview intended to acquaint readers with the general responsibilities of Federal, State, and local agencies and to distinguish between the responsibilities of highway agencies and other types of agencies involved in hazmat transportation. The issues addressed in this section include:

1. Regulation of hazmat transportation/
2. Routing of hazmat shipments.
3. Regulation and routing of explosive shipments.
4. Regulation and routing of radioactive shipments.
5. Regulation and routing of hazardous waste shipments.
6. Signing of hazmat routes.
7. Enforcement of hazmat transportation regulations.
8. Hazmat incident detection.
9. Emergency response.
10. Incident traffic management.
11. Incident site cleanup.
12. Hazmat incident and accident reporting.
13. Monitoring hazmat flows.
14. Personnel training.
15. Research in hazmat transportation safety.
16. Information exchange.

Each of these issues is discussed below.

1. Regulation of Hazmat Transportation

For purposes of this discussion, the regulation of hazmat transportation refers to the establishment of regulations concerning vehicle condition and operation, labeling, packaging, loading, shipping papers, and driver requirements. Other aspects of hazmat transportation regulation, such as routing regulations and specific requirements for shipments of explosives, radioactive materials, and hazardous waste shipments, are dealt with in subsequent sections.

a. Federal agencies: Regulations for hazmat transportation are established at the Federal level by the U.S. Department of Transportation through the Office of Hazardous Materials Transportation (formerly the Materials Transportation Bureau) of the Research and Special Programs Administration (RSPA). This office promulgates the regulations (49 CFR*) that apply to hazmat transportation in interstate commerce.[24,25] Hazardous materials in intrastate commerce are not regulated at the Federal level except for hazardous substances and hazardous wastes regulated by EPA, which are also regulated under 49 CFR.

Carriers of hazardous materials in interstate commerce are also subject to the Federal motor carrier safety regulations promulgated by the Office of Motor Carriers (OMC) of the Federal Highway Administration (FHWA). The Federal motor carrier safety regulations are applicable to all trucks, not just hazmat carriers, and address safety issues of concern in all types of trucking, independent of cargo type, including safe vehicle condition, safe operation of vehicles, and safe driver performance.

Federal agencies also conduct programs that are intended specifically to assist State agencies in regulating hazmat transportation safety. These programs are described in the following discussion of State agency programs.

b. <u>State agencies</u>: The role of State agencies in regulation of hazmat transportation safety has been increasing dramatically in recent years, both because of increased State awareness of hazmat transportation safety issues and Federal programs to encourage State activity.

From 1981 through 1986, the RSPA Office of Hazardous Material Transportation conducted the State Hazardous Materials Enforcement Development (SHMED) program to encourage State activity in hazmat transportation safety management. SHMED provided a one-time grant to States that agreed to adopt 49 CFR as a State regulation and to establish hazmat inspection and enforcement programs. In all, 25 States participated in the SHMED program.[84]

The SHMED program expired in 1986, and has been effectively replaced by a broader Federal program that addresses motor carrier safety, in general, as well as hazmat transportation safety. This program is the Motor Carrier Safety Assistance Program (MCSAP), and it is administered by the FHWA Office of Motor Carrier Safety. Rather than a one-time grant, the MCSAP program provides ongoing implementation grants to States that agree to participate in the program. Participation in the MCSAP program requires:

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* The Federal hazardous materials transportation regulations are contained in Title 49, Code of Federal Regulations, Parts 100 through 189. These parts of the regulations are usually referred to in the hazmat transportation field by the citation 49 CFR. In fact, Title 49 also contains many other transportation-related regulations, including the Federal motor carrier safety regulations in Parts 390 through 397. However, following conventional practice in the field, Parts 100 through 189 will be referred to here as 49 CFR.

- Agreement to adopt both the Federal Motor Carrier Safety regulations and the highway-related portions of the Federal Hazardous Materials regulations (49 CFR), or comparable rules, as State regulations (see footnote on p. 46).

- Development of an enforcement and safety program plan and designation of a lead agency to administer the plan.

- Agreement to devote adequate resources to administration of the program and the enforcement of the regulations.

- Establishment of statutory authority for regulation of private and for-hire motor carriers and provision for the right of entry into vehicles and terminal facilities to permit compliance inspections.

Over 40 States are participating in the MCSAP program.[84]

State activity in hazmat transportation regulation has substantially increased in the 1980's, both because of increased State interest and the SHMED and MCSAP programs. Many States have adopted 49 CFR as a State regulation for intrastate commerce, as well as interstate commerce, so that the hazmat transportation safety regulations are gradually becoming applicable to all hazmat truck shipments. The establishment of safety regulations for intrastate hazmat shipments is an important goal, because most intrastate shipments have not previously been subject to any safety regulations.

A recent survey conducted by the Virginia Transportation Research Council for the Transportation Research Board (TRB) Committee on Planning and Administration of Transportation Safety found that at least 34 States have adopted 49 CFR as the basis for State regulation of hazmat transportation safety.[12] Each of the six States whose practices were reviewed in depth in this study has adopted 49 CFR as a State regulation. In five of these six States, 49 CFR currently applies to both interstate and intrastate hazmat shipments. In the remaining State, the implementation problems in applying 49 CFR to intrastate hazmat shipments are being studied, and a regulation for intrastate shipments is expected to be adopted in about 1 year.

California requires all companies transporting hazardous materials in the State to be licensed by the California Highway Patrol (CHP). The licensing arrangements apply to a company as a whole and not to individual trucks. The administrative scheme for this licensing process includes provisions for advance telephone arrangements with out-of-state carriers entering the State. In addition, every individual cargo tank used in the State must be inspected and certified by the CHP. At least 26 States require transporters of hazardous materials or hazardous waste to register with the State and pay a fee.[12,84] Fees of this type are one method of financing a State's regulatory, enforcement, or emergency response activities.

The role of State highway agencies in regulation of hazmat transportation safety varies widely. In three of the six States visited as part of the present study (Illinois, New Jersey, and Wisconsin), the State highway agency is the agency responsible for adopting hazmat transportation safety regulations. In Illinois and New Jersey, the State highway agency has an office with specific responsibility for regulation of hazmat transportation safety. In Wisconsin, the State patrol is part of the State highway agency and has been assigned regulatory (as well as enforcement) responsibility for hazmat transportation safety. In California, Virginia, and Washington, regulatory authority for hazardous materials transportation is assigned to another agency (State patrol, utilities and transportation commission, or environmental agency), and the State highway agency has only an advisory or support role.

State agencies that operate specific highway facilities, such as toll road authorities, have also established 49 CFR as the hazmat transportation regulation for highway facilities under their jurisdiction.

c. Local agencies: Local agencies do not generally have a role, other than an advisory one, in the establishment of hazmat transportation safety regulations. Where local agencies have tried to adopt overly restrictive regulations, they have been found by RSPA to be inconsistent with Federal regulations.

2. Routing of Hazmat Shipments

This discussion addresses the Federal, State, and local roles in routing control for hazmat shipments. The discussion applies to routing controls for general hazmat shipments. Specific issues related to routing of radioactive, explosive, and hazardous waste shipments are discussed in subsequent sections.

a. Federal agencies: Under the Hazardous Materials Transportation Act (HMTA) of 1975, the U.S. Department of Transportation has authority to regulate the routing of hazmat shipments. Responsibility for establishment has been assigned within the USDOT to the RSPA Office of Hazardous Materials Transportation. To date, this authority has been exercised only in relation to routing of radioactive shipments. Thus, for most shipments of hazardous materials, there are no routing regulations under 49 CFR. RSPA is currently studying the adoption of routing regulations for nonradioactive hazardous materials.[95] Section 397.9 of the Federal motor carrier safety regulations has a very general limitation on routing of hazardous materials shipments:

> "Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places where crowds are assembled, tunnels, narrow streets or alleys."

Guidance to State and local agencies on the establishment routes for hazmat shipments has been provided through research funded by the FHWA Offices of Research, Development and Technology. In particular, an implementation report entitled "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials" was published by FHWA in 1980.[10]

These guidelines have been reissued in 1989 in a revised form by RSPA.[94] The need for further updates to these guidelines is addressed in section VI of this report.

b. State agencies: State agencies differ in their authority over routing of hazmat shipments and the manner in which they exercise that authority. A recent American Association of State Highway and Transportation Officials (AASHTO) survey of hazardous materials routing and signing practices found that State agencies have routing authority over hazmat shipments in about half of the States (22 out of 46 agencies responding). The remaining States have no authority to regulate the routes used by hazmat shipments. It is important to note that the States that do not currently exercise routing authority are not preempted from doing so by Federal regulations. Rather, these States do not exercise routing authority because their legislatures have not chosen to enact appropriate legislation and designated a State agency to administer that legislation. Of the States that have routing authority, only five do not actually exercise this authority. New or expanded routing authority is currently being sought through legislation in nine States that currently have routing authority and two States that do not.[6]

In three of the States visited in the present study -- Illinois, New Jersey, and Wisconsin -- there is no statutory authority, either within the State highway agency or within any other State agency, to establish route preferences for hazmat shipments or to prohibit hazmat shipments from particular routes. The establishment of hazmat route preferences or route prohibitions in these States would probably require legislation. In addition, there is no general statutory authority for regulation of hazmat routing in Virginia, but the Virginia Department of Transportation does have authority to regulate or prohibit hazmat shipments at bridges and tunnels.

Two of the States that were visited -- Washington and California -- have authority to regulate the routing of hazmat shipments by prohibiting hazardous materials from specific routes. In Washington, this authority is exercised for State highways by the Washington State Department of Transportation which has complete authority to prohibit specific classes of vehicles from any particular State highway. This authority has not generally been exercised, except to prohibit trucks carrying flammable materials from the reversible lanes of the I-5 freeway in Seattle.

In California, the authority to prohibit hazardous materials or hazardous waste shipments from particular routes rests with the CHP. By law, the CHP must consult with the California Department of Transportation (Caltrans) concerning any hazmat prohibition on a State highway.

c. Local agencies: Local authority over hazmat routing varies widely from State to State and from community to community. A number of hazmat routing studies conducted by metropolitan planning organizations (MPOs) have led to the establishment of designated hazmat routes, typically for through shipments rather than local pickups and deliveries. One example of this type of study was conducted by the North Central Texas Council of Governments for the Dallas-Fort Worth metropolitan area.[57,81,82] The implementation of a metropolitan areawide routing plan of this type requires cooperation (and, possibly, legislative action) by all affected municipalities and participation of the State highway agency.

The recent AASHTO routing and signing survey found that local agencies are active in exercising routing control over hazmat shipments in 19 of the 46 States responding. In seven of these States, local agencies exercise routing control over <u>all</u> highways within their municipal limits; in the remaining 12 States, local agencies exercise routing control only for non-State highways. Local agency restrictions on hazmat routing are subject to review by State agencies in 8 of the 19 States where local agencies exercise routing control. However, such activities would be subject to State agency review in several other States where local agencies are not currently active in routing control over hazmat shipments.[6]

Of the States visited in the present study, the broadest authority over hazmat routing prohibitions is held by local agencies in Washington State, which have complete authority to prohibit hazardous materials on streets and highways under their jurisdiction. This authority has been exercised by only one city in Washington.

In California, local agencies can establish route restrictions or prohibitions for hazardous materials or hazardous waste shipments on highways under their jurisdiction, subject to review by the CHP. Any route restriction or prohibition is subject to the following requirements:

- The route in question must be appreciably less safe than a reasonable alternate highway.
- The restriction or prohibition must not be precluded or preempted by Federal law.
- The restriction or prohibition must not eliminate necessary access to local pickup and delivery points or reasonable access to fuel, repairs, rest, or food facilities within 0.5 mi (0.8 km) of State highways.
- The restriction or prohibition cannot be made if no other lawful alternative exists.

The CHP acts as an arbitrator in the case of disagreements among cities or objections from the trucking industry. This process is initiated by a petition from a local government or a trucking firm. The CHP must hold a public hearing as part of this process.

In the other four States visited, the legal authority of local governments to establish routing regulations is unclear. Only one city in these four States is known to have established hazmat routes.

In addition to routing restrictions, some municipalities have chosen to control hazmat shipments through time-of-day restrictions or curfews. Curfews have generally been applied only to certain types of hazmat shipments, such as radioactive materials.

A variety of curfew types have been employed. Most commonly, certain types of hazmat shipments are restricted from traveling on congested highways during the morning and evening peak periods. Broader curfews may restrict hazmat shipments to nighttime hours. Both of these approaches are intended to reduce the likelihood of a congestion-related traffic accident resulting in a hazmat release and to minimize the number of motorists directly exposed to any release that should occur. In contrast, some municipalities have considered the opposite approach of requiring hazmat shipments to move during daylight hours on weekdays when the community's emergency response capability is at its highest.

The variety of curfew requirements in different communities imposes a burden in terms of additional delays and costs of shippers and carriers of hazardous materials. A 1986 study developed scheduling models to predict the delays resulting from curfews in multiple cities along a shipment route and to select the optimal shipment schedule.[26] Their model includes the capability to consider constant (deterministic) and uncertain (stochastic) travel times between cities. The major implications of uncertain travel times are that (a) the relative advantages of precise dispatching decrease as the uncertainty in travel times increase, and (b) the optimal departure time is earlier when travel times are uncertain than when they are known with certainty.

3. Regulation and Routing of Explosive Shipments

a. Federal agencies: Shipments of explosive materials are regulated at the Federal level by the RSPA Office of Hazardous Materials Transportation through the requirements of 49 CFR, which includes special restrictions on the type and condition of trucks used, loading and unloading procedures, delivery procedures, emergency transfers, and required documents for explosive shipments. Federal regulations restrict the locations where trucks transporting explosives can be parked and require that a truck transporting explosives must be attended at all times by the driver or another qualified representative of the motor carrier except when the vehicle is parked on the premises of the shipper, carrier, or consignee or in a designated safe haven. There are no Federal regulations that define requirements for safe havens for explosive shipments.

Federal regulations do not establish routing requirements for explosive shipments, but do require that the driver must have in his possession a written routing plan and, except in emergencies, the driver must follow that routing plan.

b. State agencies: Most States do not have regulations for explosive shipments that go beyond those in 49 CFR. An exception is California, which has implemented a network of designated routes for explosive shipments.

The California Highway Patrol (CHP) has statutory authority to designate routes for transportation of explosives. The CHP publishes maps showing the designated routes, required inspection stations, safe stopping places, and safe parking places for explosive shipments. The map shows the locations of specific commercial truck stops that are designated as "safe stopping places." Drivers may stop at these facilities for food, fuel, or other reasons, but the truck must be attended at all times. Some commercial truck stops are also identified as having "safe parking places" which are designated areas where a truck carrying explosives can be parked unattended. Thus, these "safe parking places" are considered to be designated safe havens under 49 CFR. Drivers are not permitted to stop at any location other than an inspection station, safe stopping place, or safe parking place, unless the vehicle is disabled or unless ordered to stop by a police officer.

In other States, there appears to be substantial confusion over the concept of designated safe havens for explosive shipments, since 49 CFR does not specify criteria for establishment of designated safe havens.

c. Local agencies: In most States, local agencies have a limited role in regulation of explosive shipments, as in general regulation of hazmat transportation. One general exception is Illinois, where the establishment of designated safe havens for explosive shipments is a local function. Two safe havens in Illinois have been designated by local authorities, but there are no general criteria for safe havens.

4. Regulation and Routing of Radioactive Shipments

a. Federal agencies: Federal involvement in shipments of radioactive materials is greater than for other types of hazardous materials for several reasons. First, the U.S. Department of Transportation has, to date, exercised its authority over routing of hazmat shipments exclusively in the area of radioactive shipments. Second, packaging requirements for shipments of spent nuclear fuel are regulated by the Nuclear Regulatory Commission. Third, the U.S. Departments of Energy and Defense are frequent shippers of radioactive materials.

Regulations developed by the RSPA Office of Hazardous Materials Transportation control routing of large-quantity shipments of radioactive materials. These regulations establish the Interstate highway system as the preferred route for radioactive shipments. Where an Interstate bypass around a city is available, the bypass must be used in preference to the route through the city. States and local governments cannot arbitrarily or unilaterally ban radioactive shipments totally or from particular routes, but acceptable alternative routes can be developed for particular sections of an Interstate highway based on agreement among all affected jurisdictions. State and local laws or regulations are subject to preemption by action of the U.S. Department of Transportation.

Other aspects of 49 CFR regulate the quantities of radioactive material that can be shipped in a single vehicle, loading techniques, and acceptable radiation levels inside and outside the vehicle.

RSPA has published a guide for risk analysis in routing of radioactive shipments entitled "Guidelines for Selecting Preferred Highway Routes for Large Quantity Shipments of Radioactive Materials."[64]

The Nuclear Regulatory Commission is charged with promoting safety in handling and transporting radioactive materials. This authority is derived from the Atomic Energy Act of 1954. The Nuclear Regulatory Commission is responsible for the development of safety standards for packaging of higher level radioactive materials and the development of shipment security requirements. Through a memorandum of understanding between the USDOT and the Nuclear Regulatory Commission, each agency has agreed to adopt and enforce the regulations developed by the other.[62]

The U.S. Departments of Energy and Defense are frequent shippers of radioactive materials and radioactive waste related to both civilian and military nuclear programs. A DOE report provides an overview of regulations and safety considerations in transportation of radioactive materials.[121]

b. State agencies: Shipments of radioactive materials are a high visibility issue that is of direct concern to many States. While States cannot adopt regulations that conflict with Federal laws or regulations, States have been active in establishing inspection, notification, permitting, and escort requirements.

A number of States, including Illinois, Washington, and Wisconsin, require radioactive shipments entering the State to be inspected for compliance with Federal and State regulations. States may also inspect shipments originating within the State at their point of origin. Inspections of radioactive shipments are not usually the responsibility of the State highway agency, but are more typically performed by the State police.

Radioactive shipments do not usually require a permit from the State highway agency, but shipments of spent nuclear fuel are often transported in a large lead cask that causes the truck to exceed established weight limits. Thus, such shipments require a permit from the State highway agency, not because they are radioactive, but because they are overweight. However, the permitting process provides an opportunity for advance notification for State agencies to learn about the shipment. Overweight permits often restrict shipments to certain hours, but these requirements are no different for radioactive and nonradioactive shipments. The AASHTO Task Force on Size and Weight Regulation is currently considering appropriate requirements for a standardized vehicle for spent nuclear fuel shipments that might simplify the permitting process.

In some States, permits and advance notification are also required by a State health or nuclear safety agency. At least 18 States have advance notification requirements for shipment of spent nuclear fuel or other radioactive materials by highway.[84] For example, the Illinois Department of Nuclear Safety requires shippers of spent nuclear fuel to obtain permits, to provide advance notification of shipments, and to pay a fee used to support the State nuclear safety program. This policy was recently upheld by RSPA as not inconsistent with Federal laws and regulations. The Illinois State Police escort all shipments of spent nuclear fuel passing through the State.

c. Local agencies: Local agencies do not typically have a direct role in regulation or routing of radioactive shipments. However, a recent review found that 136 localities have established laws that require carriers to notify local officials when hazardous materials are going to be transported.[13] Most commonly, advance notification requirements of this type apply to radioactive shipments.

5. Regulation and Routing of Hazardous Waste Shipments

Shipments of hazardous waste are subject to regulation and, in some cases, routing control as described in the following section.

a. Federal agencies: Shipment of hazardous waste in both interstate and intrastate commerce is subject to all established U.S. Department of Transportation requirements, including the Federal motor carrier safety regulations and Federal hazardous materials transportation regulations. Shipments of hazardous waste are also regulated by the EPA both to ensure safe transportation of the waste and to ensure its proper disposal or treatment. This authority derives from the Resource Conservation and Recovery Act (RCRA). Regulations developed by EPA under RCRA must be consistent with USDOT regulations.[63] Hazardous waste shipments require an EPA hazardous waste manifest to facilitate tracking of their ultimate disposal or treatment.

b. State agencies: Most State highway agencies do not regulate shipments of hazardous waste any differently than other hazardous materials shipments. An exception to this general rule is California, where State laws specifically allow the CHP, in consultation with Caltrans, to establish routing restrictions for either hazardous waste shipments or hazardous materials shipments or both. Despite the lack of any special interest in hazardous waste shipments by highway agencies, most States have a State environmental agency that shares the responsibility for hazardous waste shipments with the U.S. EPA and is involved in monitoring these shipments through tracking of the hazardous waste manifest. At least 18 States require advance notification for hazardous waste shipments by highway.[84]

c. Local agencies: Local agencies do not generally have a role in the regulation of hazardous waste transportation, except in California where local agencies share the State authority described above.

6. Signing of Hazmat Routes

a. Federal agencies: At the Federal level, traffic control device requirements, including signs for hazmat routing, are the responsibility of the FHWA Office of Traffic Operations (OTO). OTO is responsible for publication of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), which sets criteria for uniform application of signs, signals, and markings.[35] The MUTCD is used by State and local agencies throughout the United States.

A 1983 FHWA study evaluated several candidate hazmat route signs.[66] This evaluation compared the candidate signs with respect to both understanding and personal preferences by truck drivers, police officers, and the general public. The sign that received the highest rating featured a side view of a truck with the letters "HC" (for Hazardous Cargo) on the bed of the truck.

OTO has recently adopted new signs for incorporation in the MUTCD to designate preferred hazmat routes and hazmat route prohibitions. These signs are illustrated in figure 10. Preferred hazmat routes are to be identified by MUTCD Sign R14-2 which has block letters "HC" in black on white background inside a green ring. The letters "HC" stand for Hazardous Cargo. Hazmat route prohibitions are to be identified by MUTCD Sign R14-3 which has block letters "HC," in white on a black background, inside a red ring with a diagonal slash. These signs are similar to those recommended by McDonald, except that they do not include the side view of a truck.[66] Figure 11 illustrates text versions of these signs, bearing the legends "Hazardous Cargo Route" and "No Hazardous Cargo."

b. International agencies: There is also international interest in hazmat route signing. Despite efforts by the United Nations and the European Conference of Ministers of Transport, the signs used for hazardous materials routes and prohibitions in Europe are not uniform among countries.[86]

Canada has conducted a laboratory study of 10 different permissive/prohibited sign pairs for dangerous goods routes and found that none of the tested signs inherently conveyed the intended meaning.[15] The routing sign finally adopted by Canada uses a solid black diamond symbol, representing the shape of the hazmat placard used in North America. Both permissive signs (with a green ring) and prohibition signs (with a red ring and diagonal slash) may be used. Figure 12 illustrates the Canadian signs.

c. State agencies: Posting of signs for hazmat route preferences or prohibitions on the State highways is generally a function of the State highway agency. State agencies generally use the signs in the national MUTCD, although some States have their own State MUTCDs that expand on the national criteria.

In the recent AASHTO routing and signing survey, States were asked how hazmat route prohibitions and route preferences should be communicated to the driving public. In the case of route prohibitions, 8 States prefer the use of maps or permits, 9 States prefer the use of field signs, and 10 States prefer a combination of maps and field signs. In the case of route preferences, 10 States prefer the use of maps or permits, 4 States prefer field signs, and 5 States prefer a combination of maps and field signs. These findings indicate that a substantial number of States would prefer to implement hazmat routes without posting signs and that the perceived need for signing is stronger in the case of route prohibitions than route preference.[6]

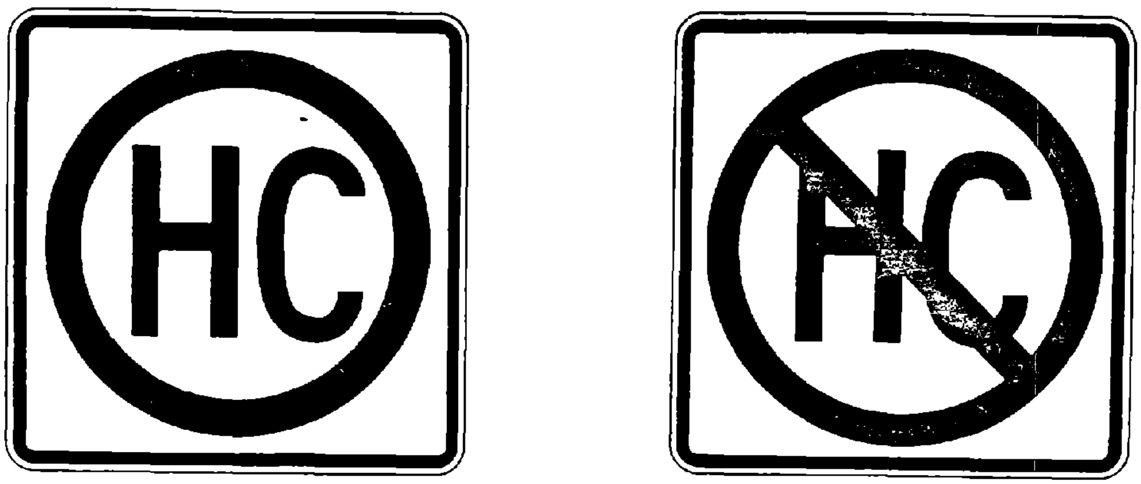

Figure 10. MUTCD symbol signs for hazmat route preferences and prohibitions.[35]

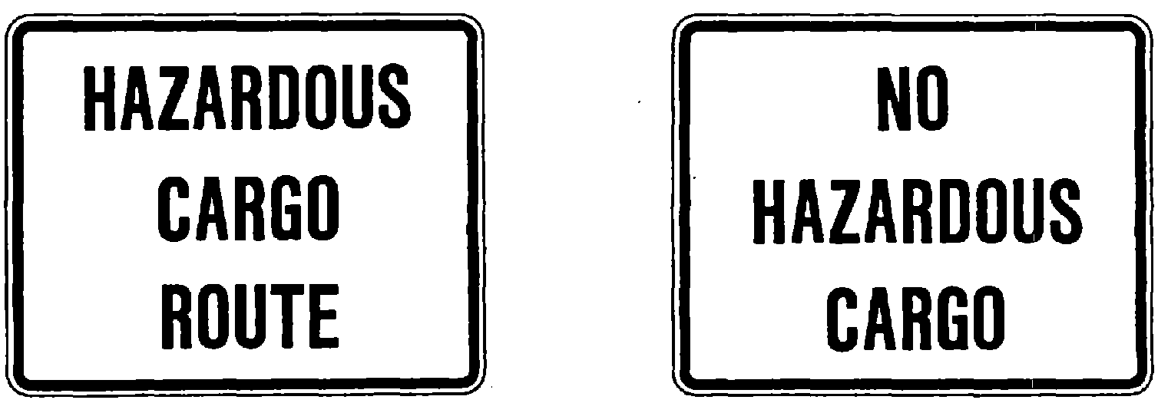

Figure 11. MUTCD text signs for hazmat route preferences and prohibitions.[35]

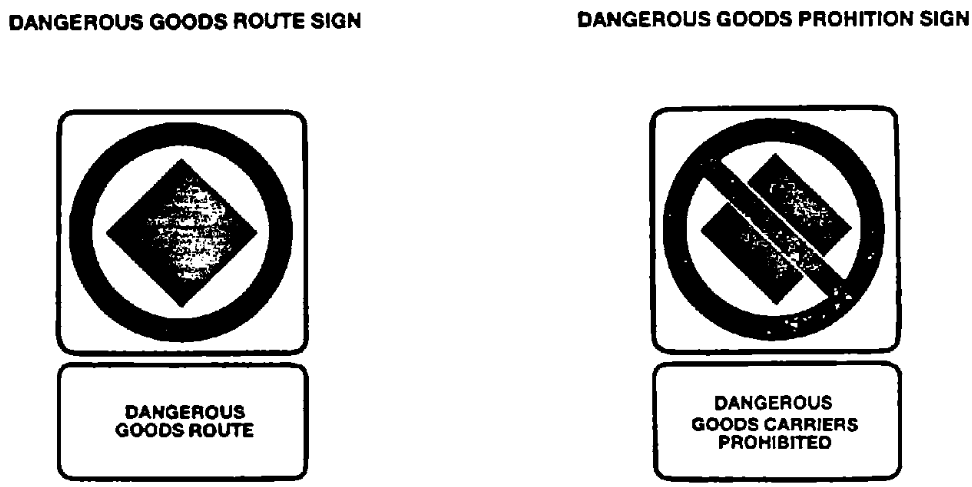

Figure 12. Symbol sign for hazmat route preferences and prohibitions used in Canada.[86]

Since hazmat route preferences or prohibitions have been implemented in only a few States, most State agencies have not adopted a hazmat routing sign. It is expected that most States will use the new signs incorporated in the national MUTCD, if these signs fully meet their needs. The recent AASHTO routing and signing survey found that 15 States feel that the MUTCD design for "HC" route signs is adequate for their needs, 3 States do not feel that the MUTCD is adequate for their needs, and 20 States are not sure. This uncertainty is important and indicates that many States have not yet come to grips with the practical problems of implementing hazmat routes.[6]

Only one of the six States visited in the present study has adopted a sign for identifying hazmat routes. The California Department of Transportation (Caltrans) has adopted a standard sign for hazmat routes featuring a solid black diamond-shaped placard (similar to the Canadian hazmat route sign discussed above). The California sign has both permissive and prohibitive versions for hazmat route preferences and prohibitions, respectively. The sign incorporates block letters "HM" for hazardous materials route preferences and prohibitions and "HW" for hazardous waste route preferences and prohibitions.

Caltrans adopted their placard symbol sign prior to the adoption of the signs in figures 10 and 11 for the national MUTCD. During the visit as part of this study, Caltrans personnel expressed several concerns about whether the national MUTCD signs can meet their needs. In particular, Caltrans is concerned that:

- The national MUTCD sign will be less recognizable to hazmat truckers than the familiar placard shape.
- The use of the letters "HC" on the national MUTCD sign may be inappropriate because "hazardous cargo" is a broader term than "hazardous materials." For example, "hazardous cargo" would include a load of wild animals.
- The national MUTCD sign does not distinguish between hazardous materials and hazardous waste routes, which Caltrans must do under California law.

Other State and local agencies that have implemented hazmat prohibitions for specific facilities have typically used large rectangular signs (with sizes and shapes similar to freeway guide signs) with either white letters on a red background or black letters on a yellow background.

d. Local agencies: Local agencies generally follow the national MUTCD and the signing policies adopted at the State level in their State. In the past, local agencies have developed their own signs when no sign has been adopted at the State level. The incorporation of a hazmat route sign in the national MUTCD will encourage local agencies to use that sign in the future.

7. Enforcement of Hazmat Transportation Regulations

a. Federal agencies: The Federal agency with primary responsibility for enforcement of hazmat regulations is the U.S. Department of Transportation. Other Federal agencies are involved in enforcement of regulations for specific types of hazardous materials within their scope, including the Environmental Protection Agency for hazardous waste shipments and the Nuclear Regulatory Commission for high-level radioactive shipments.

Within USDOT, enforcement responsibilities for the highway mode are assigned to the FHWA Office of Motor Carrier Safety. RSPA deals with intermodal enforcement issues including container manufacturing and testing. Civil penalties up to $10,000 per violation (or per day for continuing violations) are the most common enforcement mechanism under the HMTA. Other available enforcement mechanisms are criminal penalties, compliance orders, and imminent hazard orders. There is no Federal licensing of hazmat carriers required under the HMTA, so there are no license suspensions or revocation proceedings that can be used as enforcement tools at the Federal level.[62]

Neither RSPA nor FHWA has the size of field staff that would be needed for a major enforcement effort. Therefore, recent efforts have focused on stimulating State enforcement activity -- first through the SHMED program, and now through the MCSAP program. Thus, most hazmat transportation enforcement in the highway mode is conducted at the State level.

b. State agencies: State enforcement programs in hazmat transportation safety have been expanding rapidly in recent years, primarily in response to the Federal SHMED and MCSAP programs, although some important State programs (including the Illinois program) predate these Federal programs. According to the Office of Technology Assessment, an informal survey of States participating in the SHMED program in 1983 found the most common violations identified in roadside inspections to be: (a) failure to display placard correctly; (b) failure to brace containers of material; (c) leaking discharge valves on cargo tanks; (d) improperly described cargo; (e) inaccurate or missing shipping papers; and (f) excessive radiation levels in cab of truck.[84]

Responsibility for enforcement of hazmat transportation safety regulations falls outside the responsibilities of the State highway agencies in most, but not all cases. Five of the six States visited as part of this study -- California, New Jersey, Virginia, Washington, and Wisconsin -- have enforcement programs that operate in a similar manner, although they differ in scale and stage of implementation. In these States, enforcement of State hazmat regulations is typically performed by the State police through truck inspections at fixed weigh scales and at temporary roadside locations. Violations cited by the State police are generally adjudicated in a local court in the jurisdiction where the violation occurred. Fines for violations vary, but \$50 to \$500 per violation is not unusual. In some cases, State highway agencies provide direct or indirect support to these police enforcement activities, because the weigh scales where much of the enforcement activities take place are often owned or operated by the State highway agency.

Enforcement officers report four problems commonly encountered in prosecuting hazardous materials violators. First, because of a lack of training or experience, officers often do not provide adequate documentation in the inspection report or have not followed correct procedures. As a result, many cases must be set aside or the charges reduced. Second, enforcement officers find that many judges and local prosecutors have difficulty understanding hazardous materials regulations and respond by dismissing cases or lowering penalties without cause. A third problem is the difficulty of obtaining assistance from other agencies in preparing evidence for court proceedings. State agencies are sometimes unwilling to cooperate in testing hazardous materials or in providing other technical assistance. Fourth, State enforcement agencies complain that fines are too low to serve as a deterrent to noncompliance. Many carriers and shippers treat fines as a cost of doing business.[84]

The one major exception to the general pattern is the hazmat enforcement program in Illinois. Illinois has one of the largest State enforcement programs, with 70 full-time State police officers involved in enforcing the State hazmat transportation safety regulations. However, violations cited by the State police in Illinois are adjudicated through an administrative proceeding within the State highway agency rather than through a judicial proceeding in a local court. Fines for violators are determined by compliance officers in a section of the Illinois Department of Transportation (IDOT) that deals exclusively with hazmat transportation safety issues. Fines for single violations typically range from $1,250 to $2,500, and multiple violations on a single vehicle might result in fines from $1,500 to $3,000. The IDOT compliance officers also have enforcement authority and participate in 2-day special compliance efforts held at different locations throughout the State 8 to 10 times per year. The combination of large-scale enforcement activities, swift administrative adjudication, and relatively high fines has resulted in a substantial increase in compliance with hazmat regulations in Illinois.

State agencies may also conduct compliance audits at carriers' terminal facilities. In some cases, this is a State police responsibility, although, in Virginia, carrier audits are the responsibility of the Department of Waste Management, and in Washington State they are the responsibility of the Utilities and Transportation Commission.

c. Local agencies: In most States, local police agencies have the same authority as State police agencies to cite violators of hazmat transportation regulations. One exception is Illinois, where enforcement of hazmat transportation regulations is strictly a State function. As a practical matter, however, most local police agencies do not have either the resources or the expertise for hazmat enforcement, so the vast majority of enforcement effort is conducted at the State level.

8. Hazmat Incident Detection

a. Federal agencies: Federal agencies have no direct on-scene role in the detection of hazmat incidents that occur on the highway system. However, Federal agencies do have an indirect role in encouraging more effective detection of incidents at the State and local levels.

b. State agencies: State agencies have a primary role in the detection of hazmat incidents and the coordination of emergency response. However, the State highway agency has only an occasional role in incident detection.

A few State highway agencies operate real-time freeway surveillance systems in major metropolitan areas which are capable of detecting highway incidents, including hazmat incidents. Although some hazmat incidents are also first detected by highway maintenance crews in the field, incidents typically first come to the attention of State police through routine patrols or telephone reports. Many State environmental agencies and/or emergency management agencies also maintain 24-hour telephone hotlines for reporting of emergencies, including highway incidents. There is a need for improved methods for informing State highway agencies about the occurrence of hazmat incidents. State highway engineers often complain that they are the last to be informed when hazmat incidents occur.

c. Local agencies: Local police departments and emergency management agencies have a similar role to State agencies in detecting and reporting hazmat incidents. Local highway agencies generally have a minimal role in this activity.

9. Emergency Response

a. Federal agencies: Federal agencies do not have a direct role as an on-scene responder to hazmat incidents on the highway, but generally play a coordinating role. The lead agency at the Federal level in the emergency response level is the Federal Emergency Management Agency (FEMA) which has responsibilities for coordinating, planning, training, and response capabilities for all types of emergencies.

The RSPA Office of Hazardous Materials Transportation assists State and local agencies to improve their emergency response capabilities through the provision of readily available, accurate information for emergency responders. In particular, RSPA publishes and distributes over 1 million copies of the USDOT Emergency Response Guidebook to State and local responders.[114] RSPA has also published a guide for local officials entitled, "Community Teamwork: Working Together to Promote Hazardous Materials Transportation Safety."[63]

The National Response Center operates a 24-hour toll-free telephone number for receiving reports of hazmat discharges or releases and notifying appropriate State and local authorities. It also maintains a limited capability to provide technical information to on-scene personnel.[63]

Although privately funded by the Chemical Manufacturers Association, the Chemical Transportation Emergency Center (CHEMTREC) plays an important national role in coordinating emergency response to hazmat incidents. CHEMTREC, which can also be contacted through a 24-hour toll-free number, provides immediate advice and technical information on materials involved in a hazmat incident. More importantly, CHEMTREC initiates communication among other concerned parties, such as the shipper or manufacturer, to facilitate response through use of their expertise in handling the materials under emergency circumstances.[63]

b. State agencies: State agencies play a critical role in emergency response to hazmat incidents on the highway, especially those that occur on State highways and outside city limits. The primary responders at the State level can include State police agencies, State emergency management agencies, State environmental agencies, State health agencies, and State nuclear safety agencies. The role of the emergency responders is to contain the spill so that it can subsequently be cleaned up. There is general agreement that a single on-scene coordinator is needed to manage response at an incident site.[69,73] Practices differ among States, but it is not uncommon for the senior State police officer present to be in command at an incident site. According to a recent survey, at least 18 States maintain or finance the equipment, training, and maintenance of hazmat emergency response teams. Additional States are developing State-supported teams.

A 1980 study reports that, for radiological emergencies, 29 States have trained response teams in a central office responsible for the entire State; 14 States have field offices that provide trained personnel when alerted to an incident by the central office; and the remaining States rely on local public safety or public health personnel to make an initial assessment of the incident and contact appropriate State authorities, if necessary.[69]

Increasingly, State highway agencies are training their field personnel about how to deal with a potential spill if they encounter one. Most State highway agencies play only a supporting role in emergency response to hazmat incidents. An exception to this general rule is the California Department of Transportation (Caltrans) which has 71 two-man teams with specialized equipment and training for responding to hazmat spills. These personnel are not full-time hazmat specialists, but are supervisory-level personnel with other duties who are on call if a spill occurs. The main responsibility of these teams is to identify the material spilled and decide how to deal with it. However, their level of involvement in emergency response is unusual for highway agencies.

A recent AASHTO survey on control and cleanup of hazardous materials spills found that 56 percent of State highway agencies had some personnel trained for emergency response to hazmat incidents.[5] Furthermore, the survey indicated that 86 percent of these agencies use the USDOT Emergency Response Guidebook and 67 percent of State highway agencies carry the guidebook in some of their vehicles.[5,114] However, unless they are first on the scene, State highway agencies generally leave emergency response activities to personnel with more training and experience and concentrate on their responsibilities in incident traffic management and cleanup (discussed in the following sections).

A few State highway agencies have found that they can assist emergency responders from other agencies by prepositioning emergency response supplies (sand, absorbent materials, foam generators, etc.) in highway agency facilities. This is a logical role for State highway agencies, since they have an established network of maintenance yards at key locations throughout the State. For example, the Illinois EPA plans to purchase and maintain three different types of Hazardous Materials Response Trailers. The trailers will be stored in IDOT maintenance yards and taken to the scene by IDOT personnel on request. However, the IDOT personnel will turn the trailer over to emergency response personnel and will not remain at the scene.

c. Local agencies: Local agencies, including fire departments, police agencies, emergency management agencies, and health agencies, play an important role in emergency response. In many cases, the local fire chief is in command at an incident site. However, it is unusual for a local highway agency to have a direct role in emergency response to highway hazmat incidents.

10. Incident Traffic Management

a. Federal agencies: Federal agencies have no direct role in traffic management for hazmat incidents on the highway.

b. State agencies: Traffic management for hazmat incident sites is primarily the function of State police and highway agencies for incidents on State highways. State police agencies are generally responsible for securing the site and keeping motorists and onlookers away from the site and out of danger. State highway agencies are generally responsible for providing traffic control devices and establishing and signing detour routes if the highway is closed. Thus, the primary role of the State highway agency is to provide for safe traffic flow. In States that contract for maintenance with local highway agencies, these functions are performed by the local agencies.

c. Local agencies: Local police and highway agencies generally perform the same functions described above for State agencies at incident sites that are within city limits or off the State highway system.

11. Incident Site Cleanup

a. Federal agencies: Federal agencies generally have no direct role in the cleanup of hazmat spills on the highway. However, in some major spills, the U.S. Environmental Protection Agency may become involved to ensure that the spill is properly cleaned up. The EPA can impose requirements on the carrier involved to mitigate environmental damage and to pay for cleanup costs.[63]

b. State agencies: Responsibility at the State level for cleanup of hazmat spills on the highway generally rests with either the State highway agency, the State police agency, the State environmental agency, or the State health agency. Table 16 summarizes the distribution of lead agencies in cleanup activities at the State level from a recent AASHTO survey of 43 States on control and cleanup of hazardous materials spills.[5]

Table 16. Lead agencies at the State level in cleanup of hazardous materials spills.[5]

Agency	Percent of states
State environmental agency	53
State police agency	20
State health agency	12
State emergency management agency	8
State highway agency	7
	100

In some States, the lead responsibility was shared by more than one agency. The State highway agency had the lead responsibility for cleanup in only three States, and participated in cleanup activities in six additional States. In the six States visited as part of the present study, only the California and Washington highway agencies participate directly in cleanup activities. Caltrans has nine spill contractors on call throughout the State to clean up hazmat incident sites. In Virginia, the State highway agency assumes responsibility for cleanup activities only if other responders do not adequately clean up the site. In Illinois, New Jersey, and Wisconsin, the State highway agency has no role in cleanup activities.

c. Local agencies: Local agencies that may become directly involved in cleanup activities include local fire departments, emergency management agencies, and health agencies. Local highway agencies generally have only a support role. Under a unique arrangement in California, partial State reimbursement for local cleanup costs is available through the State health agency, and State contractors are available to assist in cleanup activities.

12. Hazmat Accident and Incident Reporting

a. Federal agencies: Three Federal agencies receive reports of hazmat accidents and incidents from involved carriers. These are the RSPA Office of Hazardous Materials Transportation, the FHWA Office of Motor Carrier Safety, and the U.S. Environmental Protection Agency. Each of these reporting systems is dependent on self-reporting by the carrier responsible for the spill.

RSPA requires reports of hazmat releases from involved carriers within 15 days following the discovery of the spill.[62,93] In addition, hazardous materials incidents involving a fatality, serious injury, or property damage in excess of $50,000, or involving radioactive materials or etiologic agents, must be immediately reported to the National Response Center. The RSPA reporting requirements apply only to carriers engaged in interstate transportation of hazardous materials. There is no minimum quantity released or minimum property damage threshold for reporting hazmat incidents to RSPA. Any incident, no matter how small, is technically reportable if the hazardous material escapes from its container. It is not necessary for the hazardous material to escape from the vehicle in order for the incident to be reportable. The only exceptions to this general rule are small quantity releases of battery acid and certain paint products which were excluded from the reporting requirements in 1981. In addition, hazardous substances that are regulated by EPA and do not fall in any of the established hazard classes under 49 CFR are considered to be Other Regulated Materials-Class E (ORM-E). Releases of material classified as ORM-E are required to be reported only if the quantity released exceeds a reporting threshold.

The FHWA requires reports of truck accidents involving regulated interstate motor carriers.[33] Reports are required for accidents involving a fatality, an injury, or at least $4,200 in property damage. The FHWA reports identify whether the involved truck was carrying hazardous materials or whether those hazardous materials were released. Both the RSPA and FHWA data bases have been analyzed in this study and are discussed further in sections IV and V of this report.

The U.S. Environmental Protection Agency requires reports of spills of hazardous materials or hazardous waste by a motor carrier or anyone else.[63] These reports are received by EPA regional offices, several of which have developed computer data bases for managing these data. These data are used by EPA to monitor cleanup activities and assess carrier responsibility.

b. State agencies: State agencies also operate reporting systems for hazmat accidents and incidents. The police accident reporting systems of 15 States contain data on whether the involved vehicles were transporting hazardous materials. However, only 3 of these 15 States also record whether hazardous materials were released as a result of the accident. These States are Louisiana, Missouri, and Wyoming.

Several States also maintain reporting systems for hazardous materials spills on the highway. The recent survey by the Virginia Transportation Research Council for TRB indicates that at least 23 States maintain reporting systems for hazmat spills.[12] Typically, these reporting systems are operated by the State environmental agency and include a record of all spills that come to their attention, similar to the record of spills kept by the EPA. In Illinois, the hazmat incident reporting system is operated by the State highway agency. Reporting to this system is voluntary, but response agencies are encouraged to submit a report any time that equipment is dispatched. The Illinois reporting system began operation on January 1, 1987.

c. Local agencies: Local agencies do not typically operate hazmat incident reporting systems, although many local agencies initiate hazmat incident reports to the State reporting systems discussed above.

13. Monitoring Hazmat Flows

a. Federal agencies: There are no Federal programs for monitoring hazmat flows on specific highways or corridors. The only type of hazmat flow data gathered at the Federal level is the Truck Inventory and Use Survey (TIUS) conducted every 5 years by the Bureau of the Census.[14] This survey provides some fairly gross estimates of vehicle-miles of travel carrying specific types of hazardous materials. However, these data can be categorized geographically only by the State in which the truck is registered and not by the State(s) in which the travel occurred.

b. State agencies: Most States have not put a major effort into determining the volumes or types of hazardous materials moving on specific routes. In a few States, the State highway or emergency management agency has performed placard counts to document hazmat flows on some routes. For example, reports prepared for State agencies in Arizona (references 88, 91, and 92) and Virginia (reference 90) have characterized the hazmat flows on major routes in those States.

The New Jersey Department of Transportation has devoted more effort than most States to characterizing hazmat flows. The New Jersey DOT has purchased data from the TRANSEARCH data base and has prepared a report documenting the quantities of hazardous materials shipments with origins or destinations in New Jersey (data on shipments moving through the State are apparently unavailable).[78,109] The New Jersey DOT is presently working to break down the commodity flow data by mode and Standard Transportation Commodity Code (STCC) at the county level.

The documentation of hazmat flows has some general application in characterizing the nature of the hazardous setting priorities for emergency response capabilities, but it is difficult to see any major benefits from expanding the collection of this type of data.

c. Local agencies: Most local agencies have not developed any effort to monitoring hazmat flows. The one existing hazmat risk assessment model intended for use by small communities, known as the Kansas State University (KSU) model, encourages local agencies to make placard counts as part of the risk assessment process.[98] The major benefit of this activity is increasing community awareness of the potential of hazmat incidents.

An extensive hazmat flow study based on placard counts has recently been completed in Dane County, Wisconsin.[27] The study was part of the county's effort to develop a comprehensive hazardous materials emergency plan.

14. Personnel Training

a. Federal agencies: Federal agencies are active in conducting, funding, and encouraging hazardous materials training for State and local personnel. Training is conducted for enforcement of hazmat regulations and planning for and responding to hazmat incidents. Funding for programs of this type is provided through the Federal Emergency Management Agency, the U.S. Department of Transportation, and the U.S. Environmental Protection Agency. USDOT funding for training activities related to hazmat enforcement may be obtained by States as part of the MCSAP program. FEMA and EPA funding grants for training are available for improving emergency response to hazardous materials incidents.

b. State agencies: State agencies are both developers and consumers of training programs related to hazmat transportation safety. A number of States have developed hazmat training courses or adapted courses developed at the Federal level. Such courses have been developed and presented by State highway, police, emergency management, and environment agencies; by State universities; or by State training organizations such as the California Specialized Training Institute.

Training in hazmat transportation safety is important for State highway agency personnel, even in States where the highway agency does not have a lead role in hazmat regulation or hazmat incident response. At a minimum, highway agency field personnel should have a basic hazmat awareness course on what to do in case they should encounter an overturned truck on the highway. Highway agencies are also frequent carriers of certain types of hazardous materials (e.g., asphalt, paint, etc.), and their personnel need training in proper handling of these materials.

c. Local agencies: Local agency personnel need much of the same kind of training as State personnel in hazmat transportation regulation and basic hazmat awareness. In addition, local fire and police personnel are often the key responders to hazmat incidents and need hazmat emergency response training. Such training is often available to local agencies through Federal or State programs.

15. Research

a. Federal agencies: A substantial amount of research in hazardous materials transportation safety is conducted at the Federal level. Research related to highway transportation of hazardous materials has been sponsored by the USDOT Research and Special Programs Administration, the Federal Highway Administration, the U.S. Environmental Protection Agency, the National Transportation Safety Board, and the U.S. Department of Energy.

b. State agencies: State agencies are also active in research related to hazmat transportation safety on the highway. In particular, noteworthy hazmat transportation safety evaluations have been conducted by the States of Arizona (references 88, 91, and 92), California (reference 17), New Jersey (references 78 and 109), Virginia (references 13 and 90), and Washington (references 117 and 118). Typically, State research has been directed toward documenting the magnitude of hazmat transportation safety problems and improving the State's ability to manage these problems effectively.

c. Local agencies: Local agencies perform very little research in the hazmat transportation safety field. Local efforts are typically directed more toward improving planning and emergency response than toward research.

16. Information Exchange

a. Federal agencies: All Federal agencies with responsibilities related to hazardous materials transportation participate to some extent in information exchange. The Federal Emergency Management Agency and the USDOT Research and Special Programs Administration have taken a lead in this activity by setting up an electronic bulletin board service to provide State and local emergency response personnel and other interested parties with information regarding prevention, preparation, and mitigation of hazardous materials emergencies. The system provides a bulletin service and nine information conferences from which users can select, including:

- Calendar of Federal information and training events.
- Calendar of State information and training events.
- Calendar of conferences.
- Literature listings.
- Available instructional listings.

- On-line data bases and toll-free numbers.
- Experiences, regulations, laws, and news events.
- Organizational resources.
- Messages.

b. State and local agencies: All types of State and local agencies with responsibilities related to hazardous materials transportation participate to some extent in information exchange and can have access to the electronic bulletin board operated by FEMA and RSPA.

D. Summary

The preceding discussion illustrates the division of responsibilities in hazmat transportation safety between Federal, State, and local agencies and the variety of organizational approaches used by State and local governments to meet their responsibilities. Highway agencies do not always have a lead role in hazmat transportation safety, but usually play at least a key support role because they operate the highway system over which hazmat shipments move. A key finding of the study is that, in every area of responsibility related to hazmat transportation safety, the State highway agency has either a lead or a key support role in at least some States.

Many previous analyses have stressed the importance of designating a single lead agency to deal with hazmat transportation safety issues; and certainly, in any field as complex as hazmat transportation, leadership is critical. However, the management of hazmat transportation safety is, by nature, a cooperative venture with many diverse responsibilities to be met, and no State has attempted to meet these responsibilities within a single agency.

Highway agencies, police agencies, fire departments, emergency management agencies, and environmental agencies all have an important role to play, and these agencies must cooperate effectively. The successful State programs reviewed in this study were characterized by (1) strong commitments on the part of agency management to work together on hazmat safety issues and (2) effective day-to-day cooperative relationships among personnel at the working level with hazmat responsibilities in each agency. A number of States have formed hazardous materials commissions or interagency working groups to promote cooperation in hazmat transportation safety. The State emergency response commissions being formed under SARA Title III should solidify these cooperative working relationships which are the key to effective management of hazmat transportation safety.

IV. DATA SOURCES

This section of the report reviews the sources of accident, incident, and exposure data related to highway transportation of hazardous materials. The first portion of the discussion is an overview which defines the meaning of accident, incident, and exposure data as related to highway transportation of hazardous materials. Then, both existing and potential new sources of hazmat incident, accident, and exposure data are reviewed and critiqued.

A. Overview of Accident, Incident, and Exposure Data

Effective use of hazmat transportation safety data requires a complete understanding of and a careful distinction among accident, incident, and exposure data. Each type of data is discussed in more detail in the remainder of this section.

Accident data bases contain reports of traffic accidents obtained either from police reports, from motorist or motor carrier reports, or from independent follow-up investigations. Each record in an accident data base documents the characteristics of a particular accident or a particular accident-involved vehicle. The accident data bases of interest to this study are those that contain data on truck accidents where it can be determined whether or not the trucks involved in the accidents were carrying hazardous materials. It is also desirable to be able to determine whether a hazardous materials release occurred in a particular accident.

Incident data bases contain reports of occurrences where a hazardous material was unintentionally released. The incidents of primary interest to the proposed study are releases of hazardous materials during their transportation by highway. Several types of incidents need to be considered including (1) releases due to traffic accidents, (2) releases due to valve or container leaks, and (3) releases due to fires or explosions.

Figure 13 illustrates the overlapping nature of accident and incident occurrence. The figure shows that total highway trips or total highway vehicle-miles (represented by Block A) can be subdivided into three categories: hazardous materials shipments (B); other truck shipments that involve similar vehicles but do not involve hazardous materials (C); and highway travel by vehicle types other than trucks (D). Each shipment or trip may either involve a traffic accident or not; hazardous materials shipments can also involve an incident (i.e., a release) even if no accident occurs. Thus, as figure 13 illustrates, some incidents are not accidents (F), some accidents are not incidents (L), and some occurrences are both incidents and accidents (M). Figure 14 presents a classification scheme for accidents and incidents based on recent work by the Organization for Economic Cooperation and Development.[86]

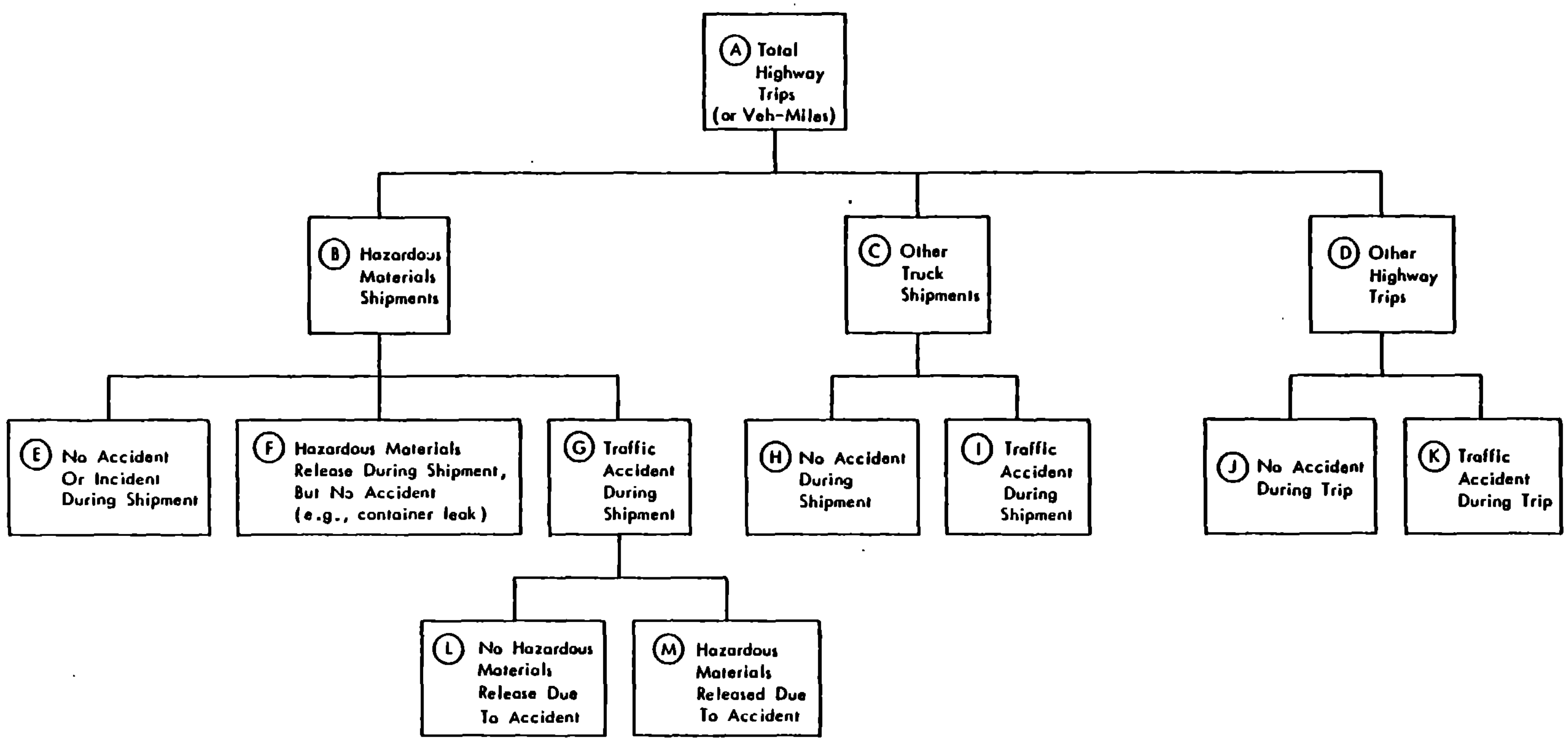

Figure 13. Relationships between accident, incident, and exposure data.

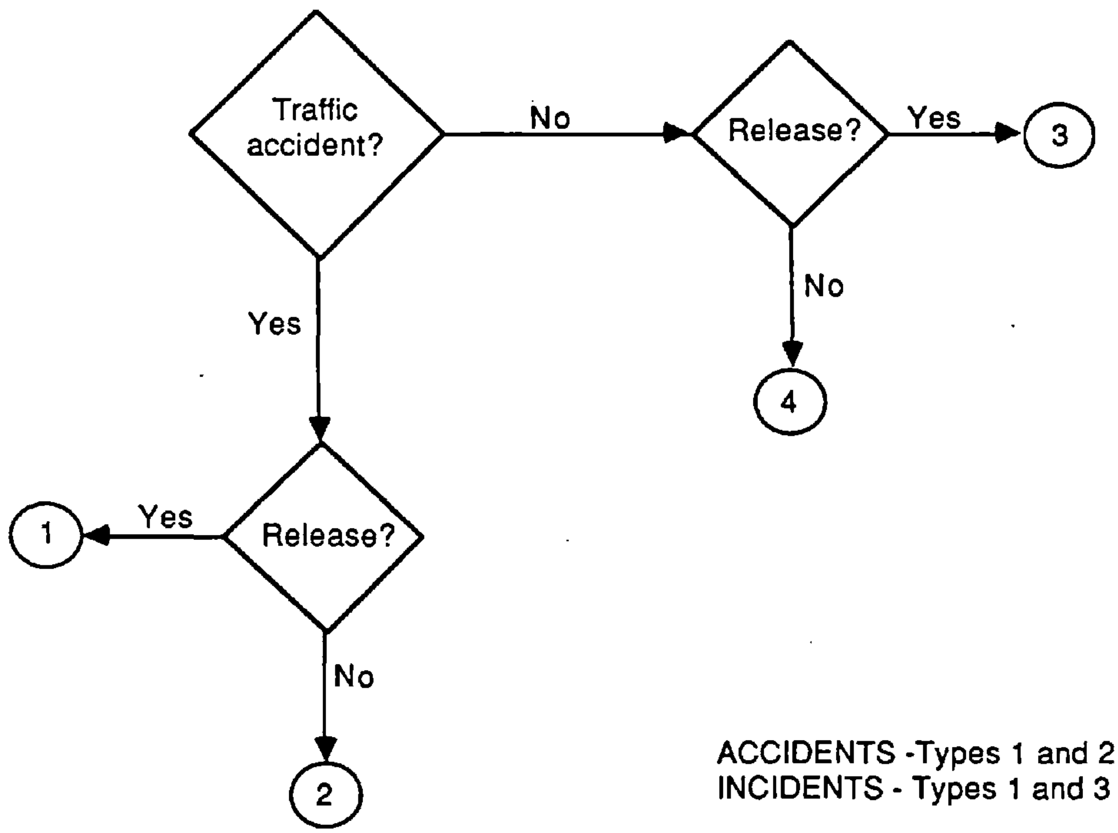

Figure 14. Classification scheme for on-highway events and causes of resulting fatalities and injuries for trucks carrying hazardous materials.

Accident and incident data are interesting by themselves because they indicate the frequency with which particular events occur. However, the assessment of accident or incident risk requires corresponding exposure data. Exposure is a measure of opportunities for accidents or incidents to occur, such as number of hazardous materials shipments, tons of hazardous materials shipped, or, best of all, vehicle-miles of hazardous materials shipments. Thus, Block B in figure 13 represents the exposure for hazardous materials accidents and incidents.

Risk measures, such as accident or incident rates per million vehicle-miles, can be expressed as the ratio of frequency of accidents or incidents to exposure:

$$R = \frac{A}{E} \tag{1}$$

where R represents a measure of risk (e.g., accident rate); A represents a frequency measure (e.g., number of accidents); and E represents an exposure measure (e.g., vehicle-miles of travel). To be useful in establishing hazardous materials transportation policies, risk measures must be made very specific. For example, an accident rate for a particular type of truck traveling on a particular type of road can be obtained if both the accident and exposure populations are stratified accordingly.

One major difficulty in past analyses of truck accidents, that is also a difficulty in hazmat transportation safety analyses, is that exposure data that correspond well to the available accident or incident data are seldom available. It is often necessary to "force fit" disparate sources of data such as the FHWA Motor Carrier Accident Reports and the Census Bureau's Truck Inventory and Use Survey to determine truck accident rates. Mismatches between accident, incident, and exposure data limit the ability to perform valid research related to hazmat transportation safety. Better data sources are needed in future research to improve the correspondence between accident, incident, and exposure data.

The following existing and potential new sources of accident, incident, and exposure data are reviewed in the remainder of this section:

<u>Accident Data</u>

Fatal Accident Reporting System (FARS)
National Accident Sampling System (NASS)
FHWA Motor Carrier Accident Data Base
State traffic accident record systems

<u>Incident Data</u>

RSPA Hazardous Materials Incident Data Base
EPA Spill Reports
State hazmat incident reporting systems
Canadian data

Exposure Data

Truck Inventory and Use Survey (TIUS, 1977 and 1982)
Commodity Transportation Survey (CTS)
FHWA Motor Carrier Census
Canadian data
Toll road data
Hazmat carrier data

These data sources have been investigated through a review of published literature and data base documentation, through contacts with the agencies that maintain these data bases, and through analysis of the most promising data bases. The most useful sources in the literature concerning these data bases were a recent study of hazardous materials transportation by the Office of Technology Assessment and a paper prepared as an outgrowth of that study.[61,85] Table 17 presents a brief summary of the major existing accident, incident, and exposure data bases. Table 18 compares the variables available in the major existing accident and incident data bases.

B. Accident Data

The existing sources of data concerning traffic accidents involving hazardous materials are reviewed below. A critique of available traffic accident data for use in hazmat analyses is presented.

1. Fatal Accident Reporting System (FARS)

The Fatal Accident Reporting System, operated by the National Highway Traffic Safety Administration (NHTSA), contains data on every police-reported traffic accident in the United States that results in a fatality. FARS receives data on approximately 40,000 to 50,000 fatal accidents per year. However, only about 120 to 150 of these accidents involve vehicles carrying hazardous materials. The FARS data indicate, for each vehicle involved in each accident, whether that vehicle was carrying hazardous materials. There is no indication of whether the hazardous materials being carried were released or whether the fatalities or injuries that resulted from the accident were related to the release. Because of the available sample size and the lack of detail concerning hazmat involvement in each accident, the FARS data are not very useful for safety evaluation of highway transportation of hazardous materials.

2. National Accident Sampling System (NASS)

The National Accident Sampling System is also operated by NHTSA. The system includes data on approximately 9,000 accidents per year sampled from police-reported accidents in 35 to 50 representative Primary Sampling Units located throughout the United States. Prior to 1987, approximately 75 accidents per year investigated by NASS involved vehicles carrying hazardous materials.

Table 17. Summary of existing accident, incident, and exposure data bases.

Data base/agency	Type of data base	No. of records	Hazardous materials factors	Related factors	Comments
ACCIDENT DATA BASES					
FARS-Fatal Accident Reporting System (USDOT/NHTSA)	All fatal traffic accidents in U.S.	40,000-50,000 accidents per year (1976-present) Approximately 120-150 accidents per year involve hazardous materials	Presence or absence of hazardous cargo (no indication of whether hazardous cargo was released)	Truck type Other vehicles involved Accident type and manner of collision Accident severity Type of roadway location Environmental conditions Travel speed First harmful event Most harmful event Fire occurrence	Virtually complete reporting of fatal accidents Data are based on police reports and other independent sources No corresponding exposure data
NASS-National Accident Sampling System (USDOT/NHTSA)	Accident sample drawn from 35-50 representative Primary Sampling Units (PSUs)	Approximately 9,000 accidents per year (1979-1986 Approximately 75 accidents per year involve hazardous materials	Presence or absence of hazardous cargo (no indication of whether hazardous cargo was released)	Truck type Other vehicles involved Accident type and manner of collision Accident severity Type of roadway location Environmental conditions Travel speed First harmful event Most harmful event Fire occurrence	Data are based on police reports and independent investigations by PSU teams Data for truck accidents tend to be incomplete No corresponding exposure data No data on trucks for 1987 and later years
FHWA Motor Carrier Accident Reports (USDOT/FHWA/OMC)	Accidents involving vehicles of regulated interstate motor carriers	Approximately 30,000-40,000 accidents per year (1973-present)	Presence or absence of hazardous cargo Principal type of cargo Occurrence of hazardous material spillage	Truck type Other vehicles involved Accident type and manner of collision Accident severity Highway type and No. of lanes Environmental conditions Driver condition Fire/explosion occurrence	Restriction of data base to regulated interstate carriers creates a sample that is not nationally representative Self-reported data from carriers are not verified from independent sources FHWA estimates 20% to 40% unreported accidents No corresponding exposure data

Table 17. Summary of existing accident, incident, and exposure data bases. (continued)

Data base/agency	Type of data base	No. of records	Hazardous materials factors	Related factors	Comments
ACCIDENT DATA BASES (Concluded)					
State traffic accident records systems	Accident data assembled from police and motorist report forms	Over 6 million accidents per year in all 50 States	15 States identify presence of hazardous material in accident-involved vehicles. Only Louisiana, Missouri, and Wyoming identify whether or not hazardous materials were released	Truck type Other vehicles involved Accident type and manner of collision Accident severity Type of roadway location Environmental conditions Travel speed First harmful event Contributing circumstances	Different data format for each State Many accidents not reported Accident reporting thresholds vary
INCIDENT DATA BASES					
Hazardous Materials Incident Reports (USDOT/RSPA/OMHT)	Incidents involving unintentional release of hazardous materials	7,900 incidents per year (1971-present) About 10% of releases are due to traffic accidents	Type of hazardous materials involved Quantity released Type of container and packaging Nature of packaging failure	Type of vehicle or facility Persons injured or killed Property damage	Incidents and accidents are clearly underreported Nontransportation-related incidents are included (e.g., truck terminals, loading docks, etc.) Self-reported data from carriers are not verified from independent sources
EPA Spill Reports	Incidents involving unintentional release of hazardous materials	-	Verbal description of nature of emergency, type of material spilled, and volume spilled	Location Type of source (motor vehicle/other) Nature of response	Many nontransportation-related releases are included Based on self-reported data from shippers, carriers, or owners Computerized only in some EPA regions
State spill reporting systems	Incidents involving unintentional release of hazardous materials	-	Type of hazardous materials involved Nature of response action Nature of cleanup action	Location Persons injured or killed Property damage	Systems of this type are operated by environmental or transportation agencies in some States
Canadian data	Incidents involving unintentional release of hazardous materials in all Canadian provinces	Approximately 500 incidents per year	Type of hazardous materials involved Quantity released	Persons injured or killed Property damage	Nontransportation-related incidents are included (e.g., truck terminals, loading docks, etc.) Self-reported data from carriers are not verified from independent sources

Table 17. Summary of existing accident, incident, and exposure data bases. (continued)

Data base/agency	Type of data base	No. of records	Hazardous materials factors	Related factors	Comments
EXPOSURE DATA BASES					
TIUS-Truck Inventory and Use Survey (Bureau of the Census)	Survey of a sample of truck owners in all 50 States	Approximately 84,000 truck records in 1982 survey	Percentage of time the truck was used to haul hazardous materials Type of hazardous materials hauled	Truck miles per year Percentage of mileage in home State Truck size and characteristics Operator class Range of operation	Conducted every 5 years (1977 and 1982) 1982 TIUS has smaller sample size than 1977 TIUS Many incomplete results, especially at State level
CTS-Commodity Transportation Survey (Bureau of the Census)	Survey of transportation modes used by a specific sample of companies to ship specific commodities	Approximately 16,000 records in 1977 survey	Type of commodity shipped	Mode of transport Weight of shipment Origin region Destination region	Multimodal data base includes highway, rail, air, and water Data base can be used to determine percentage of particular hazardous materials shipped by particular modes Data base is limited to particular commodities It is not always possible to identify hazardous materials shipments in the data base. Only shipments from manufacturer to first destination are included. Responses are voluntary; approximately 20% nonresponse rate may introduce biases
FHWA Motor Carrier Census (USDOT/FHWA/OMC)	Census of operations by individual motor carriers	Approximately 250,000 motor carrier records	Type of hazardous materials carried Container type used for each USDOT hazardous material class	Home State States served Carrier classification Types of commodities carried Miles operated Number of drivers Numbers of trucks, tractors, and trailers	
Canadian data	Survey of a sample of specific shipments	Approximately 8,000 shipment records in 1984 survey of for-hire trucking	Type of hazardous materials carried Quantity of hazardous materials carried	Distance traveled Revenue received	Includes separate surveys of for-hire and private trucking in Canada Does not include local shipments (under 25 km) or transborder shipments to/from the U.S.

Table 18. Variables included in selected accident and incident data bases.

Variable	FHWA Motor Carrier Accident Reports	State accident data bases	RSPA Hazmat Incident Reporting System	EPA and State hazmat spill reporting systems	Canadian hazmat incident reporting system
Frequency of accidents involving a hazmat truck	X	1/			
Frequency of incidents involving a hazmat release			X	X	X
Accident/incident consequences					
Fatalities	X	X	X		X
Injuries	X	X	X		X
Property damage amount	X	X	X		X
Hazmat release	X	2/	X	X	X
Quantity released			X	X	X
Fire	X	X	X		X
Explosion	X	X	X		X
Evacuation			3/		X
Type of truck involved					
Single-unit/articulated truck	X	X4/			5/
Number of trailing units	X	X4/			5/
Cargo area configuration (van/flatbed/tanker/etc.)	X	X4/	6/		5/
Incident cause					
Traffic accident/other cause			X		5/
Type of other cause			X		5/
Shipment data					
Type of hazardous material transported/released	X	1/	X	X	X
Origin of shipment			X		X
Destination of shipment			X		X
Type of container or packaging			X		X
Geographic location					
Exact location (e.g., milepost)		X		X	
County		X		X	
State/province	X	X	X	X	X
Highway type					
On-highway/off-highway	X	7/	8/	X	X
Freeway/non-freeway		9/		9/	
Number of lanes	X	X			
Divided/undivided	X	X			
Location on highway system					
Urban/rural	10/	X			X
Tangent/curve		X			
Intersection/non-intersection	X	X			
Interchanges or ramps	X	X			
Railroad grade crossings	X	X	X		

Table 18. Variables included in selected accident and incident data bases. (continued)

Variable	FHWA Motor Carrier Accident Reports	State accident data bases	RSPA Hazmat Incident Reporting System	EPA and State hazmat spill reporting systems	Canadian hazmat incident reporting system
Accident type and manner of collision					
Number of vehicles involved (single-vehicle/multiple-vehicle)	X	X	X		
Collision/non-collision	X	X	X		
Type of collision (head-on/rear-end/angle)	X	X	X		
Object struck		X			
Time of accident/incident					
Year	X	X	X	X	X
Month	X	X	X	X	X
Date within month	X	X	X	X	X
Day of week	X	X	X	X	X
Time of day	X	X	11/		X
Day/night	X	X			
Lighting condition	X	X			
Pavement surface condition (Dry/wet/ice and snow)	X	X			
Emergency response data Agencies responding				X	X

Notes:

1 Available in 15 States.
2 Available in 4 States.
3 New data item being added to RSPA data.
4 Adequacy of coding schemes varies between States.
5 Available in narrative only.
6 Available only for some types of incidents (e.g., tank truck overturning).
7 All accidents are on-highway.
8 Can be determined from available data for approximately 87% of incidents.
9 Can be determined from location or data milepost.
10 Coded as residential, business, or urban area.
11 Included on reporting form but apparently not included in computerized data.

The data included in NASS for these cases are very similar to FARS. There is no indication in the computerized data whether a hazmat release occurred and whether or not any of the fatalities and injuries in the accident were related to the hazmat release. Because of the available sample size and the lack of detail concerning hazmat involvement in each accident, the NASS data are not very useful for safety evaluation of highway transportation of hazardous materials. Furthermore, NASS was revised in 1987 to collect data on passenger-carrying vehicles only. Therefore, present and future NASS data is not applicable to hazardous materials transportation.

3. FHWA Motor Carrier Accident Reports

The FHWA Office of Motor Carriers (formerly the Bureau of Motor Carrier Safety) maintains a data base of accident reports filed by regulated interstate motor carriers.[33] The FHWA data base is invaluable as a nationwide picture of safety in the trucking industry. The key variables included in the data base have been identified in table 18. The FHWA Motor Carrier Accident Reports provide the only national data base that can be used to examine the frequency and distribution of truck accidents that resulted in a hazmat release, in comparison to accidents involving hazmat-carrying trucks and truck accidents, in general. Some of the key findings concerning the proportion of accidents involving hazmat-carrying vehicles that result in a release in section V of this report are based on the FHWA Motor Carrier Accident Reports.

Two important disadvantages of this data base should be noted. First, while nationwide in scope, the data do not include all truck accidents, but only those of regulated interstate motor carriers and intrastate carriers of Hazard Class ORM-E materials. Second, the FHWA accident data are dependent on self-reporting by carriers. Because of the self-reporting nature of the system, there is likely to be underreporting of accidents to FHWA. One previous study noted that the percentage of property-damage-only accidents is substantially smaller in the FHWA data than in data on police-reported accidents from the NASS, indicating that minor accidents are probably underreported to FHWA.[28] The property damage threshold for reporting truck accidents to FHWA was $2,000 for the entire period covered by this report. As of January 1, 1986, the reporting threshold has been raised to $4,200.

4. State Traffic Accident Records System

Each of the 50 States maintains an automated traffic accident records system containing data from police accident reports and, in some cases, accident reports filed by motorists. In most States, both State and local police agencies contribute data to this system. The key variables from State traffic accident records systems that are often used in hazmat transportation safety analyses have been listed in table 18.

The police report forms of the 50 States have been reviewed in the NHTSA publication, "State Accident Report Forms Catalogue 1985."[75] The review found that the police accident report forms of 15 States indicate whether or not hazmat-carrying vehicles were involved in each reported accident. These States are Alabama, California, Florida, Illinois, Kansas, Louisiana, Maine, Minnesota, Missouri, New Hampshire, New York, Ohio, Pennsylvania, South

Carolina, and Wyoming. The Pennsylvania accident report form has the most complete description of the type of hazardous materials involved in each accident, including both a hazard class and a placard number.

In 13 of these 15 States, the data on the police report forms clearly distinguish which of the accident-involved vehicles were (and were not) carrying hazardous materials. However, in only 3 of these 15 States, is it possible to determine whether a hazmat release resulted from the accident. These States are Louisiana, Missouri, and Wyoming. The police accident report for a 16th State, South Dakota, does not indicate whether hazmat-carrying vehicles were involved in the accident, but does indicate whether a hazmat release occurred. While only the police accident forms in all of these States have been reviewed, it is assumed that all of the hazmat data items coded by police officers are retained in each State's computerized accident records system.

5. Critique of Available Accident Data

The utility of the available accident data for hazmat transportation safety analyses is limited by the small amount of hazmat data available in computerized accident records. In 34 States, there is no hazmat data at all in the traffic accidents records system. In an additional 13 States, the accident records system contains data on either the involvement of hazmat-carrying vehicles, the occurrence of a hazmat release, or both in each accident. Only 3 States have data on both of these key variables in their traffic accident records systems.

State interest in hazmat transportation issues is increasing. In the future, States that add hazmat involvement data to their police accident report forms should be encouraged to include both involvement of hazmat-carrying vehicles and occurrence of a hazmat release. States that have included only one of these variables in their accident records systems should be encouraged to include both. States should also be encouraged to add data on the type of hazardous materials being transported.

The FHWA Motor Carrier Accident Reports already contain data on both involvement of hazmat-carrying vehicles and involvement of hazmat releases. Thus, the FHWA data base does not need to be improved in this respect.

Another element of State traffic accident records systems that needs improvement is the coding scheme for truck types. In the flurry of interest in truck safety analyses that followed the passage of the 1982 Surface Transportation Assistance Act (STAA), many States found that their accident coding schemes were unable to distinguish clearly between the various types of trucks. At a minimum, two key variables are needed for hazmat transportation safety analyses -- truck configuration and cargo area configuration. The coding of truck configuration should, at a minimum, distinguish between the following types of trucks:

- Single-unit or straight trucks.
- Tractor-semitrailer combination trucks (singles).
- Straight truck with full trailer.

- Tractor-semitrailer-full trailer combination trucks (double).
- Tractor-semitrailer-full trailer-full trailer combination trucks (triples).

The data needed for cargo area configuration should, at a minimum, distinguish between vans, flatbeds, tankers, and bulk solid carriers. Many State accident records systems have been improved in the last few years to include these distinctions between truck types. These distinctions between truck types can also be made correctly in the FHWA Motor Carrier Accident Reports.

Finally, there is a need for better coordination between traffic accident and hazmat incident records systems. When a hazmat release occurs as the result of a traffic accident, both types of data bases should cross-reference the record number or identifier in the other file so that data from both files can be used together as needed. This is particularly important because, as shown in table 18, hazmat incident records tend to omit many of the key truck accident variables, and vice versa.

C. Incident Data

The existing sources of data concerning hazmat incidents are reviewed here. These data sources include: the RSPA Hazardous Materials Incident Reporting System; the EPA Spill Reports; State hazmat incident reporting systems; and the Canadian dangerous occurrence reports. A critique of available hazmat incident data is presented and possible new sources of hazmat incident data are described.

1. RSPA Hazardous Materials Incident Reporting System

The following discussion presents an overview of the RSPA Hazardous Materials Incident Reporting System (HMIR) and addresses the problem of underreporting of hazmat incidents to this system.

a. Overview: A highway-related hazardous materials incident is an unintentional release of a hazardous material during or in connection with its transportation by highway. Hazmat incidents in all modes, including highway transportation, are required by law to be reported to the RSPA HMIR by all carriers engaged in interstate transportation.[93] RSPA receives nearly 5,000 reports of highway-related hazmat incidents each year. Except for incidents involving hazardous substances or hazardous wastes classified under 49 CFR in Hazard Class ORM-E, carriers engaged solely in intrastate transportation are not required to report hazmat incidents to RSPA. It is not clear how many incidents that occur are not reported for this reason.

There is no minimum quantity released or minimum property damage threshold for reporting hazmat incidents to RSPA. Any incident, no matter how small, is technically reportable if the hazardous material escapes from its container. It is not necessary for the hazardous material to escape from the vehicle. The only exceptions to this general rule are small-quantity releases of electric battery acid, certain paint products, and materials in Hazard Class ORM-E.

The RSPA reporting requirements are in the process of being expanded to include incidents in which a highway is closed for 1 hour or more or persons are evacuated from the vicinity of a potential incident site, even if no hazmat release occurs. There have been instances in which an overturned truck carrying hazardous materials caused a major highway to be closed for many hours and the surrounding population to be evacuated because of the possibility of a release. Such incidents will now be reportable to RSPA even if no release occurs. The revised HMIR report form will also distinguish explicitly between incidents that occur en route during transportation and incidents that occur in terminal and loading areas.

b. Underreporting problems: The RSPA HMIR data are based entirely on self-reporting by carriers. The self-reporting nature of the system undoubtedly leads to underreporting of incidents, but the level of underreporting is uncertain.

A 1986 study by the Office of Technology Assessment[85] (OTA) raised substantial concern about the level of underreporting to the RSPA HMIR. OTA compared the RSPA data for 1 year (1983) to the FHWA Motor Carrier Accident Reports for the same year and compared the HMIR data to accidents investigated by the National Transportation Safety Board (NTSB) over a longer period. Unfortunately, the OTA analysis appears to be based on misinterpreted data, at least as far as the comparison of the RSPA and FHWA data is concerned.

Table 19 presents a comparison of the RSPA and FHWA data for 1983 that appeared in table 2-16 of the OTA report. The table asserts that there were 1,602 hazmat vehicular accidents reported to FHWA and "approximately" 211 reported to RSPA. There were, in fact, 1,602 hazmat vehicular accidents reported to FHWA in 1983, but this is the total number of accidents involving hazmat-carrying vehicles. Only 282 of these accidents (276 definite and 6 probable) involved a hazmat release. The remaining accidents did not involve a hazmat release and, thus, were not required to be reported to the HMIR. The number of hazmat releases resulting from traffic accidents reported to the HMIR in 1983 is also incorrect in table 19. There were not "approximately" 211 releases, but exactly 300. These 300 releases were the result of 268 distinct accidents (i.e., some accidents released more than one material).

A corrected version of table 19 is presented as table 20. Only 130 of the traffic accidents shown in the table are common between the reporting systems. The remaining accidents (152 for RSPA and 138 for FHWA) were reported to one reporting system and not to the other.

A comparison of deaths, injuries, and property damage in the RSPA and FHWA data files, drawn from table 2-17 of the OTA report, is presented in table 21.[85] The comparisons of the two data bases for the numbers of deaths, injuries, and property damage in tables 19, 20, and 21 are all misleading because the FHWA and RSPA data bases use different reporting requirements. All deaths and injuries from accidents to motor carriers in interstate

Table 19. Comparison of FHWA motor carrier accident data with RSPA Hazmat Incident Reporting System (HMIR) for 1983.[85]

Category	FHWA	RSPA
Number of vehicular accidents	1,602	Approximately 211[a]
Injuries	1,479	Maximum 121
Deaths	154	Maximum 8
Average property damage per accident	$16,800	Approximately $1,534

[a] Approximation is based on the total number of highway incidents for 1983 multiplied by the percentage of incidents which are the result of vehicular accidents (4.5%).

Table 20. Comparison of FHWA motor carrier accident data with RSPA Hazmat Incident Reporting System (HMIR) for 1983 (corrected).

Category	FHWA	RSPA
Number of vehicular accidents	282	268
Injuries	249	6
Deaths	28	5
Average property damage per accident	$30,650	$20,540

Table 21. Misreporting of consequences in RSPA hazmat incident data in comparison to FHWA motor carrier accident data for 1983.[85]

Source	Number of matching incidents	Deaths	Injuries	Property damage
FHWA Motor Carrier Accident Reports	502	50	490	$10,077,004
RSPA Hazmat Incident Reporting System (HMIR)	502	5	59	4,404,000

commerce are reportable to FHWA, while only deaths and injuries that are directly due to a hazardous materials release are reportable to RSPA. The same interpretation probably holds for property damage from hazmat incidents reported to RSPA, but this point is not clear from the instructions for completing the hazmat incident report.[93]

Table 21 is also incorrect in another way. The table purports to show 502 "matching incidents" between the FHWA and RSPA files for 1983, which is not possible since there were only 282 accidents reported to FHWA and 268 accidents reported to RSPA. The problem lies primarily in the criteria used for matching. The OTA report states on p. 77 that only three common fields exist for the two data bases: year, month, and State of release.[85] The report states that, because of this, incidents occurring at different locations in the same State or on different days during the same month might be erroneously matched. In fact, there are several additional common fields that could be used for matching including the day of the month, the name of the city where the accident occurred, the name of the carrier, and the type of hazardous material transported.

A review of the two files produced the following results:

- Of 282 highway accidents in the FHWA file for 1983 that resulted in a hazmat release, 130 (or 46 percent) were found in the RSPA file and 152 (or 54 percent) were not.
- Of 268 highway accidents in the RSPA file for 1983 that resulted in a release of at least one hazardous material, 130 (or 49 percent) were found in the FHWA data base and 138 (or 51 percent) were not.

If is not clear to what extent accidents reported to FHWA and not reported to RSPA, or vice versa, represent noncompliance by carriers since the reporting requirements for the two data bases differ.

Table 22 presents a corrected version of table 21. The table shows the number of fatalities and injuries that resulted from the 130 matching incidents in the FHWA and RSPA data bases for 1983. The 130 cases common to both files involved a total of 10 fatalities and 109 injuries. However, only two of these fatalities and four of these injuries had causes that were attributed to the release (by being reported on the RSPA form). Although the available accident sample size is very small, these data suggest that in accidents in which there was a release, about 80 percent of the fatalities and 95 percent of the injuries that occur are not due to the release.

Table 22. Comparison of consequences of hazmat accidents reported to both FHWA and RSPA (corrected).

Source	Number of matching incidents	Deaths	Injuries
FHWA Motor Carrier Accident Reports	130	10	109
RSPA Hazmat Incident Reporting System (HMIR)	130	2	4

Finally, the OTA report cites four "notable" accidents, which appeared in the FHWA file and not in the RSPA data, as evident of underreporting. The accidents occurred in:

- Highland Park, Illinois, on March 22, 1983, killing one, injuring four, and causing $120,000 in damages.
- Kemmerer, Wyoming, on April 7, 1983, killing five, injuring two, and causing $26,500 in damages.
- Georgetown, Kentucky, on May 1, 1983, killing three, injuring nine, and causing $75,000 in damages.
- Hurricane, Utah, on November 21, 1983, killing three, injuring three, and causing $100,000 in damages.

In fact, according to the FHWA data base, none of these accidents should have been reported to RSPA. The Highland Park accident involved a fire in a truck that was not carrying hazardous materials. The remaining three accidents involved trucks that were carrying hazardous materials, but there is no indication that there was a hazmat release in any of the three accidents.

The conclusion drawn by OTA that there is substantial underreporting to RSPA is probably correct. However, the data presented by OTA in support of this conclusion have been misinterpreted and do not adequately quantify the degree of underreporting. It is likely that any data base dependent on voluntary reporting by carriers, including the FHWA data base, will experience underreporting. Any discrepancies between the RSPA and FHWA reporting systems could be easily resolved by greater exchange of data between these agencies. There is a greater need to quantify how many reportable accidents and incidents are not, in fact, reported to either agency.

2. EPA Spill Reporting System

The EPA requires incidents involving an unintentional release of hazardous materials to be reported. These reports include both transportation-related and nontransportation-related spills. Like other Federal and State reporting systems, the EPA data are dependent on self-reporting by shippers and carriers. The purpose of this system is to allow EPA to keep track of the incident and ensure that it is properly cleaned up. The data are primarily verbal descriptions of the incident, the location, and the material(s) involved. The extent of computerization of these data varies between EPA regions. Given the unstructured format of these data, they are unlikely to be useful for analysis of hazmat incident risks.

3. State Spill Reporting Systems

Many State environmental agencies also operate spill reporting systems similar in concept to the U.S. EPA system. These systems are generally based on reports from the shipper or carrier. Thus, this system is "spill-based," in that the spiller initiates the report. Existing systems in some States can now provide overall statistics on hazmat incident frequencies and, over time, more States are expected to develop incident reporting systems. State highway agencies, and public agencies that operate specific facilities such as toll roads, bridges, and tunnels, maintain records of incidents on their facilities that come to their attention, and these are reported to whatever State reporting system is in place.

The Illinois Department of Transportation has started a hazmat incident reporting system that is "response-based" rather than "spill-based." Response agencies (e.g., police agencies, fire departments, cleanup contractors, etc.) are encouraged to make voluntary reports of their activities in response to hazmat incidents whenever personnel and equipment are dispatched. Several response agencies may report each incident which increases the likelihood that at least one report on each incident will be received. Spillers are also encouraged to make voluntary reports to this system. The Illinois DOT system only started operation on January 1, 1987, so only 2 years of experience have been accumulated. However, this system shows promise of providing a more complete record of the hazmat incidents that occur than the systems of other States because of the wide variety of agencies that are encouraged to report to the system.

4. Canadian Data

Transport Canada, the Canadian equivalent of the U.S. Department of Transportation, operates a reporting system of dangerous occurrences in hazardous materials transportation (in other words, hazmat incidents).[110] Approximately 500 such reports are received each year, and the reporting system has been in place in its current form since 1985. The key variables included in the Canadian data are summarized in table 18. These data are potentially of interest to U.S. analysts because truck equipment and operating conditions in Canada are more similar to those in the United States than any other country, and because Canada also has a hazmat exposure data base that could potentially be analyzed together with these incident data.

5. Critique of Available Hazmat Incident Data

There are two key issues that need to be addressed to improve the quality of hazmat incident data. These are (1) increasing the proportion of incidents that are reported and (2) improving the linkage between incident and accident data.

Current hazmat incident data do not provide a complete picture of the magnitude of hazardous materials transportation safety problems. At both the Federal and State levels, incident reporting criteria should require all incidents to be reported. The distinction between incidents involving interstate and intrastate carriers is artificial and should be eliminated. Underreporting will be a problem in any voluntary system, but improved methods are needed to increase the proportion of incidents that are reported. The Illinois DOT reporting system that encourages reports from multiple agencies whenever response personnel or equipment is dispatched is a promising method for increasing the proportion of incidents that are reported.

Better linkage is needed between incident and accident data at both the Federal and State levels. The discussion in section V of this report documents that traffic accidents are the major cause of serious hazmat incidents. However, table 18 illustrates that the variables included in incident and accident data are quite distinct, and a complete picture of both the causes and consequences of particular incidents cannot be formed without both types of data. For example, incident data seldom provide specific information on the location of the incident or the truck configuration involved. Accident data seldom provide specific information on the specific material used. It is unrealistic to suppose that a substantial number of new variables can be added to either existing incident or accident reporting systems. Therefore, there needs to be a better link between these systems.

One method of providing a better linkage between incident and accident reporting systems is to include a field in each record system that cross-references the report number or record number of the incident in the other data base. This approach is equally applicable to the reporting systems maintained at the Federal level by RSPA and FHWA and the reporting systems that exist or will be developed in the future at the State level. Not only would this type of linkage allow analysts to access the accident data for particular incidents, but it would also provide a channel for the incident data bases to include available data on unreported incidents that occur in reported accidents. This approach might ultimately lead to a combined reporting system for accidents and incidents, where an incident report would be made on a supplementary form to the accident report. (Of course, provision would still have to be made for reporting of highway incidents not related to traffic accidents and for reporting of incidents in other modes of transportation.)

6. Potential New Sources of Hazmat Incident Data

There are no new potential sources of hazmat incident data. All hazmat incident data are likely to continue to be collected by either Federal or State agencies. However, there are some new potential sources of hazmat exposure data (toll roads, hazmat carriers, etc.) discussed in the next section of this report. Corresponding incident data for specific hazmat carriers or toll roads could be obtained from existing sources and used together with the exposure data from toll roads or hazmat carriers to develop measures of the risk of specific types of incidents.

D. Exposure Data

The existing and potential new sources of hazmat exposure data are reviewed here. The existing data sources include: the Truck Inventory and Use Survey; the Commodity Transportation Survey; the FHWA Motor Carrier Census; and Canadian data. A critique of available exposure data for hazmat transportation by highway is presented and possible new sources of hazmat exposure data are discussed.

1. Truck Inventory and Use Survey (TIUS)

The Truck Inventory and Use Survey is part of the Census of Transportation conducted once every 5 years by the Bureau of the Census.[14] The survey is based on a random sample of trucks selected from State registration records. Truck owners are sent a survey questionnaire to be completed describing the characteristics and use of that particular truck. One of the questions asked of truck owners is the percentage of time that that particular truck is used to carry hazardous materials. (Responses to the hazmat question are provided in five broad categories: 0 percent; below 25 percent; 25 percent to 49 percent; 50 percent to 74 percent; and 75 percent to 100 percent). The survey results are entered into a computer data base including appropriate expansion factors for use in making statewide and national estimates from the sample data.

The TIUS is virtually the only form of available exposure data that presents nationwide statistics on highway transportation of hazardous materials. The TIUS data can be used to estimate vehicle-miles of travel and ton-miles of materials shipped for generalized categories of materials and for specific types of trucks; however, the TIUS cannot provide exposure estimates for specific highway types. The 1977 TIUS data for hazardous materials transportation by highway were analyzed in the recent OTA study and an analysis of the 1982 TIUS data was performed in this study and is presented in section V of this report.

2. Commodity Transportation Survey (CTS)

The Commodity Transportation Survey is a survey of the transportation modes used by a sample of approximately 16,000 companies to ship specific commodities. The survey contains data on the types of commodities shipped, the mode of transportation, the shipment weight, and the origin and destination of the shipment. However, the CTS provides origin-to-destination flow data only on shipments from manufacturing plants to first destinations, missing the rest of the distribution chain and all nonmanufactured goods. The data base includes information on highway, rail, water, and air shipments and can be used to determine the proportion of particular hazardous materials that are shipped by specific modes. However, the data base is limited to particular commodities, and it is not always possible to identify hazardous materials shipments in the data. Since the survey includes only specific companies and specific commodities and does not contain any specific data on travel distances that could be used to compute vehicle-miles of travel or ton-miles of cargo shipped, it cannot provide reliable exposure data for hazardous materials transportation by highway.

3. FHWA Motor Carrier Census

The FHWA Motor Carrier Census includes data on the operation of approximately 250,000 individual motor carriers. The data base includes data on the types of trucks used, the types of hazardous materials carried, and the container types used to carry specific hazardous materials, but it cannot be used to obtain reliable estimates of exposure data, such as vehicle-miles or ton-miles.

4. Canadian Data

Transport Canada maintains an exposure data base on dangerous goods (hazardous materials) shipments in Canada. This data base is based on separate surveys of for-hire trucking and private trucking conducted by Statistics Canada at periodic intervals. The most recent survey was in 1984. The data are maintained in microcomputer data base files in dBASE III.

The for-hire trucking survey was conducted with firms earning more than $100,000 annually in intercity freight revenue. The survey consists of a representative sample of intercity shipments. Local shipments (defined as those of 25 km or less) are not included. Transborder shipments between Canada and the United States are also not included in the sampling scheme. Approximately 8,000 shipments or series of shipments were sampled in the most recent survey. Shipment origins and destinations can be identified by province and by specific metropolitan areas. These data could be used together with the Canadian incident data described above to perform hazmat risk analyses. The data can be used to determine exposure estimates by vehicle-miles and by ton-miles for specific materials, but cannot provide exposure estimates for specific truck types and highway types.

The Canadian incident and exposure data suffer from the same lack of correspondence as comparable U.S. government data bases. The incident and exposure data are collected independently, the incident data are probably subject to underreporting biases, and the exposure data are based on a relatively small sample from a large population of shipments.

5. Critique of Available Exposure Data

Exposure data are needed in hazmat accident and incident studies as a measure of the opportunities for accidents and incidents to occur. However, the available exposure data are collected independently of the available accident and incident data, through surveys that are not structured to provide corresponding data. The reporting requirements for hazmat accident and incident data and the criteria for inclusion in hazmat exposure surveys are not compatible. There is a need for hazmat exposure surveys to be conducted so that they correspond to the available accident and incident data.

Exposure data that can be broken down by all variables of interest are also needed. Hazmat exposure data can usually be broken down by type of material and sometimes by type of truck. However, highway type (freeway/non-freeway, number of lanes, divided/undivided) and area type (urban/rural) are key factors in predicting truck accident rates, and hazmat exposure data can seldom be broken down by highway type and area type.

The following discussion focuses on two potential new sources of hazmat exposure data intended to meet these needs more completely than existing data.

6. Potential New Sources of Hazmat Exposure Data

Two potential new sources of hazmat exposure data have been investigated in this study. These are toll road data and hazmat carrier data. Each of these sources holds promise of providing a better match with hazmat accident and incident data than has been possible in the past. However, each approach would require a substantial research effort to develop reliable exposure data and perform a valid hazmat risk study.

a. Toll road data: One potential source of hazmat exposure data that has not been fully utilized is data from toll roads and turnpikes. Collection of exposure data, such as vehicle-miles of travel or ton-miles shipped by specific truck types or for specific materials, is much simpler on toll roads and turnpikes than on other types of highways. The ticket-controlled portions of toll roads are best suited to exposure data collection because all vehicles entering or leaving the highway must pass through a toll barrier. A ticket is obtained by the driver at the entry point and is surrendered at the exit point along with payment of the toll. Thus, the ticket creates a record of the distance traveled by a specific vehicle that could be matched with data on the type of truck and type and quantity of material transported. Toll roads with this type of ticket-controlled operation are found in Florida, Indiana, Kansas, Maine, Massachusetts, New Jersey, New York, Ohio, Oklahoma, and Pennsylvania.

The feasibility of this type of study has been demonstrated. A study of truck accident rates on the ticket-controlled portions of four toll roads was recently conducted by the Insurance Institute for Highway Safety.[89] This study obtained data on distance traveled based on the entry and exit points shown on the toll tickets and data on truck type based on the vehicle classification systems used for toll collection purposes. (The vehicle classifications systems used by the four participating toll roads were compatible with the study objectives.)

Toll road authorities do not routinely record whether or not trucks using the facility are carrying hazardous materials or what specific material is being carried. Thus, cooperation of the toll road authority would be needed to collect data of this type from entering or exiting vehicles. A data collection effort of this type was recently conducted on the Pennsylvania

Turnpike. Placarded trucks carrying hazardous materials on the Pennsylvania Turnpike are required to have a permit purchased by their company from the turnpike authority. For a period of 6 months, placarded trucks showing a hazmat permit were given a card to complete including data on the entry point, exit point, type of truck, material transported, and quantity transported. Although these data have never been fully analyzed, they demonstrate the feasibility of this data collection approach.

Any data collection effort of this type would require the active cooperation of several toll road authorities. This cooperation could probably be obtained by working through the hazardous materials transportation committee of the International Bridge, Tunnel, and Turnpike Association (IBTTA), which has an active interest in this issue.

Data on hazmat accidents could be obtained through the toll road authority or through the police agency responsible for accident investigation on the facility. Data on hazmat incidents could be obtained through the toll road authority or through the State environmental agency. Federal data from the RSPA and FHWA reporting systems should be used to ensure that the available accident and incident data are as complete as possible. Because toll roads have regular police patrols, the available accident and incident data should be among the most reliable for any part of the highway system.

The only major drawback of a study of toll road data is that only one type of highway can be effectively studied -- divided highways with full access control. Most ticket-controlled toll roads are located in rural areas, although portions of the New Jersey and Pennsylvania Turnpikes are in heavily urbanized areas. However, within this limited class of highways, toll roads offer an excellent controlled environment within which to study hazmat accident and incident risks.

b. Hazmat carrier data: Another potential new source of exposure data for hazmat accident and incident risk analyses is from the internal records of hazmat carriers, including for-hire carriers and private carriers. Data from for-hire carriers would probably be more interesting than private carrier data, because for-hire carriers typically operate a wider variety of trucks and carry a wider variety of products.

Most for-hire trucking firms, including hazmat carriers, have computer systems to track individual shipments. These computer systems are typically large data bases in which each record represents a particular truckload or consignment. These records typically include most of the key variables needed for hazmat exposure analysis, including:

- Type of truck.
- Type of material shipped.
- Quantity of material shipped.
- Truck weight.
- Origin location.
- Destination location.
- Distance traveled.
- Departure time.

- Arrival time.
- Time en route.

Carriers use these data as the basis for generating shipment manifests, driver records, and customer billings.

Hazmat accident and incident data corresponding to the exposure data could be obtained from the carrier as well. In the case of an interstate carrier, these accidents and incidents have presumably already been reported to RSPA and FHWA. A key advantage of the use of carrier data over government data bases is the almost perfect match that can be obtained between hazmat accident, incident, and exposure data.

A study based on hazmat carrier data would require the active participation of several carriers. It would be desirable to involve a mix of carriers of different sizes that transport different types of materials. In structuring such a study, it should be recognized that any data obtained from carriers would have to be treated as confidential and carriers would need to be assured that this confidentiality would be maintained. The involvement of several carriers would ensure that the reported data could not be used to determine the safety records or business patterns of particular carriers.

As in the case of toll road studies, hazmat carrier studies cannot determine the role of highway type or area type in the risk of hazmat accidents and incidents. However, a carefully structured study based on carrier data could control for the effects of these variables and ensure that the risks of particular truck types or materials could be correctly determined. A recent study (reviewed in section II of this report) used such an approach to match accident data and exposure data for tractor-semitrailer and twin-trailer trucks.[40] This study, conducted for a major nationwide trucking firm, assembled accident data for trips between pairs of terminals for which the company used both types of trucks. Thus, the accident data sets for both kinds of trucks applied to trips on the same days, over identical routes, under identical conditions. Thus, disaggregating the data by origin-destination pairs can provide nearly perfect comparability of exposure between specific types of trucks or specific types of materials shipped.

V. ANALYSIS OF EXISTING DATA BASES

This section presents the results of an analysis of existing incident, accident, and exposure data bases.

A. Analysis of Hazmat Incident Data

The frequencies, causes, circumstances, and consequences of hazmat incidents have been characterized based on 5 years of data (1981-1985) from the RSPA Hazardous Materials Incident Reporting system (HMIR). The reporting requirements for this data base have been documented in section IV of the report.

1. Annual Incident Frequencies

Table 23 presents a summary of the hazmat incidents reported to RSPA in the years 1981 to 1985, inclusive. A total of 28,433 incidents was reported during this period. Two interesting observations can be made from the data in table 23. First, there was a major decrease in the frequency of reported hazmat incidents from 1981 to 1982. There was a change in the reporting requirements for hazmat incidents in 1981, so that small quantity spills of battery acid and paint no longer need to be reported.

Table 23. Annual hazmat incident frequencies by type of location, 1981-1985.

Type of location	1981	1982	1983	1984	1985	Total
On-highway	3,914	2,663	2,325	2,417	2,228	13,547 (47.6%)
Off-highway	3,476	2,230	2,041	1,475	1,955	11,177 (39.3%)
Unknown	1,275	766	504	610	554	3,709 (13.1%)
TOTAL	8,665	5,659	4,870	4,502	4,737	28,433

Second, it should be noted that only a portion of the incidents in table 23 occurred during transportation on public highways. It is not always possible to distinguish clearly between on-highway and off-highway incidents in the RSPA data. However, the following types of incidents can be presumed to occur on the highway:

- Incidents caused by a traffic accident.
- Incidents caused by cargo shifting or damage by other freight.

- Incidents that occurred in a different city and/or State than either the origin or the destination of the shipment.

- Incidents in which the city or State where the incident occurred is unknown.

The following types of incidents can be presumed to occur off the highway:

- Incidents involving loading or unloading.

- Incidents involving material dropped in handling.

- Incidents involving external puncture not caused by a traffic accident.

The location of incidents that do not fit any of the above definitions cannot be presumed.

Table 23 shows that 39 percent of hazmat incidents occur at locations off of public highways, such as terminals or shipping yards. Approximately 48 percent of hazmat incidents occur on the highway, and the location of the remaining 13 percent of incidents cannot be determined.

Hazmat incidents that do not occur on public highways are not of direct concern to highway agencies, because these incidents could not involve a release onto a highway right-of-way. Therefore, the 11,117 off-highway incidents and the 3,709 unknown location incidents in table 23 have been excluded from the subsequent analyses in this report. The subsequent analyses address only the 13,547 incidents that one can be reasonably sure did occur on public highways.

2. Causes of Hazmat Incidents

Table 24 presents the distribution of hazmat incidents by the type of failure that occurred. The major failure types are body or tank failures (20 percent), valve or fitting failures (24 percent), and cargo shifting (37 percent).

Traffic accidents were found to constitute approximately 11 percent of all hazmat incidents. This is a higher proportion of traffic accidents than reported in previous studies, because off-highway incidents have been excluded from the data.[85]

Severe incidents are of greatest concern in the management of hazardous materials transportation safety. There is no commonly accepted definition of what constitutes a severe incident. Table 24 illustrates the distribution of failure types in on-highway hazmat incidents for progressively less restrictive definitions of incident severity ranging from "death only" to "all reported incidents." The severe nature of unintentional releases of hazardous

Table 24. Distribution of on-highway hazmat incidents by failure type and incident severity, 1981-1985

Failure type	Death only No.	Death only %	Death or injury No.	Death or injury %	Death or injury or explosion No.	Death or injury or explosion %	Death or injury or explosion or fire No.	Death or injury or explosion or fire %	Death or injury or explosion or fire or property damage over $100K No.	Death or injury or explosion or fire or property damage over $100K %	Death or injury or explosion or fire or property damage over $50K No.	Death or injury or explosion or fire or property damage over $50K %	Death or injury or explosion or fire or property damage over $10K No.	Death or injury or explosion or fire or property damage over $10K %	All reported incidents No.	All reported incidents %
Traffic accident	32	(91.4)	107	(35.5)	112	(34.7)	188	(41.7)	233	(46.4)	355	(56.1)	723	(68.1)	1,427	(10.8)
Body or tank failure	0	(0.0)	37	(12.3)	38	(11.8)	40	(8.9)	42	(8.4)	42	(6.6)	63	(5.9)	2,741	(20.2)
Valve or fitting failure	0	(0.0)	86	(28.6)	88	(27.2)	101	(22.4)	101	(20.1)	104	(16.4)	112	(10.5)	3,289	(24.3)
Cargo shifting	0	(0.0)	39	(13.0)	44	(13.6)	52	(11.5)	52	(10.4)	54	(8.5)	70	(6.6)	4,945	(36.5)
Fumes or venting	0	(0.0)	2	(0.7)	2	(0.6)	2	(0.4)	2	(0.4)	2	(0.3)	2	(0.2)	15	(0.1)
Other	3	(8.6)	30	(10.0)	39	(12.1)	68	(15.1)	72	(14.3)	76	(12.0)	92	(8.7)	1,100	(8.1)
TOTAL	35		301		323		451		502		633		1,062		13,547	

materials in traffic accidents can be clearly seen in table 24. Note that although traffic accidents constitute just 11 percent of all reported incidents, they constitute 35 percent to 68 percent of the severe incidents, depending on the definition selected for severe incidents. In the 35 incidents in which a fatality occurred due to a release, over 90 percent (32 incidents) were caused by traffic accidents.

Valve or fitting failure is the second leading failure type in these various definitions of severe incidents. Valve or fitting failures, which constituted 24 percent of all incidents, were attributed to 29 percent of the incidents that resulted in deaths or injuries and lesser percentages of other severity level definitions. No other failure type accounted for more than 14 percent of the severe incidents for any of the severity levels examined. Thus, regardless of the definition selected for a severe incident, traffic accidents account for a much more important part of the hazardous materials highway safety problem than is suggested by overall release statistics.

For purposes of the tables that follow in this analysis, severe incidents have been defined as those that involve either (1) a fatality or injury caused by the hazmat release; (2) property damage of $50,000 or more caused by the hazmat release; or (3) a fire or explosion. Table 24 shows that, by this definition, traffic accidents constitute 56 percent of severe incidents. In fact, nearly a quarter of traffic accidents that cause a hazmat release result in a severe incident.

The general causes of hazmat accidents are summarized in table 25. Approximately 50 percent of incidents are attributable to human error and 35 percent of incidents to package failure. Previous analyses of the RSPA data base have indicated that, overall, human error is responsible for over 60 percent of hazmat incidents. The lower proportion of hazmat incidents attributable to human error and the higher proportion of incidents attributable to package failure in table 25 occur because human error predominates in off-highway loading/unloading incidents, which have been excluded from the analysis. It should be noted that the literature suggests driver error as a significant cause of traffic accidents; thus, in this sense, "human error" is ultimately responsible for a large portion of the traffic accidents shown in table 25. When the analysis shown in table 25 is limited to severe incidents, traffic accidents dominate, of course, as they did in table 24. However, in severe incidents not caused by traffic accidents, package failure is actually a larger cause of severe incidents than human error.

3. Type of Hazardous Material Involved

Table 26 presents the distribution of the type of hazardous material released in hazmat incidents. Where more than one hazardous material was released in a single incident, the incident was classified on the basis of the primary material released (listed first in the RSPA data file).

Table 26 shows that the predominant hazardous materials released are flammable and combustible liquids (46 percent) such as gasoline, and corrosive materials (40 percent). Poisonous gases and liquids constitute 5 percent of all releases. No other single hazard class constitutes more than 3 percent of releases.

Table 25. Distribution of on-highway hazmat incidents by cause of release, 1981-1985.

Cause of release	All reported incidents No.	All reported incidents %	Severe incidents only No.	Severe incidents only %
Traffic accident	1,457	(10.8)	355	(56.1)
Human error	6,845	(50.5)	101	(16.0)
Package failure	4,691	(34.6)	128	(20.2)
Other	550	(4.1)	49	(7.7)

Table 26. Distribution of on-highway hazmat incidents by material released, 1981-1985.

	All reported incidents						Severe incidents only					
	Total		Incidents caused by traffic accidents		Incidents due to other causes		Total		Incidents caused by traffic accidents		Incidents due to other causes	
Material released	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
ORM -- Class A	103	(0.8)	11	(0.8)	92	(0.8)	2	(0.3)	2	(0.6)	0	(0.0)
ORM -- Class B	10	(0.1)	3	(0.2)	7	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)
ORM -- Class C	25	(0.2)	15	(1.0)	10	(0.1)	2	(0.3)	2	(0.6)	0	(0.0)
ORM -- Class D	11	(0.1)	0	(0.0)	11	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)
ORM -- Class E	184	(1.4)	38	(2.6)	146	(1.2)	12	(1.9)	7	(2.0)	5	(1.8)
Organic peroxide	115	(0.8)	0	(0.0)	115	(1.0)	5	(0.5)	0	(0.0)	5	(1.8)
Blasting agent	9	(0.1)	6	(0.4)	3	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Combustible liquid	599	(4.4)	327	(22.4)	272	(2.3)	77	(12.2)	64	(18.0)	13	(4.7)
Flammable liquid	5,667	(41.9)	702	(48.2)	4,965	(41.1)	268	(42.3)	214	(60.3)	54	(19.4)
Flammable solid	91	(0.7)	8	(0.5)	83	(0.7)	9	(1.4)	1	(0.3)	8	(2.9)
Oxidizer	396	(2.9)	28	(1.9)	368	(3.0)	25	(3.9)	3	(0.8)	22	(7.9)
Nonflammable compressed gas	142	(1.0)	33	(2.3)	109	(0.9)	19	(3.0)	7	(2.0)	12	(4.3)
Flammable compressed gas	136	(1.0)	47	(3.2)	89	(0.7)	27	(4.3)	16	(4.5)	11	(4.0)
Poisonous gas or liquid A	9	(0.1)	0	(0.0)	9	(0.1)	2	(0.3)	0	(0.0)	2	(0.7)
Poisonous gas or liquid B	635	(4.7)	31	(2.1)	604	(5.0)	26	(4.1)	4	(1.1)	22	(7.9)
Irritating material	8	(0.1)	0	(0.0)	8	(0.1)	1	(0.2)	0	(0.0)	1	(0.3)
Radioactive material	36	(0.3)	9	(0.6)	27	(0.2)	3	(0.5)	1	(0.3)	2	(0.7)
Explosive -- Class A	4	(0.0)	3	(0.2)	1	(0.0)	1	(0.2)	1	(0.3)	0	(0.0)
Explosive -- Class B	4	(0.0)	0	(0.0)	4	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Explosive -- Class C	12	(0.1)	4	(0.3)	8	(0.1)	4	(0.6)	1	(0.3)	3	(1.1)
Corrosive material	5,345	(39.5)	192	(13.2)	5,153	(42.6)	150	(23.7)	32	(9.0)	118	(42.4)
TOTAL	13,541		1,457		12,084		633		355		278	

Table 26, and subsequent tables, break down the distribution for all hazmat incidents into incidents caused by traffic accidents and incidents due to other causes. These data indicate that flammable and combustible liquids constitute 71 percent of the releases due to traffic accidents, as opposed to 46 percent of all incidents. By contrast, corrosive materials account for only 13 percent of the releases in traffic accidents, but 43 percent of releases due to other causes. Thus, it appears that corrosive materials, by their nature, are much more likely to produce a valve, fitting, or container failure than other placarded materials.

Table 26 also shows the distribution of severe hazmat incidents by type of material released. About 55 percent of severe incidents involve flammable and combustible liquids, as compared to 46 percent of all incidents. Thus, flammable and combustible liquids are overrepresented in severe incidents as compared to total incidents. The opposite appears to be true of corrosive materials. Corrosive materials are involved in 24 percent of severe incidents, as compared to 40 percent of all incidents.

4. Temporal and Geographic Patterns

a. Month: Table 27 presents the distribution of hazmat incidents months of the year. The table shows that the relative proportion of hazmat incidents is highest in summer months and lowest in winter months. This probably reflects seasonal trends in hazmat shipment volumes. Interestingly, the distribution of hazmat incidents due to traffic accidents is more constant from month-to-month and does not show the marked seasonal trend found in the distribution of incidents due to other causes.

b. Time of day: Data are not available to construct a distribution of hazmat incidents by time of day similar to time of day distributions that can be assembled for traffic accidents. The time of a traffic accident is generally determined to within a few minutes by a police investigation. By contrast, a hazmat release may occur during transportation and not be discovered until the truck reaches its destination. Thus, a precise time of day for the incident often cannot be determined.

c. Geographic location: Table 28 presents the distribution of hazmat incidents by regions of the United States. For consistency, table 28 uses the same regions used in the recent Office of Technology Assessment study.[5,6] These regions are illustrated in figure 15. The predominant regions of the United States for hazmat incidents are the Middle Atlantic, South Atlantic, and East North Central (Great Lakes) States.

The hazmat incident frequencies by State in the 10 highest States are presented in table 29.

Table 27. Distribution of on-highway hazmat incidents by month, 1981-1985.

Month	All reported incidents						Severe incidents only					
	Total		Incidents caused by traffic accidents		Incidents due to other causes		Total		Incidents caused by traffic accidents		Incidents due to other causes	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
January	967	(7.1)	135	(9.3)	832	(6.9)	51	(8.1)	36	(10.1)	15	(5.4)
February	1,021	(7.5)	135	(9.3)	886	(7.3)	43	(6.8)	28	(7.9)	15	(5.4)
March	1,130	(8.3)	100	(6.9)	1,030	(8.5)	48	(7.6)	24	(6.8)	24	(8.6)
April	1,263	(9.3)	113	(7.8)	1,150	(9.5)	48	(7.6)	23	(6.5)	25	(9.0)
May	1,215	(9.0)	111	(7.6)	1,104	(9.1)	59	(9.3)	31	(8.7)	28	(10.1)
June	1,351	(10.0)	120	(8.2)	1,231	(10.2)	57	(9.0)	34	(9.6)	23	(8.3)
July	1,380	(10.2)	134	(9.2)	1,246	(10.3)	60	(9.5)	33	(9.3)	27	(9.7)
August	1,447	(10.7)	122	(8.4)	1,325	(11.0)	63	(10.0)	33	(9.3)	30	(10.8)
September	1,185	(8.7)	113	(7.8)	1,072	(8.9)	51	(8.1)	24	(6.8)	27	(9.7)
October	1,108	(8.2)	130	(8.9)	978	(8.1)	63	(10.0)	35	(9.9)	28	(10.1)
November	811	(6.0)	120	(8.2)	691	(5.7)	43	(6.8)	29	(8.2)	14	(5.0)
December	669	4.9)	124	(8.5)	545	(4.5)	45	(7.4)	25	(7.0)	22	(7.9)
TOTAL	13,547		1,457		12,090		633		355		278	

Table 28. Distribution of on-highway hazmat incidents by region, 1981-1985.

Region	All reported incidents						Severe incidents only					
	Total		Incidents caused by traffic accidents		Incidents due to other causes		Total		Incidents caused by traffic accidents		Incidents due to other causes	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
New England	309	(2.3)	44	(3.0)	265	(2.2)	30	(4.8)	15	(4.2)	15	(5.4)
Middle Atlantic	2,164	(16.0)	160	(11.0)	2,004	(16.7)	93	(14.7)	49	(13.8)	44	(15.9)
South Atlantic	2,068	(15.3)	219	(15.1)	1,849	(15.4)	109	(17.3)	61	(17.2)	48	(17.3)
East North Central	2,617	(19.4)	177	(12.2)	2,440	(20.3)	79	(12.5)	38	(10.7)	41	(14.8)
East South Central	1,163	(8.6)	110	(7.6)	1,053	(8.8)	40	(6.3)	22	(6.2)	18	(6.5)
West North Central	1,785	(13.2)	166	(11.4)	1,619	(13.5)	56	(8.9)	31	(8.7)	25	(9.0)
West South Central	1,308	(9.7)	225	(15.5)	1,083	(9.0)	85	(13.5)	55	(15.5)	30	(10.8)
Pacific Northwest	477	(3.5)	108	(7.4)	369	(3.1)	38	(6.0)	28	(7.9)	10	(3.6)
Pacific Southwest	1,575	(11.7)	235	(16.2)	1,340	(11.1)	99	(15.7)	53	(14.9)	46	(16.6)
Alaska and Hawaii	18	(0.1)	7	(0.5)	11	(0.1)	3	(0.5)	3	(0.9)	0	(0.0)
TOTAL	13,484		1,451		12,033		632		355		277	

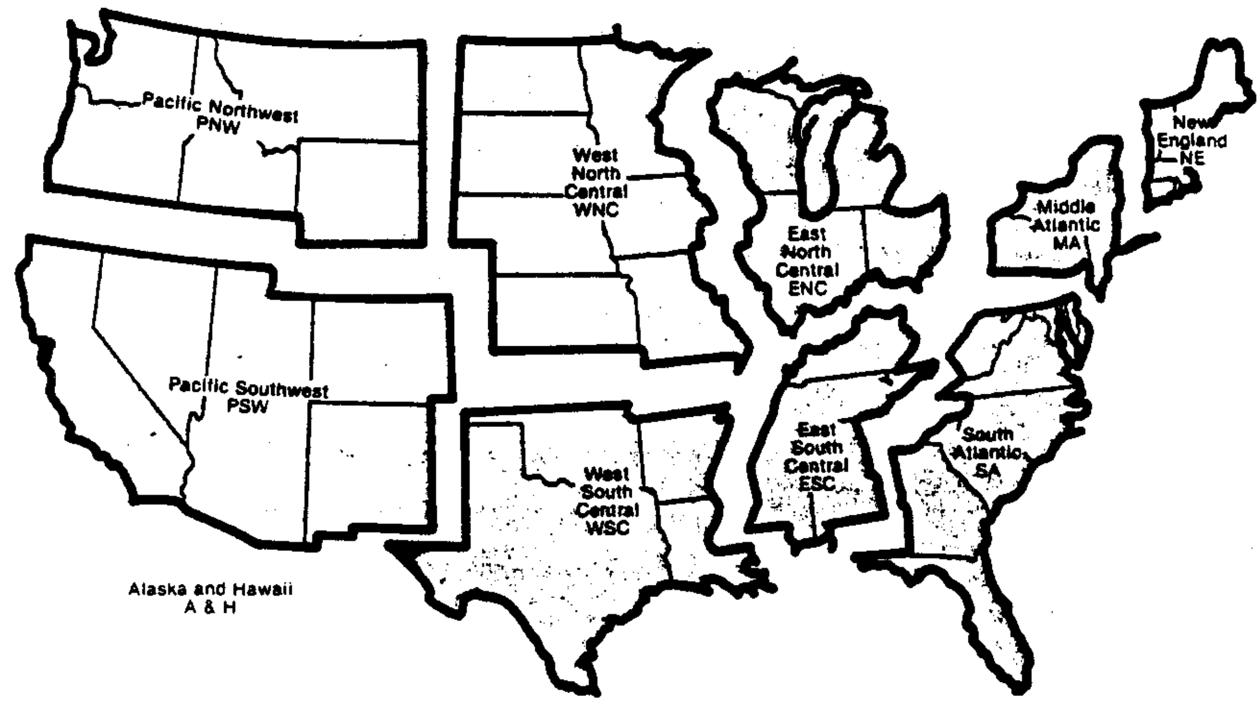

Figure 15. Regions of the United States used in data base analyses.[85]

Table 29. Distribution of on-highway hazmat incidents by State for 10 highest States, 1981-1985.

	All reported incidents						Severe incidents only					
	Total		Incidents caused by traffic accidents		Incidents due to other causes		Total		Incidents caused by traffic accidents		Incidents due to other causes	
State	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Pennsylvania	1,340	(9.9)	73	(5.0)	1,267	(10.5)	43	(6.8)	26	(7.3)	17	(6.1)
California	763	(5.7)	62	(4.3)	670	(5.6)	49	(7.8)	20	(5.6)	29	10.5)
Ohio	749	(5.6)	93	(6.4)	687	(5.7)	28	(4.4)	15	(4.2)	13	(4.7)
Illinois	742	(5.5)	45	(3.1)	697	(5.8)	23	(3.6)	9	(2.5)	14	(5.1)
Missouri	654	(4.9)	105	(7.2)	615	(5.1)	19	(3.0)	10	(2.8)	9	(3.3)
Texas	589	(4.4)	58	(4.0)	484	(4.0)	43	(6.8)	25	(7.0)	18	(6.5)
North Carolina	555	(4.1)	39	(2.7)	520	(4.3)	21	(3.3)	11	(3.1)	10	(3.6)
New York	553	(4.1)	35	(2.4)	495	(4.1)	31	(4.9)	16	(4.2)	15	(5.8)
Tennessee	481	(3.6)	38	(2.6)	454	(3.8)	9	(1.4)	4	(1.4)	5	(1.4)
Indiana	434	(3.2)	27	(1.9)	396	(3.3)	12	(1.9)	6	(1.7)	6	(2.2)
Others	6,624	(49.1)	876	(60.4)	5,748	(47.8)	354	(56.1)	213	(60.2)	141	(50.8)
TOTAL	13,484		1,451		12,033		632		355		277	

5. Vehicle and Operational Factors

Very few vehicle and operational factors are available for hazmat incidents. For example, hazmat incident data do not generally indicate the type of truck involved in the incident. The RSPA data do indicate that 821 incidents, or 3 percent of all incidents in the 1981-1985 period, involved tank trucks overturning.

One factor that is available is the type of carrier (for-hire or private) reporting the incident. Table 30 illustrates the distribution of hazmat incidents by type of carrier. The table shows that private carriers experience 27 percent of incidents due to traffic accidents, but only 3 percent of incidents due to other causes. This finding suggests the possibility of underreporting of incidents due to other causes by private carriers. Table 30 also shows that the proportion of severe incidents involving private carriers is substantially larger than the proportion for all incidents. This finding is also consistent with the hypothesis of underreporting of minor incidents by private carriers.

Table 30. Distribution of on-highway hazmat incidents by type of carrier, 1981-1985

	All reported incidents						Severe incidents only					
	Total		Incidents caused by traffic accidents		Incidents due to other causes		Total		Incidents caused by traffic accidents		Incidents due to other causes	
Type of carrier	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
For-hire	12,850	(94.9)	1,067	(73.2)	11,783	(97.5)	518	(81.8)	258	(72.7)	260	(93.5)
Private	695	(5.1)	390	(26.8)	305	(2.5)	115	(18.2)	97	(27.3)	18	(6.5)
TOTAL	13,545		1,457		12,088		633		355		278	

6. Consequences of Incidents

The RSPA data base includes the consequences of each reported incident, including the number of deaths and injuries and the dollar amount of property damage. In the case of incidents related to traffic accidents, the RSPA data include only deaths and injuries that are directly due to the hazmat release. Other deaths and injuries due to the accident are not reported. The same interpretation probably holds for property damage from hazmat incidents, but this point is not clear from the instructions for completing the hazmat incident report.[92]

Table 31 presents a frequency distribution of the number of deaths resulting from highway-related hazmat incidents. The table shows that deaths resulted from only 0.3 percent of incidents.

Table 31. Distribution of number of deaths per on-highway hazmat incident, 1981-1985.

Number of deaths per incident	Total No.	Total %	Incidents caused by traffic accidents No.	Incidents caused by traffic accidents %	Incidents due to other causes No.	Incidents due to other causes %
0	13,510	(99.7)	1,425	(97.8)	12,085	(99.9)
1	27	(0.2)	25	(1.7)	2	(0.0)
2	6	(0.1)	5	(0.3)	1	(0.0)
3	0	(0.0)	0	(0.0)	0	(0.0)
4	0	(0.0)	0	(0.0)	0	(0.0)
5	0	(0.0)	0	(0.0)	0	(0.0)
6	0	(0.0)	0	(0.0)	0	(0.0)
7	1	(0.0)	1	(0.1)	0	(0.0)
8	1	(0.0)	1	(0.1)	0	(0.0)
TOTAL	13,545		1,457		12,088	

Table 32 presents a frequency distribution of the number of personal injuries resulting from highway-related hazmat incidents. The table shows that only 2 percent of hazmat incidents resulted in injuries. Thus, it is apparent that the deaths and injuries from hazmat releases result from a relatively small proportion of the total number of incidents.

Table 33 summarizes the consequences of hazmat incidents for the period 1981 to 1985, inclusive. During this period, there were 57 deaths and 473 injuries from on-highway hazmat incidents, or an average of approximately 11 deaths and 95 injuries per year in the United States. Approximately 90 percent of the deaths and 25 percent of the injuries attributed to releases were due to traffic accidents. On average, 10 deaths and 23 injuries per year were attributed to releases due to traffic accidents. Releases due to traffic accidents were about 100 times more likely to cause deaths and 3 times more likely to cause injuries than releases due to other causes.

On-highway releases resulted in about $10 million in reported property damage per year at at average reported cost of about $3,600 per incident. Releases due to traffic accidents resulted in about 80 percent of the total reported property damage costs. Releases in traffic accidents resulted in about 30 times more reported property damage costs per incident than did releases due to other causes.

Table 34 summarizes the type of consequences resulting from hazmat incidents. The table shows that 98 percent of incidents result in spillage of hazardous materials as the only consequence. Fires result from 1 percent of incidents and explosions from 0.2 percent of incidents.

Table 32. Distribution of number of injuries per on-highway hazmat incident, 1981-1985.

Number of injuries per incident	Total No.	Total %	Incidents caused by traffic accidents No.	Incidents caused by traffic accidents %	Incidents due to other causes No.	Incidents due to other causes %
0	13,268	(98.0)	1,375	(94.4)	11,892	(98.4)
1	192	(1.4)	66	(4.5)	126	(1.0)
2	46	(0.3)	9	(0.6)	37	(0.3)
3	20	(0.1)	3	(0.2)	17	(0.1)
4	6	(0.0)	2	(0.1)	4	(0.0)
5	1	(0.0)	0	(0.0)	1	(0.0)
6	0	(0.0)	0	(0.0)	0	(0.0)
7	4	(0.0)	2	(0.1)	2	(0.0)
8	3	(0.0)	0	(0.0)	3	(0.0)
9	0	(0.0)	0	(0.0)	0	(0.0)
10	1	(0.0)	0	(0.0)	1	(0.0)
11-15	1	(0.0)	0	(0.0)	1	(0.0)
16-20	0	(0.0)	0	(0.0)	0	(0.0)
21-25	1	(0.0)	0	(0.0)	1	(0.0)
TOTAL	13,543		1,457		12,086	

Tables 33. Summary of consequences of on-highway hazmat incidents, 1981-1985.

	All incidents	Incidents caused by vehicle accidents	Incidents due to other causes
Number of incidents	13,547	1,457	12,090
Number of deaths	54	50	4
Deaths per incident	0.0040	0.0340	0.0003
Number of injuries	473	115	358
Injuries per incident	0.035	0.079	0.030
Total property damage ($)	48,297,000	38,412,000	9,885,000
Property damage per incident ($)	3,565	26,364	818

Table 34. Distribution of on-highway hazmat incidents by result of release, 1981-1985.

	Total		Incidents caused by traffic accidents		Incidents due to other causes	
	No.	%	No.	%	No.	%
None	19	(0.1)	5	(0.3)	14	(0.1)
Fire	63	(0.5)	36	(2.5)	27	(0.2)
Explosion	7	(0.1)	2	(0.1)	5	(0.0)
Fire and explosion	14	(0.1)	4	(0.3)	10	(0.1)
Spillage	13,317	(98.3)	1,328	(91.1)	11,989	(99.2)
Spillage and fire	115	(0.8)	79	(5.4)	36	(0.3)
Spillage and explosion	6	(0.0)	1	(0.1)	6	(0.0)
Spillage, fire, and explosion	2	(0.0)	2	(0.1)	0	(0.0)
TOTAL	13,543		1,457		12,086	

Hazmat incidents caused by traffic accidents result in a greater proportion of fires and explosions than other types of incidents. The data in table 34 show that 8 percent of hazmat incidents due to traffic accidents result in fires and 0.6 percent result in explosions. This finding is consistent with the results in table 26 that indicate that 71 percent of the releases due to traffic accidents involve flammable or combustible liquids. The higher proportion of fires and explosions in traffic accidents also indicates the important role of the forces generated by the accident in initiating these fires and explosions.

Table 34 indicates that 19 hazmat incidents (0.1 percent) involved neither a spill, a fire, or an explosion. These 36 incidents were investigated further, and it was found that 12 of the incidents were miscoded and did, in fact, involve a hazmat spill. Most of the remaining incidents involved shipments of radioactive materials where no material was "spilled." According to the reporting criteria of 49 CFR 171.5, some sort of low-level contamination and/or crushing or opening of an outer package may have occurred in these cases.

B. Analysis of Traffic Accident Data

This section of the report presents the analyses of traffic accident data reported to the FHWA Office of Motor Carriers and by police agencies in Missouri.

1. FHWA Truck Accident Data Base

The FHWA Office of Motor Carriers (formerly Bureau of Motor Carrier Safety) maintains a data base of truck accident reports filed by regulated interstate motor carriers.[33] The reporting requirements for this data base have been documented in section IV of the report. The following section presents tables of the characteristics of truck accidents in general and accidents involving hazmat-carrying trucks. Selected tables also indicate the breakdown of accidents involving hazmat-carrying trucks into accidents where the hazardous materials being carried were and were not released.

a. Annual accident frequencies: Table 35 presents the annual accident frequencies reported to FHWA for all truck accidents and for accidents involving hazmat-carrying trucks. A few accidents in the FHWA file that appear to have occurred in terminal areas or other off-highway sites have been eliminated. Overall, hazmat-carrying trucks experienced approximately 5 percent of all truck accidents.

Table 35 shows a general uptrend in accident frequencies from 1981 through 1985. Some observers have interpreted this as reflecting an increase in truck accident rates, although it could also indicate an increase in vehicle-miles of travel by trucks.

Table 35 shows that approximately 15 percent of accidents involving trucks carrying hazardous materials result in a hazmat release. This estimate is slightly lower than the 20 percent estimate developed in research for the Environmental Protection Agency (EPA).[2,3] Furthermore, this EPA estimate was developed indirectly, while the 15 percent estimate presented here for the probability of a release is based on actual data. (The rationale for the EPA estimate is presented in section VI of this report.) Underreporting of accidents to FHWA may produce a bias in the estimate presented here. However, past research has shown that accident reporting levels increase as accident severity increases.[4,16,107] Therefore, accidents resulting in a release are more likely to be reported than other accidents, and 15 percent should be a conservative (upper bound) estimate of the overall proportion of hazmat accidents resulting in a release. Tables in the following sections of the report examine the effect of selected factors on the probability of a release given an accident.

The FHWA data base is incomplete for some factors for the years 1982 and 1983. In those years, selected accident factors were not entered into the computer data base as an economy move. Entry of all available data was resumed in 1984. For the sake of consistency, the following tables in this section are based on data for 1984 and 1985 only, so that each table is based on the same set of accidents.

b. Temporal and geographic patterns: This section addresses the temporal and geographic distribution of truck accidents in the FHWA data and compares the frequency distribution of truck accidents in general to accidents involving hazmat-carrying trucks, and further subdivides the hazmat accidents into accidents in which releases did and did not occur. The tables of truck accidents that follow indicate their frequency distribution by month, by day of week, by time of day, and by geographic location.

Table 35. FHWA-reported truck accidents by year, 1981-1985.

	1981	1982	1983	1984	1985	Total
All reported truck accidents	30,347	32,674	31,957	35,161	39,706	169,845
Accidents involving hazmat-carrying vehicles	1,753	1,729	1,602	1,752	1,951	8,787
% of hazmat accidents	(5.8)	(5.3)	(5.0)	(5.0)	(4.9)	(5.2)
Hazmat accidents with no release	1,461	1,483	1,320	1,504	1,679	7,447
Hazmat accidents in which a release occurred	292	246	282	248	272	1,340
% of releases in hazmat accidents	(16.7)	(14.2)	(17.6)	(14.2)	(13.9)	(15.2)

(1) Month: Table 36 presents the distribution of FHWA-reported truck accidents by month of the year.

(2) Day of week: Table 37 presents the distribution of FHWA-reported accidents by day of the week. There is a greater proportion of all types of accidents on weekdays than on weekends, as might be expected from decreased trucking activity on Saturday and Sunday. Further, it appears that the types of hazmat accidents that occur on weekends may be less likely to result in a release, although the differences are not large. This finding could reflect different types of materials being shipped and a different nature of trucking operations on weekends.

(3) Time of day: Table 38 presents the distribution of FHWA-reported accidents by time of day. The table indicates that truck accidents and hazmat accidents are most common during daytime hours when truck and traffic volumes are highest. However, the table also indicates that the percentage of hazmat accidents resulting in a release is highest in the nighttime hours from 1:00 AM through 6:00 AM. This finding indicates that the types of hazmat shipments made during these hours appear to be more likely to result in a release if a traffic accident occurs than the types of shipments made at other times of the day.

The findings reported above are borne out by the distribution of accidents by light condition shown in table 39. Accidents during daylight hours predominate, but the proportion of hazmat accidents resulting in releases is highest during an ill-defined period reported as "dawn." The somewhat higher probability of a release for dark, unlighted conditions, as compared to lighted streets, may suggest that releases at night are more probable in rural than in urban accidents.

(4) Geographic location: Table 40 presents the frequency distribution of truck accidents over the same regions of the United States used earlier in this report for hazmat incidents. The regional distribution of truck accidents is quite similar to the regional distribution of hazmat incidents shown in table 28. Table 40 indicates that the probability of a release given an accident to a hazmat-carrying truck is higher in accidents that occur in the western States than in the rest of the United States.

Table 41 summarizes the FHWA-reported truck accident experience by State for the 10 highest States. The list of the 10 highest States for truck accidents in table 41 differs slightly from the 10 highest States for hazmat incidents identified in table 29.

c. Type of cargo involved: Table 42 presents the frequency distribution of FHWA-reported accidents by type of cargo involved (hazardous or otherwise). The table indicates quite a distinct difference in the distribution of cargo types for hazmat-carrying trucks and trucks in general. Trucks carrying liquids in bulk constitute 50 percent of hazmat-carrying trucks in general, but only 5 percent of trucks in general. The predominance of tank trucks carrying bulk liquids represents a major difference in exposure between hazmat trucking and other forms of trucking.

Table 36. Distribution of FHWA-reported truck accidents by month, 1984-1985.

Month	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
January	7,622	(10.7)	411	(11.1)	369	(11.6)	42	(8.1)	10.2
February	6,855	(9.6)	361	(9.7)	313	(9.8)	48	(9.2)	13.3
March	6,308	(8.9)	334	(9.0)	291	(9.1)	43	(8.3)	12.9
April	5,263	(7.4)	298	(8.0)	265	(8.3)	33	(6.3)	11.1
May	5,670	(8.0)	285	(7.7)	242	(7.6)	43	(8.3)	15.1
June	5,554	(7.8)	271	(7.3)	224	(7.0)	47	(9.0)	17.3
July	5,574	(7.8)	287	(7.8)	244	(7.7)	43	(8.3)	15.0
August	5,788	(8.1)	332	(9.0)	280	(8.8)	52	(10.0)	15.7
September	5,251	(7.4)	264	(7.1)	218	(6.8)	46	(8.8)	17.4
October	6,067	(8.5)	288	(7.8)	230	(7.2)	58	(11.2)	20.1
November	5,629	(7.9)	254	(6.9)	231	(7.3)	23	(4.4)	9.1
December	5,563	(7.8)	318	(8.6)	276	(8.7)	42	(8.1)	13.2
TOTAL	71,164		3,703		3,183		520		14.0

Table 37. Distribution of FHWA-reported truck accidents by day of week, 1984-1985.

Day of week	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Monday	12,358	(17.4)	599	(16.2)	511	(16.1)	88	(16.9)	14.7
Tuesday	12,448	(17.5)	646	(17.4)	550	(17.3)	96	(18.5)	14.9
Wednesday	12,088	(17.0)	618	(16.7)	530	(16.7)	88	(16.9)	14.2
Thursday	12,167	(17.1)	611	(16.5)	519	(16.3)	92	(17.7)	15.1
Friday	12,519	(17.6)	629	(17.0)	544	(17.1)	85	(16.3)	13.5
Saturday	5,512	(7.7)	362	(9.8)	321	(10.1)	41	(7.9)	11.3
Sunday	4,072	(5.7)	238	(6.4)	208	(6.5)	30	(5.8)	12.6
TOTAL	71,164		3,703		3,183		520		14.0

Table 38. Distribution of FHWA-reported truck accidents by time of day, 1984-1985.

Time of day	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
0100-0300	6,139	(8.7)	412	(11.1)	341	(10.7)	71	(13.7)	17.2
0400-0600	6,698	(9.4)	416	(11.2)	342	(10.8)	74	(14.3)	17.8
0700-0900	10,770	(15.2)	612	(16.5)	521	(16.4)	91	(17.5)	14.9
1000-1200	12,378	(17.4)	646	(17.5)	559	(17.6)	87	(16.8)	13.5
1300-1500	12,847	(18.1)	599	(16.2)	523	(16.4)	76	(14.6)	12.7
1600-1800	10,759	(15.2)	440	(11.9)	384	(12.1)	56	(10.8)	12.7
1900-2100	6,020	(8.5)	280	(7.6)	251	(7.9)	29	(5.6)	10.4
2200-2400	5,312	(7.5)	294	(7.9)	259	(8.1)	35	(6.7)	11.9
TOTAL	70,923		3,699		3,180		519		14.0

Table 39. Distribution of FHWA-reported truck accidents by light condition, 1984-1985.

Light condition	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Daylight	43,251	(61.7)	2,114	(58.0)	1,831	(58.4)	283	(55.5)	13.4
Dark -- lighted	2,449	(3.5)	152	(4.2)	134	(4.3)	18	(3.5)	11.8
Dark -- not lighted	18,722	(26.7)	1,081	(29.7)	927	(29.6)	154	(30.2)	14.2
Dawn	3,085	(4.4)	176	(4.8)	137	(4.4)	39	(7.6)	22.2
Dusk	2,605	(3.7)	122	(3.3)	106	(3.4)	16	(3.1)	13.1
TOTAL	70,112		3,645		3,135		510		14.0

Note: Light condition missing for 1.5% of accidents.

Table 40. Distribution of FHWA-reported truck accidents by region, 1984-1985.

Region	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
New England	2,312	(3.2)	146	(4.0)	127	(4.0)	19	(3.7)	13.0
Middle Atlantic	10,003	(14.1)	515	(14.0)	452	(14.3)	63	(12.1)	12.2
South Atlantic	12,144	(17.2)	560	(15.3)	484	(15.4)	76	(14.6)	13.6
East North Central	15,075	(21.3)	598	(16.3)	525	(16.7)	73	(14.1)	12.2
East South Central	6,035	(8.5)	277	(7.5)	231	(7.3)	46	(8.9)	16.6
West North Central	6,464	(9.1)	329	(9.0)	286	(9.1)	43	(8.3)	13.1
West South Central	8,629	(12.2)	572	(15.6)	495	(15.7)	77	(14.8)	13.5
Pacific Northwest	3,579	(5.1)	227	(6.2)	184	(5.8)	43	(8.3)	18.9
Pacific Southwest	6,294	(8.9)	422	(11.5)	351	(11.1)	71	(13.7)	16.8
Alaska and Hawaii	166	(0.2)	26	(0.7)	18	(0.6)	8	(1.5)	30.8
TOTAL	70,701		3,672		3,153		519		14.1

Table 41. Distribution of FHWA-reported truck accidents by State for 10 highest States, 1984-1985.

State	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Texas	4,829	(6.8)	309	(8.4)	271	(8.6)	38	(7.3)	12.3
Pennsylvania	4,523	(6.4)	255	(6.9)	223	(7.1)	32	(6.2)	12.5
Illinois	4,412	(6.2)	158	(4.3)	144	(4.6)	14	(2.7)	8.9
Ohio	4,328	(6.1)	201	(5.5)	169	(5.4)	32	(6.2)	15.9
New York	3,084	(4.4)	146	(4.0)	125	(4.0)	21	(4.0)	14.4
California	3,057	(4.3)	184	(5.0)	155	(4.9)	29	(5.6)	15.8
Indiana	3,019	(4.3)	123	(3.3)	106	(3.4)	17	(3.3)	13.8
New Jersey	2,396	(3.4)	114	(3.1)	104	(3.3)	10	(1.9)	8.8
Georgia	2,374	(3.4)	99	(2.7)	86	(2.7)	13	(2.5)	13.1
Florida	2,263	(3.2)	119	(3.2)	106	(3.4)	13	(2.5)	10.9
Other	36,417	(51.5)	1,964	(53.5)	1,664	(52.8)	300	(57.8)	15.3
TOTAL	70,702		3,672		3,153		519		14.1

Table 42. Distribution of FHWA-reported truck accidents by cargo type, 1984-1985.

Cargo type	Accidents involving trucks not carrying hazmat No.	%	Accidents involving trucks carrying hazmat: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
General freight	23,651	(33.7)	741	(20.1)	680	(21.4)	61	(11.8)	8.2
Gases in bulk	42	(0.1)	259	(7.0)	238	(7.5)	21	(4.1)	8.1
Solids in bulk	1,310	(1.9)	40	(1.1)	28	(0.9)	12	(2.3)	30.0
Liquids in bulk	1,618	(2.3)	1,831	(49.6)	1,486	(46.8)	345	(66.6)	18.8
Explosives	12	(0.1)	70	(1.9)	63	(2.0)	7	(1.4)	10.0
Empty	15,989	(22.8)	220	(6.0)	210	(6.6)	10	(1.9)	4.5
Other	27,478	(39.2)	529	(14.3)	467	(14.7)	62	(12.0)	11.7
TOTAL	70,100		3,690		3,172		518		14.0

The data in table 42 show that liquid tankers (19 percent releases) are slightly more likely than average to release their cargo in a traffic accident, while releases in the 40 accidents involving trucks transporting bulk solids are much more likely than average (30 percent releases). On the other hand, trucks transporting gases in bulk, explosives, and hazardous materials in general freight are less likely than average to release their cargo in a traffic accident.

d. Highway factors: This section presents tables illustrating the distribution of truck accidents by highway factors, including highway type/area type, relationship to junction, and road surface condition.

(1) Highway type and area type: Table 43 presents the frequency distribution of FHWA-reported truck accidents by highway type and area type. Highway type is used here to refer to the number of lanes and the presence or absence of a median on the highway, and area type refers to the type of highway environment. These categories are necessarily defined here as presented on the FHWA accident report form completed by carriers. It should be noted that here is no formal urban/rural classification in the FHWA data, but the business areas and residential areas are probably primarily in urban areas and small towns. The data in table 43, especially the highway type data, must be interpreted with care. From the number of one-lane and three-lane roads reported, and the reporting of accidents on two-lane divided roads (not shown in table), it is apparent that some carriers may be confused about whether to report the total number of lanes on the road or the number of lanes in one direction of travel. Thus, there is a great potential in these data for confusion between two-lane and four-lane highways.

The data in table 43 support the hypothesis suggested in the discussion of table 39 that rural traffic accidents are more likely to result in hazmat releases than urban traffic accidents, presumably because of the higher speeds involved. Approximately 17 percent of the rural hazmat accidents resulted in a release, while 8 percent of hazmat accidents in business areas and 11 percent of hazmat accidents in residential areas resulted in a release.

(2) Relationship to intersecting facilities: Table 44, which shows the distribution of FHWA-reported truck accidents by their relationship to intersections, freeway ramps, and railroad-highway grade crossings, presents some very important findings concerning the likelihood of hazmat releases in different types of accidents. Intersection accidents are much less likely to result in a hazmat release than accidents in general; in fact, only 10 of 283 (or 4 percent) accidents at intersections involving hazmat-carrying trucks resulted in a release. This is much smaller than the 14 percent of all accidents involving hazmat-carrying vehicles that result in a release. Accidents involving hazmat-carrying trucks on freeway ramps are more likely to result in a release, with 22 percent releases for hazmat accidents non-ramps and 26 percent releases for hazmat accidents on off-ramps. Railroad grade crossings have the highest likelihood of a release (46 percent when an accident occurs, although the sample size for this determination is quite small.

(3) Road surface condition: Table 45 presents the distribution of FHWA-reported truck accidents by road surface condition at the

Table 43. Distribution of FHWA-reported truck accidents by highway type and area type, 1984-1985.

Highway type/area type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
Rural Areas									
1-lane	1,428	(2.2)	118	(3.4)	95	(3.2)	23	(4.8)	19.5
2-lane	15,587	(24.0)	1,242	(36.1)	1,005	(33.9)	237	(49.0)	19.1
3-lane	1,590	(2.5)	98	(2.8)	88	(3.0)	10	(2.1)	10.2
4-lane (or more) undivided	1,253	(1.9)	49	(1.4)	44	(1.5)	5	(1.0)	10.2
4-lane (or more) undivided	16,591	(26.1)	677	19.7)	579	(19.6)	98	(20.2)	14.5
Rural area subtotal	36,449	(56.2)	2,184	(63.4)	1,811	(61.2)	373	(77.1)	17.1
Business Areas									
1-lane	1,639	(2.5)	56	(1.6)	44	(1.5)	12	(2.5)	21.4
2-lane	8,583	(13.2)	342	(9.9)	307	(10.4)	35	(7.2)	10.2
3-lane	2,155	(3.3)	105	(3.0)	101	(3.4)	4	(0.8)	3.8
4-lane (or more) undivided	3,833	(5.9)	165	(4.8)	157	(5.3)	8	(1.7)	4.8
4-lane (or more) divided	8,145	(12.6)	368	(10.7)	340	(11.5)	28	(5.8)	7.6
Business area subtotal	24,355	(37.6)	1,036	(30.1)	949	(32.0)	87	(18.0)	8.4
Residential Areas									
1-lane	220	(0.3)	13	(0.4)	11	(0.4)	2	(0.4)	15.4
2-lane	2,242	(3.5)	113	(3.3)	99	(3.3)	14	(2.9)	12.4
3-lane	281	(0.4)	23	(0.7)	22	(0.7)	1	(0.2)	4.3
4-lane (or more) undivided	429	(0.7)	26	(0.8)	26	(0.9)	0	(0.0)	0.0
4-lane (or more) divided	860	(1.3)	50	(1.5)	43	(1.5)	7	(1.4)	14.0
Residential area subtotal	4,032	(6.2)	225	(6.5)	201	(6.8)	24	(5.0)	10.7
TOTAL	64,836		3,445		2,961		484		

Note: Highway type/area type data missing for 8.8% of accidents.

Table 44. Distribution of FHWA-reported truck accidents by relationship to intersecting facility, 1984-1985.

Relationship to intersecting facility	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability
	No.	%	No.	%	No.	%	No.	%	(%)
None	60,828	(85.5)	3,172	(85.7)	2,726	(85.6)	446	(85.8)	14.2
At-grade intersection	5,762	(8.1)	283	(7.6)	273	(8.6)	10	(1.9)	3.5
Off-ramp	2,376	(3.3)	116	(3.1)	86	(2.7)	30	(5.8)	25.9
On-ramp	1,884	(2.6)	110	(3.0)	86	(2.7)	24	(4.6)	21.8
Railroad grade crossing	314	(0.4)	22	(0.6)	12	(0.4)	10	(1.9)	45.5
TOTAL	71,164		3,703		3,183		520		14.0

Table 45. Distribution of FHWA-reported truck accidents by road surface condition, 1984-1985.

Road surface Condition	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release Probability
	No.	%	No.	%	No.	%	No.	%	(%)
Dry	47,025	(67.4)	2,467	(68.0)	2,089	(66.8)	378	(74.9)	15.3
Wet	13,321	(19.0)	669	(18.4)	591	(18.9)	78	(15.4)	11.7
Ice and snow	9,488	(13.6)	494	(13.6)	445	(14.2)	49	(9.7)	9.9
TOTAL	69,834		3,630		3,125		505	3.9	

Note: Road surface condition missing for 1.9% of accidents.

time of the accident. Accidents resulting in hazmat releases appear to be slightly more prevalent on dry pavement than on wet or icy pavements.

e. Vehicle and operational factors: The final set of tables obtained in the analysis of the FHWA truck accident data base deals with vehicle and operational factors. These factors include specific accident types and truck characteristics.

(1) Accident type: Table 46 presents the distribution of accident types for hazmat accidents and truck accidents in general. Multiple-vehicle collisions are the leading type of accident both for vehicles carrying (47 percent) and not carrying (52 percent) hazardous materials. However, the leading accident types that result in hazmat releases are single-vehicle overturning accidents, which constitute 41 percent of releases, and single-vehicle run-off-road accidents, which constitute 23 percent of releases. While multiple-vehicle collisions represent 47 percent of accidents for trucks carrying hazardous materials, these accidents result in only 16 percent of all hazmat releases. Single-vehicle collisions represent 53 percent of the accidents for trucks carrying hazardous materials, but result in 84 percent of all releases.

Accidents involving hazmat-carrying trucks are at least twice as likely as other truck accidents to result in an overturn. Furthermore, releases occur in 38 percent of hazmat overturns as compared to 14 percent of all accidents involving hazmat-carrying trucks. Hazmat accidents are 1.5 times as likely as other truck accidents to involve a single-vehicle running off the road, and such accidents result in a hazmat release 33 percent of the time. These accident types are characteristic of tank trucks and represent the relatively larger use of tankers in hazmat trucking as compared to trucking in general.

By contrast, single-vehicle collisions with parked cars or nonmotorists (pedestrians, bicycles, and animals) and multiple-vehicle collisions (including both car-truck and truck-truck collisions) are less likely than average to result in a release. This confirms the finding in table 44 that intersection accidents are less likely to result in a hazmat release, since accidents at intersections typically involve multiple-vehicle collisions.

The principal special concerns in accidents involving trucks carrying hazardous materials are the actual and potential consequences of hazmat releases. From this perspective, the analysis findings indicate that data on accidents involving hazmat-carrying trucks without data on whether or not a hazmat release occurred can be very misleading because the probability of a release given an accident varies widely between accident types.

(2) Truck configuration: Table 47 presents the distribution of FHWA-reported accidents by truck configuration. The table reflects the overwhelming predominance of single-trailer combination trucks in both hazmat transportation and trucking in general. The table indicates that both

Table 46. Distribution of FHWA-reported truck accidents by accident type, 1984-1985.

Accident type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability
	No.	%	No.	%	No.	%	No.	%	(%)
SINGLE-VEHICLE ACCIDENTS									
Noncollision Accidents									
Ran-off-road	4,483	(6.3)	357	(9.6)	239	(7.5)	118	(22.7)	33.1
Jackknife	4,864	(6.8)	158	(4.3)	146	(4.6)	12	(2.3)	7.6
Overturn	5,263	(7.4)	574	(15.5)	359	(11.3)	215	(41.3)	37.5
Separation of units	278	(0.4)	36	(1.0)	28	(0.9)	8	(1.5)	22.2
Fire	425	(0.6)	33	(0.9)	32	(1.0)	1	(0.2)	3.0
Cargo spillage	268	(0.4)	21	(0.6)	0	(0.0)	21	(4.0)	100.0
Cargo shifting	206	(0.3)	6	(0.2)	5	(0.2)	1	(0.2)	16.7
Other noncollision	157	(0.2)	7	(0.2)	6	(0.2)	1	(0.2)	14.3
Collision Accidents									
Collision with fixed object	7,774	(10.9)	241	(6.5)	210	(6.6)	31	(6.0)	12.9
Collision with parked vehicle	6,591	(9.3)	254	(6.9)	246	(7.7)	8	(1.5)	3.1
Collision with train	314	(0.4)	22	(0.6)	12	(0.4)	10	(1.9)	45.5
Collision with nonmotorist	1,241	(1.7)	66	(1.8)	65	(2.0)	1	(0.2)	1.5
Other collision	2,508	(3.5)	169	(4.6)	159	(5.0)	10	(1.9)	5.9
MULTIPLE-VEHICLE ACCIDENTS									
Collision with passenger car	28,316	(39.8)	1,360	(36.7)	1,313	(41.3)	47	(9.0)	3.5
Collision with truck	7,758	(10.9)	372	(10.0)	337	(10.6)	35	(6.7)	9.4
Collision with other vehicle type	703	(1.0)	27	(0.7)	26	(0.8)	1	(0.2)	3.7
TOTAL	71,149		3,703		3,183		520		14.0

Table 47. Distribution of FHWA-reported truck accidents by truck configuration, 1984-1985.

Truck configuration	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat: Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
Singe-unit	6,861	(9.6)	350	(9.5)	311	(9.8)	39	(7.5)	11.1
Single-trailer combination	57,603	(80.9)	2,886	(77.9)	2,460	(77.3)	426	(81.9)	14.8
Double-trailer combination	3,079	(4.3)	278	(7.5)	253	(7.9)	25	(4.8)	9.0
Triple-trailer combination	53	(0.1)	10	(0.3)	10	(0.3)	0	(0.0)	0.0
Truck trailer	423	(0.6)	118	(3.2)	93	(2.9)	24	(4.8)	21.2
Bobtail	2,796	(3.9)	42	(1.1)	40	(1.3)	2	(0.4)	4.8
Other	349	(0.5)	19	(0.5)	16	(0.5)	3	(0.6)	15.8
TOTAL	71,164		3,703		3,183		520		14.0

single-unit and double-trailer combination trucks are slightly less likely than average to release their cargo when involved in an accident, and single-trailer combination trucks are slightly more likely to, but the differences are not large. Truck trailers (single-unit trucks towing a full trailer) appear to have the highest likelihood of a hazmat release when involved in an accident.

Table 48 presents the distribution of accidents by cargo area configuration (van/flatbed/tanker/etc.) for single-trailer combination trucks in the FHWA data. The table shows that the majority of these accidents involve van semitrailers, while the majority of accidents for hazmat-carrying trucks involve tankers. Table 48 also indicates that the probability of a hazmat release given an accident is above average for tankers and below average for vans.

(3) Accident type and truck configuration: Tables 49, 50, and 51 illustrate the combined distribution of accident type and truck configuration for accidents involving single-unit trucks, single-trailer combination trucks, and double-trailer combination trucks. The following combinations of truck configuration and accident type appear to have a particularly high likelihood of resulting in a hazmat release:

- Overturning by single-unit trucks and single-trailer combination trucks.
- Running off the road by single-trailer combination trucks.
- Truck-train collisions.
- Separation of units in double-trailer combination trucks.

For all truck types, multiple-vehicle collisions are less likely than other accident types to result in a hazmat release.

(4) Carrier type: Table 52 presents the distribution of FHWA-reported accidents by carrier type, including ICC-authorized carriers, private carriers, and other carriers.

(5) Trip type: Table 53 presents the distribution of FHWA-reported accidents by trip type, distinguishing between over-the-road and local pick-up-and-delivery trips. Accidents during over-the-road trips appear slightly more likely than average to result in a hazmat release, and local pick-up-and-delivery trips slightly less likely than average, but the differences are not large.

Table 48. Distribution of FHWA-reported truck accidents by cargo area configuration for single-trailer combination trucks, 1984-1985.

Configuration	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
Van	30,349	(64.3)	621	(24.5)	557	(26.0)	64	(16.6)	10.3
Flatbed	7,890	(16.7)	70	(2.8)	60	(2.8)	10	(2.6)	14.3
Tank	3,389	(7.2)	1,764	(69.7)	1,470	(68.5)	294	(76.4)	16.6
Other	5,597	(11.8)	76	(3.0)	59	(2.7)	17	(4.4)	22.4
TOTAL	47,205		2,531		2,146		385		15.2

Note: Cargo area configuration missing for 17.8% of accidents.

Table 49. Distribution of FHWA-reported truck accidents by accident type for single-unit trucks, 1984-1985.

Accident type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat: Combined		No release		Hazmat release		Release probability
	No.	%	No.	%	No.	%	No.	%	(%)
SINGLE-VEHICLE ACCIDENTS									
Noncollision Accidents									
Ran-off-road	363	(5.3)	41	(11.7)	35	(11.3)	6	(15.4)	14.6
Jackknife	21	(0.3)	1	(0.3)	1	(0.3)	0	(0.0)	0.0
Overturn	340	(5.0)	60	(17.1)	42	(13.5)	18	(46.2)	30.0
Separation of units	16	(0.2)	0	(0.0)	0	(0.0)	0	(0.0)	-
Fire	39	(0.6)	8	(2.3)	7	(2.3)	1	(2.6)	12.5
Cargo spillage	13	(0.2)	2	(0.6)	0	(0.0)	2	(5.1)	100.0
Cargo shifting	5	(0.1)	1	(0.3)	1	(0.3)	0	(0.0)	0.0
Other noncollision	17	(0.2)	1	(0.3)	1	(0.3)	0	(0.0)	0.0
Collision Accidents									
Collision with fixed object	583	(8.5)	21	(6.0)	21	(6.8)	0	(0.0)	0.0
Collision with parked vehicle	692	(10.1)	21	(6.0)	21	(6.8)	0	(0.0)	0.0
Collision with train	28	(0.4)	2	(0.6)	2	(0.6)	0	(0.0)	0.0
Collision with nonmotorist	273	(4.0)	6	(1.7)	6	(1.9)	0	(0.0)	0.0
Other collision	282	(4.1)	15	(4.3)	14	(4.5)	1	(2.6)	6.7
MULTIPLE-VEHICLE ACCIDENTS									
Collision with passenger car	3,453	(50.3)	123	(35.1)	116	(37.3)	7	(17.9)	5.7
Collision with truck	612	(8.9)	44	(12.6)	40	(12.9)	4	(10.3)	9.1
Collision with other vehicle type	124	(1.8)	4	(1.1)	4	(1.3)	0	(0.0)	0.0
TOTAL	6,861		350		311		39		11.1

Table 50. Distribution of FHWA-reported truck accidents by accident type for single-trailer combination trucks, 1984-1985.

Accident type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability
	No.	%	No.	%	No.	%	No.	%	(%)
SINGLE-VEHICLE ACCIDENTS									
Noncollision Accidents									
Ran-off-road	3,578	(6.2)	251	(8.7)	153	(6.2)	98	(23.0)	39.0
Jackknife	4,475	(7.7)	131	(4.5)	122	(5.0)	9	(2.1)	6.9
Overturn	4,162	(7.2)	405	(14.0)	233	(9.5)	172	(40.4)	42.5
Separation of units	221	(0.4)	28	(1.0)	23	(0.9)	5	(1.2)	17.9
Fire	354	(0.6)	22	(0.8)	22	(0.9)	0	(0.0)	0.0
Cargo spillage	238	(0.4)	16	(0.6)	0	(0.0)	16	(3.8)	100.0
Cargo shifting	196	(0.3)	4	(0.1)	3	(0.1)	1	(0.2)	25.0
Other noncollision	123	(0.2)	6	(0.2)	5	(0.2)	1	(0.2)	16.7
Collision Accidents									
Collision with fixed object	6,538	(11.4)	198	(6.9)	168	(6.8)	30	(7.0)	15.2
Collision with parked vehicle	5,381	(9.3)	200	(6.9)	194	(7.9)	6	(1.4)	3.0
Collision with train	264	(0.5)	18	(0.6)	8	(0.3)	10	(2.3)	55.6
Collision with nonmotorist	864	(1.5)	54	(1.9)	53	(2.2)	1	(0.2)	1.9
Other collision	1,975	(3.4)	132	(4.6)	123	(5.0)	9	(2.1)	6.8
MULTIPLE-VEHICLE ACCIDENTS									
Collision with passenger car	22,233	(38.6)	1,112	(38.5)	1,075	(43.7)	37	(8.7)	3.3
Collision with truck	6,469	(11.2)	288	(10.0)	258	(10.5)	30	(7.0)	10.4
Collision with other vehicle type	517	(0.9)	21	(0.7)	20	(0.8)	1	(0.2)	4.8
TOTAL	57,588		2,886		2,460		426		14.8

Table 51. Distribution of FHWA-reported truck accidents by accident type for double-trailer combination trucks, 1984-1985.

Accident type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat: Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
SINGLE-VEHICLE ACCIDENTS									
Noncollision Accidents									
Ran-off-road	242	(7.9)	41	(14.7)	35	(13.8)	6	(24.0)	14.6
Jackknife	297	(9.6)	21	(7.6)	20	(7.9)	1	(4.0)	4.8
Overturn	550	(17.9)	75	(27.0)	64	(25.3)	11	(44.0)	14.7
Separation of units	25	(0.8)	5	(1.8)	3	(1.2)	2	(8.0)	40.0
Fire	9	(0.3)	2	(0.7)	2	(0.8)	0	(0.0)	0.0
Cargo spillage	5	(0.2)	1	(0.4)	0	(0.0)	1	(4.0)	100.0
Cargo shifting	4	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)	-
Other noncollision	4	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)	-
Collision Accidents									
Collision with fixed object	233	(7.6)	14	(5.0)	13	(5.1)	1	(4.0)	7.1
Collision with parked vehicle	167	(5.4)	9	(3.2)	8	(3.2)	1	(4.0)	11.1
Collision with train	7	(0.2)	0	(0.0)	0	(0.0)	0	(0.0)	-
Collision with nonmotorist	48	(1.6)	4	(1.4)	4	(1.6)	0	(0.0)	0.0
Other collision	126	(4.1)	10	(3.6)	10	(4.0)	0	(0.0)	0.0
MULTIPLE-VEHICLE ACCIDENTS									
Collision with passenger car	1,022	(33.2)	70	(25.2)	68	(26.9)	2	(8.0)	2.9
Collision with truck	319	(10.4)	25	(9.0)	25	(9.9)	0	(0.0)	0.0
Collision with other vehicle type	23	(0.7)	1	(0.4)	1	(0.4)	0	(0.0)	0.0
TOTAL	3,079		278		253		25		9.0

Table 52. Distribution of FHWA-reported truck accidents by carrier type, 1984-1985.

Carrier type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
ICC-authorized	58,795	(82.8)	2,273	(61.8)	1,947	(61.6)	326	(63.1)	14.3
Private	10,428	(14.7)	1,300	(35.3)	1,129	(35.7)	171	(33.1)	13.2
Other	1,743	(2.5)	107	(2.9)	87	(2.8)	20	(3.9)	18.7
TOTAL	70,966		3,680		3,163		517		14.0

Table 53. Distribution of FHWA-reported truck accidents by trip type, 1984-1985.

Trip type	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability (%)
	No.	%	No.	%	No.	%	No.	%	
Over-the-road	57,158	(80.4)	2,630	(71.1)	2,244	(70.5)	386	(74.4)	14.7
Local PU&D	13,960	(19.6)	1,070	(28.9)	937	(29.5)	133	(25.6)	12.4
TOTAL	71,118		3,700		3,181		519		14.0

f. <u>Consequences of accidents</u>: Table 54 summarizes the consequences of the FHWA-reported accidents. Table 54 refers to all deaths, injuries, and property damage resulting from the accident. Unlike the consequences reported for hazmat incidents, these consequences are not necessarily the result of a hazmat release. It should be noted in table 54 that accidents involving hazmat-carrying vehicles tend to involve slightly greater consequences than truck accidents in general. Accidents in which a hazmat release occurs clearly involve more deaths, more injuries, and more property damage than accidents in which there is no release. The greater consequences when a release occurs may be due in part to the consequences of the release, but also indicate that the accident involved higher speeds or greater collision forces than other accidents, which in turn may cause both the hazmat release and the higher damages.

Table 55 summarizes the distribution of the FHWA truck accident data by accident severity levels. The table shows that a hazmat release is more likely in fatal and injury accidents than in property-damage-only accidents, undoubtedly because of the greater forces involved. It is important to note that 83 percent of the fatalities and 85 percent of the injuries in accidents involving hazmat-carrying trucks occur in accidents in which there is no hazmat release. The comparison of all cases common to both the FHWA and RSPA files in table 22 provides insight on the cause of injuries and fatalities. Although the accident sample size in table 22 is small, the table suggests that in accidents in which a release occurs, about 80 percent of the fatalities and 95 percent of the injuries that occur are not due to the release. Thus, when a traffic accident occurs, traditional accident causes, and not the properties of the hazardous materials transported, may be responsible for the vast majority of the fatalities and injuries involving hazmat-carrying trucks.

Combining the above estimate with the previously noted finding that, for release events, approximately 90 percent of deaths and 25 percent of injuries were attributable to traffic accidents, the estimates of the fatalities and injuries shown in figure 16 can be derived. The dominant role of traffic accidents is clearly shown through the estimate that roughly 96 percent of all fatalities and 97 percent of all injuries involving trucks transporting hazardous materials resulted from traffic accidents in which no release occurred. It is important to note, however, that one major disaster involving numerous fatalities or injuries due to a release could greatly alter these estimates in any given year. The concern over such possibilities along with the potential for major evacuations and route closures is, in fact, the key reason for interest in hazardous materials transportation as a separate highway safety issue.

2. Analysis of Missouri Accident Data

The Missouri State Highway Patrol maintains a Statewide Accident Reporting System (STARS) containing data on all accidents reported by police agencies in Missouri. These data are used by the Missouri State Highway and Transportation Department and local agencies in the management of highway safety problems in Missouri.

Table 54. Summary of consequences of FHWA-reported truck accidents, 1984-1985.

	Trucks not carrying hazmat	Trucks carrying hazmat: Total	Trucks carrying hazmat: No release	Trucks carrying hazmat: Hazmat release
No. of accidents	71,164	3,703	3,183	520
No. of deaths	4,994	326	273	53
Deaths per accident	0.070	0.088	0.086	0.102
No. of injuries	54,522	2,955	2,514	441
Injuries per accident	0.77	0.80	0.79	0.85
Total property damage ($)	743,643,000	56,927,000	39,609,000	17,318,000
Property damage per accident ($)	10,450	15,373	12,444	33,304

Table 55. Distribution of FHWA-reported truck accidents by accident severity, 1984-1985.

	Accidents involving trucks not carrying hazmat		Accidents involving trucks carrying hazmat						
			Combined		No release		Hazmat release		Release probability
Accident severity	No.	%	No.	%	No.	%	No.	%	(%)
Fatal	4,034	(5.7)	265	(7.2)	221	(6.9)	44	(8.5)	16.6
Injury	33,569	(47.2)	1,777	(48.0)	1,493	(46.9)	284	(54.6)	16.0
Property-damage-only	33,561	(47.2)	1,661	(44.9)	1,469	(46.2)	192	(36.9)	11.6
TOTAL	71,164		3,703		3,183		520		14.0

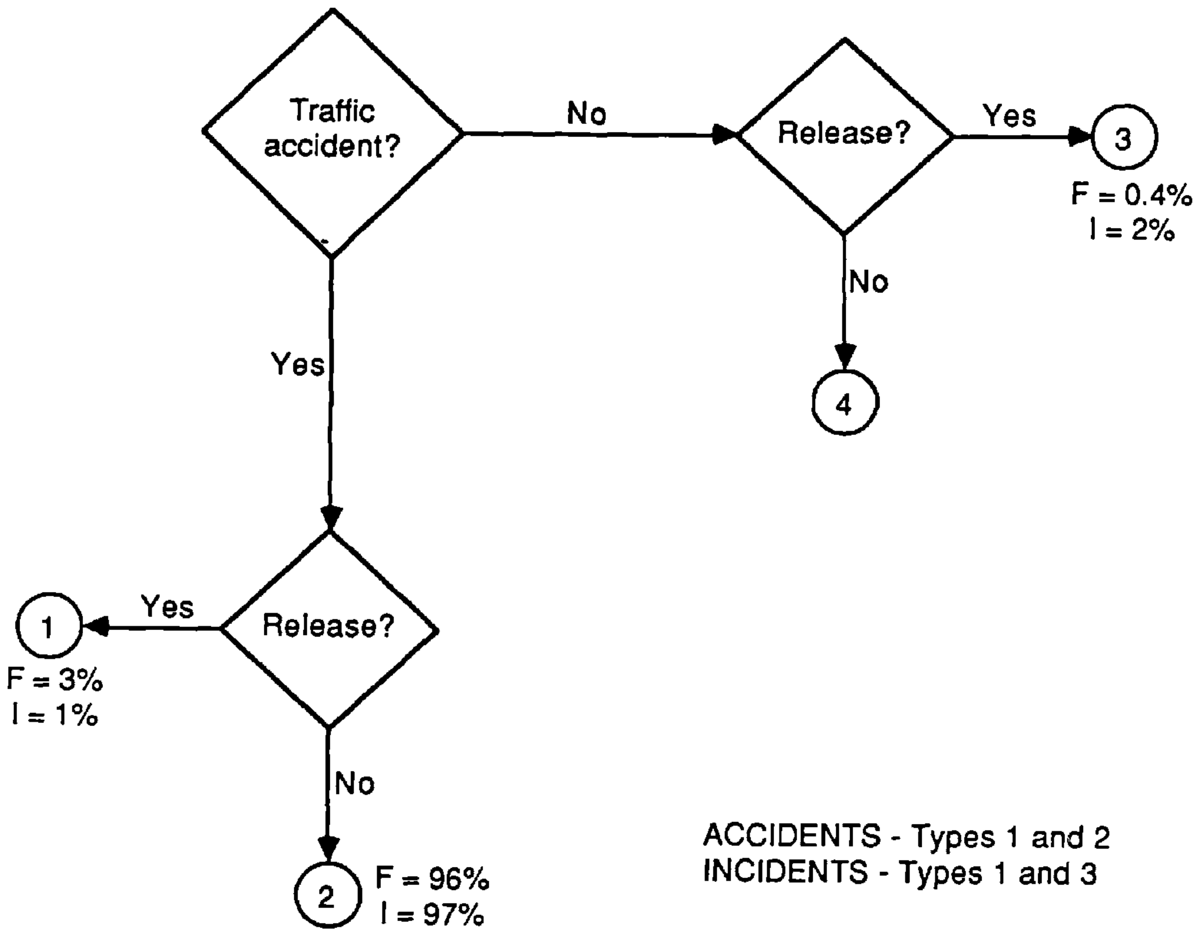

Figure 16. Classification scheme for on-highway events and causes of resulting fatalities and injuries for trucks carrying hazardous materials.

Since July 1, 1984, the STARS system has contained data identifying whether or not each vehicle involved in an accident was carrying hazardous materials, what type of hazardous materials were carried, and whether or not a hazmat release occurred. Missouri is one of only three States in the Nation that has incorporated all of these items in their police-reported accident data.

The Missouri STARS system has the advantage over the FHWA data that it contains all accidents investigated by police agencies, not just those self-reported by carriers. The STARS data also include accidents for all types of trucks and all types of carriers, not just regulated interstate carriers. In addition, each accident has been investigated by a police officer; while the experience and training of police officers vary widely, they would generally be expected to have more training and experience in accident investigation and employ the accident reporting form with greater consistency than the wide variety of individual motor carriers who report accidents to FHWA. However, it should be kept in mind that accident data based on police reports are subject to the same types of underreporting biases as carrier-reported data, although perhaps not to the same extent.

The property-damage threshold for reporting accidents in Missouri is $500, which is substantially lower than the $2,000 threshold used by FHWA. Thus, the Missouri data may contain a greater proportion of property-damage-only accidents. On the other hand, Missouri like most States classifies accidents involving Type C injuries (no visible injury) as injury accidents. FHWA classifies an accident as an injury accident only if a person receives medical treatment away from the scene. Therefore, the proportion of injury accidents in the Missouri data would also be expected to increase for this reason.

The following sections of the report present tables of police-reported accidents in Missouri involving hazmat-carrying vehicles. Comparisons to the entire population of accident-involved trucks have not been made in Missouri, although the data to make such comparisons could be obtained. These tables address most of the accident-related variables addressed above for the FHWA data, plus some new variables including area type (urban/rural), speed limit, horizontal alignment, and vertical alignment.

a. Accident frequencies: The frequencies of accidents involving hazmat-carrying vehicles and accidents in which a hazmat release occurred in Missouri are presented in table 56 for the latter half of 1984 and the entire calendar years 1985 and 1986. Table 56 indicates that Missouri experiences just over 200 accidents per year involving hazmat-carrying vehicles. Approximately 13 percent of these accidents result in a hazmat release. The percentage of hazmat accidents involving a release in Missouri (13 percent) is in good agreement with the percentage in the FHWA data for the entire United States (15 percent).

It should be noted that there appear to be some definitional problems in identification of hazardous material cargos by the investigating officers. For example, in 1985 and 1986, there were 15 accidents involving vehicle types other than trucks transporting hazardous materials. One of these accidents involved a motor home with a propane tank which would not normally be subject to hazardous materials regulations except at a few specific bridges and tunnels. Only one of these 15 accidents involving vehicles other than trucks resulted in a hazmat release.

Table 56. Annual hazmat accident frequencies in Missouri.

	1984 (July-Dec.)	1985	1986	Total
Number of accidents involving hazmat-carrying vehicles	138	210	206	554
Number of accidents with no hazmat release	119	181	182	482
Number of accidents involving a hazmat release	19	29	23	72
Percent of releases	(13.0)	(13.8)	(11.7)	(13.0)

To avoid any seasonal biases, the data for the latter half of 1984 have been omitted from the remaining tables in this section, and the tables are based on data for the entire calendar years of 1985 and 1986 only.

b. Temporal patterns: This section illustrates the distribution of the Missouri accident data for 1985 and 1986 by temporal variables, including month, day of week, time of day, and light condition.

(1) Month: Table 57 presents the distribution of hazmat accidents in Missouri by month of the year.

(2) Day of week: Table 58 presents the distribution of hazmat accidents in Missouri by day of week. As in the nationwide FHWA data, there is a greater proportion of accidents on weekdays than on weekends.

(3) Time of day: Table 59 presents the distribution of hazmat accidents in Missouri by time of day. Although based on a much smaller sample of accidents, the Missouri data in table 59 are very similar to the nationwide data in table 38. There are many more accidents in the daytime than in the nighttime hours, but the nighttime accidents involve a higher probability of a hazmat release.

These findings are confirmed by the distribution of accidents by light condition in table 60, which indicates that nearly 75 percent of accidents involving hazmat-carrying vehicles occur during daylight, but that accidents after dark on unlighted roads are substantially more likely to result in hazmat release.

c. Type of hazardous cargo involved: Table 61 presents the distribution of police-reported hazmat accidents in Missouri by type of hazardous cargo involved.

Table 57. Distribution of police-reported hazmat accidents in Missouri by month, 1985-1986.

Month	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
January	32	(7.7)	27	(7.4)	5	(9.4)	15.6
February	32	(7.7)	29	(8.0)	3	(5.7)	9.4
March	26	(6.3)	20	(5.5)	6	(11.3)	23.1
April	38	(9.1)	32	(8.8)	6	(11.3)	15.8
May	30	(7.2)	26	(7.2)	4	(7.5)	13.3
June	41	(9.9)	36	(9.9)	5	(9.4)	12.2
July	39	(9.4)	32	(8.8)	7	(13.2)	17.9
August	36	(8.7)	31	(8.5)	5	(9.4)	13.9
September	30	(7.2)	30	(8.3)	0	(0.0)	0.0
October	43	(10.3)	38	(10.5)	5	(9.4)	11.6
November	37	(8.9)	31	(8.5)	6	(11.3)	16.2
December	32	(7.7)	31	(8.5)	1	(1.9)	3.1
TOTAL	416		363		53		12.7

Table 58. Distribution of police-reported hazmat accidents in Missouri by day of week, 1985-1986.

Day of week	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Monday	64	(15.4)	54	(14.9)	10	(18.9)	15.6
Tuesday	67	(16.1)	60	(16.5)	7	(13.2)	10.4
Wednesday	77	(18.5)	67	(18.5)	10	(18.9)	13.0
Thursday	53	(12.7)	47	(12.9)	6	(11.3)	11.3
Friday	81	(19.5)	70	(19.3)	11	(20.8)	13.6
Saturday	41	(9.9)	35	(9.6)	6	(11.3)	14.6
Sunday	33	(7.9)	30	(8.3)	3	(5.7)	9.1
TOTAL	416		363		53		12.7

Table 59. Distribution of police-reported hazmat accidents in Missouri by time of day, 1985-1986.

Time of day	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
0100-0300	29	(7.0)	24	(6.6)	5	(9.6)	17.2
0400-0600	21	(5.1)	14	(3.9)	7	(13.5)	33.3
0700-0900	60	(14.5)	53	(14.7)	7	(13.5)	11.7
1000-1200	88	(21.3)	79	(21.9)	9	(17.3)	10.2
1300-1500	86	(20.8)	74	(20.5)	12	(23.1)	14.0
1600-1800	74	(17.9)	71	(19.7)	3	(5.8)	4.1
1900-2100	27	(6.5)	23	(6.4)	4	(7.7)	14.8
2200-2400	28	(6.8)	23	(6.4)	5	(9.6)	17.9
TOTAL	413		361		52		12.6

Table 60. Distribution of police-reported hazmat accidents in Missouri by light condition, 1985-1986.

Light condition	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Daylight	310	(74.7)	277	(76.5)	33	(62.3)	10.6
Dark -- lighted	41	(9.9)	38	(10.5)	3	(5.7)	7.3
Dark -- not lighted	64	(15.4)	47	(13.0)	17	(32.1)	26.6
TOTAL	415		362		53		12.8

Table 61. Distribution of police-reported hazmat accidents in Missouri by cargo type, 1985-1986.

Type of hazardous cargo	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Gases in bulk	138	(33.2)	128	(35.3)	10	(18.9)	7.2
Solids in bulk	77	(18.5)	70	(19.3)	7	(13.2)	9.1
Liquids in bulk	187	(45.0)	152	(41.9)	35	(66.0)	18.7
Explosives	14	(3.4)	13	(3.6)	1	(1.9)	7.1
TOTAL	416		363		53		12.7

The classes of hazardous material used in Missouri account for explosives and bulk shipments of gases, solids, and liquids but do not include an equivalent of the "general freight" or "other" categories used by FHWA which could be used to represent packaged materials. This may explain the particularly high percentage of "solids in bulk" in the Missouri data which could be used by police officers as a catch-all for packaged materials. The FHWA data show that accidents involving solids in bulk are particularly likely to result in a hazmat release, while those involving general freight are not. Because these two types of accidents may be mixed together, the data for the "solids in bulk" category in table 61 are not considered reliable.

In contrast, the data in table 61 for liquids in bulk are in very close agreement with the data in table 42 with respect to both the overall percentage of hazmat accidents involving liquids in bulk and the percentage of accidents in which liquids in bulk are released. The data in table 61 indicate that liquid tank trucks are more likely than other truck types to experience hazmat release if an accident occurs.

d. <u>Highway factors</u>: This section presents distributions of the Missouri accident data by highway factors including highway type, area type, speed limit, relationship to junction, horizontal and vertical alignment, and road surface condition.

(1) <u>Highway and area type</u>: There is no variable available for the Missouri accident data that explicitly identifies the type of highway (number of lanes, divided/undivided, freeway/nonfreeway) on which each accident occurred. The highway class is a useful surrogate for highway type. Table 62 presents the distribution of the Missouri hazmat accident data by highway class.

Table 62. Distribution of police-reported hazmat accidents in Missouri by highway glass, 1985-1986.

	Accidents involving hazmat-carrying vehicles						
	Combined		No release		Hazmat release		
Highway class	No.	%	No.	%	No.	%	Release probability (%)
Interstate	96	(23.1)	82	(22.6)	14	(26.4)	14.6
U.S. or State route	145	(34.9)	121	(33.3)	24	(45.3)	16.6
Supplementary or county road	55	(13.2)	46	(12.7)	9	(17.0)	16.4
City street	118	(28.4)	113	(31.1)	5	(9.4)	4.2
Other	2	(0.5)	1	(0.3)	1	(1.9)	50.0
TOTAL	416		363		53		12.7

Interstate highways consist exclusively of divided freeways. The U.S. and State routes in Missouri are primarily rural two-lane highways, but also include urban highways, multilane highways, and non-Interstate freeways. The supplementary roads (lettered routes) and county roads in Missouri together constitute what could be the rural county road system in most States. The category for city streets consists exclusively of municipal streets under local maintenance.

Table 62 indicates that all of the highway classes described above experience a substantial proportion of hazmat accidents. The probability of a hazmat release given an accident is lowest on city streets.

Table 63 confirms the importance of area type (urban/rural) in predicting the probability of a hazmat release. There are nearly equal numbers of accidents in urban and rural areas in Missouri, but rural accidents are approximately three times as likely to result in a hazmat release. The greater likelihood of a hazmat release in rural accidents undoubtedly results from the higher speeds involved (and, thus, the higher forces generated in accident situations), but could also relate to the types of accidents that occur, the types of cargos transported, and the types of trucks used.

Similar findings are also evident in table 64, which presents the distribution of hazmat accidents in Missouri by speed limit. The table demonstrates that the probability of a hazmat release given an accident is highest on highways with speed limits of 45 mi/h (72 km/h) or more.

Table 63. Distribution of police-reported hazmat accidents in Missouri by area type, 1985-1986.

Area type	Accidents involving hazmat-carrying vehicles: Combined No.	Combined %	No release No.	No release %	Hazmat release No.	Hazmat release %	Release probability (%)
Urban	210	(50.5)	197	(54.3)	13	(24.5)	6.2
Rural	206	(49.5)	166	(45.7)	40	(75.5)	19.4
TOTAL	416		363		53		12.7

Table 64. Distribution of police-reported hazmat accidents in Missouri by speed limit, 1985-1986

Speed limit (mi/h)	Accidents involving hazmat-carrying vehicles: Combined No.	Combined %	No release No.	No release %	Hazmat release No.	Hazmat release %	Release probability (%)
25 or less	60	(14.7)	59	(16.5)	1	(1.9)	1.7
30	35	(8.6)	32	(9.0)	3	(5.8)	8.6
35	65	(15.9)	59	(16.5)	6	(11.5)	9.2
40	26	(6.4)	24	(6.7)	2	(3.8)	7.7
45	21	(5.1)	17	(4.8)	4	(7.7)	19.0
50	2	(0.5)	2	(0.6)	0	(0.0)	0.0
55	200	(48.9)	164	(45.9)	36	(69.2)	18.0
TOTAL	409		357		52		12.7

Note: All data are prior to increase of Interstate highway speed limit to 65 mi/h for passenger cars and 60 mi/h for trucks in May 1987.

(2) Relationship to intersecting facilities: Table 65 presents the distribution of the Missouri hazmat accidents by relationship to intersecting facilities. The table indicates similar percentages of intersection and railroad grade crossing accidents to those in the nationwide FHWA data (see table 44). Table 65 also confirms that intersection accidents are much less likely than other types of accidents to result in a hazmat release. None of the railroad grade crossing accidents in Missouri resulted in a hazmat release, but the sample size (five accidents) is very small and the FHWA data in table 44 are considered more reliable in this respect. Accidents on freeways ramps are not identified separately in the Missouri data.

Table 65. Distribution of police-reported hazmat accidents in Missouri by relationship to intersecting facility, 1985-1986

Relationship to intersecting facility	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
None	367	(88.2)	316	(87.1)	51	(96.2)	13.9
Intersection	44	(10.6)	42	(11.6)	2	(3.8)	4.5
Railroad grade	5	(1.2)	5	(1.4)	0	(0.0)	0.0
TOTAL	416		363		53		12.7

(3) Alignment: The distribution of Missouri accidents by horizontal and vertical alignment is presented in tables 66 and 67, respectively. Table 66 shows that the probability of a hazmat release is nearly twice as high on horizontal curves as on tangent sections of highway. Similarly, the probability of a hazmat release if an accident occurs, presented in table 67 is higher on grades than on level highway sections, and is highest at hillcrests.

(4) Road surface condition: The distribution of hazmat accidents in Missouri by road surface condition (dry/wet/ice and snow), presented in table 68, is very similar to the nationwide distribution in table 45. The Missouri data suggest that, given an accident, hazmat releases are more likely under wet pavement than under dry pavement conditions, while the nationwide data imply the opposite conclusion. However, the sample size of accidents in Missouri is too small for this finding to be statistically significant.

e. Vehicle and operational factors: The final set of tables obtained from the Missouri accident data pertain to vehicle and operational factors, including accident type and truck configuration.

(1) Accident type: Table 69 presents the overall distribution of accident types for hazmat accidents in Missouri. The data for multiple-vehicle collisions are also broken down by manner of collision (head-on/rear-end/etc.). As in the nationwide FHWA data (see table 46), the predominant accident types are overturning accidents, fixed object collisions, and multiple-vehicle collisions. The sample size for the Missouri accident analysis is smaller and, thus, more subject to variation than in the nationwide data; however, the same patterns are evident. Overturning and other types of noncollision accidents are most likely to result in a hazmat release while multiple-vehicle collisions are least likely.

Table 66. Distribution of police-reported hazmat accidents in Missouri by horizontal alignment, 1985-1986.

Horizontal alignment	Accidents involving hazmat-carrying vehicles						Release probability (%)
	Combined		No release		Hazmat release		
	No.	%	No.	%	No.	%	
Straight	339	(82.3)	302	(83.7)	37	(72.5)	10.9
Curve	73	(17.7)	59	(16.3)	14	(27.5)	19.2
TOTAL	412		361		51		12.4

Table 67. Distribution of police-reported hazmat accidents in Missouri by vertical alignment, 1985-1986.

Vertical alignment	Accidents involving hazmat-carrying vehicles						Release probability (%)
	Combined		No release		Hazmat release		
	No.	%	No.	%	No.	%	
Level	264	(64.5)	234	(65.5)	30	(57.7)	11.4
Hill	129	(31.5)	110	(30.8)	19	(36.5)	14.7
Crest	16	(3.9)	13	(3.6)	3	(5.8)	18.8
TOTAL	409		357		52		12.7

Table 68. Distribution of police-reported hazmat accidents in Missouri by road surface condition, 1985-1986.

Road surface condition	Accidents involving hazmat-carrying vehicles						Release probability (%)
	Combined		No release		Hazmat release		
	No.	%	No.	%	No.	%	
Dry	296	(71.5)	260	(71.8)	36	(69.2)	12.2
Wet	85	(20.5)	72	(19.9)	13	(25.0)	15.3
Ice & snow	33	(8.0)	30	(8.3)	3	(5.8)	9.1
TOTALS	14		362		52		12.6

Table 69. Distribution of police-reported hazmat accidents in Missouri by accident type and manner of collision, 1985-1986

Accident type and manner of collision	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
SINGLE-VEHICLE ACCIDENTS							
Noncollision accidents							
Overturn	51	(12.3)	28	(7.7)	23	(45.1)	45.1
Other	11	(2.6)	5	(1.4)	6	(11.8)	54.5
Collision accidents							
Collision with fixed object	61	(14.7)	49	(13.4)	12	(23.5)	19.7
Collision with other obejct	3	(0.7)	2	(0.5)	1	(2.0)	33.3
Collision with parked vehicle	23	(5.5)	22	(6.0)	1	(2.0)	4.3
Collision with non-motorist	10	(2.4)	10	(2.7)	0	(0.0)	0.0
Collision with train	5	(1.2)	5	(1.4)	0	(0.0)	0.0
MULTIPLE-VEHICLE ACCIDENTS							
Head-on collision	12	(2.9)	11	(3.0)	1	(2.0)	8.3
Rear-end collision	67	(16.1)	66	(18.1)	1	(2.0)	1.5
Sideswipe -- meeting	11	(2.6)	11	(3.0)	0	(0.0)	0.0
Sideswipe -- passing	55	(13.2)	55	(15.1)	0	(0.0)	0.0
Angle collision	67	(16.1)	64	(17.5)	3	(5.9)	4.5
Other collision	40	(9.6)	37	(10.1)	3	(5.9)	7.5
TOTAL	416		365		51		12.3

Similar conclusions are evident in the accident type distributions presented in tables 70 and 71 for single-unit trucks and single-trailer combination trucks, respectively. A separate table for double-trailer combination trucks is not presented, because the data are too sparse to be meaningful.

(2) Truck configuration: The overall distribution of Missouri hazmat accidents by truck configuration is presented in table 72. This table is in good agreement with the nationwide FHWA data in table 47, indicating that accidents involving single-trailer combination trucks are more likely to result in a hazmat release than single unit trucks. The sample size for double-trailer combination trucks in table 72 is too small to be meaningful.

f. Consequences of accidents: The consequences of the Missouri hazmat accidents are summarized in table 73. As in the nationwide FHWA data, accidents involving a hazmat release tend to involve more deaths and injuries than accidents that do not involve a release. Table 74 indicates clearly that hazmat releases are most likely in fatal accidents and least likely in property-damage-only accidents.

C. Analysis of Exposure Data

This section of the report presents the analysis of the exposure data available from the 1982 Truck Inventory and Use Survey (TIUS) conducted by the Bureau of the Census.[14] This survey is conducted every 5 years based on a random sample of trucks selected from State registration records. Truck owners are sent a survey questionnaire to be completed describing the characteristics and usage of that particular truck. The results are entered into a computer data base including appropriate expansion factors for use in making statewide and national estimates from the same data.

The TIUS is virtually the only form of exposure data available at the national level that addresses hazmat transportation by highway. The tables shown below illustrate the type of exposure estimates that can be developed from the TIUS. Tables 75 through 78 present the results obtained from analysis of the 1982 TIUS data.

Table 75 presents TIUS estimates of the entire U.S. truck population and the portion of those trucks used in hazmat transportation. The table shows the estimated number of trucks in each category and the estimated annual vehicle-miles of travel by those trucks. The estimated vehicle-miles of travel for hazmat-carrying trucks include all travel by those trucks, even if they carry hazardous materials only part of the time. It should be kept in mind that the 1982 TIUS was performed prior to the passage of the 1982 Surface Transportation Assistance Act (STAA), which has markedly increased the number of double-trailer combination trucks in use in the United States.

Table 70. Distribution of police-reported hazmat accidents in Missouri by accident type and manner of collision for single-unit trucks, 1985-1986.

Accident type and manner of collision	Combined No.	Combined %	No release No.	No release %	Hazmat release No.	Hazmat release %	Release probability (%)
SINGLE-VEHICLE ACCIDENTS							
Noncollision accidents							
Overturn	17	(10.4)	10	(6.8)	7	(46.7)	41.2
Other	5	(3.1)	2	(1.4)	3	(20.0)	60.0
Collision accidents							
Collision with fixed object	21	(12.9)	19	(12.8)	2	(13.3)	9.5
Collision with other object	1	(0.6)	1	(0.7)	0	(0.0)	0.0
Collision with parked vehicle	15	(9.2)	15	(10.1)	0	(0.0)	0.0
Collision with non-motorist	2	(1.2)	2	(1.4)	0	(0.0)	0.0
Collision with train	1	(0.6)	1	(0.7)	0	(0.0)	0.0
MULTIPLE-VEHICLE ACCIDENTS							
Head-on collision	7	(4.3)	6	(4.1)	1	(6.7)	14.3
Rear-end collision	27	(16.6)	26	(17.6)	1	(6.7)	3.7
Sideswipe -- meeting	2	(1.2)	2	(1.4)	0	(0.0)	0.0
Sideswipe -- passing	11	(6.7)	11	(7.4)	0	(0.0)	0.0
Angle collision	36	(22.1)	36	(24.3)	0	(0.0)	0.0
Other collision	18	(11.0)	17	(11.5)	1	(6.7)	5.6
TOTAL	163		148		15		9.2

Table 71. Distribution of police-reported hazmat accidents in Missouri by accident type and manner of collision for single-trailer combination trucks, 1985-1986.

Accident type and manner of collision	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
SINGLE-VEHICLE ACCIDENTS							
Noncollision accidents							
Overturn	30	(13.4)	14	(7.5)	16	(43.2)	53.3
Other	6	(2.7)	3	(1.6)	3	(8.1)	50.0
Collision accidents							
Collision with fixed object	34	(15.2)	25	(13.4)	9	(24.3)	26.5
Collision with other object	2	(0.9)	1	(0.5)	1	(2.7)	50.0
Collision with parked vehicle	7	(3.1)	6	(3.2)	1	(2.7)	14.3
Collision with non-motorist	8	(3.6)	8	(4.3)	0	(0.0)	0.0
Collision with train	0	(0.0)	0	(0.0)	0	(0.0)	-
MULTIPLE-VEHICLE ACCIDENTS							
Head-on collision	4	(1.8)	4	(2.1)	0	(0.0)	0.0
Rear-end collision	36	(16.1)	34	(18.2)	2	(5.4)	5.6
Sideswipe -- meeting	8	(3.6)	8	(4.3)	0	(0.0)	0.0
Sideswipe -- passing	42	(18.8)	42	(22.5)	0	(0.0)	0.0
Angle collision	28	(12.5)	25	(13.4)	3	(8.1)	10.7
Other collision	19	(8.5)	17	(9.1)	2	(5.4)	10.5
TOTAL	224		187		37		16.5

Table 72. Distribution of police-reported hazmat accidents in Missouri by vehicle type and truck configuration, 1985-1986.

Vehicle type and truck configuration	Accidents involving hazmat-carrying vehicles: Combined No.	%	No release No.	%	Hazmat release No.	%	Release probability (%)
Single-unit truck	163	(39.2)	148	(40.8)	15	(28.3)	9.2
Single-trailer combination truck	224	(53.8)	187	(51.5)	37	(69.8)	16.5
Double-trailer combination truck	14	(3.4)	14	(3.9)	0	(0.0)	0.0
Nontruck	15	(3.6)	14	(3.9)	1	(1.9)	6.7
TOTAL	416		363		53		12.7

Table 73. Summary of consequences of police-reported hazmat accidents in Missouri, 1985-1986.

	Accidents involving hazmat-carrying vehicles: Total	No Release	Hazmat Release
No. of accidents	416	363	53
No. of deaths	15	9	6
Deaths per accident	0.036	0.025	0.113
No. of injuries	181	144	37
Injuries per accident	0.44	0.40	0.70

Table 74. Distribution of police-reported hazmat accidents in Missouri by accident severity, 1985-1986.

	Accidents involving hazmat-carrying vehicles						
	Combined		No release		Hazmat release		
Accident severity	No.	%	No.	%	No.	%	Release probability (%)
Fatal	11	(2.6)	7	(1.9)	4	(7.5)	36.4
Injury	121	(29.1)	98	(27.0)	23	(43.4)	19.0
Property-damage-only	284	(68.3)	258	(71.1)	26	(49.1)	9.2
TOTAL	416		363		53		12.7

Table 75. Estimated number of trucks and miles traveled by truck type from 1982 TIUS.

	Entire truck population				Hazmat-carrying trucks			
Truck type	No. of trucks	%	Annual veh-mi, millions	%	No. of trucks	%	Annual veh-mi, millions	%
Single-unit	32,112,000	(95.7)	320,000	(85.2)	261,000	(56.0)	3,900	(24.3)
Single-trailer combination	877,000	(2.6)	46,000	(12.2)	186,000	(39.9)	11,000	(68.5)
Double-trailer combination	32,000	(0.1)	2,000	(0.5)	9,000	(1.9)	660	(4.1)
Triple-trailer combination	1,000	(0.0)	60	(0.0)	450	(0.1)	36	(0.2)
Truck trailer	537,000	(1.6)	7,500	(2.0)	10,000	(2.1)	460	(2.9)
TOTAL	33,559,000		375,560		466,450		16,056	

Table 76. Estimated number of trucks and miles traveled by cargo area configuration for single-trailer combination trucks from 1982 TIUS.

	Entire truck population				Hazmat-carrying trucks			
Cargo area configuration	No. of trucks	%	Annual veh-mi, millions	%	No. of trucks	%	Annual veh-mi, millions	%
Van	437,000	(49.8)	27,000	(58.8)	119,000	(64.0)	7,200	(64.5)
Flatbed	197,000	(22.5)	7,700	(16.8)	12,000	(6.5)	720	(6.5)
Tank (liquid or gas)	72,000	(8.2)	4,200	(9.1)	48,000	(25.8)	2,900	(26.0)
Tank (bulk solid)	12,000	(1.4)	710	(1.5)	1,400	(0.8)	80	(0.7)
Other	159,000	(18.1)	6,300	(13.7)	5,500	(3.0)	260	(2.3)
TOTAL	877,000		45,910		185,900		11,160	

Table 77. Estimated number of trucks and miles traveled by cargo area configuration for double-trailer combination trucks from 1982 TIUS.

	Entire truck population				Hazmat-carrying trucks			
Cargo area configuration	No. of trucks	%	Annual veh-mi, millions	%	No. of trucks	%	Annual veh-mi, millions	%
Van	15,900	(48.9)	1,100	(55.3)	7,400	(81.0)	550	(83.3)
Flatbed	7,600	(23.4)	380	(19.1)	300	(3.3)	20	(3.0)
Tank (liquid or gas)	1,300	(4.0)	80	(4.0)	700	(7.7)	40	(6.1)
Tank (bulk solid)	1,800	(5.5)	120	(6.0)	100	(1.1)	10	(1.5)
Other	5,900	(18.2)	310	(15.6)	640	(7.0)	40	(6.1)
TOTAL	32,500	1,990	9,140	660				

Table 78. Estimated number of trucks and miles traveled by percent of time carrying hazardous materials from 1982 TIUS.

	Entire truck population				Hazmat-carrying trucks			
Percent of time carrying hazmat	No. of trucks	%	Annual veh-mi, millions	%	No. of trucks	%	Annual veh-mi, millions	%
0%	33,098,000	(98.6)	359,600	(95.7)	0	(0.0)	0	(0.0)
Below 25%	244,000	(0.7)	10,000	(2.7)	244,000	(52.9)	10,000	(62.6)
25%-49%	117,000	(0.3)	3,000	(0.8)	117,000	(25.4)	3,000	(18.8)
50%-74%	20,000	(0.1)	800	(0.2)	20,000	(4.3)	800	(5.0)
75%-100%	80,000	(0.2)	2,200	(0.6)	80,000	(17.4)	2,200	(13.8)
TOTAL	33,559,000		375,600		461,000		16,000	

Table 75 illustrates that the vast majority of trucks are, and truck travel in the United States is by, single-unit trucks. However, most of the travel by single-unit trucks is in local pick-up-and-delivery operations and on relatively short trips. Single-trailer combination trucks represent only 3 percent of registered trucks, but accumulate over 12 percent of annual vehicle-miles by trucks. Only a very small portion of truck travel is by truck types other than single-unit trucks and single-trailer combinations.

Single-unit trucks constitute the majority of trucks used at least part of the time in hazmat transportation. However, yable 75 indicates that over 68 percent of annual vehicle-miles for hazmat-carrying trucks are traveled by single-trailer combination trucks. Single-unit trucks constitute 24 percent and double-trailer combinations constitute 4 percent of travel by hazmat-carrying trucks.

Table 76 presents a similar breakdown of trucks and truck travel by cargo area configuration for single-trailer combination trucks. The majority of the trucks in both the general truck population and the hazmat-carrying truck population have enclosed van semitrailers. Vans constitute 65 percent of travel by hazmat-carrying trucks. Liquid or gas tankers constitute 26 percent of travel by hazmat-carrying trucks and flatbeds constitute 7 percent.

Table 77 presents comparable data on the distribution of cargo area configurations for double-trailer combination trucks. The table shows that van trailers are even more predominant among double-trailer combination trucks than among single-trailer combination trucks. Double tankers for liquids, which have been reported in some States to have safety problems, constitute only 6 percent of travel by hazmat-carrying doubles, and only 0.3 percent of travel by all types of hazmat-carrying trucks.

Table 78 presents the distribution of trucks and vehicle-miles of travel by the percentage of time carrying hazardous materials. The table shows that only about 17 percent of hazmat-carrying trucks carry hazardous materials nearly all of the time. In fact, the majority of hazmat-carrying trucks and vehicle-miles are by trucks that carry hazardous materials less than 25 percent of the time.

Other available data in the 1982 TIUS allow trucks and truck travel to be broken down by State of registration, carrier type, and principal product carried. However, the TIUS data cannot be disaggregated by any of the highway characteristics of direct interest to highway agencies.

VI. RISK ASSESSMENT AND ROUTING

This section of the report discusses the risk assessment and routing methods appropriate for highway transportation of hazardous materials. First, existing risk assessment models and routing methods are reviewed. Then, a detailed critique of the FHWA routing guidelines for hazardous materials is presented together with recommendations for revising these guidelines.

A. Existing Risk Assessment Models and Routing Methods

The following discussion describes the existing risk assessment models and routing methods applicable to highway transportation of hazardous materials. Risk assessment models are used to quantify the potential risk to population or property of transporting hazardous materials over particular routes. Routing methods are techniques for using risk assessment results to compare alternative routes for hazmat shipments.

First, the general types of risk assessment models that have been developed are identified. Then, four specific routing methods for highway shipments of hazardous materials are reviewed. Finally, several examples of routing studies using these methods are presented.

1. Types of Risk Assessment Models

A classification of risk assessment models was developed by Rowe in NCHRP Synthesis of Highway Practice 103, "Risk Assessment Processes for Hazardous Materials Transportation."[96] Risk assessment models are classified into four types including: enumerative indices; regression models; network and distribution models; and probabilistic models. Each of the four types of risk assessment models is reviewed below. The examples of each type of risk assessment model cited below include all transportation modes and are not limited to just the highway mode.

a. Enumerative indices: Enumerative indices are risk assessment models based on a rating or scoring scheme. Two examples of enumerative index models are the Garbor and Griffith model and the Kansas State University (KSU) model.[37,97]

The Garbor and Griffith model is based on counts of the number of chemical plants, storage facilities, and their proximity to population and transportation facilities. The KSU model uses prepared tables to convert traffic counts, route mileage, placard counts, and form of threat, to indices used to classify risks as low, medium, or high. The same type of index is generated for a community's emergency response preparedness, referred to as a "vulnerability" index. The KSU model is reviewed in greater detail later in this section of the report.

The limitation of models based on enumerative indices is that they lack precision. High risk situations may be masked in the aggregation process. However, from a small community's perspective, they are easy to use, in terms of data acquisition and computational requirements. They can provide an excellent review of a community's average vulnerability, but they do not help to identify particular locations or situations of unusually high risk nor specific means to reduce these risks. Their greatest value may be to promote greater community awareness through the process of applying the model.

b. Regression models: Regression models use measurable parameters such as average daily traffic, number of heavy volume intersections, number of signals, type of road or railroad, and road or railroad condition as independent variables. These independent variables are then related to accident probabilities per million vehicle-miles, usually for a specific vehicle type, as the dependent variable.

Regression models are usually route-specific, since the data available are for specific routes. A good example of a regression model is the FHWA or Urbanek model, which was developed specifically for use in routing decisions.[10,94,116] The accident probabilities determined from regression models are usually multiplied by a consequence estimate, typically representing the nature and extent of the population at risk.

The equations used to predict accident probabilities in regression models contain parameters whose values are set on the basis of previous research or the judgment of the model developer. The values of the variables in the regression model are based on actual site-specific data gathered by the model user. A weakness of regression models is that neither the model developer nor the model user typically has access to enough historical data on low-probability, high-consequence events to obtain a reliable model.

Regression models are more suited to choosing between alternative routes than to providing a community with the overall risk or even the specific risk problems of a specific route.

c. Network and distribution models: Network and distribution models are intended to choose routes based on specific criteria (e.g., minimum risk) through a network of routes that is usually national or regional in scope. These models use historical data, national average data, or site-specific data as the basis for estimating accident rates for specific links. Some models of this type use population density as a consequence measure.[41,59]

Because these models generally use national data bases, they primarily assess either national or regional transportation risks for a given mode of transport, or a given commodity class. One such distribution model uses a shortest path algorithm with weights for each link in the transportation network based on the product of accident probability and accident consequence.[120] In this respect, this model is similar to the probabilistic risk assessment models discussed below.

d. Probabilistic risk assessment models: Probabilistic risk assessment models are based on the conditional probability of an accident and the magnitude of its consequences as the two principal components. Models of this type differ in: (1) how they combine parameters or sets of parameters into the two components to arrive at the risk estimate; (2) the level of detail required for data acquisition; and (3) the methods used to acquire data and/or estimate the model parameters.

Several different definitions of risk have been used. The National Academy of Sciences panel on risk analysis and hazard evaluation used the conditional probability of an accident resulting in loss as its definition of risk.[72] Several other models all use an expected value of risk, defined as the product of the conditional accident probability and the estimated magnitude of consequences.[46,55,68,120]

Probabilistic risk assessment models also differ in the level of detail in the required data. Some models start with the shipment of a particular material by a specified mode over a specified route or distance. The expected risk for each case is found by developing estimates of the likelihood of an accident and the magnitude of consequences. Each individual expected risk is then aggregated over all paths, modes, vehicle types, cargos, etc., to obtain an estimate of absolute expected risk. The models in references 7 and 87 are examples of this type. NCHRP Synthesis of Highway Practice 103 classifies this approach as a "bottom-up," since analysis starts with data at the finest level of detail available, and the data must be relatively complete.[96] By contrast, the "top-down" approach starts with aggregated data and attempts to break down the estimates to the finest level of detail permitted by the available data.

Some models use fault-tree analysis to develop probabilities.[46,68] Others use average accident rates by mode and vehicle type. Dispersion models for population exposure and simulations to determine spill behavior are two of many approaches that have been tried to estimate accident consequences.[38]

2. Kansas State University Model

One of the earlier risk assessment models for hazmat transportation in the United States is the KSU model.[97] This model is used to determine the average risk of hazmat incidents and average vulnerability (lack of emergency response preparedness) for a community as a whole. Community risk and vulnerability are rated on an ordinal scale as low, medium, or high. The KSU model is intended primarily for communities with populations under 50,000.

The KSU model is applied in a series of 14 steps; the first 11 steps constitute the risk assessment and the last three steps constitute the evaluation of community preparedness and the selection of an emergency response plan. The authors provide detailed guidance, with tables and forms, for carrying out the analysis. This guidance is provided in a user's manual presenting the step-by-step process so that local officials need no technical expertise to apply the model.[98]

In applying the KSU model, the user develops values for two major components: a risk factor and a consequence factor. The risk factor takes into account the quantities and types of hazardous materials flowing through the community. A Twelve-Hour Average Density (THAD) subfactor is determined from placard counts of hazmat carrying vehicles and route mileages. The types of hazardous materials shipped are considered in a subfactor called the Average Form of Threat (AFT); this factor is based upon an adjusted placard count which gives additional weight to large bulk shipments, exceptionally hazardous materials (e.g., explosives), and "triple threat" materials (e.g., materials that could result in fires, explosions, and toxic releases). The risk factor is determined by entering a table with both a THAD value and an AFT value.

The consequence factor in the KSU model is based on four surrogate measures for the potential extent of consequences. These are the environment subfactor; the population-density subfactor; the property subfactor; and the manufacturing and storage subfactor. These four subfactors are additive and consider consequences with 0.5 mi (0.8 km) on either side of 1.0-mi (1.6 km) route segments for all transportation modes present in the community (highway, rail, air, and water).

The 14 steps in application of the KSU model are:

Step 1. Obtain Maps and Available Photographs -- Obtain community maps that can identify all forms of transportation and storage of hazardous materials. Topographical maps, for example, are important for accident mitigation after the fact.

Step 2. Conduct a Manufacturing and Storage Establishment Survey -- Identify all source and repositories of hazardous materials within the community.

Step 3. Obtain Traffic Data on Pipelines, Barges, Air, and Rail -- Acquire traffic count data.

Step 4. Plot 1-Mile Route Segment Corridors -- Use maps to plot impact corridors 0.5 mi (0.8 km) on either side of routes for all transportation modes.

Step 5. Plot Manufacturing and Storage Data -- Add source and storage data to the maps.

Step 6. Conduct Hazmat Traffic Surveys -- Conduct traffic surveys where data are not otherwise available, particularly for highways.

Step 7. Determine Risk Subfactors -- Determine 12-hr average density (THAD) of traffic based on traffic counts and route lengths, and adjust for hazmat placard counts, hazmat shipment quantities (based on vehicle types), and hazard class, using tables provided with the model.

Step 8. Determine Risk Factor -- Convert step 7 to a risk factor, using table provided with the model.

Step 9. Determine Consequence Subfactors -- Obtain data on surrogate measures for hazmat incident consequences including environmental conditions, population densities, exposed property, and manufacturing and storage facilities.

Step 10. Determine Consequence Factor -- Sum the four subfactor values of step 9.

Step 11. Determine Risk Index -- Use the values of the risk and consequence factors to determine a risk index. Express the risk index to a high, medium, or low risk level.

Steps 12-14. Evaluate emergency response capability to determine the estimated degree of community vulnerability.

The KSU approach is limited by the resources available to carry out the total process and the possible lack of sensitivity to specific problem areas. However, the model does provide a community with a reasonable overview of its vulnerability to risk. If this vulnerability is high, then further studies should be conducted. The use of the model has been demonstrated through application to several small communities.[47]

NCHRP Synthesis of Highway Practice 103 has proposed a simplified approach to hazmat risk assessment based on a modification of the KSU model.[96] This approach, referred to as a "scoping analysis," is intended as a quick method to determine whether a community has an overall problem related to hazmat transportation and to identify specific high-risk situations. The scoping analysis considers only three key commodities: gasoline, chlorine, and anhydrous ammonia. These three products are transported in and through most communities and have historically been involved in more than 50 percent of all multiple-fatality accidents involving hazardous materials.

In contrast, another recent study by the Association of Bay Area Governments (ABAG) in metropolitan San Francisco has developed a modified version of the KSU model that, with data at a greater level of detail, can be used for hazmat routing analyses.[53] The ABAG approach is reviewed below.

3. FHWA Guidelines for Hazmat Routing

The FHWA publication, "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials," presents the most widely used risk assessment procedure for highway transportation of hazardous materials.[10] The overall procedure in the guide determining appropriate routes for hazmat shipments is referred to as the FHWA routing method. The key element of this method is a risk assessment model known to many users as the "Urbanek model." These guidelines have been reissued in 1989 in revised form by RSPA.[94]

a. Overview of the FHWA routing method: Figure 17 illustrates the structure of the FHWA routing method. Prior to the application of the risk assessment model, the alternative routes under consideration are evaluated with respect to two types of mandatory factors: physical factors and legal factors. The physical factors considered are those that might make a particular alternative route infeasible, such as weight restrictions on bridges or height restrictions at underpasses. Other physical constraints might include inadequate shoulders for breakdowns, extensive construction activities, or inadequate parking and turning spaces. Legal factors that

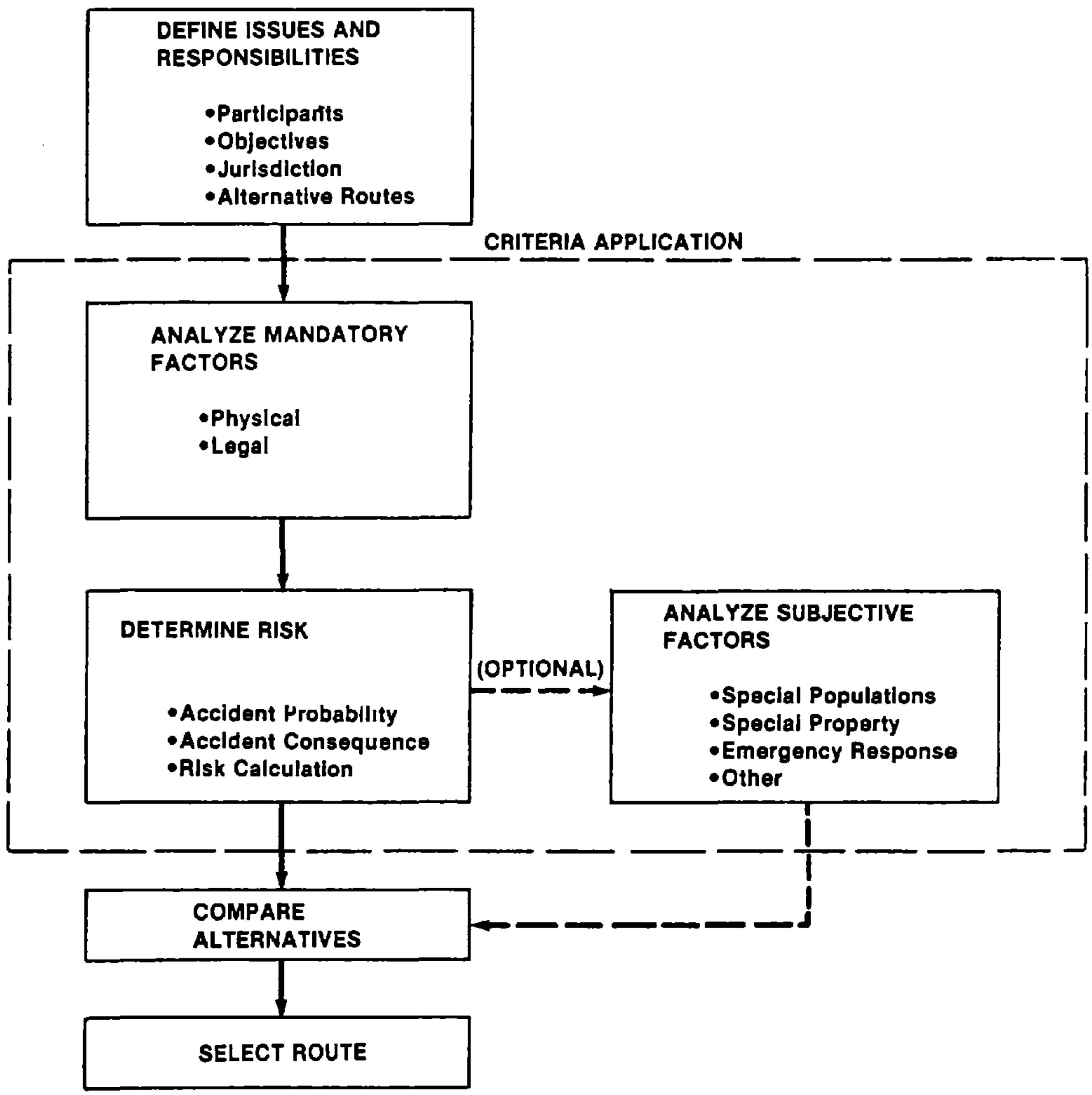

Figure 17. Structure of FHWA hazardous materials routing method.[10]

could limit the feasibility of a particular alternative route include laws and regulations that prohibit trucks or hazardous materials on specific roadways, bridges, tunnels, or toll roads. Any alternative route that is found to be infeasible due to physical or legal factors can be eliminated from consideration at this point.

The next step in the FHWA routing method is to conduct a quantitative evaluation of the alternative routes using the risk assessment model, which is discussed in the next section of this report. The output of this analysis is a risk estimate for each alternative route.

The final step in the FHWA routing method is to consider subjective factors that cannot be easily quantified but may increase the consequences of a hazmat release on one route relative to another. The subjective factors most frequently considered are:

- Special populations, such as schools or hospitals, that would be particularly difficult to evacuate in the event of a hazmat release.

- Special land uses, such as watersheds, reservoirs, and other ecologically sensitive areas that would be damaged by a hazmat release.

- Emergency response capabilities, including the location, manpower, and training level of emergency response teams.

The consideration of these factors is optional, and no specific procedures for their consideration are provided in the guide.

The final choice of the safest feasible route for hazmat shipments is based on the quantitative results of the risk assessment and the evaluation of the subjective factors.

b. Overview of the FHWA risk assessment model: The FHWA risk assessment model is intended to compare the risks involved in hazmat transportation by highway on two or more selected alternative routes. In many cases, the alternative routes are not homogeneous in highway type, traffic volume, population density, or level of development; therefore, it is usually necessary to divide each alternative route into segments that are relatively homogeneous. The total risk for a route is then determined as the sum of the calculated risks for all segments of that route.

There are three steps in the determination of risk using the model. These are:

- Determine accident probability.

- Determine accident consequence.

- Calculate risk.

Each of these steps is described below.

(1) Determine accident probability: The probability of a hazmat accident is computed in the risk assessment model from the following equation:

$$P(A)_i = AR_i \times L_i \times FHZ \qquad (2)$$

where: $P(A)_i$ = probability of a hazardous materials accident for route segment i

AR_i = accident rate per veh-mi for all vehicle types on route segment i

L_i = length (mi) for route segment i

FHZ = fraction of all accidents that involve a hazmat release

The first term in equation (2) is the accident rate per vehicle-mile (AR_i) for the route segment in question. Since hazardous materials release rates are not generally available for specific route segments and truck accident rates were thought to be similarly unavailable, the risk assessment model is based on the general accident rate for all vehicle types.

The FHWA guide urges the use of actual accident histories for the route segments in question, whenever possible. Accident predictive models are provided for use when actual accident data are not available. Accident predictive equations from published literature are provided for three highway types: freeways; two-lane highways; and urban arterials.[70,107] A number of alternative predictive models were reviewed before making the choice to use these particular models.[116]

The second term in equation (2) is the length of the route segment (L_i). Length is considered in the determination of accident probability because it is a direct measure of the exposure of vehicles to the risk of accidents. For example, if one alternative route is twice as long as another, a vehicle traveling the longer route has twice the risk of an accident due to the difference in length alone, even if the accident rates of the two segments are the same.

The third and final term in equation (2) is the fraction of all accidents that involve a hazmat release (FHZ). This fraction was estimated by Urbanek and Barber from available data.[116] They examined 4.5 years of hazmat incident data from the DOT Research and Special Programs Administration (RSPA) and found a total of 2,104 hazmat releases due to the traffic accidents. They also estimated that there were 93,200,000 traffic accidents in the United States during the same period. Thus, the fraction of traffic accidents involving a hazmat release was estimated as:

$$\frac{2,104}{93,200,000} = 2.3 \times 10^{-5}$$

A worksheet for performing the calculation of accident probability is provided in the FHWA guide.[10]

(2) Determine accident consequences: The risk assessment model considers two types of consequences from an accident involving a release of hazardous materials. These are personal injury consequences and property damage consequences. Both of these consequences are compared between routes based on the population potentially exposed and the value of the property potentially exposed to a hazmat release.

The model assumes that the personal injury consequences of a hazmat release are proportional to the population potentially exposed to the release. The population potentially exposed to a release may be estimated on the basis of residential population, employment, motorists, or a combination of the three. The application of the model to residential populations is illustrated in the guide. The four steps in evaluation of exposed residential population are:

- Delineate the potential impact zone on census tract maps that include the area around the route segment in question. The extent of the potential impact zones for various classes of hazardous materials is based on the impact distances shown in table 79, which is presented in the updated form used in the revised guidelines recently issued by RSPA.[94]

- Determine what proportion of each census tract is located within the impact zone.

- Multiply the census tract population by the proportion of the census tract within the impact zone.

- Sum the exposed populations for all census tracts along the route segment.

A worksheet for performing these calculations is provided in the FHWA guide.

Table 79. Potential impact distances for various classes of hazardous materials.[94]

Hazardous materials class	Impact distance
Combustible Liquid (CL)	0.5 mi all directions
Flammable Liquid (FL)	0.5 mi all directions
Flammable Solid (FS)	0.5 mi all directions
Oxidizer (OXI)	0.8 mi all directions
Nonflammable Gas (NFG)	1.0 mi all directions
Flammable Gas (FG)	0.5 mi all directions
Poison (POI)	1.0 mi all directions
Corrosive (COR)	1.0 mi all directions
Explosives (EXP)	0.5 mi all directions

A similar approach is used for the assessment of property damage consequences, which is considered to be an optional component of the risk assessment model. The property damage consequences of a hazmat release are assumed to be proportional to the value of the property adjacent to the route segment in question. (It should be noted that the model considers only property adjacent to the roadway, not property within the entire impact zone for population risks defined above.) Five land-use types are considered by the model: high-density residential; medium-density residential; low-density residential; commercial; and industrial. The steps in the assessment of the value of property exposed to a hazmat release are as follows:

- Determine lineal frontage for each land-use type.
- Estimate dollar value per linear foot for each land-use type.
- Multiply lineal frontage of each land-use type by the associated value per lineal foot, and sum across all land-use types for each route segment.
- Add the value of roadway structures owned by the highway agency on the route segment.

A worksheet for assessing the value of property exposed to a hazmat release is also provided in the FHWA guide.

(3) Calculate risks: Risk is calculated in the Urbanek model as the product of the probability of a hazmat accident and the population or property damage consequences of an accident. Thus, in general:

$$\text{Risk} = \text{Probability} \times \text{Consequences} \tag{3}$$

The population risk is computed in the Urbanek model as:

$$RPOP_i = P(A)_i \times POP_i \tag{4}$$

where: $RPOP_i$ = population risk along route segment i

POP_i = number of persons within the specified impact zone width exposed to a hazardous materials release along route segment i

The property damage risk is computed in the Urbanek model as:

$$RPD_i = P(A)_i \times PV_i \tag{5}$$

where: PV_i = total property value along route segment i

The total population risk or total property damage risk for each alternative route is computed by summing all of the individual risks along each route. The risk assessment model does not provide a method for combining or weighting the population and property damage risks for a route, so these risks must be considered separately.

4. RSPA Model for Shipments of Radioactive Materials

A risk assessment model for routing of shipments of radioactive materials has been developed by the Research and Special Programs Administration (RSPA) of the USDOT.[64] An example of a shipment of radioactive materials might be a shipment of spent nuclear fuel from a nuclear reactor to a storage or processing site. The model does not attempt to quantify the risk of a release of radioactive material in an absolute sense, but does assess the relative risks of possible alternative routes for shipments of radioactive materials.

The primary factors considered by the RSPA model in comparing alternative routes for shipment of radioactive materials are:

- Normal radiation exposure.
- Public health risk from accidents.
- Economic risk from accidents.

These three factors are considered to have equal weight in the evaluation of alternative routes. Each of these factors is discussed below.

The normal radiation exposure is a risk that is unique to radioactive materials. This factor is the risk associated with the relatively low level of radiation exposure that will be experienced by motorists and the general public, even when no release of radioactive materials occurs. The model used to consider normal radiation exposure considers the following elements for each alternative route: average population density along route; length of route; average flow rate; average speed of vehicles on the route; and distance between opposing lanes.[45] The average flow rate and the average speed of vehicles on the route are used to determine the average spacing between vehicles traveling in the same direction on the route, which determines their expected exposure to radiation. The exposure to radiation of motorists traveling in the opposite direction is based on the distance between opposing lanes. Shipment-specific levels of radiation are not considered in the model because these would not vary between alternative routes.

Public health and economic (property damage) risks from radioactive materials released due to traffic accidents are also considered to be primary risk factors. A release of radioactive material due to a traffic accident will occur only if the package containing the radioactive material is subjected to accident forces that exceed the package design standards. Two factors are considered in assessing these risks: (1) the frequency of accidents that could result in a release; and (2) the consequences from such accidents in terms of the number of people and extent of property that could be exposed to radiation if a release occurs. Both of these factors typically vary between alternative routes.

The RSPA model recommends that the accident risk estimates be based on actual traffic accident data from State or local agencies responsible for the routes under consideration. A range of possible accident risk measures are suggested for use including, in descending order of desirability:

- Hazardous material truck driver fatality rate.
- General truck driver fatality rate.
- Hazardous material truck fatal accident rate.
- General truck fatal accident rate.
- General vehicle traffic fatality rate.
- General traffic accident rate.

- Accident rate from accident predictive models.

These measures, although expressed as accidents per million vehicle-miles, are not intended to estimate the risk of a radiation-releasing accident in absolute terms, but rather provide a relative comparison between routes. Thus, one of the above measures should be selected and the same measure should be used for all routes under consideration. The emphasis on fatal accidents and accidents in which the truck driver is killed is intended to focus the analysis on the risk of accidents that might generate sufficient forces to result in a release of radioactive material. It is obvious that some compromises must be made in the choice of an accident rate measure. There are unlikely to be enough hazardous material truck driver fatalities on most highways to allow a valid comparison of risk between alternative routes; thus, one of the lower priority accident measures will probably need to be chosen. At the other extreme, the use of accident predictive models, as in the Urbanek model, is the lowest priority and is considered to be less desirable than the use of actual accident data.[10,94,116] Once the relative accident rate per million vehicle-mile is estimated, this rate can be multiplied by the length of each route (or route segment) to obtain a relative accident frequency.

The public health and economic (property damage) consequences of a release of radioactive material are also estimated. When radioactive material is released as the result of a traffic accident, the population in an area of approximately 25 mi^2 (65 km^2) downwind of the release is generally exposed to low levels of radioactivity. The public health risk is based on the number of persons who could potentially be exposed to radiation; this is estimated from the population density on either side of each alternative route, out to a distance of 10 mi (16 km). The population within a 5-mi (8 km) band is considered most critical and is given greater weight in the analysis. Economic (property damage) consequences are estimated in terms of the decontamination costs for the different types of land uses within 10 mi (16 km) of each alternative route; as in the case of public health risks, land uses within a 5-mi (8 km) band surrounding the highway receive greater weight in the analysis.

The estimates of the three primary risk factors are normalized to place them on a dimensionless 0 to 1 scale and are combined into a measure of overall risk, giving each factor equal weight.

Secondary (nonradiation) factors that may be used in the RSPA model to compare routes are:

- Emergency response capabilities.
- Evacuation.
- Location of special facilities.
- Traffic fatalities and injuries.

These factors are optional and may be used where they are considered appropriate to the comparison of particular routes.

5. Abkowitz Model

A risk assessment model has been developed by Abkowitz et al. for assessment of the risk of a release during highway shipment of hazardous wastes.[2,3] The Abkowitz model is intended for use by the EPA in environmental impact statements, which usually include an evaluation of the "do-nothing" alternative (not making any hazmat shipments). Thus, the model is intended to provide absolute measures of risk rather than just relative comparisons between routes.

The Abkowitz model considers the risk of three types of incidents: container failures due to vehicle accidents; container failures en route due to causes other than vehicle accidents; and releases at shipment terminal points. The following assumptions were made concerning these three types of incidents:

- The probability of a truck accident in which a release occurs is independent of the type of waste being transported and the container type used in shipment.
- The probability of occurrence of an incident at any point along the route is a nonzero constant that, exclusive of truck accidents, depends only on the type of container used.
- The probability of occurrence of an incident at a shipment terminal point depends only on the container type used.
- The expected amount released as a result of an incident depends on the container type used and the specific cause of the release (failure mode). It does not depend on the location of the incident.

The risk of hazmat releases is expressed in this model as the fraction of the total quantity of hazardous materials shipped that will be released. This model can be expressed as:

$$FR = FRPM(CT,RAR)*D + FRTP(CT) \tag{6}$$

where: FR = fraction released

FRPM(CT,RAR) = expected fraction released per mile shipped for a specified container type CT and a specific highway type with releasing accident rate RAR

CT = container type

RAR = expected releasing accident rate (releasing accidents per million veh-mi) for highway type HT

D = distance traveled (mi)

FRTP(CT) = expected fraction released at terminal points

Table 80 presents the expressions recommended in references 2 and 3 for estimating FRPM(CT,RAR) and FRTP(CT) in equation (6).

Table 80. Estimates of fraction of hazardous material released by container type.[2,3]

Container class	Expected fraction released per mile shipped [FRPM(CT,RAR)]	Expected fraction released at terminal points [FRTP(CT)]
Cylinders	$1.3 \times 10^{-6} + 0.13$ RAR[a]	1.4×10^{-4}
Cans	$2.6 \times 10^{-6} + 0.12$ RAR	4.0×10^{-4}
Glass	$1.7 \times 10^{-6} + 0.27$ RAR	2.6×10^{-4}
Plastic	$4.1 \times 10^{-6} + 0.14$ RAR	5.2×10^{-4}
Fiber boxes	$1.3 \times 10^{-6} + 0.12$ RAR	6.1×10^{-5}
Tanks	$4.2 \times 10^{-6} + 0.19$ RAR	7.6×10^{-6}
Metal drums	$2.4 \times 10^{-6} + 0.10$ RAR	2.9×10^{-4}
Open metal containers	$7.5 \times 10^{-6} +$? RAR[b]	1.2×10^{-3}

[a] RAR is the releasing accident rate per million veh-mi for a particular highway type (see Table 81).

[b] Estimates of the contribution of traffic accidents to release for this container type are unreliable.

Expected rates for releasing accidents, defined as traffic accidents of sufficient severity to release all or part of the hazardous cargo, were incorporated in this model in the following form:

$$RAR(HT) = AR(HT) * P\ (R|A) \tag{7}$$

where: RAR(HT) = expected releasing accident rate for highway type HT

AR(HT) = expected truck accident rate for highway type HT

P(R|A) = probability of a hazmat release given an accident

Table 81 presents the accident rate data used in these estimates. The truck accident rate estimates for different highway types in table 81 are those presented earlier in this report (see table 9).

Table 81. Accident rates resulting in a hazardous materials release by highway type.[2,3]

Highway type	Truck accident rate [AR(HT)] (accidents per million veh-mi)	Probability of a hazmat release given an accident [P(R|A)]	Expected releasing accident rate [RAR] (releasing accidents per million veh-mi)
Interstate (freeway)	0.65	0.20	0.13
U.S. and State routes (rural highways)	2.26	0.20	0.45
Interrupted flow due to intersections (urban arterial)	3.65	0.20	0.73
Composite	1.40	0.20	0.28

The probability of a hazmat release given an accident [P(R|A)] was determined indirectly. First, the authors of references 2 and 3 noted that 1982 Federal Railroad Administration (FRA) data indicate in 601 train accidents, consisting of 2,770 cars carrying hazardous materials, there were 109 cars that released hazardous materials.[36] Second, previous work by a different author indicated that tank trucks involved in accidents are 10 times more likely to spill than rail tank cars.[39] These two factors yield a probability of release estimate of 0.4 for tank trucks, which was adjusted downward to 0.2 by the authors of references 2 and 3 to compensate for the higher damage threshold for an FRA reportable accident in comparison to the damage threshold used in the RSPA Hazmat Incident data base. The indirect estimation of [P(R|A)] is probably the weakest element of the Abkowitz model.

However, this probability is treated as constant for all routes and does not affect the relative comparison between routes; instead, it functions only as a scale factor to express the relative accident rates of alternative routes so that they can be meaningfully interpreted.

6. Routing Studies for General Hazardous Materials

A number of routing studies for major metropolitan areas have applied the routing methods discussed above. These studies are reviewed here with emphasis on how the existing routing methods were adapted to fit the needs of particular metropolitan areas.

a. Dallas-Fort Worth study: The North Central Texas Council of Governments completed in 1985 a well-documented, detailed study which employed the FHWA routing method in the selection of an appropriate routing strategy for hazmat shipments.[57,81,82] A number of modifications and enhancements to the FHWA procedures were made as part of this study, including:

- Replacing manual computations with an automated system based on data base analyses. This was necessary to enable detailed computations on the scale required for a regional study.
- The factor used in the Urbanek model to represent the fraction of all accidents that involve a hazmat release (FHZ) was ignored, because it is constant for all alternative routes.
- The property damage consequences of hazmat releases were not considered due to lack of data on land use. However, both population and employment were considered in assessing the potential for deaths and injuries due to hazmat release.
- The impact area was based on a worst-case scenario, and population and employment within 2 mi (3.2 km) of each alternative route were considered.
- Map overlays were developed to indicate the locations of schools, hospitals, shopping centers, water supplies, etc., for consistent application of the subjective factors.

The Dallas-Fort Worth study used a path-building algorithm to determine minimum risk routes for hazmat shipments. Minimum-risk routes were determined between every pair of entry and exit points to the metropolitan Dallas-Fort Worth highway system. In nearly every case, the minimum-risk routes between points were the shortest freeway routes that did not pass through either downtown Dallas or downtown Fort Worth; these minimum-risk routes thus made substantial use of the beltways surrounding the central cities.

The impact of restricting hazmat shipments to the minimum-risk routes was evaluated by comparing the minimum-risk routes to minimum-distance routes between the same points. The minimum-distance routes were used to represent the routes that drivers of hazmat-carrying vehicles would use in the absence of any hazmat routing restrictions; in fact, route choice by drivers is more complex, and takes into consideration travel time, congestion, and safety in addition to travel distance. The minimum-risk routes were found to result in a 50 percent reduction in population exposure and an 80 percent reduction in employment exposure, or a net reduction in risk of approximately 60 percent, in comparison to the minimum-distance routes. An equivalent statement is that the risk of permitting trucks to use the minimum-distance routes was found to be 2.625 times higher than restricting them to the minimum-risk routes. The minimum-risk routes were found to require 2.161 times as many vehicle-miles of travel as the minimum-distance routes. Since the ratio 2.625/2.161 is greater than 1.0, there was assumed to be a positive benefit in restricting hazmat shipments to the minimum-risk routes.

An interesting sidelight to the study was the treatment of hazmat routing on freeways in the vicinity of downtown Dallas which, under the minimum-risk routes, would be used only for shipments with origins or destinations within the city. The routing plan developed in the first phase of the study recommended that hazmat shipments be prohibited from freeway segments located on elevated structures or on depressed roadways near the central business district, and that hazmat shipments use the arterial street system instead. However, the risk assessment conducted in the second phase of the study found that the total risk of using the freeways was lower than the total risk of using the arterial street system. This conclusion is not surprising given that freeways generally have lower accident rates than arterial streets and are generally located farther from surrounding development.

The routing plan developed in the study has been approved by the North Central Texas Council of Governments and has now been adopted by ordinance in all 16 of the affected communities.

b. Portland study: A hazmat routing study conducted in Portland, Oregon, was also based on the FHWA routing method.[23] The study initially focused on three categories of shipments: (1) local deliveries; (2) access to industrial zones; and (3) through shipments. It was quickly realized that the adoption of a routing plan for local deliveries would be nearly impossible. It was found that some carriers made deliveries to over 200 local customers and could not reasonably adhere to a fixed routing scheme. Therefore, the responsibility for routing of local deliveries was placed on carriers. Four industrial areas were considered in the study; alternative access routes were available for only one of the four areas. Routes for through shipments were examined by considering possible combinations of alternative routes between all entry and exit points to the metropolitan area.

The Portland study considered potential risks to population, employment, and property. In contrast to the Dallas-Fort Worth study, the impact area extended only 0.25 mi (0.4 km) from the highway, which was considered adequate for first phase evacuation. Portland paid special attention to the effects of roadway characteristics and the potential for high-consequence accidents. Factors considered were: lane and shoulder width; number of stops and heavy volumes of traffic; traffic weaving; and lane changes. Tunnels and rail-highway grade crossings were also considered because of the potential for disastrous consequences.

As a result of the study, hazmat shipments were banned on two routes, and it was recommended that several other routes not be used. Carriers had their choice of eight recommended route alternatives. To implement the study results, Portland issued advisory pamphlets presenting the recommended routes to local truckers, hazmat facility loading dock managers, and weigh stations. Other results of the study included an inventory of emergency response resources, and increased local awareness of the need for equipment and training for emergency response personnel along the recommended routes, establishment of reduced speed limits in areas of high risk, and time of day restrictions on certain types of hazmat shipments.

c. Columbus study: A third local study based on the FHWA routing method was conducted in Columbus, Ohio.[105] The risk assessment found the I-270 beltway to be the safest route around or through Columbus. The Columbus study found a need to consider other objective and subjective factors beyond the results of the risk assessment. These factors included:

- Special populations (schools, hospitals, etc.).
- Land usage.
- Number of highway structures.
- Operational costs to carriers.

The consideration of operational costs to carriers recognized that the use of less than optimal routes can result in additional vehicle operating costs and driver wages for carriers. In fact, several of the recommended routes were shorter than the only viable alternative. For example, the southwest leg of I-270 on the beltway around the city was found to be 2.1 mi (3.3 km) shorter than the combined length of the I-71 (south leg) and I-70 (west leg) through the center of the city.

Although property values were not considered quantitatively in the risk assessment, land use was considered qualitatively. Large segments of the recommended I-270 beltway route passed through agricultural land, while the alternatives through the city were more urban in nature.

The number of highway structures (underpasses and overpasses) on I-270 was fewer in number than the alternatives, and I-270 was preferred for this reason.

Finally, special populations (schools, hospitals, etc.) were considered. No special populations were found along the recommended I-270 route.

d. Cleveland study: The Northeast Ohio Areawide Coordinating Agency (NOACA) performed a study in 1987 of hazardous materials routes in the Cleveland metropolitan area.[83] The scope of the study included all Interstate routes, many State highways, and selected county or municipal streets on which significant truck movements occur. The risk assessment of these routes was based on the FHWA routing method with the following modifications:

- The study used truck accident rates rather than general vehicle accident rates recommended in the FHWA guidelines. The truck accident rates were based on 3 years of truck accident data for the segments being analyzed and truck volume data for one of those 3 years.

- The truck accident rate was multiplied by the percentage of placarded trucks observed by NOACA in a recent field survey. However, the same percentage was used for all routes studied, so this factor had no effect on the results.

- Risks for both daytime and nighttime populations along the analysis segments were considered. Nighttime population included the resident population (from census data) in the impact zone, plus motorists. Daytime population included daytime household population, plus employment, plus school enrollment, plus motorists. Daytime household population was defined as the sum of the population over age 65, plus twice the population under age six. The population under age six was multiplied by two based on the assumption that there was at least one caretaker for each child.

The risk assessment results were used to identify the route segments with the highest daytime risk, the highest nighttime risk, and the highest difference in risk between daytime and nighttime. A critical path algorithm was used to define recommended routes for through truck movements in the Cleveland area.

e. San Francisco Bay Area study: The KSU risk assessment model was originally intended solely as a tool to rate risk and vulnerability for entire communities on an ordinal scale (low, medium, high). However, as part of a regional assessment of hazmat transportation in the San Francisco Bay Area by the Association of Bay Area Governments (ABAG), a modified KSU model was developed for use in hazmat routing studies.[8,9,53]

The following modifications to the KSU model were made by ABAG:

- The risk index is calculated individually for each mode of transport and each route segment, so that relative hazards throughout the community can be compared. The original KSU model derived a single risk index for the entire community.

- The 1-mi (1.6 km) wide corridors used in the KSU model were divided into subcorridors: the 0.5 mi (0.8 km) closest to the route (0.25 mi or 0.4 km on each side) is assigned the calculated risk index. The outer 0.25 mi (0.4 km) on both sides receives a risk index reduced to the proportion of materials transported that belong to the higher risk categories (flammable, flammable gas, explosive, and poison gas).

- An adjustment factor is applied to the risk index for each mode of transport to account for the differences in the safety records of the individual modes.

- The tables used to rate the effects of Adjusted Placard Count, Average Form of Threat, Risk Factor, and Population Subfactor were recalibrated to accommodate urban conditions.

- The overall community index for level of risk was dropped in favor of maps indicating relative risks throughout the community.

The modified model was demonstrated through application to hazmat routing in a suburban community with a population of approximately 40,000 (Union City, California).

f. Toronto study: A recent study in Toronto, Ontario, is a good example of a hazmat routing study based on an alternative to the FHWA routing method.

The Toronto study concluded that traditional methods of risk assessment were lacking because they considered the number of persons or amount of property potentially exposed to a hazmat release, but not the probability that the exposed persons or property would actually be harmed by a release.[103] It was noted that the consequences of hazmat spills may range from negligible to a major catastrophe, and that this variability is not considered by the FHWA approach. Thus, the spill impact area is itself a variable whose probability distribution should be considered. Therefore, the authors used a fault-tree approach to try to integrate these variabilities along routes and select the minimum risk route. Variations in exposure to risk for different links and nodes of the highway network were estimated through a fault-tree network, a family of damage propagation relationships, and truck accident statistics. These estimates were employed to compute minimum risk routes for specific types of hazmat shipments.

The fault-tree approach to risk assessment was tested through application to a computer representation of the highway network of metropolitan Toronto. This test considered chlorine as the material being shipped. The evaluation found various paths between points in the highway network including minimum time routes, minimum truck operating cost routes, and minimum-risk routes. Accident rates were estimated for different environmental conditions, including both dry pavement and wet pavement, and the minimum-risk routes were found to differ under dry and wet conditions. In fact, it was found, in general, that minimizing different attributes resulted in the selection of different routes. Since decision makers must often consider several selection factors or criteria in selecting routes, this approach provides the decision makers with quantitative data as a basis for consideration of each of these factors.

7. Routing Studies for Radioactive Materials

Routing studies for radioactive shipments are usually based on the RSPA risk assessment model, discussed above. This model considers three primary risk factors -- normal radiation exposure, public health risk from accidents, and economic risk from accidents -- as well as optional secondary (nonradiation) factors.

A recent study provides a good example of the use of risk assessment to select routes for radioactive shipments.[50] This study used a modified version of the RSPA method to select a route for shipments of spent nuclear fuel between the Surry and North Anna power stations in Virginia. The following modifications were made to the RSPA method:

- A method was developed for incorporating wind rose data (i.e., temporal distribution of wind direction and speed) in the assessment of public health and economic risks.
- The estimation of economic risks was modified to include decontamination costs for undeveloped land.
- A roadway geometrics factor was added to the determination of secondary (nonradiation) risks to reduce the tendency of the method to select rural secondary roads based on their low population density.
- A ranking system was developed to implement the emergency response capabilities factor. This ranking was performed for the individual cities and counties through which alternative routes passed and considered timely response, personnel availability, personnel training for handling radioactive material, and availability of needed equipment.
- Consideration of shipment costs based on time and distance traveled was also incorporated in the model.

The study resulted in selection of a shipment route that bypassed heavily populated areas. Precautions recommended for shipments included: escort vehicles; avoidance of peak traffic periods, especially in or near cities; avoidance of nighttime shipments; improvement of emergency response capabilities along the route; and preparation of an evacuation plan for sections of Richmond.

A routing model, known as HIGHWAY, developed at Oak Ridge National Laboratory, can be used to develop routing alternatives for consideration in risk assessment.[56] The HIGHWAY model is particularly appropriate for identifying candidate routes for long distance shipments. The HIGHWAY model uses a data base containing the characteristics of each segment of the U.S. highway network, including the length of each segment and the average travel speed. Candidate routes can be selected to minimize travel time, minimize travel distance, or a weighted combination of both, subject to user-specified constraints such as maximizing freeway travel, avoiding large metropolitan areas, or avoiding particular States. The HIGHWAY program only selects candidate routes, however; it does not have any capability to perform a risk assessment of alternative routes.

A computer system for risk assessment intended for highway routing studies has been developed by Sandia National Laboratories.[20] This system, known as TRANSNET, was developed to evaluate routing alternatives for shipments of radioactive materials, but is adaptable to other materials as well. TRANSNET is a system of several programs that can use input data sets in a common format. A key element of TRANSNET is RADTRAN, a risk assessment model for the radiological risks associated with transportation of radioactive materials. Another component of TRANSNET is INTERSTAT, which operates in a manner similar to the HIGHWAY model discussed above; INTERSTAT uses only the Interstate highway network, designated State alternatives to Interstate highways, and NRC-approved routes for spent-fuel shipments, but has some capabilities to consider gross data on population and accident risks along that network. Another part of TRANSNET is State GEN/State NET, which is a promising tool for State and local highway agencies.[19] State GEN/State NET requires a user to input data concerning accident rates and population densities on a particular network, but provides users a minimum-risk routing algorithm to apply to their own data. The risk evaluation in State GEN/ State NET allows the user to apply weights to different attributes of the segments included in the user's data file, such as accident rate and population density, but the program has no capability to consider products of attributes (e.g., accident rate times length times population density) as is done in the FHWA model. Users can access TRANSNET through a computer system at Los Alamos National Laboratories.

B. Revision of the FHWA Guidelines

This section presents a critique of the FHWA guidelines for hazmat routing and recommended revisions to the guidelines. These recommendations should be considered in future revisions of the FHWA guide.[10]

1. Critique of the FHWA Routing Guide

a. General structure and format: The following discussion presents a critique of the general structure and format of the routing analysis method presented in the FHWA routing guide:

- The general structure of the FHWA routing method presented in figure 17 is appropriate and need not be changed. The emphasis of the FHWA method on first identifying feasible alternative routes, then performing a quantitative risk assessment of the alternative routes and, finally, considering subjective factors in the tradeoffs between routes is a highly desirable approach and should be retained.

- The risk assessment model in the FHWA guide [and, especially, equation (2) presented in this report] gives the superficial appearance of providing an absolute measure of risk, but in reality adequate data for developing absolute measures of risk do not exist. The guide should state this clearly and should be restructured to provide the most complete assessment possible of the relative differences in risk between alternative routes.

- The FHWA guide provides an excellent step-by-step "how-to-do-it" presentation of the quantitative risk assessment procedure, including worksheets and examples. The guide also has a good general overview of the recommended approach to risk assessment. However, the report lacks an initial overall presentation of the specific relationships that make up the risk assessment model or the rationale for these relationships. In the current report, a user who wants to understand the basis for the model (as opposed to how to do the computations) has to work through the step-by-step procedure and reconstruct the model; unfamiliar users may have difficulty grasping exactly what the procedure is, why that procedure is recommended, and how it might be adapted to fit local circumstances. User credibility and understanding of the model would be increased if the report first presented the basic equations on which the model is based, and explained the rationale for each term, and the method for determining its values. Then, and only then, should user-oriented step-by-step procedures and worksheets be presented. The 1987 Canadian screening method is organized effectively in this manner, with separate volumes for the description of the risk assessment method and the worksheets, although the same goal could be achieved with separate sections within the same volume.[60]

- The FHWA guide does not necessarily meet the needs of the wide variety of potential users, which range from small communities with extremely limited staff capabilities and facilities to major metropolitan area routing studies conducted by a professional planning staff with extensive computer facilities available. The procedure in the current FHWA guide seems best suited to a medium-sized community, with a planning staff of at least one professional, and considering a limited number of alternative routes. Consideration should be given to the need for less detailed procedures suitable for small communities without professional staff or access to census data and to the need for a more sophisticated procedure suitable for major metropolitan area routing studies. The 1987 Canadian screening method provides an excellent example of the use of several predefined levels of detail for various factors to develop a flexible approach to risk assessment that fits the needs of a variety of agencies.[60]

b. Accident probability: The following discussion presents a critique of the method for determining accident probability in the FHWA routing guide:

- The FHWA guide takes the correct approach by providing a default method for estimating accident rates, but encouraging users to use their own accident data as the basis for risk assessment whenever possible. However, caution needs to be exercised in using actual accident histories for the specific route segments being analyzed. If the individual route segments are very short and/or the time periods for which accident data are obtained are very short, only a few accidents will be found for each segment. (This is particularly true if the analysis is restricted to truck accidents as discussed below.) Accident rates based on small numbers of accidents can be very unreliable and can result in artificial differences in accident rates between route segments that could incorrectly influence the choice of routes. A statistical test should be included in the procedure to assure that, if actual accident data are used for a route segment, the sample size of accidents is large enough to produce a reliable estimate of the accident rate.

  On the other hand, users should be encouraged to develop their own default accident rates based on broadly based (systemwide) data for their own highway system and use these data in preference to whatever default accident rates are provided in the guide.

- The default accident rates used by the FHWA guide are based on the general accident rate for all vehicle types. This approach is not desirable, because it fails to incorporate the effects of geometric and other factors that may be related to truck accidents, but not to passenger car accidents. Furthermore, the regression models used to predict general vehicle accident rates are based on data that are at least 15 to 20 years old. These models purport to reflect the influence of geometric and traffic factors on accidents. However, the models may not be reliable today for general accident rates, and certainly have no direct applicability to trucks. It appears desirable to base hazmat risk assessment on a subclass of accidents, such as general truck accidents, that is more closely related to the risks involved in hazmat transportation. The developers of subsequent risk assessment models have moved from dependence on general traffic accident rates. For example, the Abkowitz model is based on truck accident rates, and RSPA has developed a risk assessment method for radioactive shipments that incorporates a range of accident rate measures from specific to general, with the most specific measure for which data are available being used in any specific case.[2,3,64] The development of more reliable truck accident rates for use as a basis for hazmat risk assessment is needed.

- The FHWA guide correctly recognizes that highway type is a key variable that influences accident rates. Default estimates of accident rates are provided by separate regression models for freeways, two-lane highways, and urban arterials. However, area type (urban/rural) also needs to be recognized as a key variable.

- Data are not currently available to incorporate the accident rates for different types of trucks (e.g., single-unit trucks, tractor-semitrailer combination trucks, etc.) in equation (2). Reliable accident rates by truck type are difficult to obtain because reliable exposure data (vehicle-miles of travel) by truck type are seldom available. However, it should be recognized that, while accident rates by truck type might be used to select the appropriate truck for a particular shipment, they are not generally needed for relative comparisons of routes since the same trucks would presumably be used for each route. (The only exception to this generalization occurs at locations where a difference in the quantity of material carried by different truck types and a corresponding change in the dispersion distance of that material affect the relative degree of population exposure on two or more alternative routes. This is only likely to occur in areas with very nonuniform development.)

- The route segment length (L_i) is treated correctly in equation (2) since there is a simple proportionality between length and accident probability.

- The inclusion of the factor FHZ (2.3×10^{-5}) gives equation (2) the superficial appearance that it provides an absolute measure of risk, such as the probability of a hazmat release per trip by a hazmat-carrying vehicle over a given route segment. However, this is not the case. A dimensional analysis of Equation (2) indicates that it actually determines the expected number of hazmat releases per trip over the route segment by any type of vehicle -- passenger car or truck, whether carrying hazardous materials or not. Potential users, including Caltrans, have been reluctant to use the FHWA guide because of the awkward formulation of the FHZ term. Furthermore, it should be noted that the value of FHZ has no direct bearing on the relative comparison between routes, because FHZ is a constant multiplied directly into the accident probability for every route segment on every alternative route. An alternative formulation of Equation (2) that does not incorporate the FHZ term should be adopted. Neither the available data nor the available analysis techniques are adequate to perform an assessment of the absolute risk of a hazmat release, so a relative assessment of the differences between routes is all that is practical, and the FHWA guide should state this clearly. The FHZ factor has been eliminated in the updated version of the FHWA guidelines recently issued by RSPA.[94]

- The method for determining accident probabilities in equation (2) does not recognize the effect of the probability of a hazmat release given an accident involving a hazmat-carrying vehicle. Thus, the procedure by default treats all accidents on all highway types as equally likely to result in a release. The accident data analyses presented in section V of this report show that release probabilities vary widely with accident type, with higher release probabilities in single-vehicle accidents than in multiple-vehicle collisions. Since the proportions of these accident types are known to vary markedly between highway and area types, release probabilities will vary as a function of highway type and area type as well. The consideration of the probability of a hazmat release given an accident needs to be incorporated in the model.

- The assessment of accident probability does not consider the probability of releases from causes other than traffic accidents (e.g., valve or container leaks). The emphasis on releases due to traffic accidents is reasonable since available data indicate that approximately 38 percent to 65 percent of serious incidents from shipments on the highway result from traffic accidents (see section V of this report). The probability of a release from causes other than traffic accidents could be expressed as a function of truck type or container type, but this factor would not be directly relevant to routing evaluations since the same truck and container types would presumably be used for all alternative routes. The probability of a valve or container leak is probably proportional to the time a shipment spends on the road. The shipment time is closely related to the route segment length, whose relative effect between routes is already incorporated in equation (2). However, the proportionality of releases due to causes other than traffic accidents to time spent on the road indicates that the risk assessment procedure should either quantitatively or subjectively have a bias against routes where hazmat-carrying trucks are likely to be delayed in traffic.

c. Accident consequences: The following discussion presents a critique of the method for determining accident consequences in the FHWA routing guide:

- There is no currently accepted method of estimating the consequences of hazmat releases (e.g., persons killed, persons injured, property damaged). Therefore, the FHWA guide and other current risk assessment models assume that the consequences of a hazmat release are proportional to the number of persons or amount of property exposed to a release. This assumption should be clearly stated in the FHWA guide. In light of this necessary assumption, the 1987 Canadian screening method has gone so far as to restate the basic risk assessment formula as:[60]

$$\text{Risk} = \text{Probability} \times \text{Exposure} \tag{8}$$

  After consideration of this issue, we do not recommend the replacement of equation (3) by equation (8). The term "consequences" should be retained so that in the future, if methods of estimating actual consequences of different types of hazmat releases are developed, the role of these estimates of consequences in the risk assessment procedure will remain obvious. This approach will provide a continuing reminder to users of the current assumption of proportionality between consequences and exposure. However, the specific procedures used to evaluate population and property consequences can and should be referred to as the estimation of "population exposure" and "property exposure."

- The measure of personal injury consequences used for a given route segment in the risk assessment model in the FHWA guide is the total number of persons exposed in the impact area. The impact area is defined in most cases as a band of equal width on either side of the roadway segment, with the width of the band specified by the impact distance shown in table 79 (see next item for a discussion of impact areas that are sensitive to wind direction). This approach is incorrect because a given hazmat release does not necessarily expose all persons along the entire route segment, but only those persons within the impact distance of the specific location at which the release occurs.

  The effect of the existing procedure is to make the results of the risk assessment sensitive to the relative lengths of the route segments used for analysis. For example, suppose that two identical routes -- Route A and Route B -- with the same length, accident probability, and population density are analyzed. If Route A is arbitrarily divided into 0.25-mi (0.4 km) segments and Route B is arbitrarily divided into 1-mi (1.6 km) segments, then the analysis using the FHWA guide would conclude that Route B has four times the risk of Route A, even though the routes are, in fact, identical in risk. In route segments of different length, the increase in risk with increasing route segment length is already accounted for by the L_i term in equation (2). However, the approach used by the FHWA guide also penalizes the longer route segment because more people live along it, even if the population density (and thus, the number of persons exposed to a specific release) is the same.

From a historical perspective, it is worth noting that the apparent mistake in the treatment of route segment length was intentional on the part of the original author of the procedure. The author of the guide maintains that the procedure in the FHWA guide is a conservative approach because all of the population along a route segment could be concentrated at a single location (e.g., a large apartment building).[115] However, this approach handles this extraordinary situation correctly at the cost of handling more typical situations incorrectly. We maintain that if all of the population along a given route segment is concentrated at a single point, then the route segment is not internally homogeneous and should be divided into two or more route segments that are.

In our view, the double counting of the effect of length can be corrected most simply by dividing the population within the impact area along the entire route segment by the length of the route segment, as follows:

$$\text{Population Exposure} = \frac{POP_i}{L_i} \tag{9}$$

This term represents the linear population density along the route segment in question. Similarly, the determination of property exposure to a hazmat release suffers from the same problem as population exposure and should be reformulated as:

$$\text{Property Exposure} = \frac{PV_i}{L_i} \tag{10}$$

This term represents the average value of property per mile along the route segment. These corrections to the FHWA risk assessment procedure have been incorporated in the updated guidelines recently published by RSPA.[94]

- The FHWA guide requires, as a minimum, access to detailed population data at the census tract level. Many users of the procedure may find themselves without convenient access to such detailed data or without the analysis staff needed to use such data if it were available. Furthermore, preliminary analyses conducted with more generalized population data may be useful as a screening tool to identify and eliminate obviously unsuitable routes. The guide should provide users with some default estimates of population density on which such a preliminary analysis could be based.

- The impact distances in table 79 need to be adjusted based on the latest available information. The accompanying text encourages the use of conservative estimates of impact distances, but should perhaps cite other sources that users might consult to determine these distances for specific materials. The FHWA guide should refer users to the latest available data on dispersion and evacuation distances, including the USDOT Emergency Response Guidebook (which was available only as an unpublished draft when the FHWA guide was originally developed) and other recent research.[10,114]

- The impact distances shown in table 79 include both distances that extend equally in all directions and distances that extend in a specified distance downwind. However, the FHWA guide does not describe explicitly how to determine the population exposure for materials that are dispersed downwind. This issue needs to be addressed explicitly in a revision of the guide, because many extremely hazardous materials (including poison gases) are dispersed in this manner.

  In determining the population exposure for windborne materials, it would probably be overly conservative to include all persons within the impact distance on both sides of the route segment. However, determination of specific dispersion patterns for specific route segments is not possible without information on the time distribution of wind direction and speed (i.e., a wind rose), which is not typically available to routing analysts. In the absence of wind rose data, one possible approach is to consider persons within the impact distance on only one side of the road, but to always choose the more densely populated side. This approach requires further investigation before being adopted, however, to consider the possibility of wind shifts and to consider its applicability to heavier-than-air gases such as nitrogen tetroxide.

- The FHWA guide suggests the consideration of either population exposure, employment exposure, motorist exposure, or a combination of these three variables in evaluating personal injury risks. Specific procedures for consideration of population exposure are included in the guide. However, no guidance on the circumstances under which employment exposure or motorist exposure should be considered or the method that would be used to consider them.

- The risk assessment model in the FHWA guide treats all persons within the impact zone of a route segment as equally exposed. In practice, however, the persons closest to the road are most likely to be injured. The use of a weighting scheme to put greater weight on population near the roadway and less weight on population near the limits of the impact area should be considered. However, it is likely that the available population data at the census tract level, suggested for use by the guide, are too aggregated to support population analysis at this level of detail.

- As currently formulated, the risk assessment model in the FHWA guide addresses only one specific type of material at a time, typically the most critical material in a particular hazard class. In fact, the model has a variety of applications, including both analyses of specific materials and analyses of general hazmat routes carrying a mix of many types of materials. The possibility that computer applications of the model could incorporate a weighting system, where the risk assessment results for specific materials could be weighted by the occurrence of those materials in the traffic stream (based, for example, on a placard count), should be explored.

- The risk assessment procedure in the FHWA guide does not consider the distance between the roadway and the nearest population or property exposed to a hazmat release. With the exception of motorists (who are exposed no matter which type of facility is used to transport hazardous materials), it is generally farther from the roadway to the nearest building on controlled access freeways than on uncontrolled access urban arterials or rural highways. This greater distance could be an important advantage in containing a liquid or solid release and in minimizing the potential damage from explosions or releases of flammable materials. However, there is currently no method for quantifying this benefit.

d. Overall risk assessment and subjective factors: The following discussion presents a critique of the overall risk assessment method in the FHWA routing guide and the approach used for assessment of subjective factors:

- The overall formulation of risk as the product of accident probability and accident consequences [as in equation (3) of this report] should be retained.

- The FHWA guide provides no specific guidance on when to consider both personal injury and property risks and how to combine or weight these risks when both are considered. Several major metropolitan area routing studies have avoided this issue by considering only personal injury risks, since data on land use and property values were unavailable.[57,105] This may be the realistic situation with which many potential users are faced, particularly since the FHWA guide does not suggest any typical property values for specific land uses.

The 1987 Canadian screening method suggested some specific weights for use in combining population, property, and environmental risks.[60] Specifically, an example in the Canadian procedures suggested the following weights:

Type of Exposure	Weight Factor
Population	60%
Property	10%
Environment	30%

It is unlikely that all users could agree on a single set of weight factors appropriate for all circumstances, but at least these weights illustrate that personal injury risks (population exposure and environment exposure) should receive more weight than property risks, and immediate threats of personal injury (population exposure) should receive greater weight than long-term threats of personal injury (environmental exposure). Some guidance for users should be provided either by: (1) additional text discussing these issues, or (2) specific values of suggested weights presented as an example. In either case, the final choice of which types of exposure to consider and how to combine or weight that exposure should be left to the user.

- The FHWA guide recommends that special populations, such as schools or hospitals, that would be particularly difficult to evacuate in the event of a hazmat release be considered as a subjective factor in routing decisions. The definition of special populations should be expanded to include outdoor populations, which are more directly susceptible to the effects of hazmat releases than indoor populations. Particular consideration should be given to high concentrations of outdoor populations such as sports stadia, but other outdoor populations (parks, outdoor theatres, golf courses, etc.) should also be considered.

- Environmental risks are currently addressed in the FHWA guide as a subjective factor, whose possible effect on routing decisions is considered after completion of the quantitative risk assessment. In contrast, the 1987 Canadian screening method includes a quantitative scoring approach to the consideration of sensitive environments (see section 6.0 of the Canadian report).[60] Based on our review of the Canadian method, we do not recommend the adoption of the Canadian approach to scoring environmental factors in its current form, because we do not feel the current state of the art is adequate for quantitative assessment. However, the material in the Canadian report could form the basis for expanding the discussion of environmental issues in the FHWA guide and providing a checklist of sensitive environments to be considered.

- Emergency response capabilities are currently addressed in the FHWA guide as a subjective factor. In contrast the 1987 Canadian screening method (see sections 7.0 and 8.0) of the Canadian report includes a quantitative approach to consideration of emergency response capabilities (counting the number of trained fire squads and the number of police cars available within a 10-min response period at specific sites).[60] In the 1987 Canadian screening method, the quantitative assessment of response capabilities is translated into a rating on a scale from 1.0 (low) to 1.5 (high), and the relative risk for each route is divided by the response capability factor as follows:

$$\text{Total Score} = \frac{\text{Probability x Exposure}}{\text{Response Capability}} \quad (11)$$

  This conceptual approach for consideration of response capability is extremely interesting, but we do not recommend its adoption in its current form. Counting the numbers of available response equipment and personnel is useful, but the quality (e.g., training and experience) of response personnel is at least as important and probably more important. However, the quantitative aspects of the method might be adapted for use in the FHWA guide and conceptual approach of rating response capabilities and treating this as a divisor in the risk equation, as in equation (11), appears to have merit and should be fully explored and should be considered for inclusion in the FHWA guide if found to be practical.

2. Recommended Revisions to the FHWA Routing Guide

Based on our review and critique of the FHWA routing guide, it is recommended that this document be completely rewritten and reissued. This report presents specific enhancements to the guide that are recommended to increase its usefulness to State and local government agencies.

The ideas for these recommendations have been drawn from many sources. The recommendations concerning the format of the guide and structure of the risk assessment procedures owe a great deal to the 1987 Canadian screening assessment method for dangerous goods truck routes.[61] The recommendations concerning the assessment of accident probabilities have been developed in detail by the authors but owe their genesis to the approach recommended in references 2 and 3. Thus, we have tried to draw upon the most useful concepts currently available about hazmat risk assessment and to show

how these concepts can be fitted together into a practical risk assessment procedure.

The specific recommendations for revision of the risk assessment procedure are presented here in two groups. The first group consists of recommendations that can be implemented relatively quickly from existing data. The second group consists of recommendations that will require further research prior to implementation.

a. Recommendations that can be implemented based on existing data: The following recommendations involve complete replacement of the method for estimating accident probabilities; small, but critical, adjustments to the quantitative method for estimating accident consequences; and the expansion of the text concerning the assessment of subjective factors related to accident consequences. All of these changes can be implemented from data that are currently available in published literature except for the default truck accident rates, which can be developed from data currently available in State highway agencies. Revision of the method for estimating accident probabilities is considered vital to increase the credibility of the risk assessment procedure in the highway community. The specific recommendations are presented below.

1. The FHWA routing guide should be reissued in a two-part or two-volume format similar to the 1987 Canadian screening method. The first part should contain a clear statement of the recommended risk assessment method and its rationale, including appropriate references to previous research and other documents containing supporting information. The second part should be entirely user-oriented; this part should present worksheets and examples but should not seek to justify the procedure.

2. The guide should clearly state that the risk assessment method provides a relative comparison of the risks between alternative routes and not an absolute measure of risk.

3. The overall structure of the FHWA routing method, as presented in figure 17, should be retained.

4. The basic risk assessment formula in the guide:

$$\text{Risk} = \text{Probability} \times \text{Consequences} \qquad (12)$$

is correct and should be retained. However, it should be stated that there is no accepted method for estimating the consequences (i.e., persons injured or property damaged) by a hazmat release and that, therefore, the existing method assumes that the consequences of a hazmat release are proportional to the number of persons or amount of property potentially exposed to a release.

5. The computation of accident probability on a route segment should be revised so that it incorporates truck accident rate, segment length,

and the probability of a hazmat release given an accident. Equation (2) should be replaced with the following relationship:

$$P(R)_i = TAR_i \times P(R|A)_i \times L_i \tag{13}$$

where: $P(R)_i$ = probability of an accident involving a hazmat release for route segment i

TAR_i = truck accident rate (accidents per veh-mi) for route route segment i

$P(R|A)_i$ = probability of a hazmat release given an accident involving a hazmat-carrying truck for route segment i

L_i = length (mi) of route segment i

6. The guide should include suggested default values of truck accident rates (TAR_i) and release probabilities [$P(R|A)_i$] for various highway and area types. As a minimum, default truck accident rates and release probabilities should be included for the following types of highways:

- Rural freeways.
- Rural two-lane highways.
- Rural multilane divided highways.
- Rural multilane undivided highways.
- Urban freeways.
- Urban arterial streets.

Table 82 presents examples of typical truck accident rates developed in this study with data from California, Illinois, and Michigan. The release probabilities in table 82 are based on the distribution of typical truck accident types from the California, Illinois, and Michigan data on the probability of release given an accident for different accident types based on FHWA data as shown in table 46. The development of these default values is documented in the appendix to this report. Users could be encouraged to use these default values or to develop default values based on their own data. Many States have developed or are developing computerized accident records systems and computerized geometric and traffic volume data that can be linked together to develop Statewide accident rates and accident type distributions for specific highway and area types.

7. Users should be cautioned against using truck accident data for specific route segments unless the segment is long enough and/or enough years of accident data are included so that the accident history is large enough to be meaningful. A simple Chi-squared test can be employed to determine whether the actual accident frequency for a route segment is enough larger or smaller than the expected accident frequency to warrant replacement

Table 82. Default truck accident rates and release probability for use in hazmat routing analyses.

Area type	Roadway type	Truck accident rate (accident per million veh-mi)	Probability of release given an accident	Releasing accident rate (releases per million veh-mi)
Rural	Two-lane	2.19	0.086	0.19
Rural	Multilane undivided	4.49	0.081	0.36
Rural	Multilane divided	2.15	0.082	0.18
Rural	Freeway	0.64	0.090	0.06
Urban	Two-lane	8.66	0.069	0.60
Urban	Multilane undivided	13.92	0.055	0.77
Urban	Multilane divided	12.47	0.062	0.77
Urban	One-way street	9.70	0.056	0.54
Urban	Freeway	2.18	0.062	0.14

of the default truck accident rates with site-specific rates based on accident histories. This test is employed as follows:

Step 1. Obtain truck accident data for a particular highway segment. The truck accident data should cover as long a time period as possible without introducing extraneous effects due to traffic, geometric, and operational changes. The observed number of accidents during this period is referred to as A_o.

Step 2. Compute the expected number of truck accidents for the route segment for that same time period using systemwide default accident rates such as those presented in table 81. The expected number of truck accidents can be computed as:

$$A_e = TAR \times TADT \times L \times 365 \times N \times 10^{-6} \quad (14)$$

where: A_e = expected number of truck accidents

TAR = expected truck accident rate (accidents per veh-mi)

TADT = average daily truck traffic (veh/day)

L = length of highway segment (mi)

N = duration of study period (yr)

If $A_e \geq 5$, then use the Chi-squared procedure given in Step 3A. If $A_e < 5$, then the accident sample size is too small to use the Chi-squared procedure, and an alternative procedure in Step 3B based on the Poisson distribution should be used

Step 3A. If $A_e \geq 5$, compare the expected and observed number of accidents by computing the Chi-squared statistic:

$$\chi^2 = \frac{(A_e - A_o)^2}{A_e} \tag{15}$$

where: χ^2 = Chi-squared statistic

A_e = expected number of truck accidents

A_o = observed number of truck accidents

If $\chi^2 \leq 4$, then the expected and observed number of accidents do not differ significantly at the 5 percent significance level. Therefore, the systemwide default accident rate should be preferred to site-specific accident data.

If $\chi^2 > 4$, then the expected and observed number of accidents differ significantly. This indicates at the 5 percent significance level that the observed accident rate is lower or higher than the systemwide default value. In this case, the systemwide default accident rate should be replaced by a value based on the site-specific data. If the site-specific accident rate is greater than the default accident rate, then use the site-specific rate. If the site-specific accident rate is less than 50 percent of the default accident rate, then use 50 percent of the default accident rate. The latter restriction is included to keep very low short-term accident experience, or poor accident reporting levels in a particular jurisdiction, from causing misleading results. Even if the roadway segment has experienced no accidents during the study period, there is still risk involved in transporting hazardous materials over the segment, and the use of 50 percent of the default accident rate is recommended.

Step 3B. An alternative procedure based on the Poisson distribution is used whenever $A_e < 5$, because the Chi-squared test is not applicable to this small accident sample size. Table 83 shows critical values from the Poisson distribution for testing the significance of difference from the

If A_o exceeds the critical value given in table 83 for the known value of A_e, then the expected and observed accident frequencies differ significantly. In this case, the systemwide default accident rate should be replaced by the site-specific accident rate, calculated as:

$$TAR = \frac{A_o \times 10^6}{TADT \times L \times 365 \times N} \tag{16}$$

If $A_e < 5$, it is recommended that the default accident rate should never be decreased, because the available sample size is rarely adequate to indicate a true accident rate lower than the expected value.

Table 83. Critical values of the Poisson distribution

Expected accident frequency (A_e)	Critical value of A_o at the 5% significance level
1.0	4
1.5	5
2.0	6
2.5	6
3.0	7
3.5	8
4.0	9
4.5	9

Example. For example, suppose a 1.8-mi (2.9 km) section of rural freeway with a truck volume of 5,000 trucks per day has experienced 10 truck accidents in the last 3 years (i.e., $A_o = 10$). The expected truck accident rate for a rural freeway, based on table 82, is 0.64 accidents per million veh-mi (0.40 accidents per million veh-km). The expected number of accidents on this freeway segment for a 3-year period is:

$$A_e = 0.64 \times 10^{-6} \times 5{,}000 \times 1.8 \times 365 \times 3$$

$$= 6.3 \text{ accidents}$$

The Chi-squared statistic is calculated as:

$$\chi^2 = \frac{(6.3 - 10)^2}{6.3} = 2.17$$

Since 2.17 < 4, the observed accident frequency for the segment is not significantly different from the expected accident frequency. Therefore, the expected accident experience, rather than the observed accident experience, should be used in a hazmat risk assessment. In this case, the observed accident frequency would have to be greater than 12 truck accidents in a 3-year period to justify use of a truck accident rate higher than the expected value. If, for example, this freeway segment had actually experienced 15 truck accidents in the last 3 years, then the appropriate truck accident rate for use in hazmat risk assessment would be determined from equation (16) as:

$$TAR = \frac{15 \times 10^6}{5{,}000 \times 365 \times 3 \times 1.8} = 1.52 \text{ accidents per million veh-mi}$$

Users should be encouraged to develop their own default truck accident rates based on systemwide data for their own jurisdiction. Accident rates based on systemwide accident data for a specific State or municipality are likely to be more reliable than default rates based on data from other jurisdictions.

8. The impact distances in table 79 of this report should be periodically revised based on the latest available data on evacuation distances for general classes of hazardous materials. These evacuation distances should generally be based on the maximum evacuation distances for any specific material within a given class of hazardous materials shown in the 1987 USDOT Emergency Response Guidebook and in recent research.[114] Users performing a routing evaluation for a specific hazardous material should be encouraged to use the best available data on evacuation distances for that specific material. Users should be specifically cautioned that evacuation distances can be substantial for heavier-than-air gases, such as nitrogen tetroxide, and the latest research concerning such materials should be consulted.

9. The guide should discuss the appropriate impact distances both for routing studies for specific materials and for general hazmat routing studies on routes carrying a variety of materials. The guide should recommend the use of a conservative estimate of impact distance and emphasize the need to use consistent impact distances on each of the alternative routes being studied.

10. The guide should state clearly that it does not address routing procedures for shipments of radioactive materials because impact distances have not been established and because other factors (e.g., normal radiation exposure) need to be considered. Specific reference should be made to the most current available procedure for routing of radioactive materials (e.g., the RSPA risk assessment procedures for radioactive shipments).[64]

11. The procedures in the guide for determining population exposed to hazmat releases along a particular route segment should be retained. The population exposure should be reformulated as in the updated guidelines recently published by RSPA to avoid double counting the effect of route segment length, as described in the previous section.[94] The population risk should be calculated as shown below:

$$RPOP_i = P(R)_i \times (POP_i/L_i) \qquad (17)$$

The POP_i/L_i term in equation (17) represents the linear population density along the route segment in question.

12. A discussion should be included in the guide of when to consider employment and motorist exposure, in addition to population exposure. Users should be encouraged either (1) to use the larger of resident population or employment exposure or (2) to conduct separate evaluations of daytime and nighttime risk as was done in the hazmat routing study for the Cleveland area.[83] The consideration of motorist exposure should be recommended in situations where it is likely to be most critical: congested highways, tunnels, depressed highways, bridges, and elevated structures. Future research on these issues is also recommended.

13. The procedures in the guide for determining property exposed to hazmat releases along a particular route segment should be retained. However, the property exposure should be reformulated as in the updated guidelines recently published by RSPA to avoid double counting the effect of route segment length, as described in the previous section.[94] The property damage risk should be calculated as shown below:

$$RPD_i = P(A)_i \times (PV_i/L_i) \qquad (18)$$

In equation (18), the term PV_i/L_i represents the average value of property per mile along the route segment.

14. The guide should provide a table of representative values of property value per unit length for a range of land uses including, as a minimum, the five types of land use addressed in the FHWA guide:

- High-density residential.
- Medium-density residential.
- Low-density residential.
- Commercial.
- Industrial.

It would be desirable to expand this list to include additional land use types as follows:

- High-density residential.
- Medium-density residential.
- Low-density residential.
- Commercial--office.
- Commercial--retail.
- Industrial.
- Institutional.
- Agricultural.
- Open land.

At present, these estimates would have to be based on existing data sources including the 1987 Canadian screening method.[60]

These values should serve as default values in the procedures, but users should be encouraged to replace the default values with their own estimates if the default values appear inappropriate to their community. There is a natural reluctance to include dollar values in the procedure, since they are subject to change over time. However, it might be of greater assistance to users to provide default estimates of dollar values and warn them of the need to update them for inflation, especially since the relative values of different types of property may be stable over time.

15. The discussion of the approach used to consider sensitive environments in the FHWA guide should be expanded. Currently this factor is considered qualitatively through a subjective comparison to the results of the quantitative risk assessment. The 1987 Canadian screening method includes a quantitative procedure for assessing the effects of sensitive environments. The adoption of a quantitative method for assessing the effects of sensitive environments is not recommended without further research to establish its validity. However, the material in the Canadian report should be used to expand the discussion of environmental issues in the guide and provide a checklist of sensitive environments to be considered.

16. The discussion of the approach used to consider emergency response capabilities in the FHWA guide should be carefully expanded. Currently, this factor is considered qualitatively through a subjective comparison to the results of the quantitative risk assessment. The 1987 Canadian screening method includes a quantitative procedure for assessing emergency response capabilities.[60] Other recent work in this area should also be considered.[50] The adoption of a quantitative method for assessing emergency response capabilities is not recommended without further research to establish its validity. However, these other sources should be used to expand the discussion of emergency response capabilities in the FHWA guide.

17. The guide should provide additional guidance to users on whether personal injury risk alone or both personal injury and property risk should be considered. The adoption of a formal weighting scheme for personal injury and property risks, as is used in the Canadian method, is not recommended without further research to establish a rational basis for the values of the weights and to investigate user receptiveness to this concept. However, the discussion of the relative importance of personal injury and property risks should be expanded to emphasize that the greatest weight should be given to risks of injury to people and less weight should be given to the risk of damage to property.

18. The worksheets provided in the FHWA routing guide should be revised, as appropriate, to accommodate the recommended changes in the risk assessment procedure.

b. Recommendations that require further research: The following discussion presents recommendations for improvement of the FHWA routing guide that will require future research. These recommendations, by nature, will require more time to implement than the recommendations in the previous section. These long-term recommendations include some structural changes in the risk assessment procedure, minor revisions to the accident probability estimation procedures, and possible major changes to the determination of accident consequences. The specific recommendations are presented below.

19. It would be desirable to revise the structure of the FHWA routing guide to address the needs of at least three types of users:

- Small communities without a professional planning staff and without access to detailed accident and population data required for risk assessment.
- Medium-sized communities with a small professional planning staff that has manual access to the required accident and population data required for risk assessment.
- Major statewide or metropolitan area routing studies with a large professional planning staff and computerized access to the required accident and population data.

The scope of the current guide is most appropriate for medium-sized communities with a small professional staff and a few well-defined alternative routes.

It would be desirable for the guide to present users with procedures applicable to data availability at several different levels of detail. This approach was used in the 1987 Canadian screening method, which provides analysis procedures at three different levels of detail for five factors:

- Accident probability.
- Population exposure.
- Property exposure.
- Environmental exposure.
- Response capability.

Detail Level 1 in the Canadian method is generally based on default values and readily available roadway data for the alternative routes. Detail Levels 2 and 3 require increasingly detailed data about specific conditions on the alternative routes. It is recommended that for application in the United States, individual detail levels could address the three community sizes identified above. The guide should retain the flexibility for users to adopt different levels of detail for different aspects of the risk assessment method, which will allow evaluators to customize a method that best suits their budget, time limits, personnel availability, data availability, and needs.

20. The default estimates of truck accident rates and release probabilities should be updated to the extent possible based on future research. In particular, future truck safety research should be monitored for reliable data on truck accident rates by truck type and cargo area configuration that could be incorporated in the risk assessment procedure. Data on the differences, if any, between general truck accident rates and hazardous materials truck accident rates would also be desirable. However, these improvements in truck safety data will only be possible if the quality of exposure data available for such analyses improves in the future.

21. Future research should consider the feasibility of considering releases from causes other than traffic accidents in the risk assessment procedure. Because the probability of such releases can be assumed to be proportional to travel time, a quantitative method for considering the differences in travel time between alternative routes would be required. Such an analysis would require more detailed data on traffic operational conditions than is typically considered in risk analysis today.

22. The impact distances provided in the guide should be reconsidered periodically based on the latest research.

23. Methods of weighting the potential consequences of releases of the different materials shipped on general hazmat routes should be considered in future research. Reasonable weights for different materials could possibly be developed by users for specific routes based on hazmat flow data or field placard counts.

24. Consideration should be given to including alternative procedures in the guide for assessing population exposure at a lower level of detail than the existing procedures. For example, the 1987 Canadian screening method includes default estimates of population density (population per unit area) for central cities, suburbs, and rural areas.[60] Alternative procedures for estimating employment exposure based on land use are also provided. Simplified procedures of this type that do not require population data at the census tract level may be more appropriate for small communities than the existing procedures in the FHWA guide. Further, guidance should also be provided to users on when to consider both employment and population exposure (perhaps when employment reaches a specified percentage of population).

25. Future research is needed to develop better methods for predicting the actual consequences of hazmat releases (estimated number of persons killed or injured, estimated property damage) rather than just the number of persons exposed to a release. In particular, greater weight should be given to persons closest to the roadway as they are most likely to be killed or injured. However, analyses of this type will require both revised procedures and improved data sources to be effective. In general, new procedures of this type are appropriate for use only in analysis at the greatest level of detail.

26. Methods of incorporating wind direction and speed data (i.e., wind rose data) in hazmat risk assessments for gaseous materials are needed. Currently, some sophisticated computerized risk assessment systems, such as that used at Oak Ridge National Laboratories, can link together population and wind rose data. Wind rose data are not currently accessible to the average user of the FHWA routing guide but future development of computer capabilities could make such data more accessible, and practical procedures to apply it would then be needed (see Recommendation 30 for additional thoughts on how computer systems might enhance risk assessment by State and local agencies).

27. The development of a quantitative rating procedure for assessing sensitive environments should be considered. A quantitative procedure of this type was incorporated in the 1987 Canadian screening method. In the long run, a quantitative rating method may be desirable in the FHWA guide to ensure that sensitive environments receive complete consideration in the risk assessment.

28. The development of a quantitative method for assessing emergency response capabilities should be considered. A quantitative procedure of this type was incorporated in the 1987 Canadian screening method. In the long run, a quantitative rating method may be desirable in the FHWA guide to ensure that emergency response capabilities are thoroughly considered in the risk assessment. However, it is vital that the rating of emergency response capabilities include consideration of more qualitative factors, such as the level of training and experience of emergency responders.

29. Development of a formal procedure for weighting the contribution of population exposure and property exposure in risk assessment should be considered. Potential users, especially those with little experience in risk assessment, are unlikely to be able to develop reasonable weights without some guidance.

The 1987 Canadian screening method provides an example of specific weights recommended for use in hazmat risk assessment. Research to develop an appropriate basis for providing such weights in the FHWA guide should be considered. Weights of this type might give users a starting point for considering appropriate values for use in their community. The final choice of which types of exposure to consider and how to combine or weight that exposure should be made by the user.

30. The computer analysis needs of users of the FHWA guide for hazmat risk assessment at all levels of detail need to be thoroughly reviewed to determine whether computer programs should be developed to supplement the guide. Discussions with potential users at both the State and local levels should be conducted to determine whether there is sufficient demand for enhanced computer programs to justify their development. In particular, the need for, and feasibility of, three potential types of computer programs need to be assessed. These are:

- A microcomputer program to perform a risk assessment between alternative routes at the lowest level of detail (equivalent to Detail Level 1 in the 1987 Canadian screening method). This program would operate without access to large data base files such as census tract data and would be intended for use by small- and medium-sized communities.
- A computer program to perform risk assessment at the greatest level of detail, including access to detailed population data by census tract. This type of program would be suitable for use in hazmat risk assessments for a major metropolitan area. Today, analysis at this scale is most conveniently performed in the mainframe computer environment (although the

applicability of microcomputers to this type of analysis will undoubtedly increase over time). A thorough feasibility analysis should be performed before this type of program is developed because it may not be easy to generalize the needs of major metropolitan area studies so that a single program is applicable to more than one area.

- An expert system for hazmat risk assessment to consider the role of subjective factors together with the results of quantitative risk assessment. A system of this type could make available in a user-friendly program the opinions of a panel of experts concerning the relative risks presented by the variety of subjective factors considered in the FHWA guide.

Finally, a thorough analysis should be made of the capabilities of the computer system and risk assessment data bases assembled at Oak Ridge National Laboratories and Sandia National Laboratories to assist State and local highway agencies, including roadway, population, and wind rose data. Particular attention should be given to methods by which highway agencies could assemble the data needed to utilize the State GEN/State NET risk assessment and routing analysis system which has been developed by Sandia National Laboratories and is accessible to outside users.[19]

VII. RECOMMENDATIONS FOR FUTURE RESEARCH

This section of the report presents the recommendations of priority issues for future research in highway transportation of hazardous materials developed during the study. The first subsection describes the process by which these recommendations were developed. The second subsection presents 18 specific issues for which future research is needed, ranked in high, medium, and lower priority groups.

A. Procedure Used to Identify Future Research Issues

The priority issues for future research were developed jointly by the research team and a study review panel consisting of experts in highway transportation of hazardous materials.

An initial set of issues needing future research were identified by the research team and included in an interim report to FHWA submitted in May 1987. This report, including the recommendations for future research, was reviewed by the study review panel and discussed at its first meeting in June 1987. Several additional issues for future research were suggested by the study review panel at this first meeting. Neither the research team nor the panel attached any explicit priorities to specific issues at this time.

A revised list of 27 issues for future research was prepared in February 1988 and distributed to the study review panel. At this time, the panel was asked to rate the 27 issues for importance and probability of success. Ratings of these issues were also obtained from USDOT representatives interested in the study and from some colleagues of the panel members. Eleven responses to the request for ratings of future research issues were received. The respondees included: four State highway agency representatives; one State police agency representative; one metropolitan planning organization representative; one consultant; one NTSB representative; and three FHWA representatives.

The ratings of the 27 issues were discussed by the study review panel at their second meeting in March 1988. As a result of this meeting, some issues were dropped, several new issues were suggested, the priority of some of the existing issues was changed, and several issues that had been treated separately were judged to be closely related and were, therefore, grouped together. For example, one issue (establishing safe haven requirements for unattended vehicles) was dropped from the list because an RSPA-funded study of that issue has recently begun. The final result of this process is a set of 18 issues for which future research is recommended which represent the best collective thinking of the research team and the study review panel.

B. Priority Issues Recommended for Future Research

The 18 issues for which future research is recommended are listed in table 84 in 3 categories: high priority issues; medium priority issues; and lower priority issues. The order of the issues within each priority level is not meant to indicate the priority of the issue within that level.

These issues are all related to transportation of hazardous materials. However, it should also be recognized that there is also a great need for general truck safety research related to vehicle design, highway design, and highway operational issues, and that this research will also make a critical contribution to the safety of highway transportation of hazardous materials.

The 18 priority issues for future research in highway transportation of hazardous materials are:

High Priority Issues

1. Improve the Quality of Hazmat Safety Data

The improvement of the quality of the data available for hazmat risk assessment and routing studies was a high priority issue identified in the study. The study review panel reached a clear consensus that, while current risk assessment and routing models may need some minor improvements, there is a much greater need to improve the data used in those models. Research is needed to recommend specific improvements in data collection systems and specific changes in reporting requirements and penalties for nonreporting. Specific aspects of this problem that should be addressed in this research include:

a. Identify the real hazmat data needs of highway agencies and the feasibility and cost of collecting the needed data.

b. Quantify the degree of underreporting to current accident and incident reporting systems and recommend changes to data collection systems, reporting requirements, or penalties for nonreporting that would improve the completeness and timeliness of reporting.

c. Assess the need to expand Federal reporting requirements for accidents and incidents to include both intrastate, as well as interstate, transportation.

d. Assess the feasibility of establishing uniform incident reporting requirements and establishing a common form that meets the needs of all agencies that collect hazmat incident data (e.g., FHWA, RSPA, EPA, State agencies, etc.).

Table 84. Recommended topics for future research in highway transportation of hazardous materials.

High Priority

1. Improve the Quality of Hazmat Safety Data.
2. Demonstrate Improved Hazmat Risk Assessment and Routing Models.
3. Establish the Cost-Effectiveness of Hazmat Routing Requirements.
4. Evaluate Risk of Hazmat Incidents at Special Facilities.

Medium Priority

5. Determine Signing Needs for Hazmat Routes.
6. Establish Procedures and Set Priorities for Enforcement of Hazmat Routing Restrictions.
7. Investigate Advantages and Disadvantages of Time-of-Day Restrictions.
8. Determine Training Needs of Highway Agencies Related to Highway Transportation of Hazardous Materials.
9. Determine Which Hazardous Materials Special Requirements Should Apply To.
10. Determine Acceptable Levels of Risk and Develop Improved Methods for Communicating Risk Levels to the Public.
11. Improve Funding Mechanisms for Cleanup of Hazmat Spills.
12. Perform Hazmat Risk Assessment Based on Private "Industry-Based" Data.
13. Investigate the Possibility of Reducing the Quantities of Hazardous Materials Shipped.
14. Improve Management of Hazmat Safety at Intermodal Points.

Lower Priority

15. Improve Management Methods for Major Incidents.
16. Determine Appropriate Advance Notification Requirements for Sensitive Environments.
17. Investigate Causes of Hazmat Incidents Related to Cargo Shifting.
18. Investigate Effectiveness of Designated Lanes for Hazmat Carrying Trucks.

e. Better data are needed on the specific sequences of events that lead to hazmat releases. On-scene accident investigation teams have been suggested as one way to get such information.

f. Develop specifications for an improved hazmat exposure data base that would be compatible with existing (or improved) hazmat accident and incident data bases and would permit analysis of rates (per million veh-mi or cargo ton-mi) for specific types of accidents and incidents.

2. Demonstrate Improved Hazmat Risk Assessment and Routing Models

There is a need to make further improvements in the FHWA guidelines for establishing preferred routes for hazmat shipments, to communicate these improvements to users, and to demonstrate the risk assessment and routing procedures. The reissue of the FHWA routing guide by RSPA is a useful first step in this process. The accident probability portion of the FHWA routing model has been improved in this study. However, there is still a need to thoroughly revise the accident consequences portion of the FHWA routing model. Specific recommendations for improvements to the model are presented in section VI of this report. When these improvements are made, the FHWA routing guide should be revised and reissued.

There is a need for a project to demonstrate the implementation of the revised risk assessment and routing methodology. This project should involve working with several State or local jurisdictions in the application of the revised procedures to their road network.

There is also a need to enhance the computer tools available to users in applying the FHWA routing guide. These enhancements could include:

a. Development of a microcomputer program to apply the procedures of the FHWA routing guide.

b. Development of an expert system program to consider the role of qualitative or subjective factors on choices between alternative routes. These qualitative and subjective factors are addressed briefly in the routing guide, but the user currently has very little guidance on their importance relative to the quantitative results of the routing model.

c. Testing of the suitability of the computerized routing models developed at Oak Ridge National Laboratories and Sandia National Laboratories for use by highway agencies to apply the FHWA routing guidelines. The most promising computer system appears to be the StateGEN/StateNET program developed at Sandia National Laboratories.

3. Establish the Cost-Effectiveness of Hazmat Routing Requirements

A methodology is needed to evaluate the cost-effectiveness of hazmat routing decisions. Routing decisions may impose substantial costs on highway agencies (e.g., extensive signing needs) and on the trucking industry. Highway agencies will not be willing to make major capital investments based on uncertain data. Therefore, a method is needed to establish whether the costs are justified by a reduction in the risks and/or consequences of hazmat incidents.

4. Evaluate Risk of Hazmat Incidents at Special Facilities

The risks of hazmat incidents at special facilities such as elevated freeways, depressed freeways, bridges, and tunnels need to be determined. These risks need to be compared with the risks of comparable incidents if hazmat carrying trucks were diverted to alternate routes such as arterial streets. The comparison should consider the degree of risk to motorists, to adjacent residents, and to adjacent property and should consider the experiences of emergency response personnel at such facilities (e.g., difficulty of fighting fires on depressed or elevated freeways). The comparison should also consider that adjacent development on arterial streets is typically closer to the roadway than on freeways. Other special facility types of interest include railroad-highway grade crossings, airport runways above freeways, air-rights structures, and rapid transit facilities in freeway medians.

Medium Priority Issues

5. Determine Signing Need for Hazmat Routes

Research is needed to determine the signing needs for hazmat routes. The results of a recent survey of State highway agencies discussed in section III of this report show considerable diversity of opinion about the need for signing and the types of signs to be used. Many agencies would prefer to designate routes without posting signs, because the presence of signs may unnecessarily arouse public concern about the perceived risks of hazmat shipments. Thus, the effectiveness of hazmat routing schemes based on maps provided directly to hazmat carriers needs to be evaluated. There are also concerns about whether the hazmat route preference and prohibition signs currently included in the MUTCD will, in fact, meet all of the needs of highway agencies.

6. Establish Procedures and Set Priorities for Enforcement of Hazmat Routing Restrictions

Research is needed to establish procedures and set priorities for enforcement of hazmat routing restrictions, as well as other regulations. Specifically, how should hazmat routing requirements be enforced? Will voluntary compliance work or are patrols needed? Is signing required to make routing restrictions enforceable? What should the penalties be? How should routing restrictions be publicized? Should violations go on the driver's record? Can penalties be applied to the carrier rather than just to the driver?

7. Investigate Advantages and Disadvantages of Time-of-Day Restrictions

The advantages and disadvantages of time-of-day restrictions on hazmat routes need to be investigated. In the past, some agencies have restricted hazmat shipments to off-peak hours when congestion was lowest, while other agencies have restricted hazmat shipments to daytime hours when emergency response capabilities were highest. These contradictory approaches need to be resolved, and the economic impacts of time-of-day restrictions on through shipments and on local pickup-and-delivery operations in a metropolitan area need to be determined.

8. Determine Training Needs of Highway Agencies Related to Highway Transportation of Hazardous Materials

The training needs of highway agencies related to highway transportation of hazardous materials need to be determined. Specifically, training is needed for engineers and planners involved in routing decisions and for field personnel who may be the first to encounter a spill, but the specific types of training to meet these needs should be identified and successful ideas that have already been tried should be synthesized for users. Current training programs in California, Illinois, and other States should be reviewed and new ideas for training developed.

9. Determine Which Hazardous Materials Special Requirements Should Apply To

There is a need to determine which hazardous materials routing restrictions, safe haven requirements, and advance notification requirements should apply to. If special requirements are to be established for "extremely hazardous" or "ultrahazardous" materials or any other subset of hazardous materials, agreed list(s) of materials need to be coordinated between RSPA, EPA, and other agencies.

10. Determine Acceptable Levels of Risk and Develop Improved Methods for Communicating Risk Levels to the Public

There is a need to determine what level of risk is acceptable to the public and to better understand differences in actual and perceived risk. For example, the risks of hazmat incidents could be assessed in comparison to other public safety risks in everyday life (e.g., house fires). The solution to this problem may lie largely in developing better methods for communicating risk levels to the public.

11. Improve Funding Mechanisms for Cleanup of Hazmat Spills

There is a need for improved funding mechanisms to finance the management of hazmat transportation safety and cleanup of spills (e.g., "spiller pays" legislation). Research is needed to evaluate the effectiveness of "spiller pays" legislation in jurisdictions where it has been tried. For example, there are no reliable data on the percentage of cases in which a recovery was made, the actual percentage of cleanup costs recovered in those cases, and factors that make recovery of cleanup costs easy or difficult.

12. Perform Hazmat Risk Assessments Based on Private "Industry-Based" Data

There is a need for analysis of hazmat transportation risks based on the private data bases of hazmat carriers, as discussed in section IV of this report. "Industry-based" data collection of this sort may be the only way to obtain truly comparable data on both hazmat flows and hazmat accidents and incidents. This approach would require the voluntary cooperation of companies willing to contribute data on a confidential basis.

13. Investigate the Possibility of Reducing the Quantities of Hazardous Materials Shipped

Methods to reduce the quantities of hazardous materials that are shipped should be investigated as a means of decreasing the potential for accidents and incidents. Most previous studies have taken for granted that the quantities of hazardous materials shipped cannot be reduced, but this hypothesis has not been thoroughly investigated and tested.

14. Improve Management of Hazmat Safety at Intermodal Points

The management of hazmat safety at intermodal points (e.g., port facilities) needs to be improved. Research is needed to characterize the safety problems at intermodal points and to develop effective methods for dealing with these problems.

Lower Priority Issues

15. Improve Management Methods for Major Incidents

There is a need to improve methods for detection and management of major hazmat incidents, with emphasis on freeway incidents. Research should address improved freeway surveillance and incident detection methods; use of mobile motorist assistance patrols to make a rapid visual assessment of potential incidents; and improved training and response time for emergency response agencies. There is a need to establish procedures to reduce the time required for highway agencies to be informed about incidents detected by others, especially in small jurisdictions. There is also a need to improve feedback mechanisms from emergency response agencies to highway agencies after an incident to assist highway agencies in establishing hazmat transportation regulations, routing preferences, etc.

16. Determine Appropriate Advance Notification Requirements for Sensitive Environments

The appropriate role of advance notification requirements for hazmat shipments needs to be determined. Advance notification may be a particular concern for sensitive environments such as bridges, tunnels, schools, and hospitals. The type of materials that might require advance notification and the benefits of advance notification to highway agencies and emergency response agencies need to be evaluated.

17. Investigate Causes of Hazmat Incidents Related to Cargo Shifting

An investigation of hazmat incidents involving cargo shifting is needed to determine if the shifting was related to roadway geometrics or emergency maneuvers. The research should focus on whether incidents related to cargo shifting can be reduced through highway design improvements.

18. Investigate Effectiveness of Designated Lanes for Hazmat Carrying Trucks

The effectiveness of designated lanes for hazmat carrying trucks in reducing the risk of hazmat incidents should be investigated. If designated lanes are implemented on freeways, should trucks be restricted to the right lane only or should trucks be prohibited only from the far left lane? Are run-off-road and overturning accidents caused by lane-changing maneuvers and, thus, reduced by lane use restrictions?

VIII. CONCLUSIONS AND RECOMMENDATIONS

Highway Agency Responsibilities for Hazmat Transportation

1. Responsibilities for management of highway transportation of hazardous materials are divided between Federal, State, and local agencies and between highway agencies and other agencies.

2. Highway agencies do not always have a lead role in hazmat transportation safety, but usually play at least a key support role because they operate the highway system over which hazmat shipments move. A key finding of the study is that, in every area of responsibility related to hazmat transportation safety, the State highway agency has either a lead or a key support role in at least some States.

3. Management of hazmat transportation safety is a cooperative venture involving many diverse agencies, including highway agencies, police agencies, fire departments, emergency management agencies, and environmental agencies. Effective management of hazmat transportation safety depends more on close cooperation between these agencies at the management and working levels than on which agency is designated to take the lead.

Data Sources

4. There is substantial underreporting of hazmat-related accidents and incidents to Federal data bases. The degree of underreporting has not been adequately quantified.

5. Better linkage is needed between incident and accident data at both the Federal and State levels.

6. A number of States have added a data element indicating the presence or absence of hazardous materials to their police traffic accident report forms. At present, most of these State forms do not also note whether or not the hazardous materials were released as a result of the reported accident. In truck accident analyses, it cannot be presumed that any fatalities and injuries that occur are related to the presence of hazardous materials because releases occur in only 15 percent of accidents, and the probability of a release varies widely between accident types. Thus, accident report forms should also include a data element indicating whether or not a hazmat release occurred.

7. Available exposure data for hazmat shipments are collected on a different basis and cannot be related directly to the available accident and incident data. Improved exposure data are needed for assessment of hazmat transportation risks. Possible methods for obtaining improved exposure data might be through data collection from individual carriers or from toll roads.

Fatalities and Injuries

8. Approximately 99 percent of all fatalities and 96 percent of all injuries involving trucks carrying hazardous materials are not related to hazmat releases. These fatalities and injuries occur either in accidents in which there is no hazmat release or are not caused by the releases which do occur. Of the small remaining fraction of fatalities and injuries associated with releases, more fatalities occurred in releases caused by traffic accidents than in releases with other causes. For the 4 percent of injuries caused by hazmat releases, the reverse was found -- more injuries were due to releases not caused by traffic accidents. It is important to note that one major disaster involving a release could greatly alter these distributions in any given year and, in fact, this concern is the reason that hazardous materials transportation is a separate highway safety issue.

Hazmat Incidents

9. Approximately 11 percent of hazmat incidents that occur on public highways are caused by traffic accidents. This estimate of the proportion of incidents caused by traffic accidents is higher than found in previous studies, because incidents that occur off the highway in terminal, yard, and loading areas have been eliminated.

10. About 90 percent of the deaths and 25 percent of the injuries due to hazmat releases were caused by traffic accidents.

11. Between 35 percent and 68 percent of severe hazmat incidents were found to be caused by traffic accidents, depending upon the definition adopted for a severe incident. Thus, traffic accidents are far more likely to result in a severe incident than other causes.

Traffic Accidents Involving Hazmat-Carrying Trucks

12. Approximately 96 percent of the fatalities and 97 percent of the injuries in accidents involving trucks carrying hazardous materials are due to the physical collision itself and not the properties of the hazardous materials being transported.

13. Approximately 13 percent to 15 percent of accidents involving hazmat-carrying trucks result in a hazmat release.

14. Higher than average probabilities of a hazmat release are found in traffic accidents involving:

    - Truck-train accidents at railroad-highway grade crossings (45 percent release probability, based on 22 accidents).

    - Overturning in a single-vehicle accident (38 percent release probability).

- Running off the road in a single-vehicle accident (33 percent release probability).

- Trucks transporting solids in bulk (30 percent release probability, based on 40 accidents).

- Freeway off-ramps (26 percent release probability).

- Freeway on-ramps (22 percent release probability).

- Highways with speed limits of 45 mi/h (72 km/h) or more (18 percent release probability).

15. Lower than average probabilities of a hazmat release are found in traffic accidents involving:

    - Truck collisions with pedestrians, bicyclists, and animals (2 percent release probability).

    - Truck collisions with parked vehicles (3 percent release probability).

    - Truck collisions with passenger cars (4 percent release probability).

    - At-grade intersections (4 percent release probability).

    - Truck collisions with other trucks (9 percent release probability).

16. Trucks carrying liquids in bulk constitute 50 percent of accident involvements for hazmat-carrying trucks and 2 percent of accidents for other trucks. This very large difference is indicative of a major difference in tank truck exposure between hazmat and other trucking.

<u>Risk Assessment and Routing Guidelines</u>

17. The FHWA hazardous materials routing guidelines, with improvements recommended in section VI of this report, provide a valid method for assessing the relative risks of alternative routes.

18. The accident probability portion of the FHWA routing model should include terms representing truck accident rate and the probability of a hazmat release given an accident. Procedures for estimating these terms from available truck accident, truck volume, and highway geometric data are discussed in section VI and appendix A of the report. A numerical example of the estimation of these terms is presented in appendix B of the report.

19. Routing studies based on average truck accident rate data for specific highway classes within a particular jurisdiction are likely more reliable than truck accident rates calculated for the individual highway segments being evaluated. Default accident rates and release probabilities that can be used in the absence of better local data are given in this report. However, it is always preferable for a jurisdiction to develop average truck accident rates and release probabilities from its own data than to use outside data.

20. A statistical test is provided in section VI of this report to allow users to determine whether the observed truck accident rate for a specific highway segment is significantly higher (or lower) than the expected value. Where this test is significant, the user is justified in using the truck accident rate for the specific highway segment being evaluated in preference to the systemwide average.

Future Research

21. Recommended issues for future research related to highway transportation of hazardous materials, ranked by priority level, are presented in Section VII of this report. The highest priority issues are:

    - Improve the quality of hazmat safety data.
    - Demonstrate improved hazmat risk assessment and routing models.
    - Establish the cost-effectiveness of hazmat routing requirements.
    - Evaluate risk of hazmat incidents at special facilities such as elevated freeways, depressed freeways, bridges, and tunnels.

APPENDIX A

DEVELOPMENT OF TRUCK ACCIDENT RATES AND RELEASE PROBABILITIES FOR USE IN HAZMAT ROUTING ANALYSES

This appendix presents a procedure that can be used by highway agencies to develop estimated average truck accident rates and release probabilities for different highway and area types. The procedure is demonstrated using data from three States. Users are encouraged to develop truck accident rates and release probabilities from data for their own jurisdiction, using the procedure described in this appendix. However, when data appropriate for the users locality are not available, the estimates presented here based on data from the three States can be used as default values.

A. Background

Section VI of this report recommends that the FHWA guidelines for hazmat routing studies be revised to incorporate an improved method for estimating accident probabilities. Specifically, the use of truck accident rates is recommended in preference to the all-vehicle accident rates presently used in the FHWA routing guide.[10] In addition, a new term representing the probability of a hazmat release given an accident involving a hazmat carrying truck has been introduced. The revised equation for determining accident probability is:

$$P(R)_i = TAR_i \times P(R|A)_i \times L_i \tag{19}$$

where:

$P(R)_i$ = probability of an accident involving a hazmat release for route segment i

TAR_i = truck accident rate (accidents per veh-mi) for route segment i

$P(R|A)_i$ = probability of a hazmat release given an accident involving a hazmat carrying truck for route segment i

L_i = length (mi) of route segment i

The objective of the analyses performed in this appendix is to determine values of TAR and P(R|A) in equation (19). Users are encouraged to determine expected values of TAR and P(R|A) from data for their own State. Statewide averages for specific highway and area types are generally much more reliable than estimates based on accident data for the specific highway segments being analyzed in a hazmat routing study, because the sample size of accidents for individual highway segments is often not large enough to allow statistically valid comparisons between alternative routes. Where the analysis segments are relatively short and the duration of the analysis period is limited to a few years, as is often the case, estimates based on actual accident histories will be unreliable. For example, if a segment had no truck accidents in 3 years, it would clearly be incorrect to assign that segment zero risk. If, for two similar highway segments on alternate routes, one segment had one accident in 3 years and the other had two accidents, it would clearly be incorrect to assume that one segment has twice the risk of the other. Thus, it is generally more reliable to use average systemwide accident rates than to use accident histories for specific analysis segments.

There are a few cases, however, where accident rates may be substantially higher (or lower) than average, that warrant reliance on the accident history for a specific segment. Section VI of the report includes a statistical test to determine when actual accident histories are preferable to systemwide averages [see equation (15)].

The truck accident rate data used as default values in hazmat routing studies should reflect the influence of highway geometric and traffic variables that have a demonstrated relationship to truck safety. Two key variables whose strong relationship to truck accident rates has been demonstrated are highway type (two-lane highway, freeway, etc.) and area type (urban/rural). Section II of this report discusses several studies that demonstrate such relationships. Freeways generally have lower accident rates than any other highway type, and should generally be preferred to other highway types for hazmat shipments. Rural highways also generally have lower truck accident rates than urban highways for the same highway type. Thus routes that avoid urban areas are generally preferable, unless they are substantially longer or involve a less suitable type of highway. It would be desirable for the default accident rates used in hazmat routing studies to also reflect the influence of other geometric features of highways such as lane width, shoulder width, curves, grades, and intersections. Some of these relationships have been demonstrated for all-vehicle accident rates, but none of these features have been specifically related to truck accidents. The relationships developed in this appendix quantify the effect of highway type and area type on truck accident rate, but not the effects of other geometric features, which are beyond the scope of the study.

In addition to truck accident rates, the distribution of truck accident types also varies with highway and area type. Rural highways and urban freeways tend to have a larger proportion of single-vehicle noncollision accidents, while lower-speed urban highways tend to have a higher proportion of multiple-vehicle collisions. Analyses of the FHWA Motor Carrier Accident reports, presented in section V of this report, show that the probability of a release given an accident involving a hazmat carrying truck is much higher in single-vehicle noncollision accident than in single- or multiple-vehicle collision accidents. Thus, the probability of release given an accident is also expected to vary for different highway and area types.

B. Procedure for Developing Truck Accident Rates and Release Probabilities

The following discussion presents the procedures that were used to develop the default accident rates and release probabilities in table 82 and can be used by highway agencies to develop default values from their own data. Site-specific accident data for the particular alternative routes being evaluated should only be used where equation (15) indicates a need. Estimates of truck accident rates and release probabilities based on an agency's own data are preferred to the use of the default values in table 82.

1. Data Needs

Three types of data are needed to estimate truck accident rates and release probabilities in a form useful for hazmat routing analyses. These are:

- Highway geometric data.
- Truck volume data.
- Truck accident data.

In order for the analysis to be accomplished efficiently, it is desirable for these data to be available in computerized form using a common location identifier (e.g., mileposts) so that the three types of data can be linked together. Many State highway agencies have been computerizing and linking their data files and now, or soon will, have the capability to perform this type of analysis.

No State of which the authors are aware currently has the necessary data and linking capability to analyze accident rates for all public highways in the State. The best systems currently available include all highways under the jurisdiction of the State highway agency. To obtain unbiased estimates, it is desirable for the highway geometric, truck volume, and truck accident files to cover the entire State highway system. If only a subset of the State highway system is used, this subset should be selected through a statistical sampling process to maintain the unbiased nature of the estimates.

Highway geometric files are needed to define the characteristics of segments to which truck volume and accident data can be added. Highway geometric files typically consist of relatively short route segments (0.35 mi [0.56 km] or less in length) for which data on the geometric features of the segment are included. The minimum data that should be available for this analysis are:

- Number of lanes.
- Divided/undivided.
- Access control (freeway/nonfreeway).
- One-way/two-way.
- Urban/rural.

Other data typically available in highway geometric files that users might want to consider include lane width and shoulder width. In addition to roadway segment data, geometric files often include records of the geometrics of individual intersections and freeway ramps. These features could also be considered in the development of default accident rates.

Traffic volume files typically include the Annual Average Daily Traffic (AADT) and may also include either the average daily truck volume or the percent trucks in the traffic stream. In order to be useful, truck volume data needs to be given in the same location reference system as the highway geometric and accident data.

The truck accident data needed for the analysis is a subset of the accident files for all vehicle types maintained by all State highway agencies. In selecting accidents for inclusion in the analysis, it is important to use the same definition of a truck that was used in obtaining the truck volume counts. Since nearly 89 percent of the accidents in which hazardous materials are released involve combination trucks (i.e., tractor-trailers), it would be desirable to limit the accident analysis to combination trucks only. Unfortunately, however, truck volume data for combination trucks are seldom available on a systemwide basis. Therefore, it is often necessary to use truck volume data and accident data for all trucks or for all commercial vehicles. (It is important to realize that traffic counts of "all commercial vehicles" typically include both trucks and buses. Thus, when traffic volume counts for "all commercial vehicles" are used, it is important to include both bus and truck accidents in the analysis.)

Typical accident characteristics that should be included in the analysis are:

- Number of vehicles involved.
- Types of vehicles involved.
- Type of collision (if any).
- Date of accident.
- Accident severity (most severe injury).

The recommended accident type categories into which the truck accidents should be classified using these data are those shown in table 46. Each accident-involved vehicle should be treated as a separate observation (i.e., an accident involving two trucks should be counted as two accident involvements).

2. Data Processing

The processing of the data described above should be conducted in a series of five steps illustrated in figure 18. This processing can be accomplished using a standard statistical package such as the Statistical Analysis System (SAS). The key element in the processing is linking the appropriate truck volume and accident data to individual roadway segments from the highway

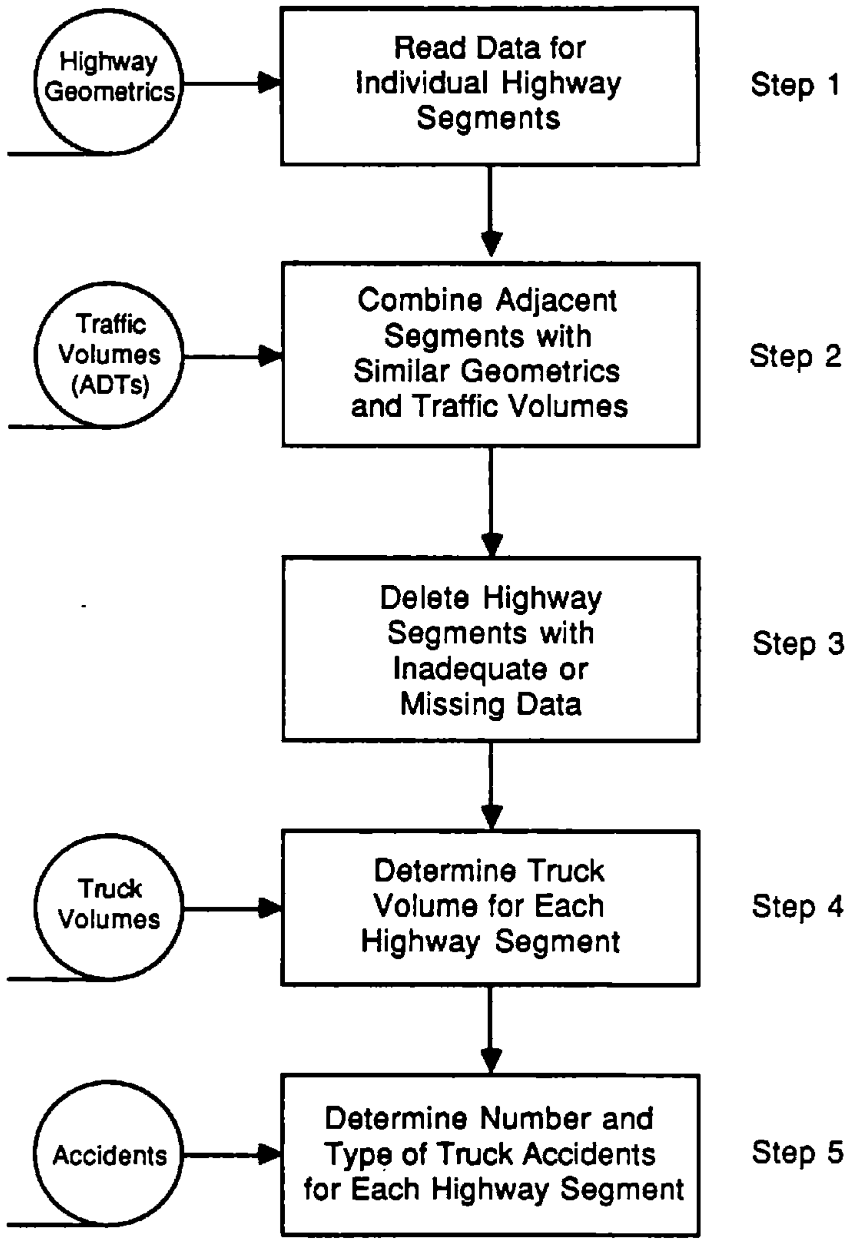

Figure 18. Step-by-step process for merging data from highway geometrics, truck volumes, and accident data files.

geometric file using a common location reference system (e.g., mileposts). Each step in the linking of the data from these files is described below.

Step 1 - The data for the individual roadway segments should be read from the highway geometric file. Only those geometric data items needed for the analysis should be read (see example list given above). The highway class (highway type and area type) of each roadway segment should defined based on the available data. Typical highway classes include:

- Rural two-lane highways.
- Rural multilane undivided highways.
- Rural multilane divided highways.
- Rural freeways.
- Urban two-lane streets.
- Urban multilane undivided streets.
- Urban multilane divided streets.
- Urban one-way streets.
- Urban freeways.

Step 2 - Individual roadway segments, which have relatively short average lengths, should be merged into longer segments whenever adjacent segments match in highway class and other selected variables and have average daily traffic volumes within 20 percent of one another. When adjacent highway segments are merged, their average daily traffic volumes should be combined using a weighted average by length, as follows:

$$ADT_C = \frac{ADT_1 L_1 + ADT_2 L_2}{L_1 + L_2} \tag{20}$$

where: ADT_C = average daily traffic volume for combined segments

ADT_i = average daily traffic for route segment i

L_i = length (mi) for route segment i

Step 3 - Eliminate from the analysis any roadway segments for which accident or truck volume data are not available or which did not fit within one of the highway classes selected.

Step 4 - The truck volumes for the merged sections should be obtained from the volume file. The truck volume data should be used, together with the length of the segment, to compute the annual veh-mi of truck travel on each segment:

$$TVMT_i = TADT_i \times L_i \times 365 \tag{21}$$

where: $TVMT_i$ = Annual truck travel (veh-mi) on route segment i

$TADT_i$ = Average daily truck volume (veh/day) on on route segment i

Step 5 - Data on truck accidents should be obtained from the accident files. Each truck accident involvement should be classified by year, accident severity, and accident type. The common location reference system used to link the accident and geometric files should be used to decide which segment the reported location of each accident falls within and to total the number of accident involvements within each segment by year, by severity level, and by accident type. Each year of data for each segment should generally be treated as a separate observation in the analysis.

The result of step 5 is a file containing the truck volumes and truck accident histories for individual highway segments that can be used to compute truck accident rates and release probabilities.

3. Data Analysis

The average truck accident rate for each highway class can be computed as the ratio of total truck accidents to total veh-mi of truck travel for that highway class. In other words:

$$TAR_j = \frac{A_{ij}}{VMT_{ij}} \tag{22}$$

where: TAR_j = Average truck accident rate for highway class j

A_{ij} = Number of truck accidents in one year on route segment i in highway class j

VMT_{ij} = Annual vehicle miles of truck travel on route segment i in highway class j

The values of TAR_j for each highway class from equation (22) can be used to replace the default truck accident rates in table 83 with values more suited to local conditions.

The probability of a hazmat release given an accident varies between highway types because it is varies with accident type and because the distribution of accident types varies markedly between highway classes. Table 46 shows the probability of release given an accident by accident type based on the analysis of the FHWA motor carrier accident report data. Table 46 was determined from the FHWA motor carrier accident reports because, for each accident involved truck, these reports both whether the truck was carrying hazardous materials and whether the hazardous materials were released. It would be desirable for users to derive values comparable to those in table 46 for their own State, but only three States currently have both data items needed to make this determination in their accident records systems.

The probability of a release given an accident involving a hazmat-carrying vehicle can be computed as:

$$P(R|A)_j = \sum_k P(R|A)_k \times P(k)_j \tag{23}$$

where: $P(R|A)_j$ = Probability of a hazmat release given an accident involving an hazmat carrying vehicle for highway class j

$P(R|A)_k$ = Probability of a hazmat release given an accident involving a hazmat carrying vehicle for accident type k (from table 49 or equivalent State data)

$P(k)_j$ = Probability that an accident on highway class j will be of accident type k (i.e., proportion of truck accidents for each accident type shown in table 49 on highway class j from State accident data)

The values of $P(R|A)_j$ from equation (23) can be used to replace the default values for the probability of release given an accident presented in table 83.

The development of the default values for truck accident rate and probability of release from table 82 using the procedure described above is illustrated in the remainder of this appendix.

C. Data Sources

The development of systemwide estimates of truck accident rate for different highway and area types using the procedure presented above requires three types of data, preferably in computerized form. These data types are: highway geometrics, truck volumes, and truck accidents. Past research linking accident data to specific highway geometric features has usually been based on selected subsets of the State highway system. However, recent progress in the availability of geometric and traffic volume files that can be linked to accident data now enables such analyses to be performed in a few States for the entire State highway system. Additional States are computerizing their geometric and traffic volume inventory files, so statewide analyses should be possible in additional States in the future.

Based on discussions with a number of agencies, three State highway agencies that could provide the data needed to develop systemwide truck accident rates were identified. These agencies were the California, Illinois, and Michigan Departments of Transportation. The type of data available from each State is discussed below.

1. Available Data Files

The California Department of Transportation (Caltrans) maintains both geometric and traffic volume files that can be linked to accident data as part of their Traffic Accident Surveillance and Analysis System (TASAS). TASAS includes both a highway geometric file and accident files that are linked by a post mile location reference system. Locations in both files are identified by unique combinations of six parameters: district, county, route number, route number suffix, post mile prefix, and post mile. The average length of highway segments in the highway geometric file was approximately 0.35 mi (0.56 km). (The segments in the geometric file are relatively short, because a new segment begins any time one of the key cross-sectional data elements for the segment changes its value.) The highway geometric file includes the average daily traffic volume for each segment, but not the truck volume or percent trucks. Therefore, truck volumes were obtained from another file that presents truck volume counts by number of axles for approximately 7,300 locations on the 15,200-mi (24,500 km) State highway system [i.e., approximately one truck volume count every 2 mi (3 km)]. The locations of the truck volume counts were identified in same post mile system as the highway geometric and accident data. The truck volume and percent trucks for each highway segment were estimated from the truck volume counts at the nearest count locations to both ends of the segment and the distances from the ends of the segment to those count locations. Manual checks of the results of this process were made, segment by segment, to assure that the estimated truck volumes were reasonable.

The Illinois Department of Transportation maintains a highway segment data base for marked (numbered) State highways. The highway data base includes both average daily traffic volumes and truck volumes for each segment. The average segment length in this file was approximately 0.085 mi (0.14 km), much shorter than the segments in the California file, probably because more variables were considered in the definition of where a new segment must begin. One version of this file contains location reference data that can be linked to the accident file. In this common reference system, locations are uniquely defined by county, route, and mile station.

The Michigan Department of Transportation maintains a file of highway segments, similar to the California and Illinois files discussed above. This highway segment file is part of the Michigan Dimensionalized Accident Surveillance (MIDAS) system. The MIDAS segment file identifies segment locations by a five-digit control section number and a milepost (distance from beginning of section) within the control section, the same location reference system used in the State's accident data. The average segment length in the MIDAS segment file is approximately 0.27 mi (0.43 km). The MIDAS segment file currently excludes freeway segments although they are in the process of being added. Therefore, the mileposts of rural and urban freeway segments were obtained from another file maintained by the State. The MIDAS segment file contains average daily traffic volumes, but not truck volumes. Therefore, truck volumes were taken from another file known as the Trunkline Vehicle Miles (TVM) file. This file contains average daily traffic and commercial traffic volume estimates for 3 recent years for highway sections between major points of change in traffic volume; these sections average approximately 1.3 mi (2.1 km) in length.

2. Highway Geometric Data

The highway geometric data available in all three States was quite extensive and only a portion of that data was used in the study. The geometric data file was used to define the highway type and area type for each highway segment. Nine highway classes (combinations of highway type and area type) were used in the study. These are:

- Rural two-lane highways.
- Rural multilane undivided highways.
- Rural multilane divided highways.
- Rural freeways.
- Urban two-lane streets.
- Urban multilane undivided streets.
- Urban multilane divided streets.
- Urban one-way streets.
- Urban freeways.

Only a few highway segments in each State could not be classified into one of these nine highway classes. For example, freeway ramps were not considered in the current study.

Other geometric and traffic control variables were available in the files. Cross-sectional elements such as lane width and shoulder width were available in all three States. Some data on the geometrics and traffic control of individual intersections were available in each of the three States. Data on individual horizontal curves were available in two of the States, and data on grades were available in one of the States. Only one of the three States included speed limit in their highway data base. Detailed consideration of the effects of these other geometric and traffic control variables was beyond the scope of the present study.

3. Traffic Volume Data

Two forms of traffic volume data were obtained for each highway segment. These were: average daily traffic volumes and truck volumes. In all three States, average daily traffic volumes were available in the highway geometric file. However, in two of the three States, truck volumes had to be obtained from other sources, as described above.

The only truck volume data currently available for most highway segments in the three States are the volumes for all commercial vehicles. (Illinois routinely counts volumes for combination trucks and publishes a map showing combination truck volumes, but these data are not available in a computerized file that can be linked to accident data.) All three States defined a commercial vehicle as any vehicle with more than two axles or more than four tires. This category generally includes single-unit trucks, combination trucks, and buses. It would be more desirable, for purposes of hazmat routing studies, to use truck volume and accident data for combination trucks only, rather than for all commercial vehicles. Most hazmat shipments are shipped by combination trucks; table 47 shows that nearly 89 percent of accidents in which hazardous materials are released involve combination trucks, and only 11 percent involve single-unit trucks. However, reliable volume data for combination trucks are not available and the analyses conducted in this study were restricted, of necessity, to all commercial vehicles.

Historically, commercial vehicles have been identified visually in volume counting. In the process of implementing the FHWA Traffic Monitoring Guide, many States are in the process of transition from manual to automated counting of commercial volumes and are relocating their permanent vehicle classification counting stations to provide better statistical representativeness of the highway system. It is not clear that States can remain completely faithful to their nominal definitions of a commercial vehicle in automated counting. For example, most automated systems have no way to distinguish between two-axle four-tire and two-axle six-tire vehicles, but a distinction between passenger cars and two-axle trucks and buses can be made with wheelbase data. There are no data available to determine the extent to which truck volumes determined from manual and automated counts differ. The automated data may, in fact, be more accurate than the manual data due to the elimination of human errors. In any case, the differences between manual and automated truck volume counting methods are unlikely to have a major effect on the accuracy of the truck accident rate estimates developed in this appendix.

Two different approaches to commercial volume counting have been used in the three States. Illinois makes commercial vehicle counts over the entire State highway system during every fourth year. The most recent commercial vehicle volume data available to this study for Illinois were taken in 1984. California and Michigan perform commercial counting on a rotating basis, as many counts as possible each year. Locations with rapidly changing traffic volumes may be counted more often than areas of slow growth. California and Michigan both count average daily traffic volumes more often than they count commercial volumes and they use the most recent ADT data to update the truck volumes (i.e., they assume that the percent trucks does not change as traffic volumes grow).

The commercial vehicle volumes in the Illinois files were incomplete for many highway segments in Chicago and surrounding counties and for scattered segments elsewhere in the State. These missing data were estimated from the truck volumes for adjacent sections in the file or from the State's published commercial volume map.

4. Truck Accident Data

Accident data were obtained from existing files in all three States for their entire State highway system. Accident data were obtained for all commercial vehicles (combination trucks, single-unit trucks, and buses). Buses are not of direct interest to this study, but accident data for buses were included because buses are included in the commercial vehicle counts used as exposure data. Only about 5 percent of the "truck" accidents included in the study were, in fact, bus accidents. Therefore, the inclusion of buses in the truck volume and truck accident data is unlikely to have a major effect on the calculated truck accident rates.

The accident data files used for the study contained a broad range of accident descriptors. The following accident characteristics were used to classify accidents and to decide whether or not particular accidents met the criteria for inclusion in the study and should be counted:

- Number of vehicles involved.
- Types of vehicles involved.
- Type of collision (if any).
- Date of accident.
- Accident severity (most severe injury).

Accidents were classified by accident type using the following categories, which are compatible with the accident classification system used by the National Safety Council:

SINGLE-VEHICLE NONCOLLISION ACCIDENTS

Run-off-road
Overturned (in road)
Other noncollision

SINGLE-VEHICLE COLLISION ACCIDENTS

Collision with parked vehicle
Collision with train
Collision with nonmotorist (animal, pedestrian, bicycle)
Collision with fixed object
Other collision

MULTIPLE-VEHICLE COLLISION

Collision with passenger car
Collision with truck
Collision with other vehicle (RV, motorcycle)

Each truck involved in an accident was treated as a separate observation in the data analysis. Thus, accidents involving two or more trucks were treated as two or more accident involvements. The categories for multiple-vehicle accidents shown above are based on the largest vehicle involved in the accident other than the vehicle under consideration. Thus, an accident involvement classified as a "collision with truck", represents one truck involvement in an accident in which at least two trucks were involved. Such accidents were classified as truck-truck collisions, even though it cannot be established with certainty whether or not the trucks actually collided (e.g., it is possible that both trucks collided with a third vehicle, but not with each other).

The severity for each accident involvement was classified by the most severe injury in the accident as a whole. This approach to severity classification is reasonable for truck accidents because very often, in a collision between a truck and a passenger car, injuries to the passenger car occupants are more likely than injuries to the truck occupants.

The accident data used in the analysis for California and Michigan covered the 3-year period from 1985 through 1987, inclusive. Only 2 years of accident data, 1986 and 1987, were used in Illinois, because the location reference system used for accidents in the Chicago area in 1985 and prior years was not fully compatible with the available highway data. A decision was made not to use the 1985 data for the rest of the State, because statewide urban area accident rates for 1985 in Illinois might be very different than for other years if the Chicago area were excluded.

D. Data Processing

All of the data files described above were obtained from the States on magnetic tape and were processed on an IBM-compatible mainframe computer using the Statistical Analysis system (SAS) following the step-by-step approach for merging the data from the available geometric, traffic volume, and accident files illustrated in figure 18. The steps used in processing these data are described below:

Step 1 - The data for the individual highway segments were read from the highway geometric file.

Step 2 - Individual highway segments, which have relatively short average lengths as described above, were merged into longer segments whenever adjacent segments were of the same highway and area types and had average daily traffic volumes within 20 percent of one another. When adjacent highway segments were merged, their average daily traffic volumes were combined using a weighted average by length in accordance with equation (20). Following this merging of adjacent sections, the average segment lengths were 2.36, 1.70, and 1.84 mi (3.80, 2.74, and 2.96 km) in California, Illinois, Michigan, respectively.

Step 3 - A few segments for which accident or truck volume data were not available or which did not fit within one of the nine highway classes listed above were deleted. In particular toll roads and bridges were eliminated from consideration in all three States and unmarked (i.e., unnumbered) routes were eliminated in Illinois because accident data could not be reliably linked to the available geometric data. Highway segments where trucks were prohibited (e.g., where the truck percentage is, in fact, zero) were also deleted. Less than 0.2 percent of the remaining highway segments had to be deleted in any of the three States because of missing accident or traffic volume data, so the results obtained are very representative of the highway system as a whole.

Step 4 - The truck volumes for the merged sections were obtained from a volume file, if they were not already available in the highway segment file. The truck volume data were used, together with the length of the segment, to compute the annual veh-mi of truck travel on each segment, in accordance with equation (21).

Step 5 - Data on truck accidents were obtained from the accident files supplied by the States. Each truck (or bus) accident involvement was classified by year, accident severity, and accident type. The common location reference system used to link the accident and geometric files was used to decide which segment the reported location of each accident fell within and to total the number of accident involvements within each segment by year, by severity level, and by accident type. Each year of data for each segment was treated as a separate observation in the analysis.

The result of step 5 was a file containing the truck volumes and truck accident histories for individual highway segments that was then used to compute truck accident rates and release probabilities.

E. Analysis Results

This section presents the results of the analysis of accident geometric and traffic volume data. First the accident rates, accident severity distributions, and accident type distributions for different highway and area type classes obtained in the analysis are presented. Next, a subsection on interpretation of results discusses the effects of accident reporting levels and the development of relationships between truck accident rate and variables other than highway and area class. Specific default values of truck accident rate and release probability are presented in the final section of the appendix.

1. Truck Accident Rates

Tables 85, 86, and 87 present the truck accident rates by highway and area type class for California, Illinois, and Michigan, respectively.

Table 85. Truck accident rates on California State highways, 1985-1987.

Highway class		Total length (mi)	No. of sections	Average truck ADT (veh/day)	No. of truck accident involvements[a]	Truck travel (MVM)	Truck accident rate (per MVM)
Area type	Roadway type						
Rural	Two-lane	8,808.96	2,607	392	6,577	3,784.97	1.73
Rural	Multilane undivided	209.13	334	858	1,070	196.58	5.44
Rural	Multilane divided	726.85	450	1,839	1,801	1,463.45	1.23
Rural	Freeway	2,068.20	405	4,791	5,759	10,850.90	0.53
Rural	TOTAL	11,813.14	3,796	1,260	15,207	16,295.90	0.93
Urban	Two-lane	513.49	648	748	1,778	420.69	4.23
Urban	Multilane undivided	141.50	341	1,116	2,251	172.84	13.02
Urban	Multilane divided	754.18	793	1,644	4,996	1,427.47	3.50
Urban	One-way street	22.26	47	1,387	223	33.81	6.60
Urban	Freeway	1,969.65	817	8,395	28,860	18,107.00	1.59
Urban	TOTAL	3,401.07	2,646	5,414	38,108	20,161.81	1.89
TOTAL		15,214.21	6,442	2,388	53,315	39,781.10	1.34

[a] Accidents involving two or more trucks are counted as two or more involvements.

Table 86. Truck accident rates on Illinois State highways, 1986-1987.

Highway class		Total length (mi)	No. of sections	Average truck ADT (veh/day)	No. of truck accident involvements[a]	Truck travel (MVM)	Truck accident rate (per MVM)
Area type	Roadway type						
Rural	Two-lane	8,705.60	3,519	287	5,712	1,822.16	3.13
Rural	Multilane undivided	278.95	202	1,068	464	217.38	2.13
Rural	Multilane divided	99.53	140	663	231	48.16	4.80
Rural	Freeway	1,366.76	258	2,854	1,320	2,847.51	0.46
Rural	TOTAL	10,450.84	4,119	647	7,697	4,935.21	1.56
Urban	Two-lane	960.01	1,414	539	4,194	377.79	11.10
Urban	Multilane undivided	569.21	787	1,033	7,316	429.10	17.05
Urban	Multilane divided	571.17	796	1,131	6,971	471.43	14.80
Urban	One-way street	108.31	283	401	805	31.74	25.36
Urban	Freeway	462.26	305	5,246	10,302	1,770.29	5.82
Urban	TOTAL	2,670.96	3,585	1,580	29,588	3,080.35	9.61
TOTAL		13,121.80	7,704	838	37,285	8,015.56	4.65

[a] Accidents involving two or more trucks are counted as two or more involvements.

Table 87. Truck accident rates on Michigan State highways, 1985-1987.

Highway class							
Area type	Roadway type	Total length (mi)	No. of sections	Average truck ADT (veh/day)	No. of truck accident involvements[a]	Truck travel (MVM)	Truck accident rate (per MVM)
Rural	Two-lane	5,679.39	1,490	342	4,733	2,127.29	2.22
Rural	Multilane undivided	63.98	118	933	621	65.35	9.50
Rural	Multilane divided	259.15	186	1,215	1,951	344.83	5.66
Rural	Freeway	1,182.63	448	2,575	3,931	3,335.04	1.18
Rural	TOTAL	7,185.15	2,242	746	11,236	5,872.51	1.91
Urban	Two-lane	718.60	1,088	525	4,515	412.99	10.93
Urban	Multilane undivided	328.39	467	930	3,466	334.34	10.37
Urban	Multilane divided	399.38	378	1,615	7,486	706.23	10.60
Urban	One-way street	89.22	134	2,480	1,959	242.32	8.08
Urban	Freeway	622.57	766	5,044	9,640	3,438.25	2.80
Urban	TOTAL	2,158.16	2,833	2,172	27,066	5,134.13	5.27
TOTAL		9,343.31	5,075	1,076	38,302	11,006.64	3.48

[a] Accidents involving two or more trucks are counted as two or more involvements.

Each of these tables represents essentially all highways under State jurisdiction in those States, except for toll roads and bridges and (in Illinois) unmarked routes. The California and Michigan tables represent 3 years of data (1985-87), while the Illinois tables represent 2 years of data (1986-87). For each highway class, the tables show the total length of highway in that class, the number of homogeneous analysis segments, the average daily truck volume, the number of truck accident involvements, the total truck travel (million veh-mi), and the truck accident rate (accident involvements per million veh-mi) computed in accordance with equation (22).

Table 88 shows a comparison of truck accident rates for all three States and includes an average accident rate for all three States combined, weighted by veh-mi of truck travel. (Note: a weighted average by veh-mi of truck travel is equivalent to combining the accident rates for the three States by summing the numerators and denominators of the accident rate expression.) It is evident in table 88 that there are substantial variations in accident rate among the three States. This, unfortunately is the case in most accident studies.

Table 88. Truck accident rates by State and combined.

Highway class		Truck accident rate (accidents per million veh-mi)			
Area type	Roadway type	California	Illinois	Michigan	Weighted average[a]
Rural	Two-lane	1.73	3.13	2.22	2.19
Rural	Multilane undivided	5.44	2.13	9.50	4.49
Rural	Multilane divided	1.23	4.80	5.66	2.15
Rural	Freeway	0.53	0.46	1.18	0.64
Urban	Two-lane	4.23	11.10	10.93	8.66
Urban	Multilane undivided	13.02	17.05	10.37	13.92
Urban	Multilane divided	3.50	14.80	10.60	12.47
Urban	One-way street	6.60	26.36	8.08	9.70
Urban	Freeway	1.59	5.82	2.80	2.18

[a] Weighted by veh-mi of truck travel.

For example, a 1988 study has demonstrated from accident data (for all vehicle types, not just trucks) on two-lane highways in seven States that accident rates for seemingly identical conditions in different States can differ by a factor as large as 3 or 4.[79] Other examples of large state-to-state differences in accident rate can be found in studies of two-lane highway safety and roadside clear recovery zones.[44,108] The data in table 88 appear to bear out this conclusion. Such differences may arise from differences in the accident reporting systems of the various States, but there is no hard evidence to support this conclusion.

The 1988 study mentioned above concludes that there are dangers in combining data from different States.[79] The authors agree and strongly encourage those performing hazmat risk analyses to develop default accident rates from data for their own State. However, it should also be recognized that the primary objective in developing truck accident rates for hazmat routing analyses is to have accident rates that represent the relative differences in risk between highway classes and not to represent the absolute risk for any particular situation. The greatest State-to-State discrepancies in table 88 tend to be those for highway classes with the smallest available sample sizes of truck accident involvements and truck travel. For example, unusually high accident rate for rural multilane divided highways in Illinois represents only about 100 mi (160 km) of highway with just 231 accident involvements and 48 million veh-mi (77 million veh-km) of truck travel in 2 years. The weighted-average accident data in table 88 minimize the influence of values based on small sample sizes and comes closer to representing the differences between highway classes than the data for any single State. Therefore, the three-State averages from table 88 are appropriate for use as default values in hazmat routing studies when no better local estimates are available. However, locally generated data are always preferable when available.

Analysis of variance results established clearly that the differences in truck accident rate between highway classes within each State shown in tables 88, 86, and 87 are statistically significant at the 5 percent significance level. Furthermore, no year-to-year differences in accident rate were found to be statistically significant, either overall or for any particular highway class; i.e., there are no time trends in the data. Stepwise regression analyses were performed to explore possible relationships between truck accident rate and the independent variables average daily traffic volume and percent trucks. While some statistically significant relationships were found, none explained a large proportion of the variation in truck accident rate (i.e., all had low R-squared values) and the independent variables selected for inclusion in the models were not consistent from State to State. Therefore, this approach was abandoned and a decision was made to rely on the accident rate values given in table 88.

2. Accident Severity

Tables 89, 90, and 91 illustrate the truck accident severity distributions by highway class in California, Illinois, and Michigan, respectively. Table 92 compares the percentage of fatal and injury accidents in the three States and the combined data.

Table 92 shows that the proportion of fatal and injury accidents for each highway class is highest in California, and is substantially smaller in Illinois and Michigan. This could, in part, represent true differences between the Western and Midwestern regions of the United States. On the other hand, a portion of this difference could represent differences in reporting levels between the States. The data in table 92 suggest that it is likely that there are differences in accident reporting levels among the three States.

Table 89. Truck accident severity distribution on California State highways, 1985-1987.

Highway class		Number of accident involvements by severity level[a]				Percent of accident involvements by severity level[a]			
Area type	Roadway type	Fatal	Injury	PDO	TOTAL	Fatal	Injury	Fatal plus Injury	PDO
Rural	Two-lane	291	2,391	3,895	6,517	4.4	36.4	40.8	59.2
Rural	Multilane undivided	43	387	640	1,070	4.0	36.2	40.2	59.8
Rural	Multilane divided	82	669	1,050	1,801	4.6	37.1	41.7	58.3
Rural	Freeway	218	2,091	3,450	5,759	3.8	36.3	40.1	59.9
Rural	TOTAL	634	5,538	9,035	15,207	4.2	36.4	40.6	59.4
Urban	Two-lane	57	558	1,163	1,778	3.2	31.3	34.5	65.5
Urban	Multilane undivided	21	662	1,568	2,251	0.9	29.4	30.3	69.7
Urban	Multilane divided	84	1,380	3,532	4,996	1.7	27.6	29.3	70.7
Urban	One-way street	4	75	144	223	1.8	33.6	35.4	64.6
Urban	Freeway	334	9,011	19,515	28,860	1.2	31.2	32.4	67.6
Urban	TOTAL	500	11,686	25,922	38,108	1.3	30.7	32.0	68.0
TOTAL		1,134	17,224	34,957	53,315	2.1	32.3	34.4	65.6

a Severity level defined by the most severe injury in the accident as a whole.

Table 90. Truck accident severity distribution on Illinois State highways, 1986-1987.

Highway class		Number of accident involvements by severity level[a]				Percent of accident involvement by severity level[a]			
Area type	Roadway type	Fatal	Injury	PDO	TOTAL	Fatal	Injury	Fatal plus injury	PDO
Rural	Two-lane	105	1,727	3,850	5,682	1.8	30.4	32.2	67.8
Rural	Multilane undivided	11	159	294	464	2.4	34.3	36.6	63.4
Rural	Multilane divided	5	85	141	231	2.2	36.8	39.0	61.0
Rural	Freeway	29	392	899	1,320	2.2	29.7	31.9	68.1
Rural	TOTAL	150	2,363	5,184	7,697	1.9	30.7	32.6	67.4
Urban	Two-lane	35	965	3,194	4,194	0.8	23.0	23.8	76.2
Urban	Multilane undivided	41	1,622	5,653	7,316	0.6	22.2	22.7	77.3
Urban	Multilane divided	28	1,549	5,394	6,971	0.4	22.2	22.6	77.4
Urban	One-way street	2	170	633	805	0.2	21.1	21.4	78.6
Urban	Freeway	55	2,672	7,575	10,302	0.5	25.9	26.5	73.5
Urban	TOTAL	161	6,978	22,449	29,588	0.5	23.6	24.1	75.9
TOTAL		311	9,341	27,633	37,285	0.8	25.1	25.9	74.1

a Severity level defined by the most severe injury in the accident as a whole.

Table 91. Truck accident severity distribution on Michigan State highways, 1985-1987.

Highway class		Number of accident improvements by severity level[a]				Percent of accident involvements by severity level[a]			
Area type	Roadway type	Fatal	Injury	PDO	TOTAL	Fatal	Injury	Fatal plus Injury	PDO
Rural	Two-lane	91	1,207	3,435	4,733	1.9	25.5	27.4	72.6
Rural	Multilane undivided	3	157	461	621	0.5	25.3	25.8	74.2
Rural	Multilane divided	24	567	1,360	1,951	1.2	29.1	30.3	69.7
Rural	Freeway	31	1,080	2,820	3,931	0.8	27.5	28.3	71.7
Rural	TOTAL	149	3,011	8,076	11,236	1.3	26.8	28.1	71.9
Urban	Two-lane	76	1,064	3,375	4,515	1.7	23.6	25.2	74.8
Urban	Multilane undivided	20	790	2,656	3,466	0.6	22.8	23.4	76.6
Urban	Multilane divided	45	1,949	5,495	7,486	0.6	26.0	26.6	73.4
Urban	One-way street	6	402	1,551	1,959	0.3	20.5	20.8	79.2
Urban	Freeway	58	2,647	6,935	9,640	0.6	27.5	28.1	71.9
Urban	TOTAL	205	6,849	20,012	27,066	0.8	25.3	26.1	73.9
TOTAL		354	9,860	28,088	38,302	0.9	25.7	26.7	73.3

a Severity level defined by the most severe injury in the accident as a whole.

Table 92. Percentage of fatal and injury truck accidents by State and combined.

Highway class		Percent fatal plus injury accidents			
Area type	Roadway type	California	Illinois	Michigan	Combined
Rural	Two-lane	40.8	32.2	27.4	34.2
Rural	Multilane undivided	40.2	36.6	25.8	35.2
Rural	Multilane divided	41.7	39.0	30.3	36.0
Rural	Freeway	40.1	31.9	28.3	34.9
Rural	TOTAL	40.6	32.6	28.1	34.7
Urban	Two-lane	34.5	23.8	25.2	26.3
Urban	Multilane undivided	30.3	22.7	23.4	24.2
Urban	Multilane divided	29.3	22.6	26.6	25.9
Urban	One-way street	35.4	21.4	20.8	22.1
Urban	Freeway	32.4	26.5	28.1	30.3
Urban	TOTAL	32.0	24.1	26.1	27.8
TOTAL		34.4	25.9	26.7	29.7

Experience indicates clearly that accident reporting levels increase as accident severity increases, so reporting levels are likely to be highest for fatal accidents and lowest for property-damage-only accidents.[4,16,107] However, reporting levels for less severe accidents may vary widely between jurisdictions.

The three States differ in their reporting thresholds for property-damage-only (PDO) accidents. Illinois uses a consistent $250 reporting threshold for PDO accidents and has for many years. California has a statewide $500 reporting threshold for PDO accidents, but individual cities in California may have lower limits. (For example, the City of Los Angeles has a $200 reporting threshold.) California has also experienced problems with underreporting by various local police jurisdictions which investigate accidents, but do not forward all of their reports to the State level. Michigan has a $200 reporting threshold for PDO accidents. However, PDO reporting levels in the various States appear to be influenced as much by the characteristics of State-local coordination as by the dollar threshold used for PDO accidents.[102]

One commonly used technique used in highway safety studies to increase consistency between accident data from different States is to limit the analysis to "tow-away" accidents (i.e., accidents in which one or more of the involved vehicles had to be towed from the scene.) However, this alternative was not possible in the present study because none of the accident files provided by the three participating States included either a tow-away code or a dollar amount of property damage in their accident data files. (In Michigan, the master accident file created by the State police department includes a tow-away code, but this code is not included in the subset of the master accident file that is intended to be linked to geometric data.) Thus, it is likely, but not proven, that PDO accident reporting levels are lower in California than in Illinois and Michigan. Furthermore, there is no formal method to adjust the data for these differences because of the lack of a tow-away criterion or a property damage amount.

3. Accident Type Distribution

Tables 93, 94, and 95 show the percentage distribution of accident types by highway class in California, Illinois, and Michigan, respectively, using the accident type classifications presented above. These tables are based solely on the accident frequencies for the specific States, highway classes, and accident types, except for single-vehicle noncollision accidents in Michigan. The accident data available from Michigan were not sufficient to classify single-vehicle noncollision accidents into the three subclasses shown in the table: run-off-road, overturned in road, and other noncollision. Therefore, the relative proportions of these subcategories of noncollision accidents were estimated from the California and Illinois data.

Tables 93, 94, and 95 illustrate that the various highway classes have distinctly different patterns of accident types. For example, the percentage of single-vehicle noncollision accidents (which have the highest probability of producing a hazmat release if an accident occurs) shown in table 96 is about twice as high on rural highways as on urban highways.

Table 93. Truck accident type distribution on California State highways, 1985-1987.

Highway class: Area type	Highway class: Roadway type	Percent of accident involvements: Single-vehicle noncollision accidents: Run-off road	Overturned	Other	Single-vehicle collision accidents: Coll. w/ parked vehicle	Coll. w/ train	Coll. w/ nonmotorist[a]	Coll. w/ fixed object	Other collision	Multiple-vehicle collision accidents: Collision w/passenger car	Coll. w/truck	Coll. w/other vehicle
Rural	Two-lane	4.5	6.6	4.4	2.4	0.0	0.6	7.0	5.7	29.8	26.6	12.4
Rural	Multilane undivided	3.6	7.5	3.9	4.3	0.0	0.4	7.5	5.7	27.4	26.1	13.7
Rural	Multilane divided	3.6	4.0	3.8	3.9	0.0	0.2	6.1	4.7	33.4	26.4	13.8
Rural	Freeway	3.5	3.3	3.8	3.8	0.0	0.4	7.4	5.0	31.3	22.3	19.4
Rural	TOTAL	3.9	5.1	4.1	3.2	0.0	0.5	7.1	5.3	30.6	24.9	15.3
Urban	Two-lane	1.5	2.6	3.4	3.6	0.0	0.3	5.1	3.9	39.6	30.7	9.3
Urban	Multilane undivided	0.2	0.6	2.6	8.5	0.0	0.8	5.1	4.0	41.3	30.1	6.9
Urban	Multilane divided	0.8	1.3	2.4	7.0	0.0	0.6	5.7	3.8	43.7	28.1	6.6
Urban	One-way street	0.0	2.2	0.9	9.4	0.0	1.3	6.3	2.2	45.7	27.4	4.5
Urban	Freeway	0.6	1.0	1.3	1.9	0.0	0.2	3.2	1.7	50.6	25.0	13.9
Urban	TOTAL	0.6	1.1	1.6	3.1	0.0	0.3	3.8	2.2	48.6	26.4	12.3
TOTAL		1.6	2.3	2.3	3.1	0.0	0.4	4.7	3.1	43.4	26.0	13.1

[a] Nonmotorists include animals, pedestrians, and bicycles.

Table 94. Truck accident type distribution on Illinois State highways, 1986-1987

Highway class: Area type	Highway class: Roadway type	Single-vehicle noncollision accidents: Run-off road	Single-vehicle noncollision accidents: Overturned	Single-vehicle noncollision accidents: Other	Single-vehicle collision accidents: Coll. w/ parked vehicle	Single-vehicle collision accidents: Coll. w/ train	Single-vehicle collision accidents: Coll. w/ nonmotorist[a]	Single-vehicle collision accidents: Coll. w/ fixed object	Single-vehicle collision accidents: Other collision	Multiple-vehicle collision accidents: Collision w/passenger car	Multiple-vehicle collision accidents: Coll. w/truck	Multiple-vehicle collision accidents: Coll. w/other vehicle
		Percent of accident involvements										
Rural	Two lane	7.4	0.9	1.3	0.04	0.04	4.8	7.3	1.0	62.5	10.5	4.2
Rural	Multilane undivided	5.6	0.9	2.4	0.0	0.0	4.3	9.3	0.2	65.3	8.6	3.4
Rural	Multilane divided	5.2	0.0	0.9	0.0	0.4	3.5	7.4	0.0	69.3	6.9	6.5
Rural	Freeway	16.8	0.8	2.9	0.1	0.0	6.9	12.4	1.1	42.3	15.1	1.6
Rural	TOTAL	8.8	0.9	1.6	0.04	0.04	5.1	8.3	1.0	59.4	11.1	3.7
Urban	Two-lane	1.5	0.6	1.3	0.1	0.1	1.3	8.5	0.8	69.2	6.9	17.4
Urban	Multilane undivided	1.1	0.3	1.0	0.1	0.1	0.8	6.7	0.8	71.5	7.4	10.4
Urban	Multilane divided	0.5	0.4	0.6	0.1	0.0	0.7	5.5	0.8	73.9	6.6	11.0
Urban	One-way street	1.0	0.4	0.0	0.1	0.0	0.9	8.0	0.7	75.4	5.0	8.6
Urban	Freeway	1.6	0.3	1.0	0.0	0.0	0.6	4.4	1.5	72.5	14.6	3.6
Urban	TOTAL	1.2	0.3	0.9	0.1	0.03	0.8	5.8	1.1	72.1	9.5	8.3
TOTAL		2.8	0.4	1.0	0.1	0.03	1.7	6.3	1.0	69.5	9.8	7.3

[a] Nonmotorists include animals, pedestrians, and bicycles.

Table 95. Truck accident type distribution on Michigan State highways, 1985-1987

Highway class		Percent of accident involvements										
		Single-vehicle noncollision accidents[a]			Single-vehicle collision accidents					Multiple-vehicle collision accidents		
Area type	Roadway type	Run-off road	Overturned	Other	Coll. w/ parked vehicle	Coll. w/ train	Coll. w/ nonmotorist[b]	Coll. w/ fixed object	Other collision	Collision w/passenger car	Coll. w/truck	Coll. w/other vehicle
Rural	Two-lane	3.5	1.8	1.4	1.7	0.1	10.5	8.1	0.4	40.8	23.7	8.1
Rural	Multilane undivided	1.4	0.9	0.8	2.1	0.2	5.5	8.9	0.3	51.0	21.1	7.9
Rural	Multilane divided	2.0	0.6	0.8	0.7	0.0	3.1	4.1	0.2	57.3	24.2	7.1
Rural	Freeway	7.9	2.4	3.4	2.8	0.0	8.3	14.0	0.7	35.7	21.2	3.6
Rural	TOTAL	4.6	1.8	2.0	1.9	0.04	8.2	9.5	0.5	42.4	22.8	6.3
Urban	Two-lane	1.3	2.1	0.6	2.2	0.1	7.1	7.8	0.4	43.7	27.3	7.4
Urban	Multilane undivided	0.3	0.2	0.8	2.9	0.0	1.6	4.9	0.2	56.0	22.1	10.9
Urban	Multilane divided	0.3	0.3	0.5	2.1	0.01	0.3	3.2	0.2	59.1	21.8	12.2
Urban	One-way street	0.6	0.8	0.2	1.1	0.0	0.2	5.6	0.1	59.6	19.1	12.7
Urban	Freeway	1.8	1.3	2.1	0.8	0.0	1.1	6.8	0.6	57.6	22.7	5.4
Urban	TOTAL	1.0	1.0	1.1	1.7	0.01	1.9	5.6	0.4	55.6	22.9	8.8
TOTAL		2.1	1.2	1.4	1.7	0.02	3.7	6.8	0.4	51.7	22.8	8.1

[a] Relative proportions of single-vehicle noncollision accident types estimated from California and Illinois data.

[b] Nonmotorists include animals, pedestrians, and bicycles.

Table 96. Percentage of single-vehicle noncollision accidents by State and combined.

Highway class		Percent single-vehicle noncollision accidents			
Area type	Roadway type	California	Illinois	Michigan	Combined
Rural	Two-lane	15.5	9.7	6.7	11.1
Rural	Multilane undivided	15.0	8.8	3.1	10.2
Rural	Multilane divided	11.4	6.1	3.4	7.2
Rural	Freeway	10.6	20.5	13.7	12.9
Rural	TOTAL	13.1	14.3	8.3	11.2
Urban	Two-lane	7.5	3.3	4.1	4.3
Urban	Multilane undivided	3.4	2.3	1.4	1.7
Urban	Multilane divided	4.5	1.4	1.1	2.1
Urban	One-way street	3.1	1.4	1.6	1.6
Urban	Freeway	2.9	2.9	5.2	3.3
Urban	TOTAL	3.3	2.4	3.1	3.0
TOTAL		6.1	4.2	4.7	5.2

On rural highways, the percentage of single-vehicle noncollision accidents is higher for two-lane highways and freeways than for multilane nonfreeways. In urban areas, two-lane highways generally have a higher percentage of single-vehicle noncollision accidents than other highway classes.

4. Probability of Release Given an Accident

The analysis of the FHWA Motor Carrier Accident Reports presented in section V of this report shows the probability of a hazmat release given an accident involving a hazmat carrying truck varies with accident type. Table 97, which summarizes the results given earlier in the report in table 46, shows that the highest release probabilities are found for collisions with trains and single-vehicle run-off-road and overturning accidents and the lowest probabilities are found for multiple-vehicle collisions. The distribution of accident types by highway class in tables 93, 94, and 95, and the release probabilities for different accident types in table 97 can be multiplied together to estimate the average release probability for accidents on each highway class. The release probability for a particular highway class is computed in accordance with equation (23) as the sum for all accident types of the proportion of each type of accident times the probability of release given an accident for that accident type.

Table 97. Probability of release given that an accident has occurred as a function of accident type.

Accident type	Probability of release[a]
SINGLE-VEHICLE NONCOLLISION ACCIDENTS	
Run-off-road	0.331
Overturned (in road)	0.375
Other noncollision	0.169
SINGLE-VEHICLE COLLISION ACCIDENTS	
Collision with parked vehicle	0.031
Collision with train	0.455
Collision with nonmotorist	0.015
Collision with fixed object	0.012
Other collision	0.059
MULTIPLE-VEHICLE COLLISION ACCIDENTS	
Collision with passenger car	0.035
Collision with truck	0.094
Collision with other vehicle	0.037

[a] Based on data in table 46.

For example, the probability of release given an accident for rural two-lane highways in California, given as 0.100 in table 98, is obtained by multiplying each element of the first row of table 93 by the corresponding element in table 97 and summing the individual products. These release probabilities by highway class are shown in table 98.

Initially, we were concerned that the release probabilities in yable 98 might be substantially different if they were based on the accident type distribution for combination trucks only rather than the accident type distribution for all commercial vehicles. However, a supplementary analysis was performed and only minor variations in the values in table 98 were found for combination trucks.

Motor carrier accidents reported to FHWA, which form the basis for table 97, have a property damage threshold of $2,400, which is 5 to 10 times higher than the thresholds used by the three States whose data was used in the study. In addition to the difference in reporting thresholds, it is also known that there is substantial underreporting of motor carrier accidents to FHWA because of the self-reporting nature of the system (see discussion in section IV of this report). However, the available data are not sufficient to adjust for this difference in reporting threshold.

Table 98. Probability of hazmat release given that an accident has occurred.

Highway class		Probability of hazmat release given an accident			
Area type	Roadway type	California	Illinois	Michigan	Weighted average[a]
Rural	Two-lane	0.100	0.074	0.073	0.086
Rural	Multilane undivided	0.100	0.071	0.064	0.081
Rural	Multilane divided	0.087	0.064	0.062	0.082
Rural	Freeway	0.083	0.111	0.095	0.090
Urban	Two-lane	0.077	0.059	0.069	0.069
Urban	Multilane undivided	0.064	0.052	0.055	0.055
Urban	Multilane divided	0.068	0.048	0.058	0.062
Urban	One-way street	0.066	0.050	0.056	0.056
Urban	Freeway	0.062	0.055	0.067	0.062

[a] Weighted by veh-mi of truck travel.

F. Final Values for Use in Hazmat Routing Analyses

Table 99 presents the recommended default values for truck accident rate and probability of release given an accident by highway class. These final values are based on the combined three-State data given in tables 88 and 98, respectively. The final values of truck accident rate and release probability can be used to as default values for TAR and P(R|A) in equation (18) when local estimates are not available.

Table 99 also shows the estimated releasing accident rate, in releases per million veh-mi, which is the product of truck accident rate and probability of release. Thus, the releasing accident rate is the product of the TAR and P(R|A) in equation (19) and represents the best available estimate of the relative risk of hazmat releases during transportation on different highway classes.

Table 99. Default truck accident rates and release probability for use in hazmat routing analyses.

Area type	Roadway type	Truck accident rate (accidents per million veh-mi)	Probability of release given an accident	Releasing accident rate (releases per million veh-mi)
Rural	Two-lane	2.19	0.086	0.19
Rural	Multilane undivided	4.49	0.081	0.36
Rural	Multilane divided	2.15	0.082	0.18
Rural	Freeway	0.64	0.090	0.06
Urban	Two-lane	8.66	0.069	0.60
Urban	Multilane undivided	13.92	0.055	0.77
Urban	Multilane divided	12.47	0.062	0.77
Urban	One-way street	9.70	0.056	0.54
Urban	Freeway	2.18	0.062	0.14

APPENDIX B

EXAMPLE OF REVISED RISK ASSESSMENT PROCEDURES FOR HAZARDOUS MATERIALS ROUTING ANALYSES

This appendix presents two numerical examples of the calculations to illustrate the revised risk assessment procedures for hazmat routing analyses presented in section VI-B of this report. The first example shows how a State would use truck accident rates and release probabilities based on their own data. The second example illustrates use of the default values of truck accident rates and release probabilities developed in appendix A of this report. These examples are not intended to illustrate all aspects of hazmat routing analyses, but do illustrate the revised procedures developed in this report.

Both examples addresses the relative risks of hazardous shipments on the simple highway network shown in figure 19. Hazmat shipments must move from Point 1 to Point 5 by either Route A or Route B, which are, respectively, 16.5 and 11 mi (26.5 and 17.7 km) long. Route A is composed of three segments designated 1-2, 2-3, and 3-5, while Route B is composed of two segments designated 1-4 and 4-5. Route A has a substantial proportion of its length on non-access-controlled facilities (two-lane and multilane divided highways), while Route B is entirely on freeways. Route B is shorter than Route A, but has nearly half its length in an urban area with high population density. Route A is longer, but is predominantly rural. The numerical examples address the relative risks of hazmat transportation based on differing assumptions concerning the truck accident rates and volumes on the alternative routes.

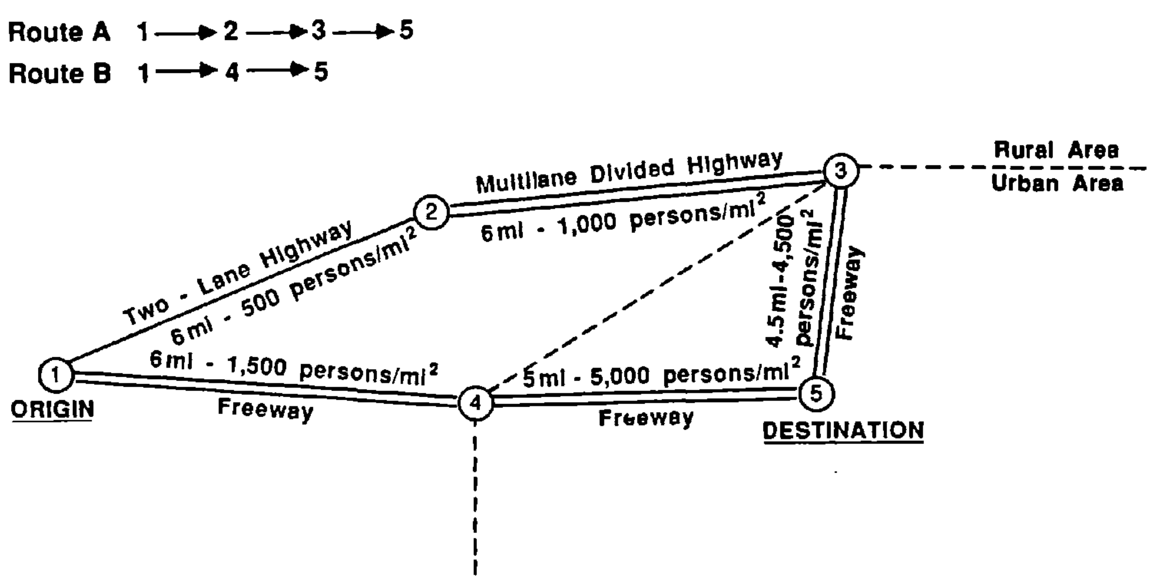

Figure 19. Highway network considered in numerical examples.

A. Example 1 -- Use of an Agency's Own Data

Example 1 involves a State highway agency that has used its own truck accident, truck volume, and geometric data to develop locally applicable values for truck accident rates and release probabilities using the procedure presented in appendix A of this report. For illustrative purposes, the California truck accident rates presented in table 85 and the California release probabilities presented in table 98 will be used in this example.

Table 100 presents the basic State truck accident data for each route segment and the application of the Chi-squared (χ^2) test to determine whether the expected truck accident rate or the site-specific accident rate should be used. For each route segment, the expected number of truck accidents in 3 years (A_e) is compared to the actual number of truck accidents observed during that same length of time. For route segments 1-2, 2-3, 3-5, and 1-4, the calculated value of χ^2 is less than 4.0, indicating that the State's estimate of the expected truck accident rate should be used in preference to the site-specific accident data. The use of the site-specific accident data would be misleading in these cases since there is no evidence that their deviations from the expected values are not just random. Route segment 4-5, however, was expected to experience 43.5 accidents in 3 years, but 65 accidents actually occurred. In this case, the computed value of χ^2 is 10.62, which is substantially greater than 4.0 and is highly statistically significant. For this segment, the State should use the site-specific accident rate of 2.37 accidents per million veh-mi (1.47 accidents per million veh-km) computed from equation (16), rather than the expected value of 1.59 accidents per million veh-mi (0.99 accidents per million veh-mi).

Table 101 illustrates the application of the revised FHWA risk assessment method based on equations (13) and (17). Accident probabilities for each route segment in the revised method are determined as the product of the expected State truck accident rates developed in table 100, the release probabilities from table 98, and the route segment lengths. The accident consequences are represented by the number of persons potentially exposed to hazmat releases per unit length calculated from the population density along the route segment and the impact zone width. In this case, an impact zone width of 0.5 mi (0.8 km) on either side of the roadway was selected. This impact zone width is appropriate for most of the materials shown in table 79.

The population risk for each route segment in table 101 is computed as the product of the accident probability and the number of persons exposed per unit length. The total population risk for each route is the summation of the risks for each of the individual segments that make up the route. The results shown in table 101 indicate that Route A involves slightly less risk than Route B. Route A would be the preferred route for hazmat shipments unless there are qualitative or subjective factors present that favor Route B.

Table 100. Comparison of truck accident rates using Chi-squared test -- Example 1

(1) Route	(2) Route segment	(3) Area type	(4) Roadway type	(5) Expected truck accident rate (accidents per million veh-mi)[a]	(6) Truck ADT (veh/day)	(7) length (mi)	(8) Expected number of truck accidents in 3 years[b] (A_e)	(9) Observed number of truck accidents in 3 years (A_o)	(10) Chi-squared statistic[c] (X^2)	(11) $X^2 > 4$?	(12) Truck accident rate for use in risk assessment (accidents per million veh-mi)
A	1-2	Rural	Two-lane	1.73	500	6.0	5.7	7	0.30	No	1.73
	2-3	Rural	Multilane divided	1.23	1,000	6.0	8.1	5	1.19	No	1.23
	3-5	Urban	Freeway	1.59	4,500	4.5	35.3	44	2.14	No	1.59
B	1-4	Rural	Freeway	0.53	1,500	6.0	5.2	9	2.77	No	0.53
	4-5	Urban	Freeway	1.59	5,000	5.0	43.5	65	10.62	Yes	2.37[d]

[a] From table 85.
[b] From equation (14).
[c] From equation (15).
[d] From equation (16).

Table 101. Risk assessment for hazmat routing using revised FHWA method -- Example 1

(1) Route	(2) Route segment	(3) Truck accident rate (accidents per million veh-mi)[a]	(4) Probability of release given an accident[b]	(5) Length (mi)	(6) Release probability[c]	(7) Population density (persons/mi^2)	(8) Impact zone width[d] (mi)	(9) Total persons exposed[e]	(10) Persons exposed per mi[f]	(11) Population risk[g]
A	1-2	1.73	0.100	6.0	1.038	800	0.5	4,800	800	830
	2-3	1.23	0.100	6.0	0.738	1,000	0.5	6,000	1,000	738
	3-5	1.59	0.062	4.5	0.444	5,000	0.5	20,000	5,000	2,218
										3,786
B	1-4	0.53	0.083	6.0	0.264	1,000	0.5	7,000	1,000	264
	4-5	2.37	0.062	5.0	0.735	5,000	0.5	20,000	5,000	3,674
										3,938

ROUTE A INVOLVES LESS RISK THAN ROUTE B

[a] From table 100.
[b] From table 98.
[c] Calculated as (3) x (4) x (5) from equation (13).
[d] From table 79.
[e] Calculated as (7) x (5) x (8) x 2.
[f] Calculated as (9)/(5).
[g] Calculated as (6) x (10) from equation (17).

B. Example 2 -- Use of Default Accident Rates

Example 2 addresses the same highway network used in the first example, with slight changes to the truck volumes and accident experience on some of the route segments. This second example illustrates the use of the default truck accident rates and release probabilities in table 99.

Table 102 presents the basic accident data for each route segment and the application of the Chi-squared (χ^2) test. The calculated values of χ^2 for route segments 2-3, 3-5, and 1-4 are less than 4.0, as in the first example, indicating that the default truck accident rate should be used in preference to the site-specific accident rate. As in the first example, the calculated value of χ^2 for route segment 4-5 is greater than 4.0, indicating that the site-specific accident rate should be used in preference to the default value.

Route segment 1-2 in table 102 presents an important exception to the Chi-squared test. This route segment is expected to experience only 2.9 truck accidents in a 3-year period. The Chi-squared test is not applicable when the expected number of truck accidents (A_e) is less than 5 and an alternative test based on the Poisson distribution should be employed. Interpolation in table 83 shows that the critical value of the Poisson distribution is 6.8 accidents when $A_e = 2.9$. Since this route segment experienced more than this critical number of accidents in 3 years, the site-specific accident rate, computed in accordance with equation (16), has been used in preference to the default value.

Table 103 illustrates the application of the revised FHWA risk assessment procedure to the data for this second example. These calculations are entirely analogous to those for the first example in table 101. The results show that, for the conditions in the second example, Route B involves slightly less risk than Route A. Route B would be the preferred route for hazmat shipments unless there are qualitative or subjective factors that favor Route A.

C. Summary

The examples illustrate that the revised FHWA risk assessment procedure presented in this report is equally applicable to routing decisions based on a highway agency's own truck accident data and decisions based on the default values of truck accident rate and release probability presented in this report. The use of truck accident rates based on an agency's own data is generally preferable, because these values will be most suited to local conditions.

The examples also illustrate the key role of the Chi-squared test in the decision to use either the default value of truck accident rate or the truck accident rate based on site-specific data for any given route segment. Finally, the second example illustrates the special case where the expected number of truck accidents is less than 5; in this case, a test based on the Poisson distribution should be used in place of the Chi-squared test.

Table 102. Comparison of truck accident rates using Chi-squared test -- Example 2

(1) Route	(2) Route segment	(3) Area type	(4) Roadway type	(5) Expected truck accident rate (accidents per million veh-mi)[a]	(6) Truck ADT (veh/day)	(7) length (mi)	(8) Expected number of truck accidents in 3 years[b] (A_e)	(9) Observed number of truck accidents in 3 years (A_o)	(10) Chi-squared statistic[c] (X^2)	(11) $X^2 > 4$?	(12) Truck accident rate for use in risk assessment (accidents per million veh-mi)
A	1-2	Rural	Two-lane	2.19	200	6.0	2.9	8	d	Yes[d]	6.09[e]
	2-3	Rural	Multilane divided	2.15	1,000	6.0	14.1	9	1.84	No	2.15
	3-5	Urban	Freeway	2.18	4,500	4.5	48.3	55	0.93	No	2.18
B	1-4	Rural	Freeway	0.64	1,500	6.0	6.3	9	1.16	No	0.64
	4-5	Urban	Freeway	2.18	5,000	5.0	59.7	76	4.45	Yes	2.77[e]

[a] From table 99.
[b] From equation (14).
[c] From equation (15).
[d] Chi-squared test is not applicable because $A_e < 5$. Therefore, A_o is compared to a critical value of the Poisson distribution (6.8), as interpolated from table 83.
[e] From equation (16).

Table 103. Risk assessment for hazmat routing using revised FHWA method -- Example 2

(1) Route	(2) Route segment	(3) Truck accident rate (accidents per million veh-mi)[a]	(4) Probability of release given an accident[b]	(5) Length (mi)	(6) Release probability[c]	(7) Population density (persons/mi^2)	(8) Impact zone width[d] (mi)	(9) Total persons exposed[e]	(10) Persons exposed per mi[f]	(11) Population risk[g]
A	1-2	2.19	0.086	6.0	1.130	800	0.5	4,800	800	904
	2-3	2.15	0.082	6.0	1.058	1,000	0.5	6,000	1,000	1,058
	3-5	2.18	0.062	4.0	0.608	5,000	0.5	20,000	5,000	3,041
										5,003
B	1-4	0.64	0.090	6.0	0.346	1,000	0.5	7,000	1,000	346
	4-5	2.77	0.062	5.0	0.858	5,000	0.5	20,000	5,000	4,290
										4,636

ROUTE B INVOLVES LESS RISK THAN ROUTE A

[a] From table 102.
[b] From table 99.
[c] Calculated as (3) x (4) x (5) from equation (13).
[d] From table 79.
[e] Calculated as (7) x (5) x (8) x 2.
[f] Calculated as (9)/(5).
[g] Calculated as (6) x (10) from equation (17).

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*U.S.GOVERNMENT PRINTING OFFICE:1990-717-000:27146