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Protective Systems for Spills of Hazardous Materials,

Volume I: Final Report

Research and Development
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FOREWORD

The highway system may be a source of a wide variety of pollutants to nearby surface and groundwater. The effects of highways on water resources can have an important role in the planning, design, construction, and operation of a transportation system. The Federal Highway Administration and State highway agencies have approached the problem in a multi-phase research effort including studies to:

Phase 1 - Identify and quantify the constituents of highway runoff.
Phase 2 - Identify the sources and migration paths of these pollutants from the highways to the receiving waters.
Phase 3 - Analyze the effects of these pollutants in the receiving waters.
Phase 4 - Develop the necessary abatement/treatment methodology for objectionable constituents.

This investigation was part of the Phase 4 effort. The emphasis is on evaluating the risks, preemptive preventive measures, and toxic material releases from accidents. Typically, the spill contaminants are not the usual constituents of highway runoff. They can occur nonpredictably for short periods and can give very high local impacts.

The final report of this investigation has two volumes: FHWA-RD-96-097 Volume I: Final Report and FHWA-RD-96-098 Volume II: Guidelines.

These publications will be of interest to engineers involved in highway water quality impacts to surface and groundwater and to highway safety specialists. Copies of these publications are being distributed to the Federal Highway Administration regional and division offices and to each State highway agency. Additional copies may be obtained from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161.

Charles J. Nemmers, P.E.
Director, Office of Engineering R&D

NOTICE

Technical Report Documentation Page

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16. Abstract

This investigation addressed the identification of potential risks from highway transportation of hazardous materials that would result in severe permanent, irreparable or catastrophic consequences, and the identification of practical and implementable physical protective systems to reduce accident incidents and/or mitigate consequences. The primary concern was to reduce or prevent contamination of surface or ground water resources from flows or other movements of materials from accidental spills of hazardous materials. The hazardous spill substances are likely to be directly toxic or indirectly result in reduced quality of receiving waters.

The results of this study are presented in two reports which are:

FHWA-RD-96-097, Protective Systems for Spills of Hazardous Materials, Volume I: Final Report

FHWA-RD-96-098, Protective Systems for Spills of Hazardous Materials, Volume II: Guidelines

This report developed a methodology using a State's panel to identify 11 generalized ranked extreme risk scenarios and identified protective systems for each. The report concludes that few physical protective systems are available to reduce risks associated with highway transportation of hazardous materials.

The companion report, (FHWA-RD-96-098) presents information on a number of protective systems that could be considered for a particular extreme-risk situation. That report does not attempt to make the decision to use or not to use these protective systems. It is not a design manual. The decision and design details remain at the discretion of the user.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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I. PROTECTIVE SYSTEMS FOR SPILLS OF HAZARDOUS MATERIALS ON THE HIGHWAY SYSTEMS

A. Introduction

Research was performed on the techniques and practices of mitigating potential extreme-risk situations that could occur during the transport of hazardous materials (hazmat) on our highway systems. This report represents the results of a comprehensive study undertaken to develop prioritized, extreme-risk scenarios; to develop a set of feasible, practical, and implementable protective systems; and to develop a manual to provide guidelines on the use and implementation of these protective systems.

1. Research overview

The specific objectives of this research study were:

- Identify potential and extreme-risk situations that develop when hazmat are spilled on the highway systems.
- Identify effective, practical, feasible, and implementable protective systems.
- Develop guidelines for implementing protective systems.

2. Scope

The scope of this research study was limited to materials spilled within the highway system. It focused on potential risks that could result in severe, long-term, permanent, irreparable, or catastrophic consequences, and existing technology and state-of-the-art knowledge for developing protective systems to mitigate these consequences. The protective systems within the scope of this study are systems that can be constructed or physically incorporated into a highway system or modifications of the system. Measures such as routing, response procedure, regulation, prohibition of shipments, and other regulatory and policy approaches to control hazardous material shipments are not within the scope of this study.

3. Specific project tasks

To accomplish the research objectives, four key tasks were performed:

- Developing or adapting risk assessment methodology that would provide a framework for any State to follow to conduct a route or site-specific risk analysis directly related to their particular needs, priorities, and policies.

- Developing and prioritizing general case scenarios of highway/receptor situations that could result in extreme conditions if a spill of hazardous materials occurred; i.e., a potentially catastrophic occurrence.
- Developing a set of protective systems keyed to the potentially catastrophic scenarios.
- Producing guidelines giving State highway agency personnel guidance on:
  - (a) The fact that potentially catastrophic situations exist within the elements of a highway system and that some potential situations can be mitigated by a protective system, particularly during construction or reconstruction of the highway.
  - (b) Evaluating the risk of potentially catastrophic situations.
  - (c) The type of protective systems to consider for incorporation into a highway system to lessen risks.

4. Research approach to the tasks

Early in the project, it was concluded that the concept of designing protective systems into highway systems specifically to prevent or mitigate hazardous material spillways is a new and unique concept. No literature exists that directly addresses this concept. Literature on systems that could be adapted to the concept, such as drainage containment systems, high-strength barrier rail, etc., was available, but first the catastrophic nature of spills had to be defined.

By its nature, a catastrophic occurrence resulting from the highway transportation of hazmat is a rare event. Not everyone agrees to a universal definition of "catastrophic occurrence." Catastrophic can mean many things to different people. Developing catastrophic scenarios that would be meaningful to the States and lead to concomitant, feasible, and practical protective systems that would be useful to the States and would have credibility with States' personnel was an early stumbling block. All sorts of catastrophic scenarios could be created, but would they be realistic or meaningful?

It was decided to contact all of the State highway agencies through the Federal Highway Administrations (FHWA) and form a project advisory panel of personnel from those States wishing to participate in the research. The panel would then be used to develop potentially catastrophic scenarios. It was a lengthy process but with this approach, there was assurance that the scenarios developed were real concerns of the States and not merely speculations of the researchers. The scenarios developed by use of the panel is documented in chapter IV. Eleven ranked catastrophic scenarios were developed.

The next task was to develop protective systems keyed to the scenarios that had been developed. These protective systems were to be feasible, practical, and implementable. In this age of modern technology, almost any system imaginable is feasible and implementable--given unlimited resources. Obviously States do not have unlimited resources; therefore, what is "practical" in this sense will ultimately be a State policy decision based on some sort of cost-effectiveness analysis. Once again, to come up with a range or a set of possible protective systems that would have credibility with States' personnel, the State panel was used to develop such a set. This ensured that the set would not be too far outside the range of what an individual State decisionmaker would consider practical or at least worth investigating by determining its cost-effectiveness. The development of the set of protective systems by the panel is documented in chapter V.

Finally, an attempt was made to obtain information on several protective systems relevant to site-specific, high-risk situations considered to be potentially catastrophic. Since the list of all possible site-specific and scenario-specific incidents could approach infinity, this was a formidable task. Also, specific, detailed operation and design details of all specific protective systems items and their adaptation (very few hardware items in the protective systems set were developed specifically for highway use) was clearly beyond the scope of the project and the expertise of the project staff. However, chapters VI and VII of this volume and Volume II: Guidelines were developed to give States' personnel insight into the characteristics, possible uses, and several examples of all types of protective systems in the set. Volume II: Guidelines provides greater detail and more in-depth information.

The information on protective systems is provided to suggest possible solutions to high-risk, potentially catastrophic scenarios. This information is included in a two volume report. This volume, Volume I, Final Report, is the research report. Volume II, guidelines, sets forth guidelines for States to use to help them determine if they have a hazardous materials problem and to determine when they should consider a physical, protective system to mitigate the problem. Neither this research report (volume I) nor the guidelines (volume II) will address design details. The design considerations will be left to the States' designers. Where sophisticated electronic or electrochemical detection equipment or communications equipment are concerned, a reputable manufacturer and/or supplier should be contacted for the latest state-of-the-art hardware. There is a need for future research and development of these systems.

5. Overview of the hazmat problem and risk analysis

As background for the potentially catastrophic scenarios and for protective systems, an overview of the current hazmat problem on U.S. highways and currently used risk analysis methodology to quantify the extent of risk from hazmat spills is presented in the next two chapters, followed by a chapter on the recommended risk model structure. Additional information of the use of the risk analysis methodology will be presented in volume II.

II. OVERVIEW OF THE CHARACTERISTICS OF ACCIDENTS AND INCIDENTS IN HIGHWAY TRANSPORTATION OF HAZARDOUS MATERIALS[1]

A. Accidents, Incidents, and Exposure

An understanding of the issues related to hazmat transportation requires an understanding and careful distinction between accident, incident, and exposure. This is particularly true when analyzing data to develop or use risk analysis models.

Accident data bases contain reports of traffic accidents obtained from police reports, motorist or motor carrier reports, or independent followup 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 in hazmat safety analyses are those that contain data on truck accidents, and the data can be used to determined whether or not the truck(s) involved in the accidents were carrying hazardous materials. It is also desirable to be able to determine whether a hazardous material release occurred in a particular accident.

Incident data bases (records of releases) contain reports of occurrences in which a hazardous material was unintentionally released. A highway-related hazardous materials incident is an unintentional release of a hazardous material during, or in connection with, its transportation by highway. The incidents of primary interest are releases of hazardous materials during their transportation by highway. Several types of on-highway incidents need to be considered: (1) release due to traffic accidents; (2) release due to valve or container leaks; and (3) release due to fires or explosions.

The U.S. Environmental Protection Agency (EPA) keeps detailed records of all hazardous material spills (incidents). Records from EPA's Region VII office in Kansas City, Missouri, show that 25 to 30 percent of all spills reported to EPA are on-highway incidents; i.e., occurring during transport. Off-highway incidents, spills in yards and terminals, etc., are not of concern in this study.

Figure 1 illustrates the overlapping nature of on-highway accident and incident occurrence. The figure shows that total highway trips or total highway vehicle-miles (veh-mi) (represented by block A) can be subdivided into three

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[1] This chapter including tables presents a summary of material and excerpts from reference 1

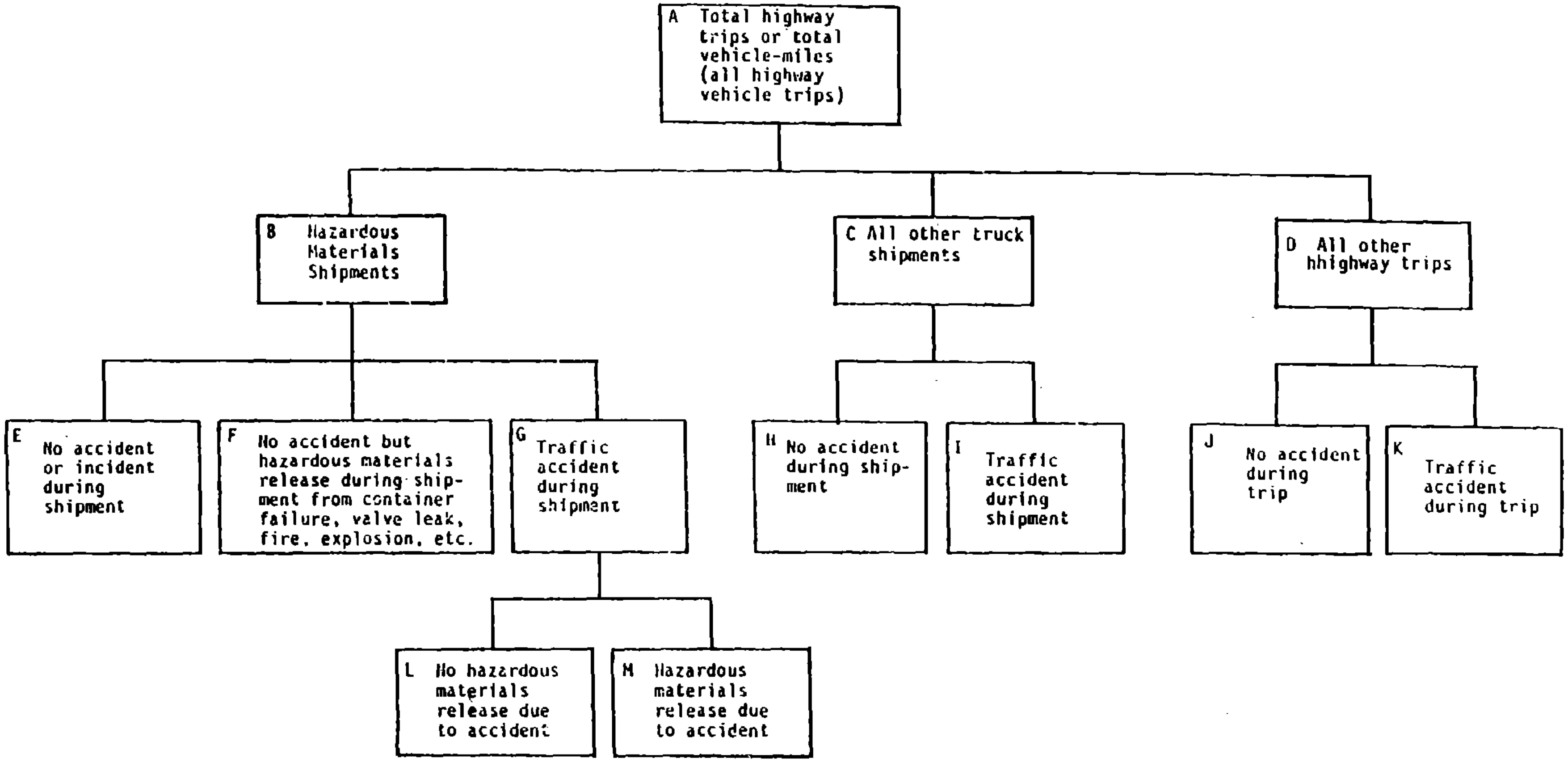

Figure 1. Relationships between accident, incident, and exposure data for on-highway events.(1)

categories:hazmat shipments--(B); other truck shipments involving similar vehicles that are not carrying hazmat--(C); and highway travel by vehicle types other than trucks--(D). Each shipment or trip may either involve a traffic accident or not; hazmat shipments can also involve an incident (i.e., a release) even if no accident occurs. Thus, as figure 1 illustrates, some incidents are not accidents--(F), some accidents are not incidents--(L), and some occurrences are both incidents and accidents--(M). Figure 2 presents a classification scheme that clearly distinguishes between hazmat accidents and incidents.

Accident and incident data are useful by themselves because they indicate the frequency with which particular events occur. However, the assessment of accident or incident risks require corresponding exposure data. Exposure is a measure of opportunities for accidents or incidents to occur, such as the number of hazardous materials shipments, tons of hazardous materials shipped, or vehicle-miles of hazmat shipments. The ideal situation would be to have the vehicle miles of hazmat shipments stratified by truck and/or hazardous material type, and highway type or even by segment type (curve, hill, exit ramp, etc.) within each highway type. Generally, exposure data is scarce or not available.

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

$$R = A/E \qquad (1)$$

where R represents some measure of risk (e.g., accidents per thousand veh-mi of hazmat carrying vehicles); A represents a frequency measure (e.g., number of hazmat vehicle accidents); and E represents an exposure measure (e.g., total hazmat veh-mi of travel). To be useful in establishing hazardous materials transportation policies, risk measures must be made very specific. An accident rate for a particular type of truck traveling on a particular type of road, or road segment such as an interstate off-ramp, can be obtained only if both the accident and exposure populations are stratified accordingly, as previously suggested as ideal. For example, if we wanted to obtain the risk of 9,000-gal (34,065-L) gasoline tank trucks exiting from an even elevated freeway ramp, we need to know the total number of 9,000-gal (34,065-L) trucks using the ramp during our analysis period, which must conform to the period for which we have accident data for the ramp. Both data sets should cover a sufficiently long period of time.

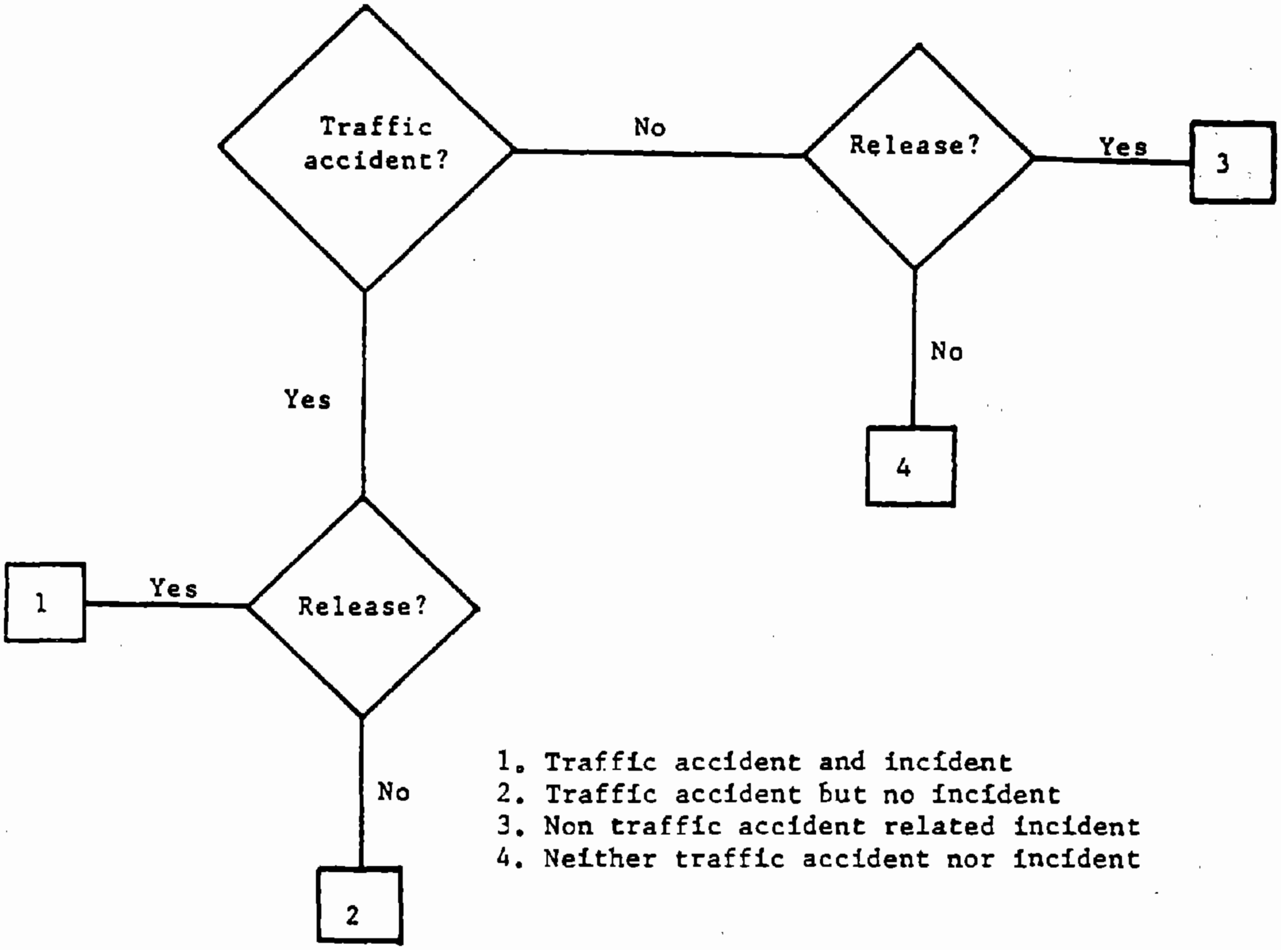

Figure 2. Classification scheme for on-highway events for trucks carrying hazardous materials.(1)

A major weakness of hazmat safety research, and truck safety research in general, is that valid exposure data corresponding to a particular accident data set is seldom available. Analysts usually make a number of assumptions and extrapolate exposure data as best they can from existing incident and accident data bases in the absence of exposure data. If States want to develop accurate, reliable risk models, they need to first have appropriate exposure data--data on how many hazmat trucks by type and by material travel on each type of highway, highway section, or highway segment on which they want accident and incident probabilities--a prime requirement for risk analysis. This fact cannot be stressed enough.

2. Hazmat incident analyses

Hazmat incidents in all modes, including highway transportation, are required by law to be reported to the U.S. Department of Transportation's Research and Special Programs Administration (RSPA) Hazardous Materials Incident Reporting System (HMIR) by all carriers engaged in interstate transportation.(3) RSPA receives nearly 5,000 reports of highway-related hazmat incidents each year. Carriers engaged solely in intrastate transportation are not required to report hazmat incidents to RSPA, and it is not clear how many intrastate incidents that occur that are not reported for this reason.

There is no minimum quantity of release or minimum property damage threshold for reporting hazmat incidents to RSPA. Any incident, no matter how small, is technically reportable if the hazmat escapes from its container. It is not necessary for the hazmat to escape from the vehicle. The only exception to this general rule is the release of small quantities of electric battery acid and certain paint products which were excluded from the reporting requirements in 1981.

The RSPA reporting requirements are in the process of being expanded to include situations involving hazmat in which a highway is closed for 1 hour or more or people are evacuated from the vicinity of a potential incident site even if no hazmat release occurs.(2) The proposed revision to the HMIR report form will also distinguish explicitly between incidents that occur en route during transportation and incidents that occur in terminal and loading areas. At present (1988), one has to deduce the distinction by the type of incident. In the RSPA data, it is not always possible to distinguish between on-highway and off-highway incidents. For the analysis shown in later tables, the following types of incidents were 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 were presumed to occur off the highway:

- Incidents involving loading or unloading.
- Incidents involving material dropped in handling.
- Incidents involving extreme puncture not caused by a traffic accident.

All other types of incidents, identifiable in the data base, were treated as "unknown."

The RSPA/HMIR data is based entirely on voluntary reporting by carriers. The voluntary nature of the system undoubtedly leads to underreporting of incidents, but the level of underreporting is uncertain. Further analysis of underreporting problems in the RSPA/HMIR is provided by previous FHWA studies.

3. Annual incident frequencies

Table 1 presents a summary of the hazmat incidents reported to RSPA during 1981 to 1985, inclusive. A total of 28,433 incidents were reported during this period. The table shows that major decreases in the frequency of reported hazmat incidents from 1981 to 1982 occurred. The decreases may have been caused by changes in reporting requirements.

It should also be noted that only a portion of the incidents in table 1 occurred during transportation on public highways. Because it is not always possible to distinguish clearly between on-highway and off-highway incidents in the RSPA, "unknown" category in table 1 has been included.

By making assumptions as to which types of accidents are on-highway or off-highway, table 1 shows that about 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

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[2] Unless otherwise noted, tables are from reference 1.

Table 1. Annual hazmat incident frequencies by type of location, 1981-1985.(1)

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	5,695	4,870	4,502	4,737	28,433 (100.0%)

the remaining 13 percent of incidents could not be determined. Subsequent analyses and the numbers presented utilize only the 13,547 incidents that one can be reasonably sure did occur on public highways.

4. Causes of hazmat incidents

Table 2 presents the distribution of hazmat incidents by the type of failure that occurred. For all reported incidents, the major failure types (second half of table) are body or tank failures (20 percent), valve or fitting failures (24 percent), and cargo shifting (37 percent).

Traffic accidents were found to be the cause of approximately 11 percent of all hazmat incidents. This is a higher portion of traffic accidents than reported in previous studies because off-highway incidents have been excluded from the data.(3,4,5,6)

Severe incidents are of greatest concern in the management of hazardous materials transportation safety. However, there is no commonly accepted definition of what constitutes a severe incident. In this section, those categories available from the data base and often used or associated with common definitions or many people's concept of "severe" were examined here as presented in table 2. Obtaining an accurate account of the quantities of released materials from the data base is questionable; thus, no attempt was made to quantify a potentially severe or catastrophic release by the quantity of release. Table 2 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 materials in traffic accidents can

Table 2. Distribution of on-highway hazmat incidents by failure type and incidents severity, 1981-1985.(1)

Failure Type	Death Only		Death or Injury		Death or Injury or Explosion		Death or Injury or Explosion or Fire	
	No.	%	No.	%	No.	%	No.	%
Traffic accident	32	(91.4)	107	(35.5)	112	(34.7)	188	(4.17)
Body or tank failure	0	(0.0)	37	(12.3)	38	(11.8)	40	(8.9)
Valve or fitting failure	0	(0.0)	86	(28.6)	88	(27.2)	101	(22.4)
Cargo shifting	0	(0.0)	39	(13.0)	44	(13.6)	52	(11.5)
Fumes or venting	0	(0.0)	2	(0.7)	2	(0.6)	2	(0.4)
Other	3	(8.6)	30	(10.0)	39	(12.1)	68	(15.1)
TOTAL	35		301		232		451	

Failure Type	Death or Injury or Explosion or Fire or Property Damage Over $100K		Death or Injury or Explosion or Fire or Property Damage Over $50K		Death or Injury or Explosion or Fire or Property Damage Over $10K		All Reported Incidents	
	No.	%	No.	%	No.	%	No.	%
Traffic accident	233	(46.4)	355	(56.1)	723	(68.1)	1,427	(10.8)
Body or tank failure	42	(8.4)	42	(6.6)	63	(5.9)	2,741	(20.2)
Valve or fitting failure	101	(20.1)	104	(16.4)	112	(10.5)	3,289	(24.3)
Cargo shifting	52	(10.4)	54	(8.5)	70	(6.6)	4,945	(36.5)
Fumes or venting	2	(0.4)	2	(0.3)	2	(0.2)	15	(0.1)
Other	72	(14.3)	76	(12.0)	92	(8.7)	1,100	(8.1)
TOTAL	502		633		1,062		13,547	

be clearly seen in table 2. 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 because of a release, over 90 percent (32 incidents) were caused by traffic accidents. Traffic accidents account for a much more significant part of the hazardous materials highway safety problem than is suggested by overall release statistics of 10.8 percent.

In the rest of the tables in this chapter, every incident has been defined as those that involve either: (1) a fatality or injury caused by the hazmat release (as separate from any accident-caused fatalities); (2) a property damage of $50,000 or more caused by the hazmat release; or (3) a fire or explosion.

5. Type of hazardous material involved

The previous study determined the distribution of the type of hazardous material released in hazmat incidents.(1) When 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). The predominant hazardous materials released are flammable and combustible liquids, such as gasoline (46 percent) 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.

The RSPA/HMIR data indicate that flammable and combustible liquids constitute 71 percent of the releases caused by traffic accidents, as opposed to 46 percent of all releases. By contrast, corrosive materials account for only 13 percent of the releases in traffic accidents, but 43 percent of the releases are 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.

The distribution of severe hazmat incidents by type of material released shows that about 55 percent of all severe incidents involve flammable and liquids, as compared to 46 percent of all incidents. Thus, flammable and combustible liquids are overrepresented in severe incidents as compared to total incidents; i.e., they tend to have more severe consequences. 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; i.e., their consequences tend to be less severe.

6. Vehicle and operational factors

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

7. Traffic accident analyses

The only nationwide source of truck accident data containing information on hazmat transportation is the Motor Carrier Accident Report data maintained by FHWA's Office of Motor Carriers (OMC), formerly the Bureau of Motor Carrier Safety.(7) This data base is valuable because it identifies whether or not each accident-involved truck was transporting hazardous materials and whether or not those hazardous materials were released. The OMC data can be used to compare the frequency and distribution of truck accidents that resulted in a hazmat release to all accidents involving hazmat-carrying trucks and truck accidents in general.

Two important disadvantages of this data base should be noted. First, while nationwide in scope, the data base does not include all truck accidents, but only those of regulated interstate motor carriers. Second, like the RSPA hazmat incident data, the OMC's accident data is dependent on voluntary reporting by carriers so there is likely to be underreporting of accidents. One previous study noted that the percentage of property-damage-only accidents in substantially smaller in the OMC data than in data on police-reported accidents from the National Accident Sampling System (NASS), indicating that minor accidents are probably not always reported to OMC.(1) The property damage threshold for reporting truck accidents to OMC was $2,000 for the entire period of data covered in this chapter. As of January 1, 1986, the reporting threshold has been raised to $4,200.(3)

The following sections present 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. All of the tables are based on less than 1 percent missing data unless otherwise noted.

8. Annual accident frequencies

Table 3 presents the annual accident frequencies reported to OMC for all truck accidents and for accidents involving hazmat-carrying trucks. Several accidents in the OMC file appear to have occurred in terminal areas or other off-highway sites and are not included in these tables.

Overall, hazmat-carrying trucks experienced approximately 5 percent of all truck accidents. This probably approximates the general proportion of trucks carrying hazardous materials, although there undoubtedly are some variations in accident rate between hazmat-carrying trucks and trucks in general.

Table 3 shows that approximately 15 percent of accidents involving trucks carrying hazardous materials result in a hazmat release. The authors believe that 15 percent is an upper limit for an overall mean value.(1) Previous studies showed higher percentages.(3,4,5,6) Twenty-nine percent had been used as somewhat of a "standard" for several years.(1) More detailed breakdowns are given in the next section.

9. Relationship to intersecting facilities

Table 4, which shows the distribution of OMC-reported truck accidents by their relationship to intersections, freeway ramps, and railroad-highway grade crossings, presents 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 out of 283 (4 percent) accidents at intersections involving hazmat-carrying trucks resulted in a release. Accidents involving hazmat-carrying trucks on freeway ramps are more likely to result in a release, with 22 percent releases for hazamt accidents on on-ramps and 26 percent releases for hazmat accidents on off-ramps. Railroad grade crossings have the highest likelihood of release when an accident occurs, with 10 of the 22 reported accidents (45 percent) resulting in a release. These figures are an example of the site-specific, State, or local data that a State would have to have for a detailed risk analysis.

10. Accident type

Table 5 presents the distribution of accident types for hazmat accidents and truck accidents in general. Multiple-vehicle collisions are the leading type of accidents for both vehicles carrying (74 percent) and not carrying (52 percent) hazardous materials. However, the leading accident types that result

Table 3. BMCS-reported truck accidents by year, 1981-1985.(1)

	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 release in hazmat accidents	(16.7)	(14.2)	(17.6)	(14.2)	(13.9)	(15.2)

Table 4. Distribution of BMCS-reported truck accidents by relationship to intersecting facilities, 1984-1985.(1)

	Accidents Involved Trucks Not Carrying Hazmat		Accidents Involving Trucks Carrying Hazmat						Probability of a Hazmat Release Given an Accident
			Combined		No Release		Hazmat Release		
Intersecting Fac.	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 5. Distribution of BMCS-reported truck accident by accident type.(1)

Accident Type Single-Vehicle Accidents	Accidents Involved Trucks Not Carrying Hazmat No.	%	Accidents Involving Trucks Carrying Hazmat: Combined No.	%	No Release No.	%	Hazmat Release No.	%	Probability of a Hazmat Release Given an Accident (%)
Noncollision									
Run-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	5,268	(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	(0.4)	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 non-collision	157	(0.2)	7	(0.2)	6	(0.2)	1	(0.2)	14.3
Collision									
With fixed object	7,774	(10.9)	241	(6.5)	210	(6.6)	31	(6.0)	12.9
With parked vehicle	6,591	(9.3)	254	(6.9)	246	(7.7)	8	(1.5)	3.1
With train	341	(0.4)	22	(0.6)	12	(0.4)	10	(1.9)	45.5
With non-motorist	1,241	(1.7)	66	(1.8)	65	(2.0)	1	(0.2)	1.5
Other	2,508	(3.5)	169	(4.6)	159	(5.0)	10	(1.9)	5.9
Multiple-Vehicle									
With passenger car	28,316	(39.8)	1,360	(36.7)	1,313	(41.3)	47	(9.0)	3.5
With truck	7,758	(10.9)	372	(10.0)	337	(10.6)	35	(6.7)	9.4
With other vehicle type									
TOTAL	71,149		3,703		3,183		520		14.0

in hazmat releases are single-vehicle overturning and run-off-road accidents, which together constitute 64 percent of releases. While multiple-vehicle collisions represent 47 percent ofthe accidents for trucks carrying hazardous materials, these accidents result in only 16 percent of all hazmat releases; thus they tend to be less severe. Single-vehicle collisions represent 53 percent of the accidents for trucks carrying hazardous materials, but result in 84 percent of all releases, so they tend to be more severe.

Accidents involving hazmat-carrying trucks are twice as likely than 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 more likely than 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 characteristics of tank trucks and represent the relatively larger use of tankers in hazmat trucking as compared to trucking in general.

11. <u>State accident data</u>

The OMC accident data base containing highway-related variables, including highway type (number of lanes, divided/undivided, access control) and area type (urban/rural), is generally inaccurate, incomplete, or unavailable. Therefore, alternative sources for these data elements in State accident data were investigated.

A review of a National Highway Transportation Safety Administration (NHTSA) publication, "State Accident Report Forms Catalogue 1985," indicates that police accident report forms of 15 States indicate whether or not hazmat-carrying vehicles were involved in a reported accident.(8) The States are Alabama, California, Florida, Illinois, Kansas, Louisiana, Maine, Minnesota, Missouri, New Hampshire, New York, Ohio, Pennsylvania, South Carolina, and Wyoming. In 13 of the 15 States, the police report forms clearly distinguish which of the accident-involved vehicles were carrying hazardous materials. It is possible to determine whether or not there was a hazmat release in only 3 of these 15 States (Louisiana, Missouri, and Wyoming). Supplementary analyses of hazmat accident characteristics were conducted with accident data from Missouri. All States should have this sort of data as as minimum to be able to do statewide risk analysis. The Missouri system, described below, would be worth investigating and possibly imitating.

12. 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. The data are used by the Missouri's Highway and Transportation Department and local agencies in the management of highway safety problems within the State. Since July 1, 1984, STARS has contained data identifying whether or not vehicles involved in an accident was carrying hazardous materials, what type of hazardous materials were carried, and whether or not a hazmat release occurred. Missouri experiences just over 200 accidents per year involving hazmat-carrying trucks.

Missouri's STARS database has the advantage over OMC's data since it contains all accidents investigated by police agencies in the State, not just those voluntarily reported by carriers. The STARS data also include accidents for all types of trucks and carriers, not just regulated interstate carriers. In addition, each accident in the data base has been investigated by a police officer, which provides greater consistency in reporting than the wide variety of individual motor carriers who report accidents to OMC. 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 OMC. Missouri's data may therefore 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. OMC 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.

13. Highway related factors

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

There are no variables coded into the Missouri accident data base that explicitly identify 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. It should be kept in mind that if such data was available it would enhance risk analysis on specific highways. Table 6 presents the distribution of the Missouri hazmat accident data by highway class.

The table 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 highest on U.S.-State routes and county roads (primarily rural) and lowest on city streets.

Table 7 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 when one looks at the distribution of hazmat accidents in Missouri by speed limit. The data shows that the probability of a hazmat release given an accident is highest on highways with speed limits of 45 mi/h (72.5 km/h) or more.

14. Conclusions from the study regarding hazmat incidents(1)

Existing accident and incident data bases provide insight into the nature of on-highway safety risks in hazmat transportation by highway. The following conclusions were drawn from analysis of these data bases:

(a) 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 were eliminated.

(b) About 90 percent of the deaths and 25 percent of the injuries were caused by hazmat releases due to traffic accidents.

Table 6. Distribution of police-reported hazmat accidents in Missouri by highway class, 1985-1986.(1)

	Accidents Involving Trucks Carrying Hazmat						Probability of a Hazmat Release Given an Accident
	Combined		No Release		Hazmat Release		
Highway Class	No.	%	No.	%	No.	%	(%)
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

Table 7. Distribution of police-reported hazmat accidents in Missouri by area type, 1985-1986.(1)

	Accidents Involving Trucks Carrying Hazmat						Probability of a Hazmat Release Given an Accident
	Combined		No Release		Hazmat Release		
Area Type	No.	%	No.	%	No.	%	(%)
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

(c) Between 35 and 68 percent of severe hazmat incidents are 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 (as defined in this chapter, table 2) than other causes.

(d) Approximately 13 to 15 percent of accidents involving hazmat-carrying trucks result in a hazmat release.

(e) 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).
- Freeway off-ramps (26 percent release probability).
- Freeway on-ramps (22 percent release probability).
- Overturning in a single-vehicle accident (38 percent release probability).
- Running off the road in a single-vehicle accident (33 percent release probability).
- Highways with speed limits of 45 mi/h (72.5 km/h) or more (18 percent release probability).
- Trucks transporting solids in bulk (30 percent release probability, based on 40 accidents).

(f) Lower than average probabilities of a hazmat release are found in traffic accidents involving:

- At-grade highway intersections (4 percent release probability).
- Truck collisions with parked vehicles (3 percent release probability).
- Truck collisions with pedestrians, bicyclists, and animals (2 percent release probability).
- Truck collisions with passenger cars (4 percent release probability).
- Truck collisions with other trucks (9 percent release probability).

(g) Most fatalities and injuries in accidents involving trucks carrying hazardous materials are due to the physical impact and not the properties of the hazardous materials being transported.

(h) 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 may be indicative of a major difference in tank truck exposure between hazmat and other trucking.

15. <u>Conclusion from the study regarding data sources</u>(1)

Many 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 material was 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 on average in only 15 percent of accidents and the probability of a release varies widely between accident types. A death could occur irrespective of the cargo type. Thus, accident report forms should also include a data element indicating whether or not a hazmat release occurred and the quantity or nature of the release.

Also, it would enhance risk assessment if a data element specifically identifying both the highway type in general and the specific segment type and/or highway element directly attributable to the accident. Accident locations must be capable of being associated with population exposure and sensitive environmental areas within appropriate impact distances, which are functions of the material properties and the quantity.

Finally, it should be stressed that corresponding exposure data is necessary if risk analysis is to be made more reliable; i.e., exposure data on what volumes and types of hazmat carrier traffic is using each highway and highway segment type, broken down by the truck type and size, hazmat type or class, and hazmat quantities. Only with these kinds of data bases can reliable values of absolute risk be determined.

III. REVIEW OF COMMON RISK PROCEDURES APPLICABLE TO HIGHWAY TRANSPORTATION[3]

A. Risk Assessment Methods

Risk analysis methods are developed to consider the effects of highway safety considerations in the management of hazmat transportation by highway. Analysts assess a risk to determine the extent of a problem or to determine if there is a problem. The process of deciding what to do about any problem is risk management. It involves a much broader array of knowledge and is aimed toward a decision about controlling the risk or mitigating the consequences. It must include the benefits (e.g., risk reduction) and costs of such control and mitigation within the proper budgetary and statutory framework for the decision.

Most analysts seek an elusive quantitative value commonly referred to as "absolute" risk where they can state emphatically that, for a given stretch of highway or highway element, there will be 1 death per year, or there is 1 chance in 100 that there will be 10 deaths in a given year or longer period, or the expected deaths per hazmat vehicle passage is 0.10×10^{-6}. All are examples of valid measures of risk. Most analyses are based on historical accident data. Critics point out that there are four things wrong with this approach:

- Adequate, reliable data is not generally available, particularly for specific locations or site-specific locations.
- Historical accident/incident data is a poor predictor of low-probability, high-consequence (LPHC) events--which most catastrophic events are.
- Past accident histories extrapolated into the future are not always accurate predictions of future accidents.
- There is an almost total void in our knowledge as to what a risk value means in terms of a threshold value where we should consider taking some remedial action or an upper limit value that flags a site or situation for immediate action; for example, how much is reduced risk worth per unit reduction?

Following this review of common models, the approach recommended by this guide will be presented in detail.

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[3] Parts of this chapter present a summary of material and excerpts from reference 1.

B. Overview of Risk Assessment Models

A classification of risk assessment models was developed in a National Cooperative Highway Research Program (NCHRP) document Synthesis of Highway Practice 103, "Risk Assessment Processes for Hazardous Materials Transportation."(9) Most of the material synthesized was taken from reference 10. Risk assessment models were classified into four types: enumerative indices, regression models, network and distribution models, and probabilistic models. Each of the four types of risk assessment models is reviewed below and the examples of each model includes all transportation modes--not just the highway mode.

1. Enumerative indices

Enumerative indices are risk assessment models based on a rating or scoring scheme. Two examples of enumerative index models are the Gabor and Griffith model and the Kansas State University (KSU) model.

The Gabor and Griffith model is based on counts of the number of chemical plants, storage facilities, and their proximity to population and transportation facilities.(11) The KSU model uses prepared tables to convert traffic counts, route mileage, placard counts, and the form of threat, to indices used to classify risks as low, medium, or high.(10) The same type of index is generated for a community's emergency response preparedness. By combining a community's risk with its preparedness, a "vulnerability" index is determined.

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 risk and/or vulnerability, but they do not help to identify particular locations, unusual situations of high risk, or specific means to reduce these risks. Thus, they are of little or no use in finding high risk situations or evaluating protective systems.

2. 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 Urbanek model, which was developed specifically to provide input to a routing model.(12,13) The accident probabilities determined from regression equations were multiplied by a consequence estimate, 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. If data is sparse, it can be aggregated for several sites. A weakness of regression models is that neither the model developer nor the model user typically has access to enough historical data on LPHC events to obtain a reliable model. Models based on aggregated data are questionable for site-specific use. Thus, their use for potentially catastrophic occurrences would be questionable.

3. 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, such as the Princeton and TSC models, use population density as a consequence measure.(14,15)

Because these models generally use national data bases, they primarily assess either national or regional transportation risks for a given mode of transportation or a given commodity class. One such distribution model, by Williams and Sheldon, uses a shortest path algorithm with weights for each link in the transportation network based on the product of accident probability and accident consequences.(16) These models are well suited for developing minimum risk routing procedures across regions but of little value for evaluating specific highway sections.

4. Probability risk assessment models

Probabilistic risk assessment models are based on the conditional probability of an incident and the magnitude of its consequences as the two principal components. Accident probabilities are usually calculated from historical accident data. Probability of a release, given an accident, depends on such things as the strength of the container, type and severity of accident and impact, etc., and requires additional data; e.g., the number of accidents of different types that result in releases. Conditional probability of an incident is the probability of a release, given that an accident has occurred. 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.(17) The Williams and Sheldon model, the Battelle models, and the University of Southern California models all use an expected value of risk, defined as the product of the conditional accident probability and the estimated magnitude of consequences:(16,18,19,20)

$$R = P(I/A) \times C, \qquad (2)$$

where:

R = risk;

$P(I/A)$ = probability of an incident (release) given an accident; and

C = consequences (usually number of persons exposed).

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 IRAS and Illinois models are examples of this type.(21,22) The NCHRP synthesis report classifies this approach as a "bottom-up" analysis because analysis starts with data at the finest level of detail available, and the data must be relatively complete.(9) 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, such as the Battelle models, use fault-free analysis to develop probabilities.(18,19) 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.(23) These models are theoretically sophisticated. Unfortunately, accurate, reliable data is not generally available; thus, the sophistication is usually lost through the use of questionable data and many assumptions.

C. Small Community Models

The KSU model approach is limited by the resources available to carry out the total process and the possible lack of sensitivity to specific problem areas.(10,24) However, the model does provide a community with a reasonable overview of its vulnerability to risks. If this vulnerability is high, then further studies should be conducted. Application of the model has been demonstrated to several small communities.(25)

A NCHRP report proposed a simplified approach to hazmat risk assessment based on a modification of the KSU model.(9) The 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.

D. 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).(10,24) Its greatest value is its inherent characteristic to serve small communities as an exercise in awareness to their hazardous materials problems. However, as part of a regional assessment of hazmat transportation by the Association of Bay Area Governments (ABAG) in the San Francisco Bay area, a modified KSU model was developed and used in hazmat routing studies.(27,28,29)

The following modifications to the KSU model were made by ABAG:(28)

- 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 are divided into subcorridors by ABAG: 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 the level of risk was not used; instead, maps which indicated relative risks throughout the community and which were color-coded as appropriate were used.

The last modification listed above, the mapping aspects, may be of value to the highway planner/designer. Highway planners and designers have always used maps indicating areas of high-cost right of way, sensitive neighborhoods and areas, and rough terrain to generally avoid. High-risk areas or areas of high consequence given a hazardous materials incidence, particularly those with catastrophic potential, could be mapped as access to avoid or where special attention such as a protective system would be necessary.

The modified model was demonstrated through application of hazmat routing in a suburban community (Union City, California) with a population of approximately 40,000.

E. Abkowitz Hazardous Waste Model

A risk assessment model was developed for highway shipment of hazardous wastes.(6) This model is intended for use by the U.S. Environmental Protection Agency (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 model considers the risk of three types of incidents: container failures caused by vehicle accidents; container failures en route because of 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, excluding 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 the model as the fraction of the total quantity of hazardous materials shipped that will be released. This model can be expressed as:

$$FR = FRPM(CT,RAD)*D + FRTP(CT) \qquad (3)$$

where:

FR = fraction released;

FRPM(CT,RAR) = expected fraction released per mi shipped for a specified container type (CT) and a specific highway type with releasing accident rate (RAR);

D = distance traveled (miles); and

FRTP(CT) = expected fraction released at terminal points.

Table 8 presents the expressions developed for FRPM(CT,RAR) and FRTP(CT).

Table 8. Estimates of fraction of hazardous materials released by container type.(30)

Container Class	Expected Fraction Released per Mile Shipped [FRPM(CT,RAR)]	Expected Fraction Released at Terminal Points [FRPT(CT)]
Cylinders	$1.3 \times 10^{-6} + 0.13$ RAR[1]	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^{-5}
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[2]	1.2×10^{-3}

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[1] RAR is the releasing accident rate per million veh-mi for a particular highway type.

[2] Estimates of the contribution of traffic accidents to the 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 developed in the following form:(5)

$$\mathrm{RAR(HT)} = \mathrm{AR(TH)} * \mathrm{P}\,(\mathrm{R}\,|\,\mathrm{A}) \qquad (4)$$

where:

AR(HT) = expected truck accident rates for highway type (HT); and

P(R|A) = conditional probability of a hazmat release given an accident.

Table 9 presents the accident rate data used in these estimates. The truck accident rate estimates for differing highway types in table 9 are those developed by a previous study by the same author.(6)

The probability of a hazmat release given an accident [P(R|A)] was determined indirectly. First, the study noted that 1982 data of the Federal Railroad Administration (FRA) indicates that in 601 train accidents, consisting of 2,770 cars carrying hazardous materials, 109 cars released hazardous materials.(30) Second, previous work indicated that tank trucks involved in accidents are 10 times more likely to spill than rail tank cars.(33) These two factors yield a probability of release estimate of 0.4 for tank trucks, which was adjusted downward to 0.2[4] to compensate for the higher

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[4] Note that this report does not recommend using this value, nor does it agree with the value in table 9.

Table 9. Accident rates resulting in release of hazardous materials by highway type.(30)

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 accident per million veh-mi)
Interstate (freeway)	0.65	0.20	0.13
U.S. and State (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

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 this 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.

F. Urbanek Model

The most widely used risk assessment model for highway transportation of hazardous materials is the Urbanek model. This model is the key element or basis of the FHWA routing method guidelines for hazardous materials that is discussed below.(13) The model was originally developed in research by Urbanek and Barber (Urbanek model).(12) It was then presented by Barber and Hildebrand in the form of a guidelines manual for direct application by users.(13)

The Urbanek model is intended to compare the risks involved in hazmat transportation on two or more selected alternative routes. In many cases, the alternative routes are not homogeneous in highway types, traffic volume, population density, or level of development; therefore, it is often 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 determining risk using the Urbanek model. These are to: (1) determine accident probability (includes use of an incident or release rate per accident); (2) determine accident consequence; and (3) calculate risk. Each of these steps is documented and critiqued below.

1. Determine accident probability

The probability of a hazmat accident is computed in the Urbanek model from the following equation:

$$P(A)_i = AR_i \times L_i \times FHZ \quad (5)$$

where:

$P(A)$ = probability of a hazardous material accident for route segment i;

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

L_i = length (mi) for route segment i; and FHZ=fraction of all accidents that involve a hazmat release.

The following critique will first consider equation (5) term by term and then examine the meaning of the probability expression as a whole.

The first term in equation (5) is the accident rate per veh-mi (AR_i) for the route segment in question. Since hazardous material release rates are not generally available for specific route segments and truck accident rates were thought to be similarly unavailable, the Urbanek model is based on the general accident rate for all vehicle types. The accident rate is expressed in units of accidents per veh-mi rather than the more conventional unit, accidents per million veh-mi, for computational convenience.

The FHWA routing guide urges the use of actual accident histories for the route segments in question whenever possible.(13) The use of actual accident data for this purpose is highly desirable because accident rates are known to vary widely from average or expected values, even on highways that are nominally similar in design. Accident predictive models are provided for use when actual accident data is not available. Accident predictive models are provided for three highway types. The models for freeways and two-lane highways are based on a California Department of Transportation study.(32) The model for urban arterials was based on a Purdue University study.(33) A number of other candidate predictive models were reviewed by the authors of the FHWA routing guide before making the choice to use these particular models. This author does not advocate the use of these predictive models. Any State should have, or be able to get, data that would be better than using these relatively old predictive models or develop their own predictive models based on State-specific, current conditions, and accident rates.

The second term in equation (5) 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 (over the total segment length) because of the difference in length alone, if the accident rates of the two segments are the same.

The third and final term in equation (5) is the fraction of all accidents that involve a hazmat release (FHZ). This fraction was estimated by Urbanek and Barber from available data. They examined 4.5 years of U.S. Department of Transportation RSPA hazmat incident data and found a total of 2,104 hazmat releases caused by traffic accidents. They also estimated that there were 93.2 million traffic accidents in the United States during the same period. Thus, the fraction of traffic accidents involving a hazmat release is estimated as:

$$\frac{2,104}{93,200,000} = 2.3 \times 10^{-5} \qquad (6)$$

It should be noted that this ratio makes no allowance for underreporting of hazmat releases in the RSPA data base. This author does <u>not</u> advocate the use of this value. Even if a State has no applicable data, we will supply a better default value or factor.

The probabilities of accidents determined from equation (5) must be carefully interpreted to avoid misleading conclusions. The inclusion of the factor FHZ gives equation (5) 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, a dimensional analysis of equation (5) indicates that what is actually determined is the probability of a hazmat release per trip over a route segment by all vehicles; i.e., any type of vehicle, passenger car, or truck, whether carrying hazardous materials or not.

Although equation (5) does not provide an absolute measure of the risk of a hazmat release, it does provide a valid, relative measure of the differences in risk between routes, if one accepts the premise that the risk of a hazmat release on a route segment is proportional to the risk of any traffic accident. The value of FHZ has no direct influence on the relative comparison between routes because FHZ is a constant factor multiplied directly into the accident probability for every route segment on all alternative routes and, therefore, it could be eliminated for relative risk studies.

The authors of the FHWA routing guide appear to have made the decision to base their risk assessment model on accidents for all vehicle types because of concerns over data availability at the time of their study (1979).(12,13) Truck accident data is available from virtually every State for specific route segments and truck accident rates, and patterns are likely to be closer to hazmat accident rates and patterns than data for accidents in general; however, no adequate predictive models for truck accidents were available in 1979.(12) The developers of subsequent risk assessment models have moved away from dependence on accident rates for all vehicle types combined. Abkowitz developed an approach based on truck accident rates.(4) 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 adequate data is available being used in any particular case.(36) These other risk assessment methods are discussed later in this section of the report.

2. Determine accident consequences

The Urbanek model (FHWA routing guide method) considers two types of consequences from an accident involving a release of hazardous materials. These are personal injury consequences and property damage consequences. Both consequences are compared between routes in a relative sense based on the population potentially exposed and the value of property potentially exposed to a hazmat release.

In practice, most models express the population consequences in number of persons potentially exposed--usually a maximum number under a worse-case scenario--using fixed distances based on an average "danger zone" distance from the highway. To use a model that predicts numbers killed, seriously injured, slightly injured, etc., is theoretically possible but extremely complex. One would have to have data on such a great number of material properties, site conditions, environmental, atmospheric and weather conditions, etc., and all possible, likely combinations that it would be far beyond the scope of the usual highway risk analysis based on data and expertise available to most State highway agencies. Considering the state of the art of current, readily available data, it would most likely be a theoretical exercise that would add little or nothing to the validity of the result.

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. Motorist population should be considered separately because in many cases (tunnels, cuts, traffic bottlenecks, etc.) they may be the most seriously affected and may be the most important factor in the final decision. The application of the model to residential populations is illustrated in the FHWA routing guide manual.(13) The four steps in evaluating of the exposed population are to (a) 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 shown in table 10; (b) determine what proportion of each census tract is located within the impact zone; (c) multiply the census tract population by the proportion of the census tract within the impact zone, (d) sum the exposed populations for all census tracts along the route segment. A worksheet for performing the calculations is provided by the FHWA routing guide manual.(13)

A similar approach is used for assessing of property damage consequences, which is considered to be an optimal component of the Urbanek model. The property damage consequences of a hazmat release are assumed to be proportional to the value of property adjacent to each roadway segment under consideration. (The Urbanek model considers only property adjacent to the roadway, not in the entire impact zone, for population risks defined above.) It is assumed that only property adjacent to the highway will be exposed to incident consequences such as fire, explosion, etc. Five land-use types are considered by the model: high-density residential, medium-density residential, low-density residential, commercial, and industrial. The steps in assessing the value of property exposed to a hazmat release are as follows:

- Determine lineal frontage for each land-use type.
- Estimate dollar value per lineal 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 routing guides manual.

Table 10. Potential impact areas for various classes of hazardous materials.(13)

Hazardous Material Classes	Potential Impact Zone
Combustible liquid (CL)	0.5 mi (0.8 km) all directions
Flammable liquid (FL)	0.5 mi (0.8 km) all directions
Flammable solid (FS)	0.5 mi (0.8 km) all directions
Oxidizer (OXI)	0.5 mi (0.8 km) all directions
Nonflammable compressed gas (NFG)	Downwind 1.3 mi (2.1 km) wide x 2 mi (3.2 km) long
Flammable compressed gas (FG)	0.5 mi (0.8 km) all directions
Poison (POI)	Downwind 0.2 mi (3.3 km) wide x 0.3 mi (0.5 km) long
Explosive (EXP)	0.5 mi (0.8 km) all directions
Corrosive (COR)	Downwind 0.5 mi (0.8 km) long x 0.7 mi (1.1 km) wide

3. Calculated risks

Risk is calculated in the Urbanek model as the product of the probability of a hazardous material accident and the population or property damage potentially exposed to hazardous materials.

The population risk is computed in the model as:

$$RPOP_i = P(A) \times POP_i \qquad (7)$$

where:

$RPOP_i$ = population risk along route segment i;

POP_i = number of persons <u>exposed</u> to hazardous materials along route segment i.

The result of the computation ($RPOP_i$) is intended to be a relative measure of the risk that personal injuries will result from a hazardous material release on a given route segment. It should be obvious that this approach inherently assumes that the number of people killed and/or seriously injured is directly proportional to the number exposed and is equal for all materials. In fact, dimensional analysis of equation (7) shows an error in this formulation that results from double counting of the length of the route segment (L_i). The increase in risk with increasing route segment length has already been accounted for by the L_i term in equation (5). However, the number of persons along a route segment (POP_i) also increases as the length of the route segment increases. A single hazmat release would expose only those people within the impact zone of the site where the release occurs, not everyone within the impact zone along the entire route segment. Thus, equation (7) should be reformulated as:

$$RPOP_i = P(A)_i \text{ x } (POP_i/L_i) \qquad (8)$$

The POP_j/L_i term in equation (8) represents the linear population density along the route segment in question and the likely number of people exposed in the vicinity of a particular incident.

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

$$RPD_i = P(A)_i \text{ x } PV_i \qquad (9)$$

where: RPD_i=property damage risk along route segment i; PV_i=property value along route segment i. The formulation of the property damage risk (RPD_i) in equation (9) suffers from the same problem as the population risk discussed above. Equation (9) should be reformulated as:

$$RPD_i = P(A) \text{ x } (PV_i/L_i) \qquad (10)$$

In equation (10), the term PV_i/L_i represents the average value of property per mile along the route segment and the likely value of the property exposed in the vicinity (impact area) of a particular incident.

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 Urbanek 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.

G. FHWA Routing Method

The heart of the FHWA routing method is the Urbanek risk assessment model, which was reviewed in the previous section. The FHWA routing method is

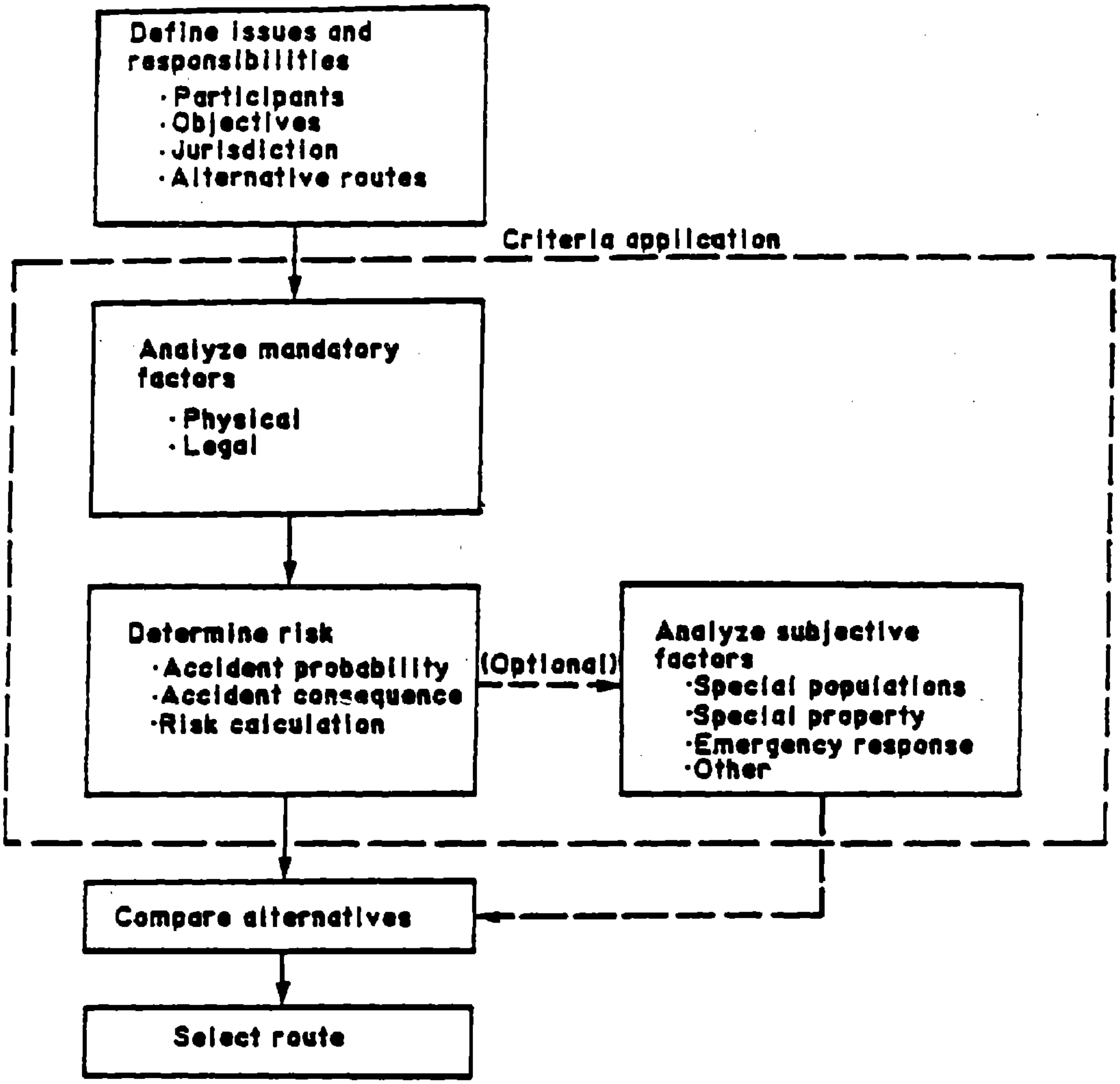

Figure 3. Structure of FHWA hazardous materials routing method.(1)

probably the most widely used technique for establishing hazmat routes. The application of this model to practical routing problems is facilitated by an implementation guide by Barber and Hildebrand.(13) Its general characteristics will be presented in this section. Details of the use will be presented in chapter IV along with recommended revisions.

Figure 3 illustrates the structure of the FHWA routing method. First, issues of importance to the community should be addressed. Jurisdiction should be established, objectives should be clearly developed, participants and a study leader selected and alternate routes selected. Before the application of the risk assessment model, the alternative routes under consideration must be evaluated for two types of mandatory factors: physical and legal factors. The physical factors considered are those that might make a particular alternative route unfeasible, 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 could limit the feasibility of a particular alternative route include laws and regulations that prohibit hazardous waste materials on specific roadways, bridges, tunnels, or toll roads. Any alternative route that is found to be unfeasible because of 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 risk using the Urbanek model. The output of this step 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; and 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 by Barber and Hildebrand.

H. RSPA Model for Shipments of Radioactive Materials

A risk assessment model for routing of shipments of radioactive materials has been developed by RSPA.(34) 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 materials in an absolute sense but does assess the relative risks of possible alternative routes for the shipment of radioactive materials.

The primary factors considered by the RSPA model in comparing alternative routes for the shipment of radioactive materials are normal radiation exposure, public health risk from accidents, and 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 was developed by Greenborg and considers the following elements for each alternative route: average speed of vehicles on the route and distance between opposing lanes.(34) 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 because of traffic accidents are also considered to be primary risk factors. A release of radioactive material caused by 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: (a) the frequency of accidents that could result in a release; and (b) 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 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 veh-mi, are not intended to estimate the risk of a radiation-releasing accident in absolute terms but to 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 of 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; therefore, 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 less desirable than the use of actual accident data. Once the relative accident rate per million veh-mi 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 people who could potentially be exposed to radiation; this is estimated from the population density on either side of each alternative route, up 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 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, and traffic fatalities and injuries. These factors are optional and may be used where they are considered appropriate to the comparison of particular routes.

It should be stressed here that this guide will <u>not</u> address radioactive materials. It is suggested that in the case of radioactive materials, the RSPA manual be followed.(34)

IV. RECOMMENDED RISK MODEL STRUCTURE[5]

After reviewing all of the currently available alternatives, it is recommended that an improved FHWA risk analysis technique (the Urbanek model) be used since they are the best practical tools available today for use by a State in determining risk of highway transportation of hazardous materials.[6] The model is not the most analytically rigorous or mathematically sophisticated, nor the best research tool, but it is usable, understandable, and adaptable to most existing and/or obtainable States' data bases.

It has been the author's observation over the past 10 years that other, more sophisticated measures, such as fault-free analysis, risk profiles, consequence models, etc., draw much research attention. However, when one needs a practical, working tool to evaluate routes or route segment, risk, models similar to the FHWA model are used. If their limitations are understood and accepted, they are valuable tools.

Most States' data bases need to be examined and enhanced through additional data acquisition on hazardous material flows if they want a really good risk analysis. The model can easily be made more rigorous or sophisticated over time as data quantity and quality improves. The resulting value of any State's risk analysis is a function of the resources that State is willing to put into data collection. Results can be enhanced or supplemented by the use of more sophisticated models once better data is available. The model has recently been improved, and is contained in a report that will be issued by FHWA in late 1989 or early 1990. A summary of the significant improvements will be presented later in this chapter. The guideline manual will present details of its use.

The model can be used for a macro-analysis of statewide routes, a macro- or micro-analysis of regional or community routes, and a micro-analysis of various segments, although caution must be used. The reliability of the results lie in the availability and accuracy of appropriate data. Assuming that the proper data is available or obtainable, good results can be expected. Volume II of this report will present details of data needs and collection.

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[5] This section is based on a summary and selected excerpts from reference 35.

[6] Improved as recommended in section E of this chapter. Those changes suggested in section A through D should also be given consideration.

Other models have been reviewed along with their data needs. Efforts could be redirected toward using other models or incorporating additional sophistication into the FHWA model if desirable and consistent with a State's data.

The Canadians studied the FHWA model and adapted it to their needs. They developed three levels of detail. The first is a macro-screening procedure, the second is a more detailed study, and the third is the most detailed level. They have made some interesting innovations; however, it must be kept in mind that their most detailed level essentially reverts back to FHWA's guideline procedures. They did provide guidelines on incorporating emergency response capability into the model. (A summary of the Canadian model is presented in appendix B of volume II.)

The discussion section A through D will be on changes that should be considered for the FHWA model. Those in section E below should definitely be incorporated. The material is excerpted from a report from another similar FHWA study.(1)

A. General Structure and Format

- The overall formulation is good and should be retained.
- The risk assessment model in the FHWA guide, especially equation (2) of the guide, gives the superficial appearence of providing an absolute measure of risk, but in reality, adequate data for developing absolute measures of risk does not exist.
- The FHWA guide provides an excellent step-by-step, "how-to-do-it" presentation; but it lacks an initial presentation of the specific relationships that make up the risk assessment model and the rationale for these relationships. The basic information should be presented first.
- The FHWA guide does not necessarily meet the needs of the wide variety of potential users. It seems best suited to a medium-sized community. Consideration should be given to less detailed procedures for small communities and more sophisticated, computerized procedures for major metropolitan areas.

B. Accident Probability

- The FHWA guide takes a correct approach in providing a default value for estaimating accident rates, while encouraging users to provide their own accident data. However, their encouragement to use actual accident rates for specific segments must be considered with caution. It is safer to use systemwide accident rates unless a proper statistical test assures that the sample size of accidents used for a specific route segment is large enough to produce a reliable estimate of the accident rate.

- The default accident rates provided by the FHWA guide are based on the general accident rate for all vehicle types. This approach is not desirable and the development of more reliable truck accident rates for use as a basis for hazmat risk assessment is needed. Better default values have been developed as part of a recent FHWA study and should be used unless a State has developed their own.(1)
- The FHWA guide correctly recognizes that highway type is a key variable that influences accident rates; however, area type also needs to be recognized as a key variable (urban or rural would be the major breakdowns; others should be considered).
- Data are not currently available to incorporate the accident rates for different types of trucks; however it should be recognized that they are not generally needed for relative comparison of risk on alternative routes of route segments since the same type trucks would normally use whichever alternative is considered. (There could be exceptions.)
- The route segment (L_i) is treated correctly in equation (2) of the FHWA guide since there is a simple proportionality between length and accident probability.
- The surrogate release factor (FHZ) in equation (2) of the FHWA guide is, at best, a crude approximation of releases but may give a user the erroneous impression that it is an absolute risk value. A dimensional analysis shows that it determines the expected number of hazmat release per trip over the route by any type of vehicle, passenger car or truck, whether carying hazmat or not. Since the FHZ term is a constant applied to each alternative, it has no direct bearing on a relative comparison. An alternative formulation of equation (2) without the FHZ term should be formulated.
- The method for determining accident probability in equation (2) does not take into account that a release is not equally likely in every accident but will vary as a function of truck type, accident type, highway type and area (urban/rural). Proper consideration of the probability of a release,

given that an accident has occurred, needs to be incorporated. Better values have been developed as part of a recent FHWA study and should be used unless a State has developed its own.

- The assessment of accident probability does not consider releases from causes other than traffic accidents, such as valve or container leaks. Since the probability of releases/consequences of this nature are proportional to time, a quantitative or subjective measure should "penalize" routes where hazmat carriers will be delayed by traffic, construction, etc.

C. Accident Consequences

- The FHWA guide, and most other currently used highway transportation risk models, use total number of persons (and total property value) exposed to a release. This approach assumes that the severity of consequences is directly proportional to exposure. Since determining separate numbers for deaths, serious injuries, minor injuries, etc. for each hazmat is very complicated, and no generally accepted or simple method is available, the exposure approach is reasonable. However, the fact that consequences are measured in terms of exposure should be emphasized and/or clarified. When more sophisticated methods of consdquence evaluation are made practical for States' use, they can easily be incorporated.
- The measure of persons exposed for a given route segment in the FHWA guide is the total number of persons exposed in some impact area. The impact area is generally defined as a band of equal width on either side of an entire route segment, with the width defined by potential impact distances that were originally taken from an early draft of the United States Department of Transportation, Emergency Response Guidebook(s), that shows recommended evacuation distances for each hazmat.(36) This approach is not realistic because a given hazmat release does not necessarily expose all persons along an entire route segment, but only those persons within the impact distance of the specific location at which the release occurs.

  The net effect of the existing procedure is to make the results of the risk assessment a function of the relative lengths of the route segments analyzed. For example, if a route A were divided into 0.25 mi (0.4 km) segments and a route B were divided into 1.0 mi (1.6 km) segments, the FHWA guide analysis would result in route segment B having four times the risk of route segment A because of the segment length alone. Even though there is a proportionality between route length and risk, :th longer segments of routes with otherwide similar attributes having higher risks, the increase in risk with increasing route length is already taken into consideration by the L_i term of equation (2) of the FHWA guide. In effect the FHWA guide considers segment length twice and creates a double counting effect.

This double counting effect can be most easily corrected by using linear population density by dividing the total population exposed within the desired impact area along the entire route segment by its length, as follows:

$$\text{Population Exposure} = \frac{PoP_i}{L_i} \qquad (11)$$

The FHWA guide's use of the total property value along an entire route segment suffers from the same double counting flaw. This can be easily corrected by using average property value per mile by dividing the total value of property exposed along the route segment by the length in miles, as follows:

$$\text{Property Exposure} = \frac{PV_i}{L_i} \qquad (12)$$

- The FHWA guide requires access to detailed population data at the census tract level. Since this data is not readily available to many users, the guide should provide users with some default values to estimate population densities in common situations.
- The impact distances given the FHWA guide need to be updated and adjusted based on the latest available information contained in the latest United States Department of Transportation Emergency Response Guidebook.(36)
- The FHWA guide presents impact distances that extend both a specific distance equally in all directions and a specified distance downwind. However, no specific guidelines are presented on using downwind distances to determine population exposures to airborne toxic materials. Wind rose data could be adapted. In the absence of wind rose data, one conservation approach would be to use the downwind distance on the most populated side of the route segment.

- The FHWA guide treats all persons within the impact zone as equally exposed; however, persons closest to the route segment are more likely to be killed or seriously injured. Weighting factors for subzones should be considered.
- The FHWA guide suggests the consideration of either population exposure, employment exposure, motorist exposure or a combination. Specific procedures are given in the guide to determine population exposure; however, none are given on the other nor guidelines on when they should be considered.
- The FHWA guide does not apply to radioactive materials. This should be made clear at the beginning of the report.
- The risk assessment model in the FHWA guide addresses only one specific material at a time. Typically, the impact distance of the most critical material in the particular hazard class is used. The possibility of computer applications of a weighting system, using common combinations of specific materials, should be explored.
- The risk assessment procedure in the FHWA guide does not consider the distance from the route segment (pavement edge) to the nearest population. This distance can vary greatly between interstate highways and those of lesser access control and between urban and rural. A method of adjusting consequences to account for this distance should be explored.

D. Overall Risk Assessment and Subjective Factors

- The overall formulation of risk as the product of accident probability and accident consequences should be retained.
- The FHWA guide should consider giving guidance on when and how to consider both personal injury and property risks and how to combine or weight these risks when both are consider.
- The FHWA guide recommends a subjective evaluation of special populations such as schools, hospitals, etc. This list should be expanded to include high concentrations of outdoor populations such as those found at sporting events, parks, outdoors, theaters, etc.
- The FHWA guide addresses environmental concerns as a subjective factor. The discussion of environmental issues should be expanded and some consideration given to providing a checklist of sensitive environmental concerns to consider.

- The FHWA guide addresses emergency response capabilities as a subjective factor. A quantitative approach should be considered. A Canadian report uses a scoring approach for response capability from 1.0 (low) to 1.5 (high) and uses a score to adjust the route segment, as follows:(37)

$$\text{Total Score} = \frac{\text{Probability x Exposure}}{\text{Response Capability Score}} \qquad (13)$$

This concept should be explored and developed more fully.

Greater details of the above critique can be found in reference 1.

E. Recommended Immediate Improvements to the FHWA Risk Assessment Guidelines

Not all of the above critiques can be translated to recommendations of immediate changes to the FHWA guide. Some of them need more thought, more research and development and/or data not readily available. There are some that could be made immediately with existing data, and these are strongly recommended in reference 1 and herein. They are summarized below and presented in detail in volume II of this report. Until such time as the FHWA rewrites and reissues a new routing guide, the author recommends that these be followed. The risk assessment procedures set forth herein and reference 1 represent the state of the art in State risk assessment--a procedure that is reliable, practical, usable, and understandable.

The recommended immediate changes, based on the thorough critique in reference 1 are:

- Eliminate double counting of segment lengths.
- Eliminate the 2.3×10^{-5} factor.
- Use truck accident rates rather than all-vehicle accident rates.
- Use the estimated probability of a hazmat release given an accident involving a hazmat-carrying vehicle.
- Use system-wide average accident rates unless a statistical analysis of specific data shows statistically significant data.
- Use site-specific accident data only for sites with significantly higher (or lower) accident rate than the systemwide average, determined by a statistical analysis.
- The recommended basic equation should be computed with the following equation, which replaces equation (2) in the FHWA guide:

$$P(R)_i = TAR_i \times P(R|A)_i \times L_i \tag{14}$$

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; and

L_i = length (mi) of route segment i.

V. SUMMARY OF RESEARCH TO DEVELOP AND PRIORITIZE SCENARIOS

A. Prioritization of Scenarios

The key task in this FHWA study was to develop and rank a set of prioritized, extreme-risk (catastrophic) scenarios. It was decided to form an advisory panel of contacts from interested States to assist in this task. It was felt that this approach would reflect the true concerns of the States in regard to potential, catastrophic situations that could occur during the transport of hazardous materials on our highway systems.

1. Background

In January 1986 preparations were begun, with the assistance of FHWA's contracting officer's technical representative for this project, to formulate the advisory panel to develop and rank scenarios. After the panel was in place, seven rounds of questionnaires were prepared and mailed to personnel in the participating States composing the panel. The questionnaires were primarily for soliciting scenarios and subsequent ranking; however, additional information was also solicited. From 7 sets of mailed questionnaires to the advisory panel, the list of 11 ranked scenarios in table 11 was developed.

It is recognized that biases in the responses would exist because of the varied background of the individual panel members, their experience, and the varied experience of the individual States with hazmat flows. However, because the research was to address a cross-section of the States' problems, it was appropriate to develop the scenarios with whatever inherent biases exist in the varied State concerns. No two States are likely to have the same concerns, and no two States would be likely to rank a set of catastrophic scenarios exactly the same, nor even all agree on the same set. The fact that a definite consensus was arrived at was in itself a major accomplishment. Twenty-eight of 30 respondents felt that the list was an excellent representation of real-world scenarios of concern to States.

2. Scenario development and prioritization

The advisory panel was asked for real or hypothetical scenarios that the members felt were of concern to their State. Approximately 60 separate, independent scenarios were suggested. Through several rounds of rankings, the original 60 were narrowed down. Most fell into a few categories such that by generalizing a statement covering the category, several of the original scenarios fit each statement. The process of narrowing the scenario down

Table 11. Ranked, generalized extreme-risk scenarios.

Rank	General Scenario Description
1	Poisonous, toxic, flammable or explosive material endangers large numbers of trapped motorists, e.g., between interchanges, in cut section, or in traffic jam downwind of poisonous or toxic gas release.
2	Chemical spills of poisonous or explosive materials that could enter underground "METRO" stations or transit 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	Release 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 in 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 petro-chemical 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.

involved incorporation the suggested items into 11 general scenario statements that covered most or all of them.

The list represents a composite listing of very broad scenarios based on rankings by a cross-section of States with different problems and evaluated by contacts with varied backgrounds. Not all of the scenarios will apply to all States, nor will the risk of each be the same in all States. The ranked set therefore should not be considered to have a relative nor an absolute scale. The list could be made specific to meet a State's particular needs. Such a list could be ranked with criteria weighted to the State's particular priorities for a more tailored ranking. This would be done best by the individual States.

For the ranking process, key to scale values was developed to aid responders. The scale is shown in table 12. Each responder gave each scenario a scale value and they were ranked by their mean scale values.

Table 12. Key to scale values.

Scale Value[1]	Key
1	Very minor incident: of little or no consequence under normal conditions.
2	Minor incident: little chance of escalation, little danger to life or serious or long-term environmental damage (aquifer, reservoir, or water supply) unless grossly mismanaged.
3	Potentially dangerous incident: but not likely to be catastrophic, danger to life or environment (aquifer, reservoir, or water supply) only if not handled properly.
4	Neutral: no clear catastrophic potential yet hard to predict.
5	Definitely dangerous incident: could be catastrophic under certain conditions of traffic, weather, or inadequate response. Could easily escalate to catastrophic situation.
6	Very dangerous incident: high catastrophic potential; high probability of loss of life, serious injury, or long-term damage to environment (particularly aquifer, reservoir, or water supply).
7	Definitely catastrophic incident: loss of life, serious injury, serious damage to environment (particularly aquifer reservoir, or water supply) is certain to be avoidable only with extreme good luck.

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[1] In general terms, where all replies are averaged, a mean value greater than four was interpreted to mean the scenario is catastrophic or has catastrophic potential.

The set of 11 ranked scenarios is sufficiently comprehensive and general enough to use in seeking a set of corresponding protective systems to incorporate into new and reconstructed highway systems.

3. Materials considered

In developing scenarios, risk analysis models, and related protective systems, it was obvious that it would not be practical to work with all hazmat or even with all 22 classes of materials. The advisory panel was polled as to what materials should be included. One from each class was suggested, and the advisory panel was asked to pick a representative material with catastrophic potential from each class. Instead, it was the consensus of the advisory panel that the six materials could represent all common material consequences and the study should work with these six: chlorine (CHL), propane (PRO), anhydrous ammonia (AA), gasoline (GAS), nitric acid (NA), and phosphorous compound (PH).

A statistical analysis of comparing mean rating scores of all possible pairs showed that chlorine was ranked significantly higher than all other materials but that there was no significantly difference pairwise between any of the other materials. This result can be seen in table 13 where a t-test of mean rating values showed that only chlorine was considered to be significantly more dangerous than the other five.

B. Catastrophic Potential Rated by Geometric Elements of Highways

One part of the study related highway geometric elements to the potentially catastrophic situations. The greatest perceived danger is from elevated facilities, followed by depressed facilities with development over them (air-rights structures) and, lastly, receptors adjacent to the facility.[7]

As adjacent facilities, nursing homes and hospitals received the highest rank for catastrophic potential, followed by schools, apartments, shopping centers, hotels, factories, and hazmat storage facilities, in that order. Hazmat storage facilities however should have had a higher ranking, perhaps number 1, because they can have a chain-reaction, multiplying effects. To better relate catastrophic occurrences to highway facility descriptors (e.g., geometric elements, such as an elevated-to-lower-level-ramp), a set of the

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[7] Here, receptor is defined as the population, property, etc., subjected to a hazmat release consequence.

Table 13. Result of statistical test of significant difference of mean response between materials (t-test on mean of all possible pairs).

	PRO[1]	CHL[1]	AA[1]	GAS[1]	NA[1]	PH[1]
PRO	---	YES	NO	NO	NO	NO
CHL	YES[2]	---	YES	YES	YES	YES
AA	NO[3]	YES	---	NO	NO	NO
GAS	NO	YES	NO	---	NO	NO
NA	NO	YES	NO	NO	---	NO
PH	NO	YES	NO	NO	NO	---

[1] PRO=Propane; CHL=Chlorine; AA=Anhydrous Ammonia; GAS=Gasoline; NA=Nitric Acid; PH=Phosphorous.

[2] YES = Significant difference in perceived threat between material pairs that intersect that cell.

[3] NO = No significant difference in perceived threat between material pairs that intersect that cell.

six representative materials, with one highway facility descriptor set for each of the six materials, were sent to the panel members.

Response was outstanding, considering the great length of the delivered set. The results from this set were intended to supplement the 11 ranked scenarios. They are too detailed to be the primary set but give added direction to both the expansion of the ranked set and site-specific applications of the decision/risk model. The set of responses and scores are shown in tables 14 and 15. Table 16 summarizes the responses for gasoline.

One respondent summed up the problem very nicely in the following statement: "All releases have to go either down, laterally, or up." Responses showed that the greatest concern is for released hazmat that can go down, e.g., from an elevated facility; next, for materials that go up, e.g., fires and explosions under overpasses and air-rights structures; and, lastly, by materials that go laterally, e.g., fire and gases that endanger adjacent lateral populations, such as high-rise apartments, schools, hospitals, etc. Note that these are entirely consistent with the set of 11 ranked scenarios. This can be seen

Table 14. Round 4 summary of results: overall rank of the catastrophic potential of various highway segments relative to individual ranking of the six hazardous materials.

Item No.[1]	Overall of Rank Segment	Rank Material						Σ	Mean Rank of Segment
		PRO	CHL	AA	GAS	NA	PH		
ala	1	2	1	5	1	1	2	12	2
alb	14	36	27	28	8	4	11	114	19
alc	46	48	46	46	46	46	46	278	46.33
a2a	2	1	2	6	2	2	3	16	2.67
a2b	16	38	28	29	9	5	12	121	20.17
a2c	47	46	47	47	47	47	47	281	46.83
a3a	3	3	3	7	3	3	1	20	3.3
a3b	15	39	29	30	10	6	7	121	20.17
a3c	48	47	48	48	48	48	48	287	47.83
a4	31	45	44	39	7	7	23	165	27.5
a5	32	43	41	45	11	8	20	168	28
b1	37	35	31	33	37	29	40	205	34.17
b2	38	34	32	32	38	39	37	212	35.33
b3	39	37	33	31	44	30	41	216	36
b4	32	44	39	34	12	15	24	168	28
b5	36	41	42	40	13	18	21	175	29.17
cla	4	4	14	8	6	9	4	45	7.5
clb	42	32	36	35	41	41	42	227	37.83
c2a	5	5	8	9	4	16	5	47	7.83
c2b	41	33	35	38	39	42	38	225	37.5
c3a	7	6	9	10	5	17	6	50	8.33
c3b	40	31	34	36	40	43	39	223	37.17
c4	26	42	38	37	18	10	22	157	26.17
c5	28	40	37	41	17	11	16	162	27
dla	13	12	7	13	26	22	25	105	17.5
dlb	10	9	5	4	21	19	13	71	11.83
dlc	6	7	4	1	16	12	8	48	8
dld	17	10	11	14	33	31	26	125	20.83
dle	20	15	12	15	34	32	27	135	22.5
dlf	21	18	13	16	27	33	28	135	22.5
dlg	18	16	18	17	36	23	17	127	21.17
dlh	43	17	40	42	42	44	44	229	38.17
d2a	19	23	15	18	22	24	29	131	21.83
d2b	11	20	10	11	19	20	14	94	15.67
d2c	8	11	6	2	14	13	9	55	9.17
d2d	25	27	16	22	28	34	30	157	26.17
d2e	29	29	17	23	29	35	31	164	27.33
d2f	35	30	30	24	23	36	32	175	29.17
d2g	24	28	20	25	35	27	18	153	26.5
d2h	44	24	43	43	43	45	43	241	40.17
d3a	22	14	22	19	24	25	36	140	23.33
d3b	12	13	21	12	20	21	15	102	17
d3c	9	8	19	3	15	14	10	69	11.5
d3d	27	19	23	20	30	37	33	162	27
d3e	34	25	24	21	31	38	34	173	28.83
d3f	30	36	25	26	25	28	25	165	27.5
d3g	23	21	26	27	32	26	19	151	25.17
d3h	44	22	45	44	45	40	45	241	40.17

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[1] Code designations such as "ala" are described in table 15.

Table 15. Ranked facility descriptors from round 4 overall ranking (table 13) of all six materials.

Rank	Item[1]	Components
1	a1a	elevated basic segment over shopping center
2	a2a	elevated weaving area (non-ramp) over shopping center
3	a3a	elevated ramp/ramp junction/acel.-decel. lanes over shopping center
4	c1a	depressed basic segment with air-rights development
5	c2a	depressed weaving area with air-rights development
6	d1c	elevated, at-grade, or depressed (nothing over or under) basic segment within one block of nursing home or hospital
7	c3a	depressed ramp/ramp junction with air-rights development
8	d2c	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) nursing home or hospital
9	d3c	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel./lanes within one block of nursing home or hospital
10	d1b	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) school
11	d2b	elevated at-grade or depressed (nothing over or under) weave section (within one block of) school
12	d3b	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel/lanes within one block of school
13	d1a	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) apartments
14	a1b	elevated basic segment over parking
15	a3b	elevated ramp/ramp junction/accel.-decel. lanes over parking
16	a2b	elevated weaving area (non-ramp) over parking
17	d1d	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) shopping center
18	d1g	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) factor
19	d2a	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) apartments
20	d1e	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) hotel
21	d1f	elevated, at-grade, or depressed (nothing over or under) basic segment (within one block of) office building
22	d3a	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel./lanes within one block of apartments
23	d3g	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel./lanes within one block of factory
24	d2g	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) factor

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[1] Column coding from original survey number.

Table 15. Ranked facility descriptors from round 4 overall ranking (table 13) of all six materials (continued).

Rank	Item	Components
25	d2d	elevated, at-grade or depressed (nothing over or under) weave section (within one block of) shopping center
26	c4	depressed drainage into storm sewer
27	d3d	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel./lanes within one block of shopping center
28	c5	depressed drainage into combined sewer
29	d2e	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) hotel
30	d3f	elevated, at-grade, or depressed (nothing over or under) ramp/ramp juction/accel.-decel./lanes within one block of office building
31	a4	elevated drainage (from el.) to storm sewer
32	a5	elevated drainage (from el.) to combined sewer
33	b4	at-grade drainage into storm sewer
34	d3e	at-grade or depressed (nothing over under) ramp junction/ accel.-decel./lanes within one block of hotel
35	d2f	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) office building
36	b5	at-grade drainage into combined sewer
37	b1	at-grade basic segment
38	b2	at-grade weaving area (non-ramp)
39	b3	at-grade ramp/ramp junction/accel.-decel. lanes
40	c3b	depressed ramp/ramp junction without air-rights development
41	c2b	depressed weaving area without air-rights development
42	c1b	depressed basic segment without air-rights development
43	d1h	elevated, at-grade, or depressed (nothing over or under) basis segment (within one block of) storage hazardous materials
44	d2h	elevated, at-grade, or depressed (nothing over or under) weave section (within one block of) storage of hazardous materials
45	d3h	elevated, at-grade, or depressed (nothing over or under) ramp/ramp junction/accel.-decel./lanes within one block of storage of hazardous material
46	a1c	elevated basic segment no development under
47	a2c	elevated weaving area (non-ramp) no development under
48	a3c	elevated ramp/ramp junction/accel.-decel. lanes no development under

Table 16. Results of the rating value for the catastrophic potential of various highway segments for gasoline.

Gasoline: faculty descriptor/reactor catastrophic potential response

Rating Summary[1]						Urban Freeway Components
Mean	Std. Dev.	Min.	Max.	6&7[2]		
					a. elevated	(1) basic segment
5.52	1.31	3	7	17		(a) over shopping center
5.04	1.40	2	7	12		(b) over parking
3.93	1.30	1	6	2		(c) no development under
						(2) weaving area (non-ramp)
5.52	1.31	3	7	17		(a) over shopping center
5.04	1.40	2	7	12		(b) over parking
3.93	1.30	1	6	2		(c) no development under
						(3) ramp/ramp junction/accel.-decel. lanes
5.52	1.31	3	7	17		(a) over shopping center
5.04	1.40	2	7	12		(b) over parking
3.93	1.30	1	6	2		(c) no development under
5.08	1.38	1	7	11		(4) drainage (from el.) to storm sewer
5.04	1.37	1	7	10		(5) drainage (from el.) to combined sewer
4.44	1.42	2	7	6	b. at-grade	(1) basic segment
4.44	1.42	2	7	6		(2) weaving area (non-ramp)
4.33	1.33	2	7	5		(3) ramp/ramp junction/accel.-decel. lanes
4.83	1.41	1	7	9		(4) drainage into storm sewer
4.93	1.36	1	7	9		(5) drainage into combined sewer
					c. depressed	(1) basic segment
5.15	1.32	2	7	13		(a) with air-rights development
4.37	1.28	2	6	5		(b) without air-rights development
						(2) weaving area
5.22	1.19	3	7	13		(a) with air-right development
4.44	1.19	2	6	5		(b) without air-right development
						(3) ramp/ramp junction
5.19	1.18	1	7	12		(a) with air-rights development
4.41	1.15	2	6	4		(b) without air-rights development
4.67	1.52	1	7	7		(4) drainage into storm sewer
4.70	1.44	1	7	7		(5) drainage into combined sewer

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[1] Based on 1-7 scale explained in table 12.

[2] Total number of respondents giving a response of 6 (very dangerous) or 7 (definitely catastrophic).

Table 16. Results of the rating value for the catastrophic potential of various highway segments for gasoline (continued).

Gasoline: faculty descriptor/reactor catastrophic potential response

Rating Summary[1]					Urban Freeway Components
Mean	Std. Dev.	Min.	Max.	6&7[2]	
					d. elevated, at-grade, or depressed (nothing over or under)
					(1) basic segment (within one block of)
4.59	1.42	1	6	9	(a) apartment
4.63	1.45	1	7	10	(b) school
4.74	1.48	1	7	10	(c) nursing home or hospital
4.56	1.40	1	6	8	(d) shopping center
4.56	1.40	1	6	8	(e) hotel
4.59	1.39	1	6	8	(f) office building
4.52	1.42	1	6	8	(g) factory
4.37	1.88	1	7	8	(h) storage of hazardous mat.
					(2) weaving sections (within one block of)
4.63	1.45	1	6	10	(a) apartment
4.67	1.47	1	6	11	(b) school
4.78	1.50	1	7	11	(c) nursing home or hospital
4.59	1.42	1	6	9	(d) shopping center
4.59	1.42	1	6	8	(e) hotel
4.63	1.42	1	6	9	(f) office building
4.56	1.45	1	6	9	(g) factory
4.37	1.88	1	7	8	(h) storage of hazardous mat.
					(3) ramp/ramp junction/acel.-decel./lanes (within one block of)
4.63	1.45	1	6	10	(a) apartment
4.67	1.47	1	6	11	(b) school
4.78	1.50	1	7	11	(c) nursing home or hospital
4.59	1.42	1	6	9	(d) shopping center
4.59	1.42	1	6	9	(e) hotel
4.63	1.42	1	6	9	(f) office building
4.56	1.50	1	7	9	(g) factory
4.24	1.88	1	7	7	(h) storage of hazardous mat.

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[1] Based on 1-7 scale explained in table 12.

[2] Total number of respondents giving a response of 6 (very dangerous) or 7 (definitely catastrophic).

in table 16. The results in table 16 were summarized without regard to material type. Material type was not significant, according to the analysis of the responses.

Table 14 shows the top ranked highway facility descriptor scenarios (HFDS) for all materials. Since the survey showed little significant difference between materials, it was concluded that for the materials given, the location of the incident was generally perceived as being more important than the material. The rankings by material were combined into an overall ranking that is shown in table 15. The detailed responses for gasoline are shown in table 17 which also shows how the respondents ranked receptor facilities adjacent to highways. They are, in order of highest catastrophic potential:

- Nursing home or hospital.
- Schools.
- Apartments.
- Shopping centers.
- Hotels.
- Factories.
- Hazmat storage facilities.

Although chlorine was perceived to be more dangerous, it was concluded that with any of the six materials, all with catastrophic potential of some degree, the location of the incident insofar as the affected populations is the controlling factor or at least is perceived to be the controlling factor. This can be seen in table 17.

Table 17. Generalized summary of round 4 results.

Rank	Approx. Avg.[1] Mean Score	Generalized 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 given: a) nursing home or hospital b) schools c) apartments d) shopping center e) hotel f) factory g) hazmat storage facilities
4	4.0	Drainage into sewage system

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[1] Based on 1-7 scale explained in table 12.

C. Environmental Scenarios

When the original scenarios were returned by the participating State representatives, it was noted that there were only a very few that related to environmental problems. Some experts believe that the public's greatest fear is contamination of water supplies. A separate round of questions was sent to the panel dealing only with environmental issues. This set of scenarios and the results can be seen in table 18.

Also, advisory panel contacts in New York, Minnesota, and Rhode Island noted that the potential for contamination of reservoirs or aquifers is a major concern in these States. It was appropriate that an environmental scenario be among the top set which will direct the guidelines.

The one non-nuclear, environmental catastrophic scenario, generalized scenario number 8, should cover all serious cases. The results shown in table 18 can be considered a supplement to this environmental scenario.

Any of the 11 scenarios could be subdivided into more specific cases, such as the round 5 results subdivided as the environmental category. A State may wish to do so in the process of making the generalized scenario list State-specific.

Table 18. Environmental scenario questionnaire and summary of results.

Rating Summary[1]					
Mean	Std.Dev.	Min.	Max.	6&7[2]	
					1. Direct spill into potable water supply
5.78	1.13	3	7	22	(a) Reservoir - direct spill
5.59	1.32	2	7	17	(b) Aquifer - little or no soil cover
4.31	1.18	1	6	5	(c) Aquifer - soil cover > 25 ft (7.6 m)
4.13	1.18	2	7	4	(d) Area of wells; within 1 mi (1.6 km)
					2. Spill into waterbed or stream within 1 mi (1.6 km)
4.88	1.26	1	7	9	(a) Reservoir
4.69	1.28	1	7	8	(b) Aquifer
					3. River
5.00	1.19	1	7	10	(a) Immediately upstream of urban area
4.44	1.34	1	6	7	(b) Rural
					4. Stream
4.31	1.38	1	6	6	(a) Rural
4.47	1.24	1	7	3	(b) Urban
4.00	1.30	1	6	4	5. Crop land
3.68	1.11	1	6	1	6. Open ground, agricultural
					7. Open ground, non-agricultural
4.00	1.05	1	5	0	(a) High runoff
4.03	1.23	1	6	3	(b) High permeability
4.22	1.18	1	6	3	(c) Sinkhole area
3.96	1.20	1	6	3	8. Ecosystem flora, fauna
					9. Sewage drainage system
4.00	1.19	1	6	3	(a) Rural
4.25	1.27	1	7	6	(b) Urban
					10. Storm water
4.13	1.26	1	5	5	(a) Rural
4.28	1.28	1	7	4	(b) Urban

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[1] Based on 1-7 scale explained in table 12.

[2] Total number of respondents given a response of 6 (very dangerous incident) or 7 (definitely catastrophic incident).

VI. SUMMARY OF RESEARCH TO DEVELOP PROTECTIVE SYSTEMS

A. Background

After ranking the 11 prioritized extreme risk scenarios, the next task was to develop "feasible, implementable, and practical" protective systems keyed to the 11 scenarios.

Deciding what were feasible, implementable, and practical protective systems proved to be very difficult. It was concluded that the practical aspect of the protective systems was the key criterion, and this could only be decided by an individual State considering its risk versus the cost/benefits of the protective system, within the context of overall State priorities and resources--requiring a management decision. Ideally, benefits should be measured in terms of risk reduction, but this would be very elusive indeed because the data necessary to do a meaningful risk reduction analysis on previously untried protective systems is just not available. Accident reduction values, for example, would initially have to be based on the judgment of traffic engineers with expertise in accident causation.

B. Panel Survey for Protective System Ideas

1. General approach

The States' advisory panel, formed for developing and ranking scenarios, was again utilized. The original protective system ideas had come from this panel, and, after these were stored and organized, the panel was surveyed to evaluate 98 protective system ideas that had been generated. The last round of the scenario prioritization process asked the panelists to present ideas on protective systems keyed to each of the eleven scenarios.

The response was very good. Although some panelists responded to some scenarios with comments such as "no hope" and left some blank, several good ideas were returned for all scenarios. These ideas for scenarios were sorted, edited, and returned to the panel as round 8. Editing of the responses was kept very minimal to keep the ideas essentially as the panelists had presented them. Several responses focused on regulatory type solutions, which were outside the scope of the project. However, the panelists had been informed of this many times. Since many still felt that these sorts of solutions were best, this was considered to be significant information. Thus, it was decided to leave these in the list to be evaluated to see how they were rated and ranked, both individually and as a group.

The key to the "1 to 7" rating scale used to rate suggested scenarios is presented in table 19. Thirty-two responses were analyzed and the mean, standard deviation, maximum and minimum scores of each protective system were calculated.

One category of protective systems (communication and detection systems) was mentioned in the responses to almost all scenarios. Exploratory work was done on these types of systems, and specific examples were sent back to the panel in a separate section at the end of round 8.

2. Philosophy of analyzing results

The responses were so varied that it was not immediately clear how to interpret the results. As an example, the results of the mean response for all protective systems associated with scenario 4 is shown in figure 4. Mean

Table 19. Key to scale values--systems.

Scale Value[1]		Key Guidelines to Assist Raters
Bad (Worst)	1	Nearly impossible to implement, not at all practical, will serve no useful purpose
	2	Very difficult to implement; little value
	3	Difficult to implement; some value possible but probably not worth the effort or cost
"Neutral"	4	Hard to judge; not clearly a "good" or "bad" idea
	5	Possible merit as practical and implementable protective system; worth further thought or development
	6	Clear cut merit as practical and implementable protective system
Excellent (Best)	7	Highly feasible, very practical, useful and efficient, excellent and very desirable

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[1] In general terms, where all replies are averaged, a value less than four would suggest that the idea would be highly difficult to design/ construct and install or would not be very useful/desirable--inappropriate.

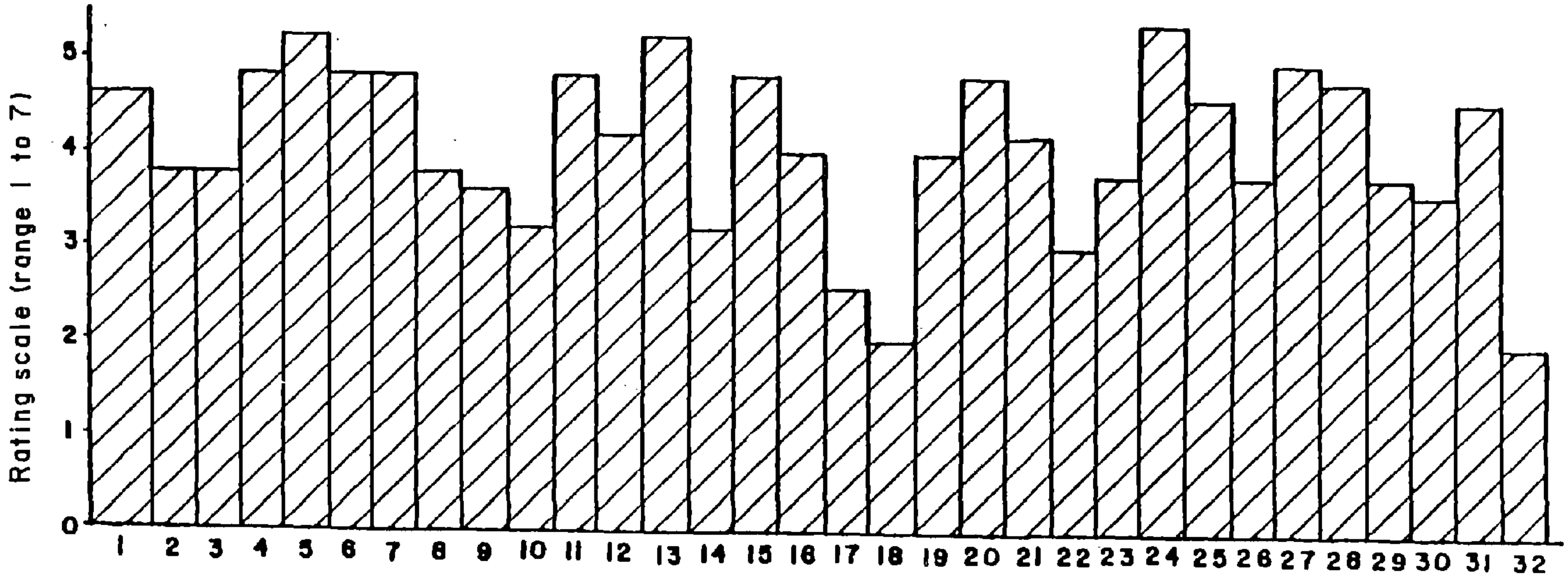

Figure 4. Scenario number 4 results.

responses for all protective systems varied from less than 2.0 to 5.3, and there are large differences between responders to the same protective systems for the same scenarios. The range on almost all individual protective systems was 1 to 7. A similar pattern can be found in the mean responses of 32 responders to all of the protective systems. The mean response to all 98 protective systems by each of the 32 respondents is shown in figure 5.

Individual responses were plotted for each protective system. The results were extremely varied. By comparing individual responses, it was found that some individuals rated consistently low, and some rated consistently high.

An attempt was made to group responders by their profession. The mean response of each group, such as State highway engineers, State environmentalists, emergency responders, consultants, professors, industry contacts, etc., was plotted. The only trend that was noted from this exercise was that the highway engineers generally rated higher than average, and the environmentalists/emergency responders generally rated lower than average.

The problem with the above rating fluctuation analysis was deciding what it meant, if anything. There was much discussion whether some individuals or groups should be weighted heavier than others. It was decided that, as in the case of the rating and ranking of the scenarios, these fluctuations represented real-world differences of opinions in a new area, highway protective systems, where varied and/or limited knowledge and experience on which to base evaluations is prevalent. Thus, it was concluded that the fluctuations did not have any clear meaning applicable to the results. It clearly came down to using a mean that reflected the various biases of the responders versus using other individuals' or groups' opinions or using weighted opinions. Since the main task is a first attempt at research into a new area, it was decided to rate the protective systems using the collective panel mean with all its inherent biases.[8]

The next decision was to determine what mean value should be considered "high" and what mean value should be considered "low." Because there was no rational way to determine this, an arbitrary mean rating of 4.0 was chosen as the cut-off point. The protective systems were listed from highest to lowest, and a reasonable number of them were picked from the top that could be handled well with the available project resources.

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[8] Not everyone will agree; but the author sees this as the difference between research and consulting or expert witnessing--and the reason the panel was formed.

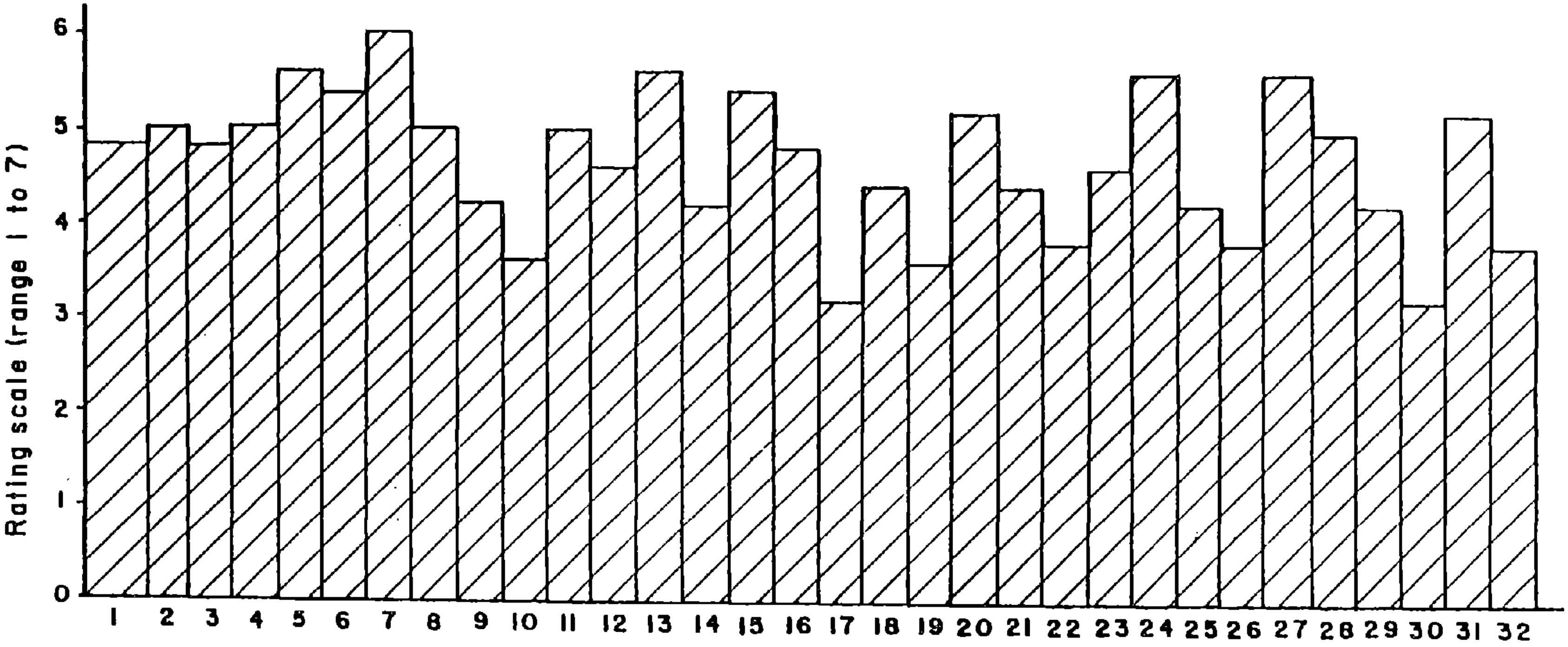


Figure 5. Mean response to all scenarios combined.

The protective systems that had a mean rating of 4.0 or greater are presented in table 20, categorized by the 11 scenarios. The last group of protective systems in the table is a summary of communication and detection systems that were suggested and highly ranked for many of the scenarios. These results can be seen in table 21.

3. Communication and detection system

One general conclusion could be readily seen from the results. Communication and detection protective systems were rated very high. This section of the questionnaire was clearly marked optional for those who felt qualified to respond. Only a few panelists responded, but the mean response was generally very high. It should be noted that communication and detection systems would be site-specific protective systems for high-risk and high catastrophic potential situations of a particular nature--not for general use.

4. Regulatory type responses

Even though it was made clear to the panel that regulatory type solutions to the scenarios were not within the scope of the project, it can be seen from table 22 that many of the panelists still suggested them. When ranked, the regulatory solutions were ranked generally higher than protective type ideas.

From table 22, a summary of the number of responses for each category of panel responses, protective and regulatory, it can be seen that the latter is a dominant factor. Thirty-four of the 76 responses rated 4 or above (45 percent) were of the regulatory type. The overall mean rating of the regulatory-type was 5.3, compared to 4.7 for protective systems. Response to nine of the individual scenarios show that the regulatory type were rated higher in every case scenario 2 was a tie (4.8), and scenario 9 had no regulatory type solutions proposed.

5. Summary

Table 23 presents a concise summary of the relevant, physical protective systems that were proposed. They are broken down into two main groups, I. Mitigating and II. Preventive Mitigation; are further categorized into:

- Detection and warning.
- Systems to facilitate escape and response.
- System to mitigate fire/explosion consequences.

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater.

SCENARIO 1 -- Poisonous, toxic flammable or explosive material endangers large numbers of trapped motorists; e.g., between interchanges, in cut section or in traffic jam downwind in poisonous or toxic gas release.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	5.1	1.9	1	7	Traversable medians
2	5.0	1.7	1	7	Emergency phone call boxes on all hazardous cargo routes
3	4.7	1.8	1	7	Crossovers
3	4.7	1.7	1	7	Median openings
4	4.6	2.1	1	7	Highway exits designed for traffic entrance (response team) from opposite direction

$\bar{X} = 4.8$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	5.2	1.3	2	7	Routing restrictions
R2	5.0	1.6	1	7	Prohibition on hours (curfews)
R2	5.0	1.7	1	7	Prohibit large trucks through congested areas (routing)

$\bar{R} = 5.1$

SCENARIO 2 -- Chemical spills of poisonous or explosive materials that could enter underground "METRO" stations or transit tunnels through sidewalk vents, etc. (Includes entry of lighter-than-air toxic or poisonous gases into adjacent or overhead transit stations.)

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	5.4	1.3	2	7	Fresh air vents at elevated levels
1	5.4	1.3	2	7	Prohibition in areas; air vents--intakes away from roads, arrows in tunnels with distance to exit, etc.
3	4.2	1.6	1	7	Coamings over street-level in-take vents with drainage away from vents. For overhead stations, the ability to crash-stop ventilation and provide positive internal pressure.
3	4.2	1.5	1	7	Pea-trap system vents to trap gases in first section

$\bar{X} = 4.8$

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater (continued).

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	4.8	1.9	1	7	Restricted routing in these areas

$\bar{R} = 4.8$

SCENARIO 3 -- Hazardous materials accidents causing release of toxic, flammable or explosive materials in tunnels.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	6.0	1.3	3	7	Arrows pointing to nearest exit
2	5.8	1.2	3	7	Effective vent systems
3	5.5	1.6	2	7	Monitoring for quick response
4	5.2	1.8	1	7	Gas detectors/alarm systems
5	4.9	1.6	2	7	Large sprinkler systems
6	4.0	1.7	1	7	Emergency exits with heavy doors

$\bar{X} = 5.2$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	5.9	1.5	1	7	Routing hazmats away from tunnels (prohibition)

$\bar{R} = 5.9$

SCENARIO 4 -- Gasoline, LNG, propane (flammables, explosive gases), etc., accidents and releases on elevated facilities, including ramps there-to, with people at risk below or in adjacent buildings.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.9	1.9	1	7	High performance barrier/rail systems, to prevent such an accident
2	4.8	1.7	1	7	Avoid use of open rails on structure
3	4.4	1.9	1	7	Robust drainage with holding reservoirs that can be isolated from regular storm drains (and later pumped) should a spill occur
4	4.2	1.6	1	7	Conduit railing for automatic spraying of water
4	4.2	1.7	1	7	Relocate or close ramps--in critical locations; install improved barriers; prohibit truck use of such ramps

$\bar{X} = 4.5$

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater (continued).

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R12	5.3	1.6	2	7	Reduced speed
R2	4.3	2.0	1	7	No hazmat through high urban area (prohibition)

$\bar{R} = 4.8$

SCENARIO 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.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.5	1.7	1	7	Communication and detection systems
2	4.3	1.7	1	7	Development of a public notification system for efficient evacuation possibly using air raid type alarms and public address systems.

$\bar{X} = 4.4$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	6.0	1.4	2	7	Evacuation planning
R2	5.9	1.6	1	7	Emergency response training
R3	5.5	1.7	1	7	Reduced speed with strict enforcement
R4	5.4	1.6	2	7	Routing/prohibition
R4	5.4	1.7	1	7	Training of personnel of schools, hospitals, hotels, nursing homes

$\bar{R} = 5.6$

SCENARIO 6 -- Releases from accidents between hazardous materials containers on highways and passenger trains or trains carrying hazardous cargo either at rail-highway crossing at grade or in situations with shared rights-of-way, such as freeways with transit in the median.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.8	1.7	2	7	Installing effective barriers between parallel transport corridors
2	4.7	1.6	2	7	Shared rights-of-way should be separated by concrete barriers
3	4.6	1.8	1	7	Higher, stronger, etc., barriers next to transit

$\bar{X} = 4.7$

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater (continued).

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	6.1	1.3	3	7	Specific training for fire department, police, etc.
R2	5.5	1.4	2	7	State-of-art crossing warning systems
R3	5.3	1.7	1	7	Reduced train speeds in urban areas
R4	5.0	1.7	1	7	Sufficient warning indicators installed reasonably well in advance of crossings
R5	4.7	1.8	1	7	Restricting hazmat transportation routes to avoid high hazard areas
R6	4.3	2.2	1	7	Law requiring full stop before crossing

$\bar{R} = 5.2$

SCENARIO 7 -- Explosive materials in 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 petro-chemical plant that could result in conflagaration.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.5	1.6	1	7	Communication and detection systems

$\bar{X} = 4.5$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	5.8	1.2	3	7	Increase inspections
R2	5.8	1.2	2	7	Ensure inspection and regulation of storage facilities
R3	5.4	1.6	2	7	Escort vehicle for explosives
R3	5.4	1.5	2	7	Control speed
R5	5.3	1.3	3	7	Mandate restrictive zoning prohibiting certain chemical storage/processing around certain traffic/population density situations
R4	5.3	1.6	2	7	Zoning restrictions to avoid population build ups in such areas, i.e., planning of industrial park siting being cognizant of the raw materials and products that will be kept in storage
R5	5.0	1.7	1	7	Routing/prohibition
R6	4.5	1.6	2	7	Thermal protective coverings on packages

$\bar{R} = 5.3$

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater (continued).

SCENARIO 8 -- Sufficient quantities of poisonous materials, such as herbicides, or dangerous biological/agents (or any material causing long-term or permanent damage) being related into a potable water supply, particularly reservoirs and susceptible aquifers and/or watersheds.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.8	1.7	1	7	Drainage gutters to direct spilled material toward collection point
2	4.7	1.6	2	7	Design with clay blanket or barrier membrane; direct drainage away from sensititve areas
3	4.5	1.4	1	6	Floating surface barrier (for insoluble petroleum oils)
4	4.4	1.5	1	7	Robust drainage with holding reservoirs that can be isolated from regular storm drains should spill occur
5	4.2	1.7	1	7	Large sumps
5	4.2	1.7	1	7	Retention basin that can automatically close to capture spillage
6	4.0	1.4	1	6	Grease trap sedimentation basin (for heavier insolubles)

$\bar{X} = 4.4$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	5.9	1.3	3	7	Ensure inspection and regulation of storage facilities

$\bar{R} = 5.9$

SCENARIO 9 -- Rural, hilly or mountainous areas with cities or towns at bottom of long or steep grades where brake failure of hazardous material carriers could cause catastrophic consequences to the populated area.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	6.0	1.4	2	7	Truck escape ramp
2	5.6	1.3	3	7	Upgrade runoffs for deceleration and extra-wide shoulders
3	4.4	1.5	1	7	Construct massive barrier and put energy absorbing material in front

$\bar{X} = 5.3$

$\bar{R}$ = None

Table 20. Protective system rating results all proposed protective systems rated 4.0 or greater (continued).

SCENARIO 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.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.7	1.8	1	7	Drainage gutters to direct spilled material toward collection point
2	4.5	1.7	1	7	Robust drainage with holding reservoirs that can be isolated from regular storm drains should spill occur
3	4.2	1.6	1	7	Large sumps
3	4.2	1.6	1	7	Design with clay blanket or barrier membrane; direct drainage away from sensitive areas

$\bar{X}$ - 4.4

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	5.9	1.4	1	7	Strict monitoring of drivers and equipment (e.g., at truck weigh stations)
R2	5.6	1.3	2	7	Routing restrictions for such materials
R3	5.4	1.6	2	7	Escort shipments

SCENARIO 11 -- Carriers of toxic flammable or explosive materials leaking material during transient in heavily populated or congested areas.

Protective type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
1	4.3	1.5	1	7	Communication and detection systems

$\bar{X} = 4.3$

Regulatory type solutions

Rank	Mean	Std. Dev.	Min.	Max.	
R1	6.2	1.2	3	7	Intensive motor carrier enforcement program putting such vehicles out of service until repaired
R2	5.7	1.4	2	7	Inspection stations for carriers of hazmats
R3	5.2	1.5	2	7	Restricted route and curfews
R4	4.7	1.6	2	7	Cleanup materials on each truck to absorb/neutralize spills

$\bar{R} = 5.5$

Total $\bar{X} = 4.7$ $\bar{R} = 5.3$

Table 21. Scenario--all scenarios, summary of communication and detection systems.

A. Detection

1. Non-Remote Sensing Techniques, general:

Mean Score	Rank	Specific Examples
5.9	1	Explosimeters
5.8	2	Colorimetric Indicators
5.4	3	TLV Sniffers
5.1	4	Water Analysis Kits

2. Remote Sensing, general:

Mean Score	Rank	Specific Examples
6.7	1	Gaseous-measuring laser radar systems (termed differential absorption lidar)
6.5	2	Plume and Haze analyzer
6.5	2	U.S. Army's remote sensing XM 21 (modified version for hazardous material detection)
6.0	4	Correlation spectrometer
5.8	5	Miehelson interferometer (eq. U.S. EPA's Remote Official Spectrometer for Emissions)
5.8	5	Van-mounted lidar
5.8	5	Aircraft-mounted lidar
5.3	8	Thermal Sensing

B. Communication

Mean Score	Rank	Specific Examples
6.3	1	Instructions available with all drivers
5.5	2	Radiation indicators on trucks
5.4	3	Instructions pasted on truck's body
5.3	4	Posted standard instructions regarding nature of hazard, preliminary protective measures, and first aid
5.2	5	Gas detectors
4.9	6	Telephone booths
4.7	7	Remote sensing alarms

Table 22. Summary comparison of regulatory-type responses to protective type responses of all proposed ideas 4.0 or greater.

Scenario	Protective-type		Regulatory-type	
	No.	Mean Score	No.	Mean Score
1	5	4.8	3	5.1
2	5	4.8	1	4.8
3	6	5.2	1	5.9
4	5	4.5	2	4.8
5	2	4.4	5	5.6
6	3	4.7	6	5.2
7	1	4.5	8	5.3
8	7	4.4	1	5.9
9	3	5.3	0	---
10	4	4.4	3	5.1
11	1	4.7	4	5.3
OVERALL	42	4.7	34	5.3

Table 23. Categorization of proposed physical, protective systems for highways.

Category		System
I.	MITIGATING	
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.	System to Mitigate Fire/Explosion Consequences	Foam blanketing systems
		Large sprinkler systems
		Effective vent systems

Table 23. Categorization of proposed physical, protective systems for highways (continued).

	Category	System
D.	Systems to Mitigate Spill Consequences	Pea-style vents to trap gases
		Effective vent systems (closed areas)
		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 membranes
E.	Specialized Situations	Fresh air vents at elevated levels (METRO)
		Coamings over street-level intake vents (METRO)
		Air intake away from roads (tunnels, METRO)
		Massive barriers with energy absorbing material (runaway trucks)
II.	PREVENTATIVE	
A.	Containment	High performance barrier systems
B.	Control	Truck escape ramps
		Upgrade truck runoffs
		Wide shoulders

- System to mitigate spill consequences.
- Specialized situation.

Preventative are categorized into:

- Containment.
- Control.

6. Conclusions

a. General. It can be concluded from this phase of the study, based on the responses of the large panel representing a broad cross-section of States' concerns, that regulatory type preventative measures dominate suggested solutions. Conversely, it can be concluded that the physical, protective system concept is not applicable as a general preventive or mitigating approach. It is limited to a few site-specific, high-risk situations where the protective system approach is clearly effective and the risk is deemed high enough to offset the cost. This is a policy decision of each State, and this decision is the heart of the practicality criteria.

b. Physical, protective systems. Only one type of protective system (barriers) was arrived at as a result of the study's findings. This type consists of various barriers to contain a hazmat vehicle on or within the roadway to prevent loss of control and going off an overhead facility, off a ramp, into a school yard, etc. Various types of barrier rails designed to contain large trucks would be typical of this category. Truck escape ramps would also fit this category.

All others can be classified as mitigating. This type dominates the responses. It includes categories, such as detection and warning systems, systems to facilitate escape and response, systems to mitigate fire/explosion consequences, systems to mitigate spill consequences, and systems related to highly specialized situations; elevated METRO vents. A few of the physical, protective systems included in table 21 could possibly fit more than one category, but each should fit predominantly into one category. They are so categorized in table 23.

Finally, considering all of the input that was received on developing and ranking protective system scenarios, it is concluded that the key to the guidelines is a manual offering general solutions that should be considered, based on risk guidelines, rather than a design manual that attempts to set forth standards that must be followed.

VII. APPROACH TO DEVELOPING PROTECTIVE SYSTEM SOLUTIONS

A. General

As covered in the previous chapter, several protective systems were suggested by the study panel to prevent and/or mitigate the 11 generalized scenarios. These were categorized, rated, and ranked. The results were presented in table 20.

The results of the study panels' ideas and ratings were presented in detail in the previous chapter. The two most significant conclusions were: (1) regulatory type preventative measures dominated the suggested solutions indicating that they are currently considered the best, or at least preferred approach to preventing and or mitigating high-risk hazardous materials accidents/incidents, and (2) the physical, protective system concept is not applicable at this point in time as a <u>general</u> preventive or mitigating approach to reducing the risk of transportation of hazmat on highway's.

Regulatory approaches were clearly outside of the scope of this study (specifically excluded), and physical protective systems were found to be limited to a few site-specific situations where: (1) the system is clearly effective and (2) the risk is deemed high enough to justify the cost. In other words, they should be cost effective just like any highway improvement.

Two major problems are: (1) the systems, such as in table 20, are, with few exceptions, are untested (never been used) in highway situations to prevent or mitigate risk of hazmat accidents/incidents and, (2) even assuming that adequate data is available to determine the risk at a specific site accurately and precisely, there is no available body of knowledge or guidelines that will guide an administrator in the interpretation of the risk value, i.e., what value is acceptable/unacceptable? What value is high enough to justify expenditure of funds on physical systems to lower this risk?

Another, related problem is in determining the effectiveness of these systems. For the most part, the systems uncovered by the researchers through literature searches and use of the panel are untested insofar as their effectiveness to reduce the risk of hazmat transportation on highways. Only after site-specific systems have been used long enough to develop statistically significant "after" data will the true risk reduction effectiveness by known. Until then, expert judgement is the only way to estimate effectiveness.

B. Philosophy

Contact with the advisory panel and the literature search confirmed that, with few exceptions, no States were using any physical protective systems to specifically address hazardous materials risk on the highway system. The few exceptions were related to systems to address tunnel fires and drainage systems to contain toxic spills. However, most of the latter appeared to be superficial as well as few in number. For example, one containment basin to prevent potential toxic spills relied on manually closing a valve for successful operation. In any emergency, someone had to know how the system worked, located and manually close the valve in time to prevent any toxic material from flowing through the system.

The only extensive and efficient physical protective systems found in the literature are in use in West Germany. A German report documents extensive use of systems to protect potable water supplies.(38) According to the report it is written into German federal law that new highways must: (1) avoid going through water catchment areas if possible or (2) be designed with barriers to keep hazmat trucks confined within the confines of the highway system and closed drainage systems to collect and contain 100 percent of any possible hazmat spill.

The philosophy of hazmat risk reduction found in the German report appears to be a good one and worth considering in the USA. Simply stated it is this: "Do all that is possible to keep trucks carrying hazmat confined within the highway system in accident situations and; do all that is possible to contain all hazmat spills from incidents that occur."

C. Background of Protective Systems Covered

The following section summarizes protective systems that were uncovered in this study. After the panel was used to come up with the systems listed in table 20, a literature search to find highway applications of all of these was undertaken. It was concluded that outside the areas of barrier rail and drainage containment systems there were none readily applicable, i.e., that fit the "practical, feasible and implementable" category.

Many of the highly ranked protective systems in table 8 are not primarily for or readily adaptable to highway systems. Examples of this group are:

- Gas detectors/alarm systems.
- Large sprinkler systems.
- Conduit railing for automatic sprinkling of water.
- Communication and detection systems.

Detection and communication systems that the all panel members suggested and ranked highly are specific examples of protective systems perceived to have great potential but are not designed or built for highway situations nor do they appear to be readily adaptable. These systems are summarized in table 9 and include such items as:

- Explosometers.
- Colormetric indicators.
- TVL (gas) sniffers.
- Spectrometers.
- Interferometers.
- Lidar.
- Thermal sensing.

This list is not all inclusive but these systems are common enough to be known to most advisory panel members but <u>not</u> specifically in highway situations. No examples of specific highway use were mentioned by the panel nor were any found in the literature. Many attempts to communicate with manufacturers, suppliers and sellers of such systems were also futile insofar as finding anyone willing or able to provide any information or adaptation to highway systems, i.e., beyond the typical equpment brochure.

The conclusions of the above are:

1. These systems have potential for risk reduction in highway systems.
2. They are not readily adoptable and need future research and development efforts by any state wishing to adopt them.

The emphasis on protective systems that are included in Volume II: Guidelines are on the practicle impelementable systems. However, automatic detection/communication systems are also included so that states can consider initiating research and development in these areas where their risk justifies such development. In this case, suppliers and manufacturers should be contacted for the latest available information and designers with expertise with these systems should be consulted.

D. Good Design Principles

1. General considerations

Marginal vehicle factors combined with marginal roadway, environmental and human factors often result in accidents. To minimize accidents, future design and maintenance programs will warrant broader shoulders, flatter slopes, longitudinal center barriers, longer acceleration and deceleration ramps, higher frictional surfaces, sufficient traffic control signs and devices, etc. To mitigate the consequences of a spill, highway designers must consider traversable medians, shoulders and other such modifications for easier access to incidents, crossovers and other escape routes, barriers capable of restraining 80,000-lb (36,320 kg) tank trucks, retention and holding basins to contain spills, communication systems for prompt notification of authorities, and response systems such as water sprinklers, foam dispensers, etc., build into or near the highway environment. Automatic monitoring devices to activate warning systems and some mitigating systems need to be further studied.

2. Specific considerations for all vehicles

The items below are not claimed to be a complete list of all possible highway safety measures, nor should they be considered exclusively for hazmat routes. There are examples of common measures to improve safety for all vehicles on all routes, as developed for another project of which author is involved.(39) Safety measures of this type should be given extra consideration on high-risk, hazmat routes. Each State should develop a complete, State-specific list of this nature.

a. Run off road type accidents:

- Effective signing and delineation, especially on horizontal curves.
- Wider lanes, curve widening.
- Higher skid resistances
- Shoulder roughening or rumble strips.

b. Head on collision type accidents:

- Median barriers.
- Wider lanes.
- One way travel or separation of lanes.
- Crash cushions for fixed objects.

c. Rear end collision accidents:

- Access control.
- Longer weaving areas.
- Longer acceleration lanes.
- Climbing lanes for slow vehicles.
- Intersection channelization.
- Improved intersection sight distance.
- Increased surface friction.

d. Angle collisions:

- Access control.
- Intersection channelization.
- Improved intersection signal controls.
- Longer weaving areas.
- Lane delineation.

e. Overturning accidents:

- Improved shoulders.
- Smooth pavement edge joints.
- Flatter embankments ≥ 6:1.
- Wider clear zones ≥ 30 ft (9.15 m).
- Wide, traversible medians or median barrier.
- Impact resisting road barrier.
- Improved curve design.
- State-of-the-art ramp design with longer deceleration lanes and improved delineation.

E. Hazmat Protective Systems

The following sections present examples from the literature of the few currently available, readily adaptable, physical protective systems to reduce the risk of hazmat accidents/incidents on highway systems. Information on some of these systems were taken from several sources; information on others were taken primarily from one source. The information presented below is a brief overview and summary of the important features of each protective system. Greater detail, more useful to States in making a decision to use any of these systems is contained in Volume II: Guidelines.

1. High performance bridge railing systems

a. General: Bridge rails are generally designed to restrain and redirect passenger cars. Collision of large trucks with these bridges, in the past, have resulted in catastrophic accidents. If these trucks are carrying hazardous materials, a potentially catastrophic occurrence is likely. Consequently, concern for reduction in the severity of these accidents has been shown by highway researchers and designers studying containment and redirection of large trucks at selected locations. The results of research and information regarding the design of bridge rails to contain and redirect large trucks are available, albeit limited. Thus, there has been an urgency for researchers to design, build, and test bridge rails that will contain and redirect large trucks. Such research has been carried out by Hirsch, Fairbanks, and Buth.(40) FHWA has a major testing program underway in this area, most of which has been reported in several reports and papers.(40,41,42,43,44,45)

The Texas Transportation Institute (TTI) and the Texas State Department of Highways and Public Transportation's San Antonio office have been studying the unique problems of a tank truck's higher center of gravity. They had been studying the problem since 1976, when an ammonia truck crashed through an upper deck bridge rail on a Houston freeway overpass, overturning and rupturing on a freeway below. Six people were killed, 78 hospitalized, and more than 100 injured. In all 184 casualties resulted. These were mostly motorists who were trapped as the resulting toxic cloud spread down the highway.

Research on bridge rail to keep buses safely directed has also been carried out with encouraging results.(41,44) In general, the objective of most of the research on high performance bridge rail systems has been to select an existing bridge rail system, redesign it and modify or strengthen it to give it the capacity to redirect buses and trucks. Several bridge rails that will remmedy the problem for large trucks have been recently designed and are discussed in the following section.

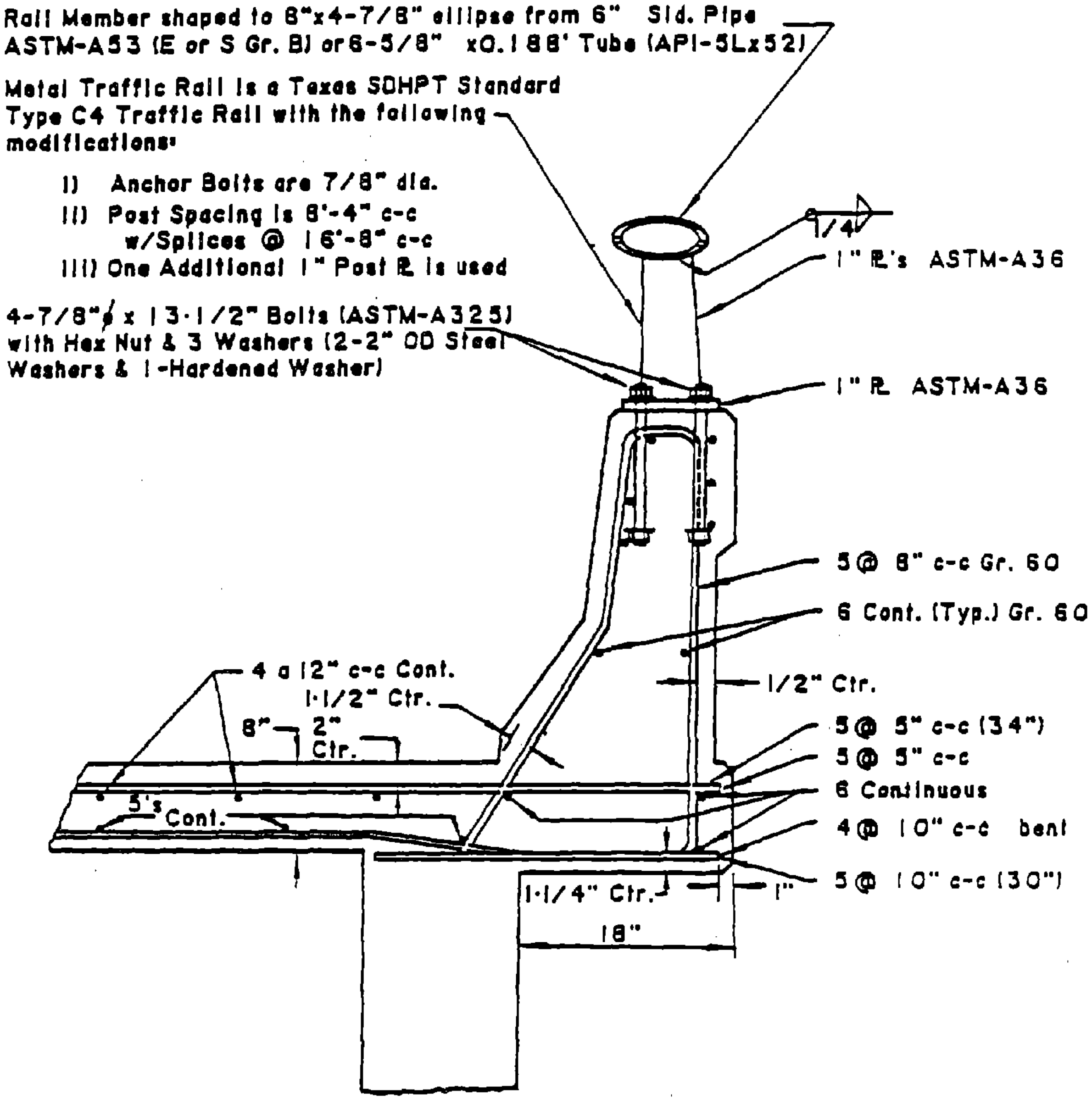
b. Recent development: A bridge rail was designed, fabricated, and tested to contain and redirect an 80,000-lb (36,320 kg) tractor/trailer combination impacting at 15 degrees and 50 mi/h (80.5 km/h).(42) The design was based on data presented in references 42, 43, and 44.

The combination rail selected was a modification of the Texas T5 traffic rail with a modified Texas C4 metal traffic rail mounted on top. The modified T5 bridge rail included a 32-in (81.3 cm) high concrete safety shaped parapet. The concrete parapet was thickened to 10.5 in (27 cm) on top and 20 in (51 cm) on the bottom and contained a large amount of reinforcing steel. This provided both flexibility and strength to minimize cracking of the concrete and permanent deflection of the rail when impacted by heavy vehicles. To minimize cracking and provide greater strength, the thickness of bridge deck below the concrete parapet was increased. Drawings of the rail are shown in figures 6, 7, and 8.

c. Crash test using the modified T5 bridge rail: A simulated bridge deck with this rail system was built at TTI's Proving Grounds and tested with a 1981 Kenworth tractor-trailer filled to 80,080 lb (36,356 kg) with sandbags. Drawings showing the dimensions of this vehicle along with loaded and unloaded weights on each axle or pair of axles are shown in figures 9 and 10.

At 48.4 mi/h (77.9 km/h) and an 14.5-degree angle, the truck impacted the rail 26 in (66 cm) downstream from post 5. The truck was contained and redirected. The truck and trailer did, however, roll 90 degrees and came to rest on its side about 175 ft (53 m) from the impact point. The roll of the truck was attributed to the sloping face of the concrete safety shape. The metal traffic rail was set back 9 1/2 in (24 cm) from the lower face of the concrete shape, 47 1/2 in (121 cm) below. Thus the trailer undergoes a roll angle of 11.3 degrees ($\tan^{-1} 9.5/47.5$) before it contacts the metal rail. In the tests where the redirection face of the rail was vertical, no roll was experienced.(42)

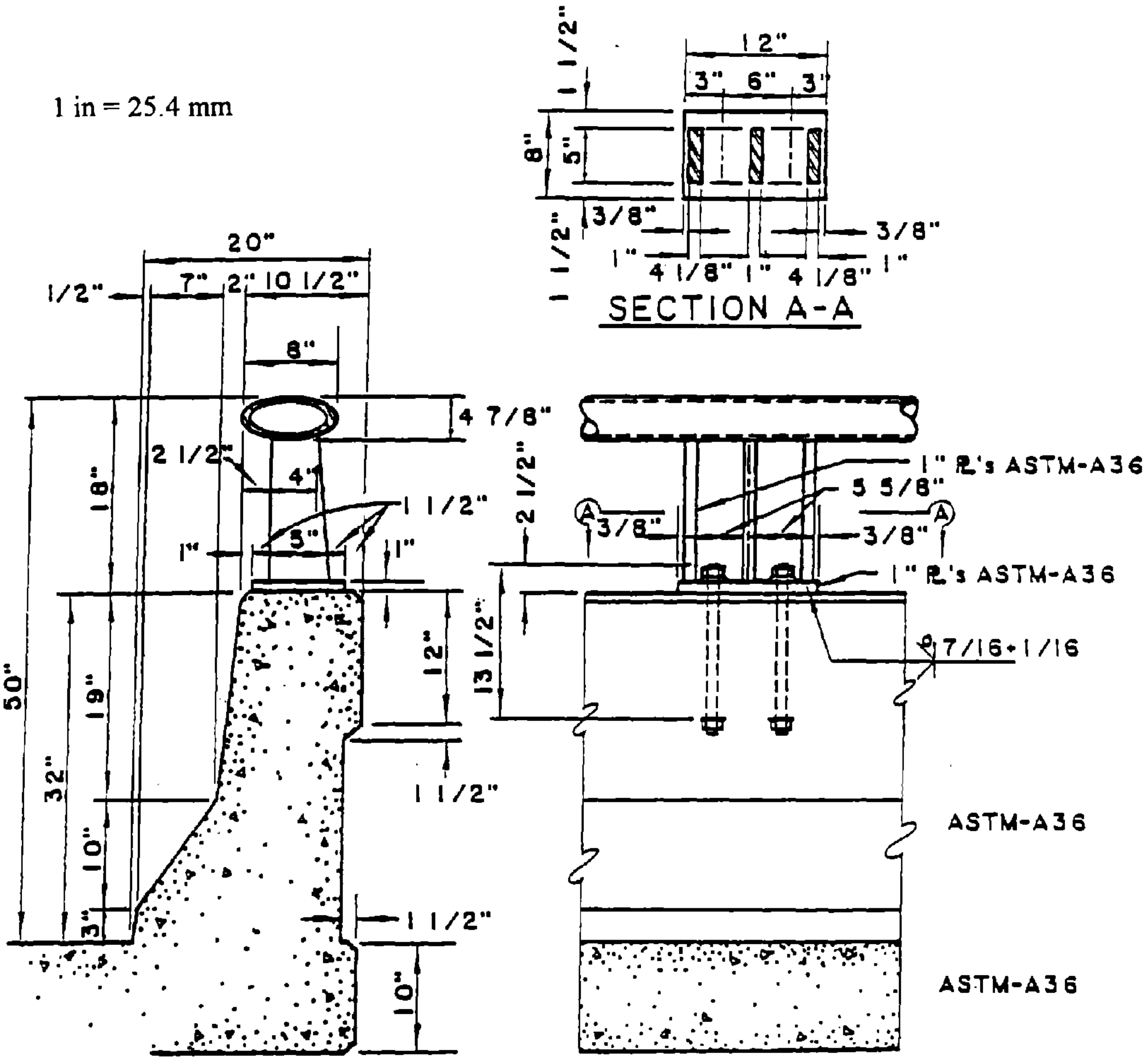
d. Crash test using collapsing ring bridge rail system (CRBRS): Kimball and others developed, designed, and tested a new concept in bridge railing that is known as the Collapsing Ring Bridge Rail System (CRBRS).(46) Even though this system represents an advancement in the state of the art of bridge rail designs, it is constructed with conventional materials and barrier elements that are currently used in highway construction. They made use of Perrone's concept of steel rings as a primary energy absorbing device for the bridge rail system.(47) This rail system was constructed using ASTM A36 steel



1 in = 25.4 mm

Figure 6. Cross section of the modified T5 bridgerail.(43)

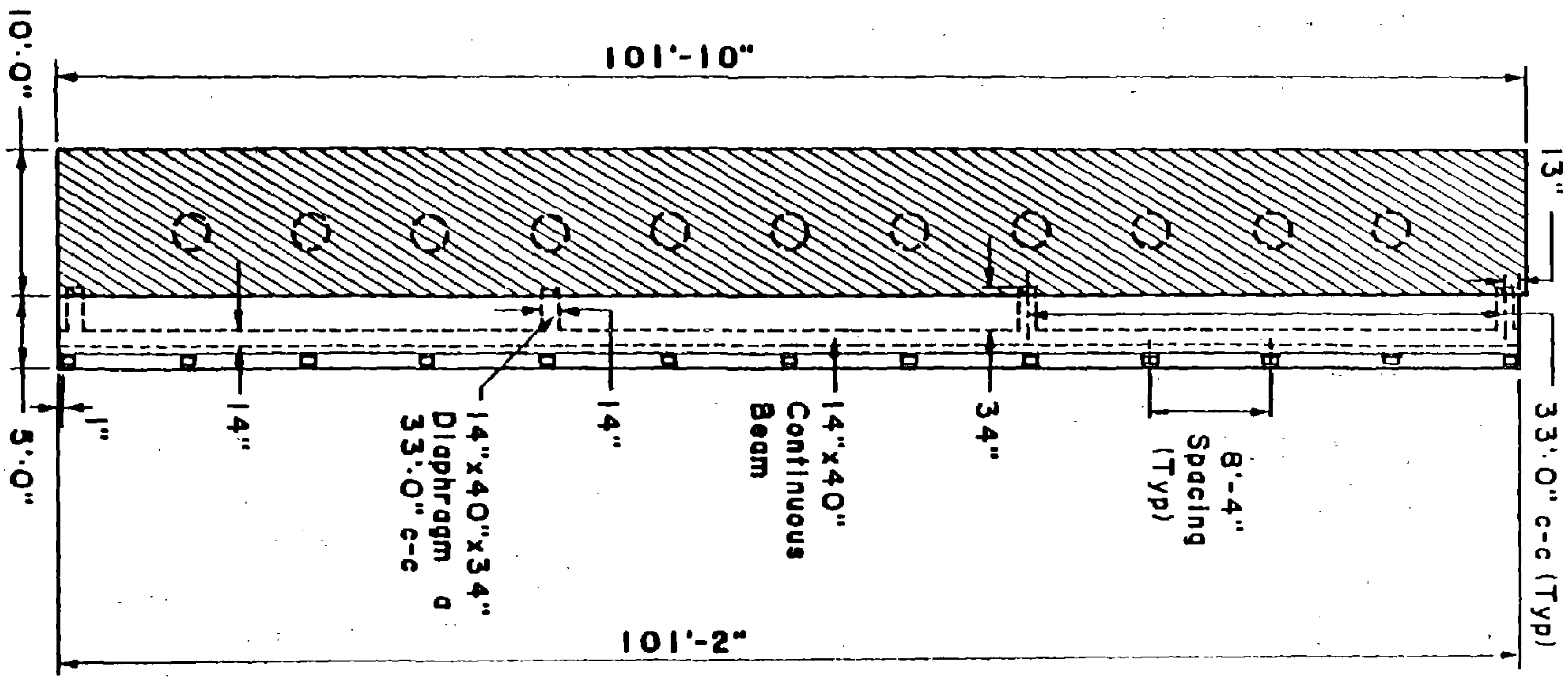
1 in = 25.4 mm



SEC. THRU RAIL

RDWY ELEV. OF RAIL

Figure 7. Dimensions and elevation of the modified T5 bridgerail.[43]

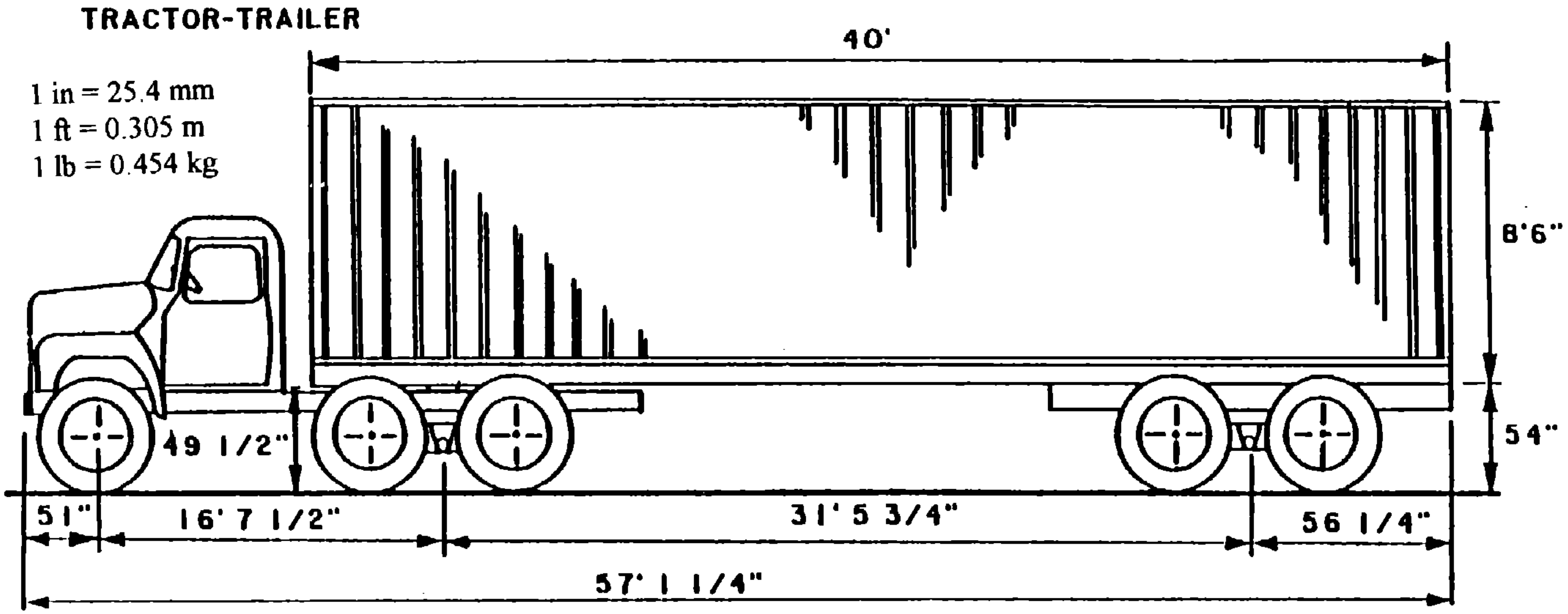


PLAN VIEW

(Metal rail member omitted for clarity)

1 in = 25.4 mm
1 ft = 0.305 m

Figure 8. Plan view of the modified T5 bridgerail. (43)



EMPTY WEIGHTS

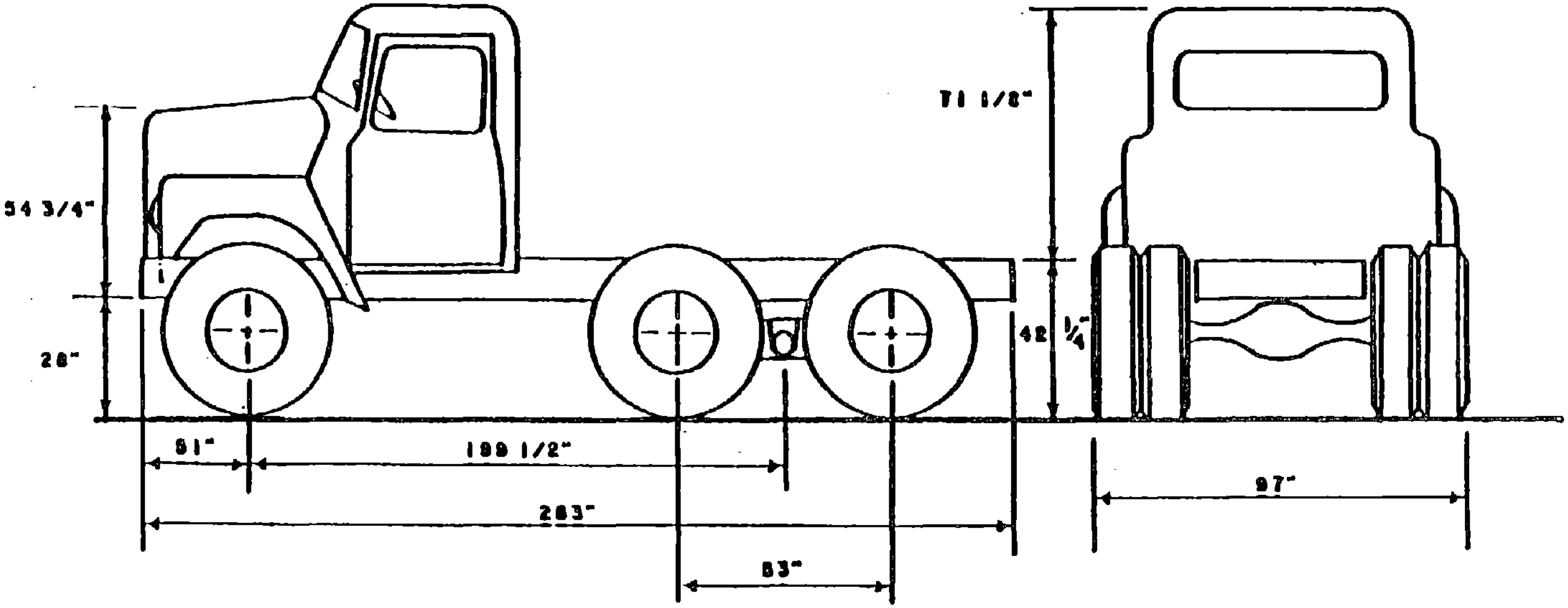
Tractor only	18,320 lbs
Trailer only	13,760 lbs
Total Empty Weight	32,080 lbs

LOADED WEIGHTS

Weights on front axle	12,020 lbs
Weight on Center axles	34,170 lbs
Weight on rear axles	33,890 lbs
Total Loaded Weight	80,080 lbs

Figure 9. Tractor-trailer with dimensions and loaded & unloaded weights. (42)

TRACTOR



EMPTY WEIGHTS

Tractor only	18,320 lbs
Trailer only	13,760 lbs
Total Empty Weight	32,080 lbs

1 in = 25.4 mm
1 ft = 0.305 m
1 lb = 0.454 kg

Figure 10. Empty tractor dimensions and weights. (42)

plate and structural shape and ASTM 500 structural tubing. The most important feature of this design was that it could be quickly repaired by maintenance crew with readily available hand tools. Figure 11 shows a schematic of a CRBR installation during crash testing. Further details can be obtained from reference 47 and in Volume II: Guidelines.

e. Conclusion: The crash tests have shown that:

- A bridge rail can be built with the concrete safety shape on a slightly modified Texas standard bridge deck to contain large van type tractor-trailer trucks.
- The CRBRS is capable of restraining articulated vehicles weighing up to 70,000 lb (31,780 kg)in 45 mi/h (72.5 km/h) 10-degree collisions and 100,000 lb in 57 mi/h (91,8 km/h), 16-degree impacts.

2. Influence of the Geometric Design of Highway Ramps on the Stability and Control of Heavy Duty Trucks

a. Introduction: The possibility of a catastrophic, hazardous materials accident/incident on ramps must be given serious attention for several reasons: (a) truck accident rates and hazardous materials incident rates are generally higher at ramp locations; (b) in urban areas, large or sensitive populations could be exposed; and (c) it is a correctable situation. Good geometric design to reduce accidents, together with the use of barrier rails to mitigate the consequences, may reduce both risk and consequences significantly in some cases.

According to Ervin, MacAdam, and Barnes, accidents experienced by tractor-semitrailers on expressway ramps were found to depend largely on interaction between highway geometrics and vehicle dynamic behavior.(48) As a part of their study, 14 individual ramps in 5 States exhibiting an unusual incidence of serious accidents involving these vehicles were selected. A computer simulation defined the geometrics of each ramp in such a way that the dynamic behavior of tractor-semitrailers could be examined. The study indicated that the maneuvering limits of certain trucks are quite low relative to those of automobiles. The study concluded that current practice in ramp design leaves an extremely small margin for the safe control of heavy vehicles.(48)

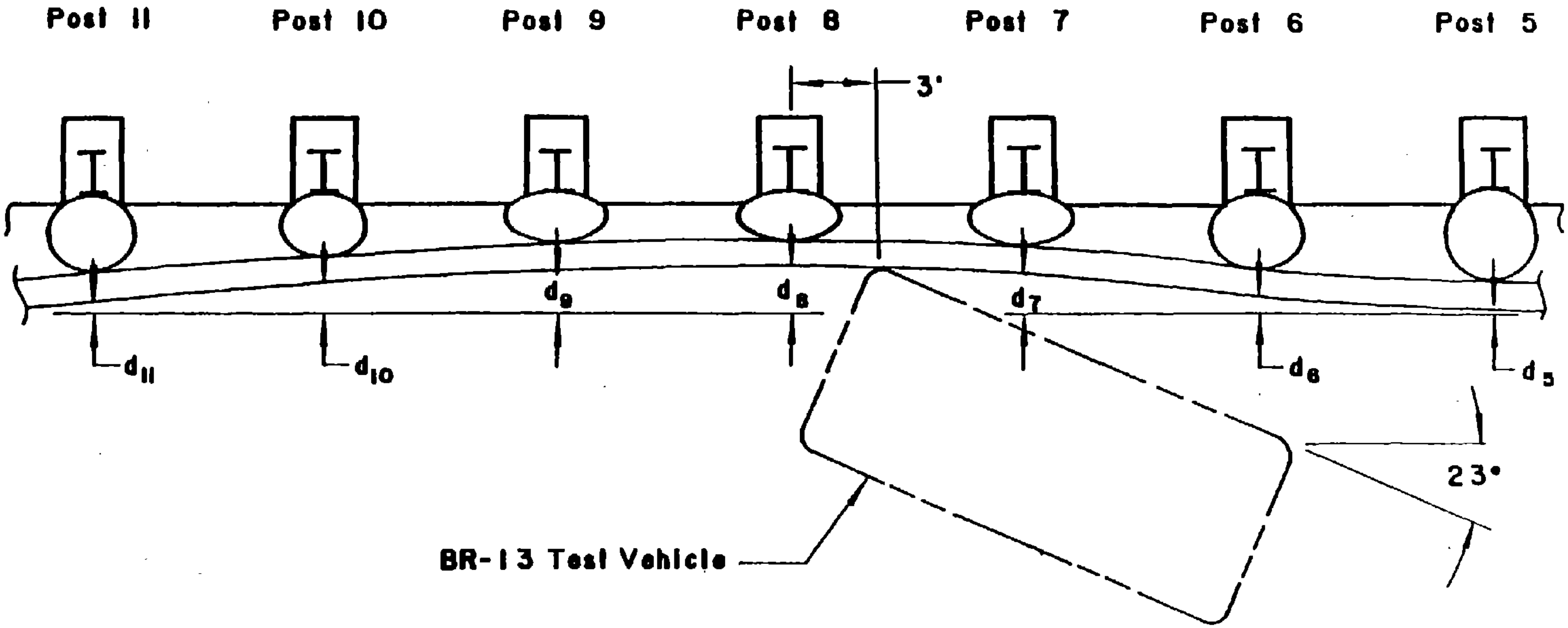


Figure 11. Schematic of crash test BR-13. (46)

Highway ramp design varies widely around the country, and when considering the margins of safety that existing ramps provide for the operation of heavy duty trucks, it is immediately apparent that the considerations underlying ramp design recommendations in the AASHTO design manual make little or no allowance for the special requirements of trucks.(49) This situation differs from the specific attention given to truck requirements in other areas of road design, such as climbing lanes, the width of turning roadways, corner radii at intersections, and certain sight distance considerations. Thus, because of variations in design that exist from one ramp to the next, and because the recommended design policies take no particular note of truck stability and control limits, it appears to be reasonable for the planner/designer to explore the conflicts trucks may encounter in negotiating highway ramps.

The accident record for trucks in general gives an impetus for such concern. For example, the 1980 accident file of OMC shows that 9 percent of all jackknife accidents and 16.8 percent of all truck rollovers occur on ramps. A ramp accident study specifically on trucks has not been performed, but some studies have found trucks to be underinvolved in the population of all aggregated ramp accidents relative to their presence in the traffic stream.(50) However, the indication in the OMC data is that trucks are over-involved in loss-of-control accidents on ramps, which suggests that the main problem trucks experience on ramps is that of controllability, while the potential for collision accidents involving trucks on ramps may be no worse, nor better, than that of other vehicles.

An FHWA project was conducted to examine the truck controllability problems on ramps and to relate them to geometric design. The individual accident reports from each ramp were examined closely to locate the approximate point on the ramp at which the loss-of-control events appeared to be occurring. Specific curves or transition areas on each ramp were given special attention. A comprehensive simulation of the dynamic behavior of heavy-duty trucks was carried out, and the inputs to this were the geometric data needed to completely define the curvature, superelevation, and grade of each ramp section of interest.(51)

Each of the selected ramps was examined by means of the simulated operation of tractor-semitrailers represented in two loading conditions: (a) a baseline loading placing the payload c.g. at 83 in (2.11 m) above the ground; and (b) a loading case with a payload c.g. at the height of 105 in (2.67 m).

The tractor-semitrailers were simulated at various speeds, and the motion response of the vehicle was then interpreted in terms of a likely loss-of-control outcome. Also, from accident reports, one can conclude that many truck drivers tend to take ramps too fast for many reasons.

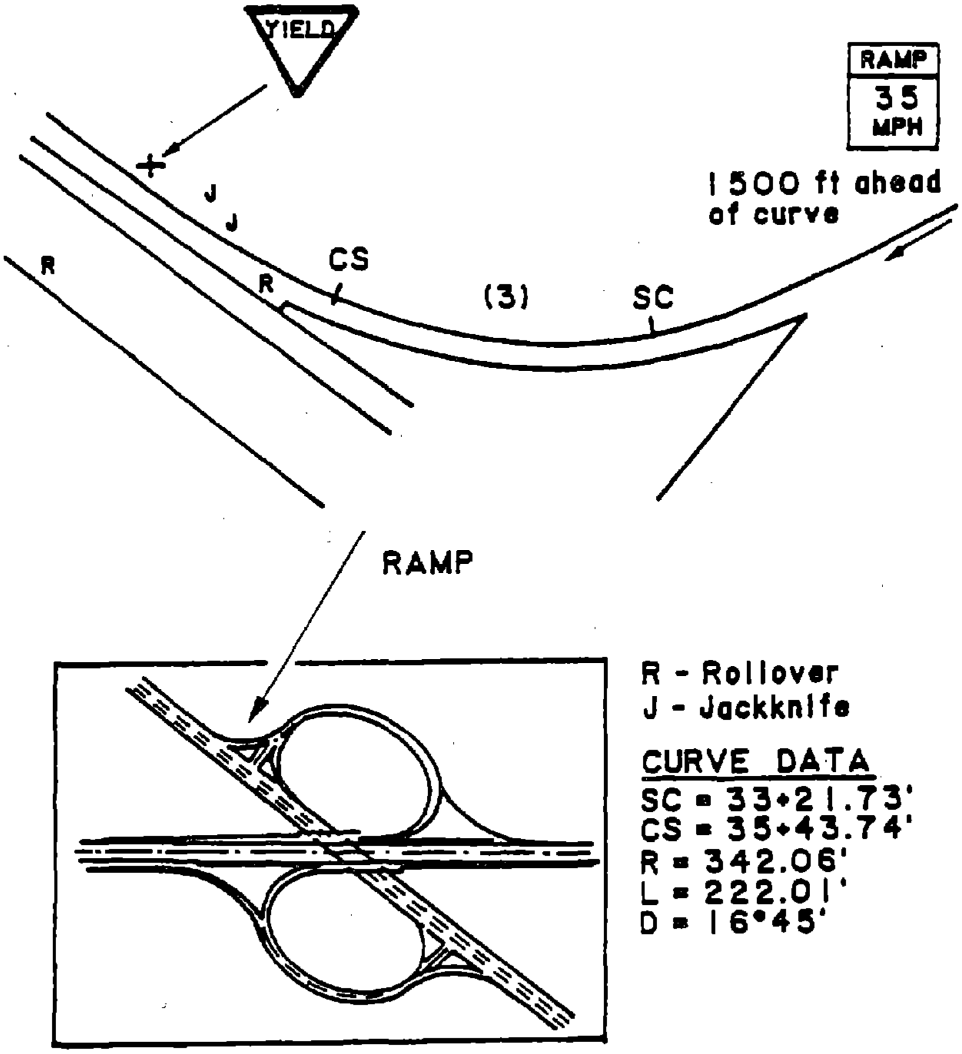
A summary of reports on a study of accidents experienced by tractor-semitrailers on expressway ramps follows. These accidents depend largely on the interaction between highway geometrics and vehicle dynamic behavior.

The results of a combined study of accident data, simulated vehicle response, and geometric details of ramp design indicate that maneuvering limits of certain trucks are quite limited relative to those of automobiles, and, therefore, current practice in ramp design leaves an extremely small margin for the safe control of heavy vehicles. The design policies that currently exist take no particular note of truck stability and control limits, which may be the main problem trucks experience on ramps.

Five cases were presented in detail in the FHWA report, with each case being characterized by the particular aspect of ramp design that appears to be connected with truck control problems of interest.(48)

- Case 1 pertains to excessive side friction factors given the roll stability limits of many trucks. (Figure 12)
- Case 2 deals with the assumption by truckers that a ramp advisory speed does not apply to all curves of a ramp. (Figure 13)
- Case 3 involves the deficiency in the deceleration lane lengths resulting in excessive speeds at the entrance of sharply curved ramps. The consequence of this is a roll-over or jackknife accident. (Figure 14)
- Case 4 deals with the sensitivity for hydroplaning on high-speed ramps. Heavy duty vehicles are known experience loss of control on wet pavements. (Figure 15)
- Case 5 deals with an obstacle--curbs placed on the outer sice of curved ramps--that may trip and overturn articulated truck combinations. (Figures 16 and 17)

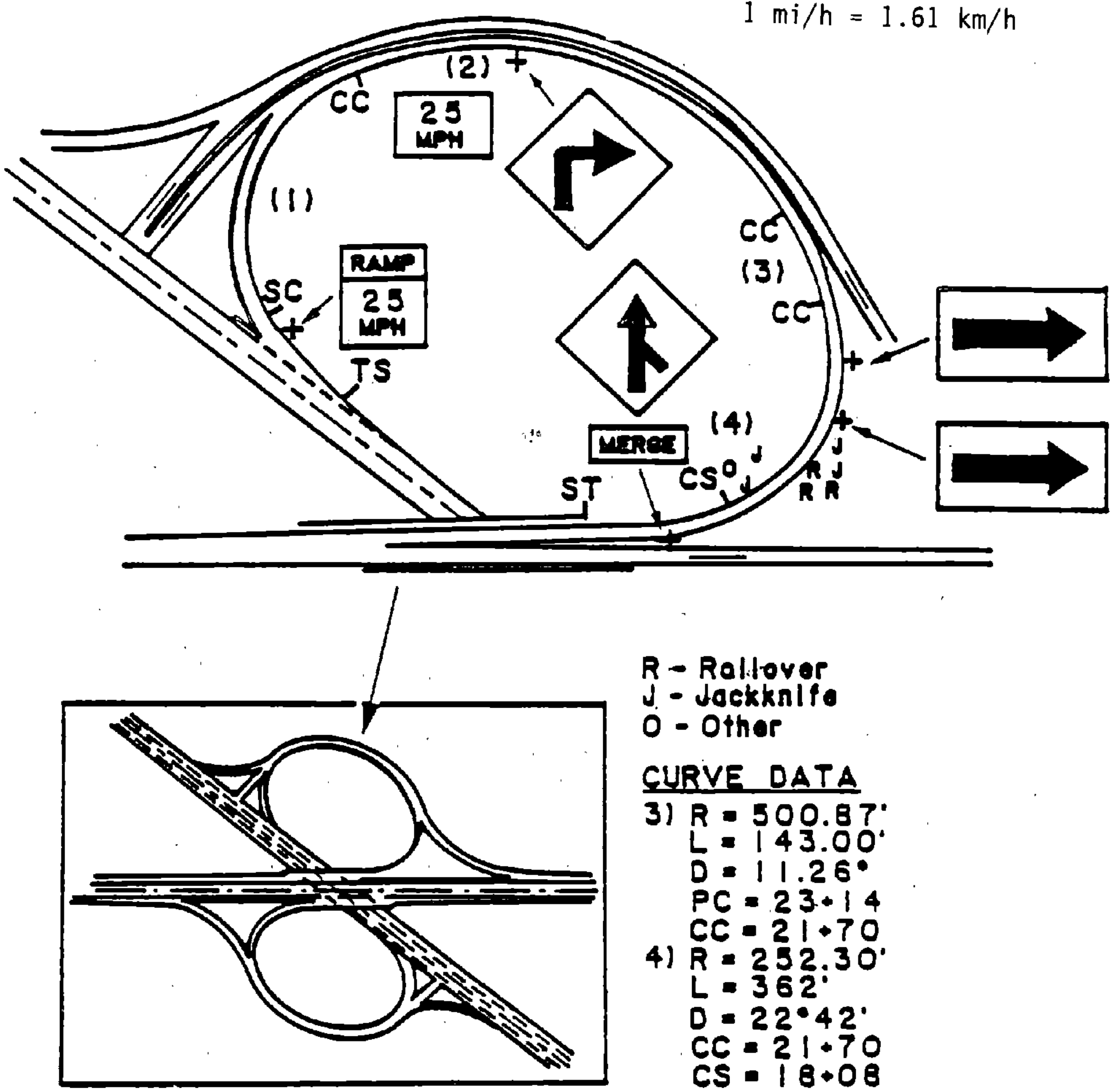
The above cases fall either into the category of inherent limitations in truck stability and control or into the category into which truck driver behavior appears to frequently involve peculiar misjudgments. Details of



1 ft = 0.305 m

Figure 12. Layout of a site that poses a challenge to the truck-roll stability level.[48]

1 ft = 0.305 m
1 mi/h = 1.61 km/h



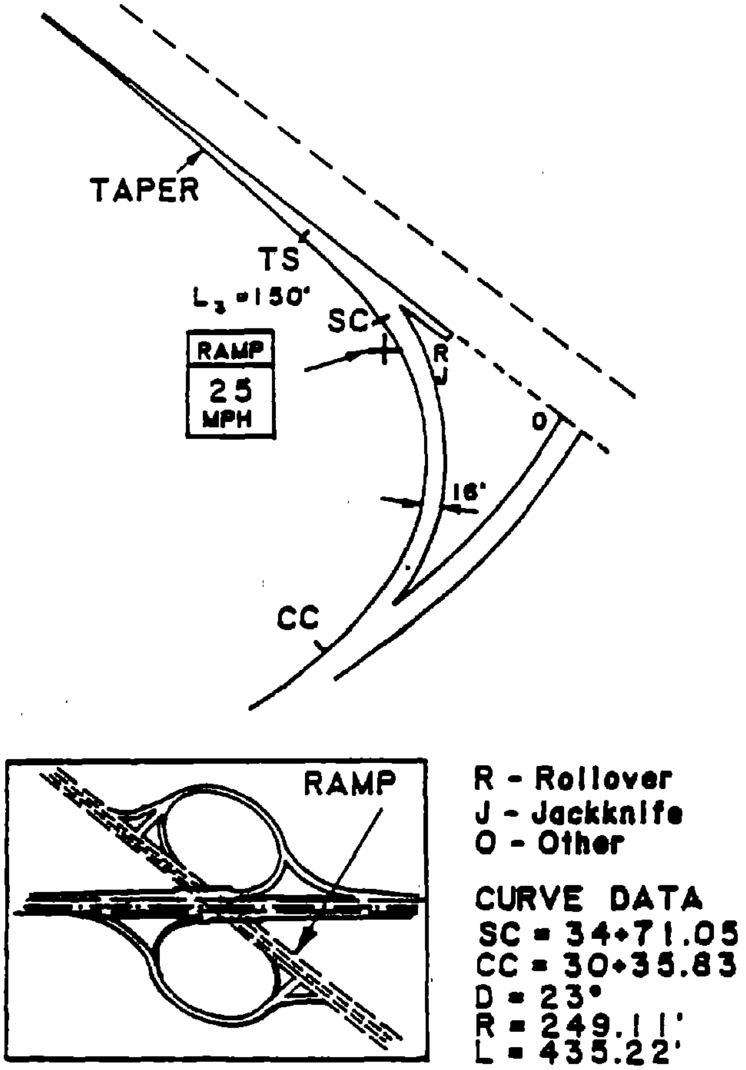
R - Rollover
J - Jackknife
O - Other

CURVE DATA

3) R = 500.87'
L = 143.00'
D = 11.26°
PC = 23+14
CC = 21+70

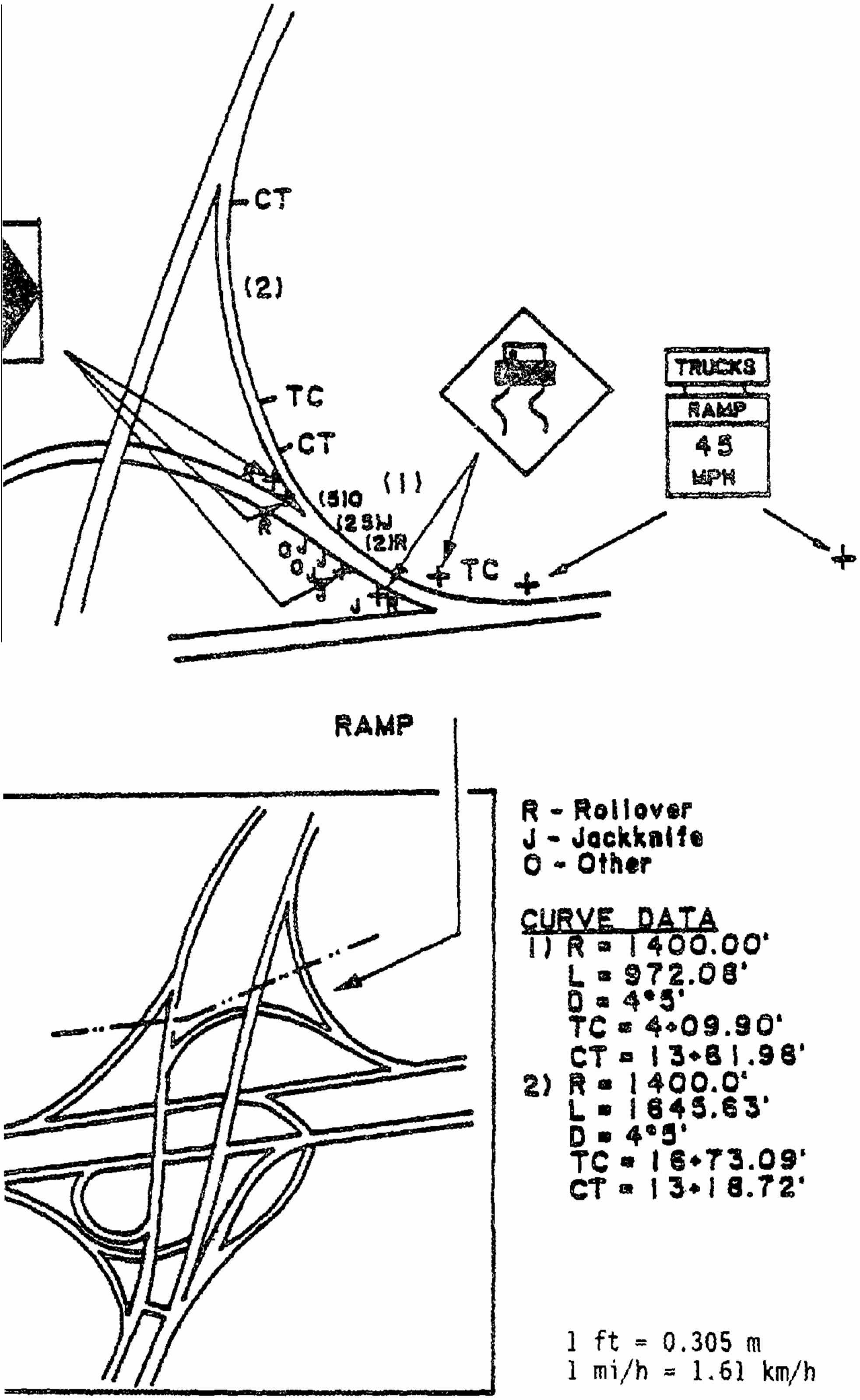
4) R = 252.30'
L = 362'
D = 22°42'
CC = 21+70
CS = 18+08

Figure 13. Layout of compound curve ramp.(48)



1 ft = 0.305 m
1 mi/h = 1.61 km/h

Figure 14. Layout of ramp with tapered deceleration lane.(48)



Layout of curved ramp site at which numerous loss-of-control

1 ft = 0.305 m
1 mi/h = 1.61 km/h

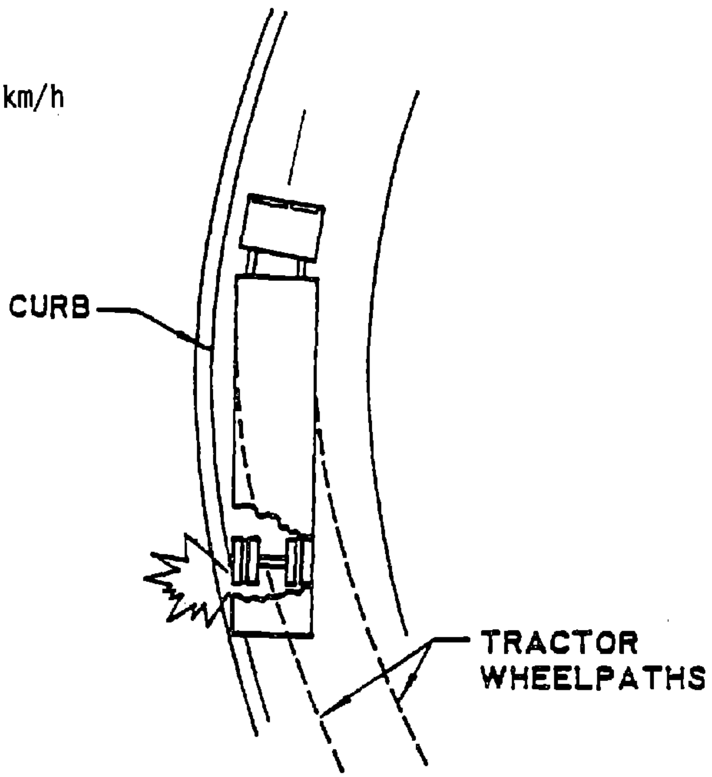


Figure 16. Outboard off tracking of semitrailer that leads to contact between trailer tires and an outside curb.(53)

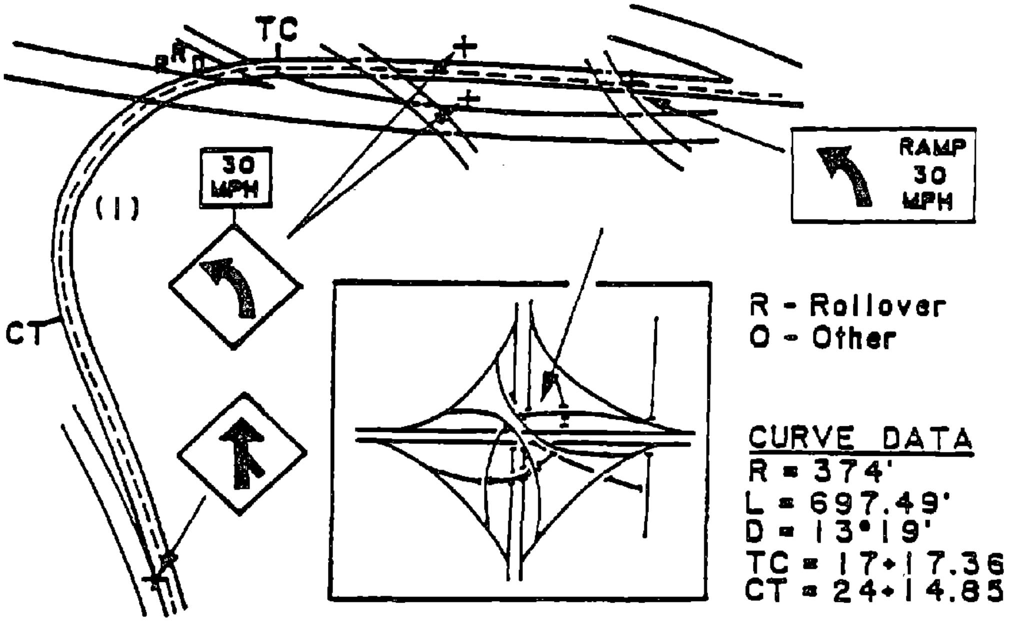


Figure 17. Layout of a typical ramp on which curb-contact accidents often occurred.(48)

these cases and their design implications are presented in Volume II: Guidelines.

3. Entrance and exit ramps design considerations for emergency use

a. General considerations: In situations where median openings are not provided over long distances, a hazardous material accident response team may have to bind its way to the accident site by making us an entrance or exit ramp. Such a step may also be beneficial if the response team is stationed closer to a highway exit/entrance ramp. Use of an entrance/exit ramp by the response team may also be necessary when an accident involving hazardous material leads to a traffic jam.

Upon entering a highway, the movement of the response team could be in any one of the following directions (see figure 18):

(a) For entrance through an exit ramp--
    (1) Movement in the opposite direction of oncoming traffic.
    (2) Movement in the direction of traffic.
(b) For entrance through an entrance ramp--
    (1) Movement in the direction of traffic.
    (2) Movement in the opposite direction of oncoming traffic.

Cases (a)(1) and (b)(1) would be possible without any design modification. However, special design considerations will likely be necessary to make cases (a)(2) and (b)(2) feasible. Design for these cases would mainly involve widening of curves along with proper radius of curvatures, shown in the shaded portion in figure 20. Negative superelevation at these points for a "wrong-way" movement could be another point of concern, but at a low turning speed of about 1 mi/h (1.61 km/h) around these curves, the superelevation problem could be assumed to be insignificant. Emergency response vehicle drivers should be aware of this condition, using caution and limiting their speed.

2. Geometric design for curve widening/radius of curvature for minimum turning paths of design vehicles

The principle dimensions affecting design are the minimum turning radius, the tread width, the wheel base, and the path of the inner rear tire.(49) Effects of driver characteristics, such as the rate at which the driver approaches centripetal acceleration and the slip angles of wheels, are minimized by assuming that the speed of the vehicle for the minimum radius (sharpest) turn is less than 10 mi/h (16.1 km/h).

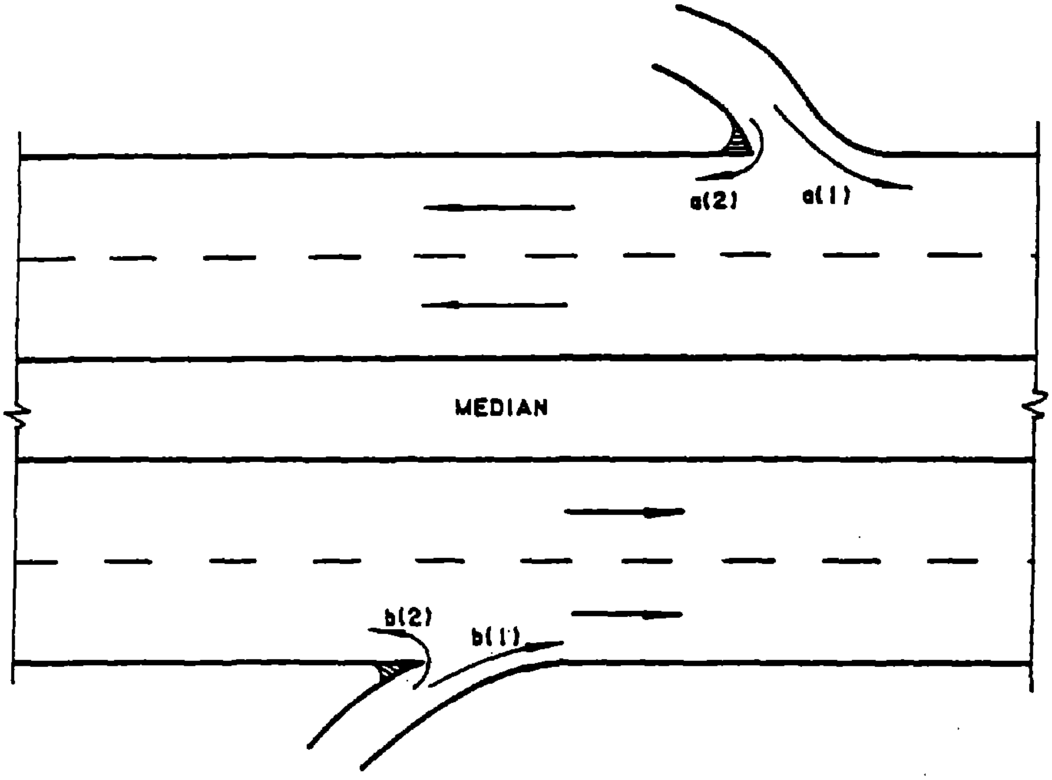


Figure 18. A sketch of the possible, desirable directions of travel for emergency vehicles.

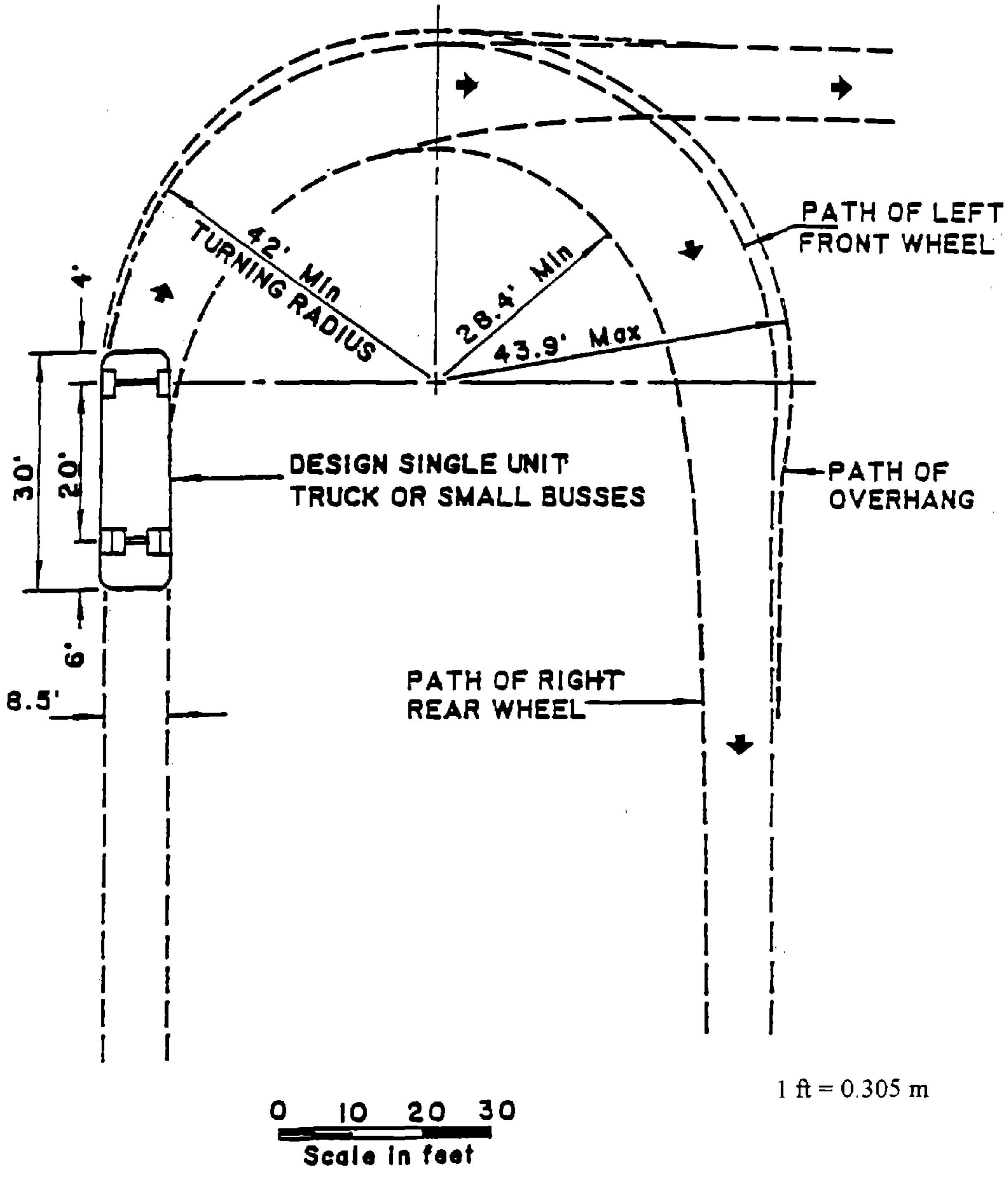
The boundaries of the turning paths of a design vehicle when making the sharpest turns are established by the outer trace of the front overhand and the path of the inner rear wheel. This assumes that the outer front wheel follows the circular arc defining the minimum turning radius as determined by the vehicle steering mechanism. The dimensions in this report are for single unit trucks. The minimum radii of the outside and inside wheel paths are given in table 24. Figure 19 is a sketch showing the minimum turning dimensions for a single unit truck, and figure 20 shows the minimum width of pavement required at turning for such a vehicle. A check of the type of emergency response vehicle in each area should be made to verify that the single unit design vehicle template is adequate. If not, it will have to be modified because it is possible that an emergency vehicle with a unique turning path may require other specific dimensions.

The proposed geometric modifications for emergency entry of a hazmat response truck through an exit ramp and moving in the direction of flow is shown in figure 21. These dimensions are in accordance with standard design

Table 24. Minimum turning radii of design vehicles.(49)

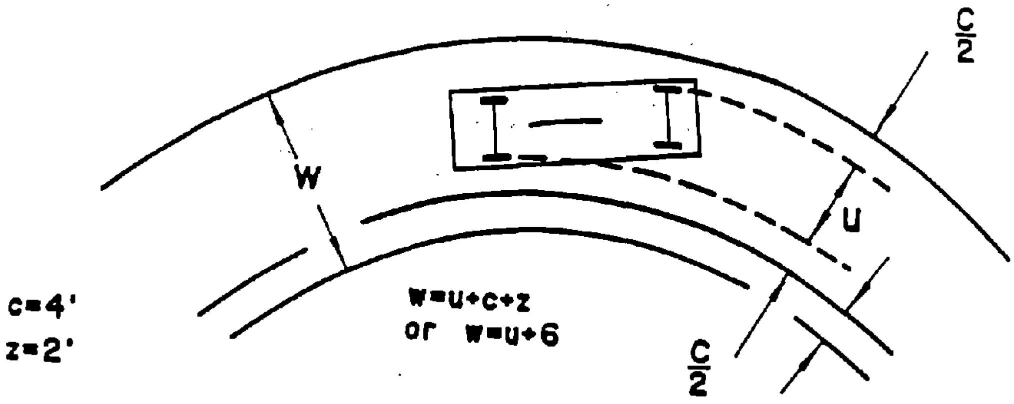
Design Vehicle Type	Passenger Car	Single Unit Truck	Single Unit Bus	Articulated Bus	Semi-trailer Intermediate
Symbol	P	SU	BUS	A-BUS	WB-40
Minimum turning radius (ft)	24 (7.32)	42 (12.8)	42 (12.8)	38 (11.6)	40 (12.2)
Minimum inside radius (ft)	15.3 (4.7)	28.4 (8.7)	23.2 (7.1)	21.0 (6.4)	19.9(6.1)

Design Vehicle Type	Semi-trailer Combination Large	Semi-trailer Full-trailer Combination	Motor Home	Passenger Car with Travel Trailer	Passenger Car with Boat and Trailer
Symbol	WB-50	WB-60	MH	P/T	B/B
Minimum turning radius (ft)	45 (13.7)	45 (13.7)	42 (12.8)	24 (7.3)	24 (7.3)
Minimum inside radius (ft)	19.8 (6.0)	19.8 (6.0)	28.4 (8.7)	5.5 (1.7)	10 (3.1)



1 ft = 0.305 m

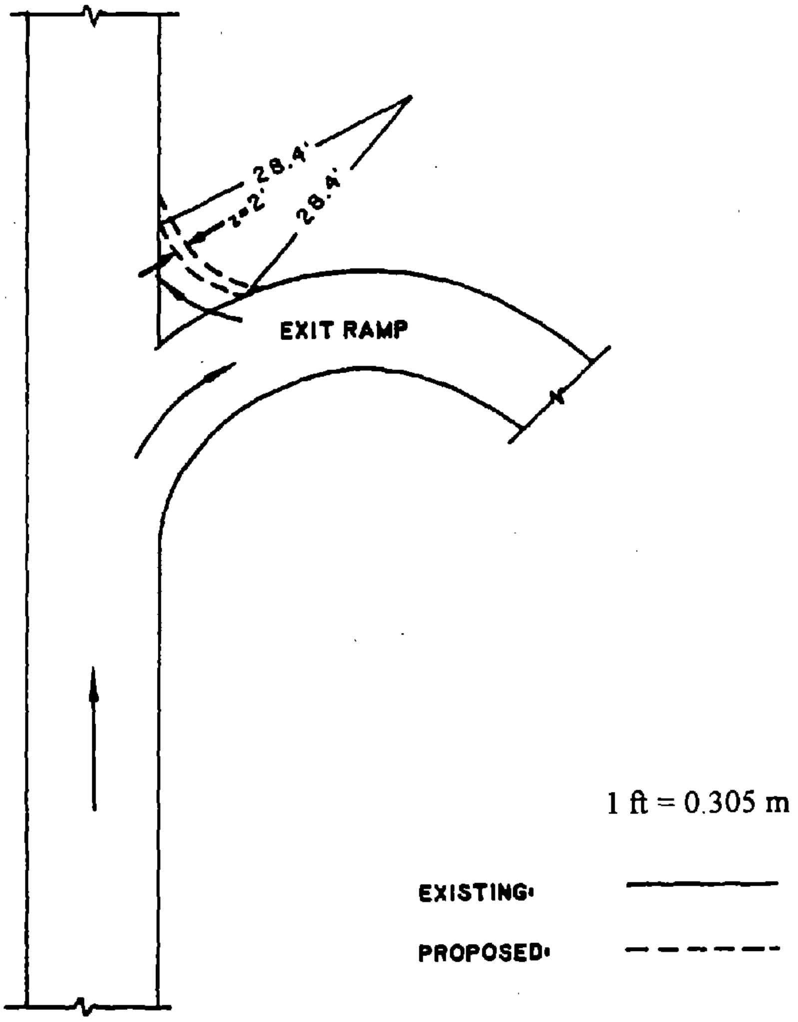
Figure 19. Minimum turning path for a single unit design vehicle.(49)



ONE-LANE, ONE-WAY OPERATION-NO PASSING

1 ft = 0.305 m

Figure 20. Details of curve width required for a single unit design vehicle.[49]



NOTE: THE DIMENSIONS SHOWN ARE THE MINIMUM REQUIREMENTS.

Figure 21. Details of turning radii for emergency vehicles based on a single unit design vehicle.

practice. However, the extra width allowance because of the difficulty of driving on curves is not mandatory in this case, as the vehicle will have enough space for its maneuver on the left side. In the figure, the existing systems are shown by continuous lines, and the dotted lines represent proposed reconstruction.

4. Alinement, construction, and maintenance of highways in water catchment area

a. Background: This section is based on a German report on protecting potable water supplies.(38) This study is important because it is the only one found in the literature specifically addressing mitigation of hazmat runoff into potable water supply areas and sensitive environmental areas.[9] It is important to consider the concepts summarized in this report because of much stricter policies and laws protecting water supplies in Germany. The concepts give the reader insight into what would be required to implement a policy of full containment; i.e., a design to keep hazmat carrying vehicles within the highway right-of-way in case of an accident and a closed highway drainage system such that any water-contaminating material spilled in a release would be fully contained to avoid reaching water supplies. Greater detail related to design principles is presented in Volume II: Guidelines.

It is written into German law that highway alinement must avoid designated, sensitive water catchment areas (any part of the watershed feeding a potable water supply) if at all possible. If this is not possible, then the highway must be designed to ensure that hazmat carrying vehicles having an accident will be contained within the right-of-way by barrier rail, berms, etc., and, in the case of a spill occurring (incident), the spilled material will enter some closed drainage system that prevents any material from entering the water supply by surface runoff or ground water transport.

The German report is quite lengthy and not available in English. Thus, presenting its main points here should be of value. However, any State with these problems should probably obtain the report and have it fully translated. Only select sections of the German report were translated. Although every attempt was made not to do so, it is possible that some points were misinterpreted or taken out of context.

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[9] The only study of this nature in the United States was a study of such a closed system by the Rhode Island Department of Transportation (RIDOT) to determine the feasibility of building a 2-mi (3.2 km) section of U.S. Route 6 across the Situate Reservoir. After determining the cost of such a system, it was decided that the cost was excessive, and it was not built.(52)

When considering protective systems to protect water supplies or sensitive environmental areas, the danger of water contamination due to traffic can be divided into two groups:

- The main result of the traffic caused by the accumulative contamination of a highway surface by exhaust fumes and oil leakage from vehicle engines, as well as particles from the abrasion of the road surface and tires.
- The unpredictable contamination based on type, location, and proportion of incidents where water-hazardous material is released.

The latter group is of primary concern in this report.

The German report separates protective measures into two groups: (a) active measures that directly stop the contamination of the highway surface as much as possible; and (b) passive measures that slow down or eliminate the consequences of contamination.

Active measures include those that reduce the normal vehicle contamination as well as minimize contamination from spills. The term "active" and "passive" may not be the best English words from the translation, but they would relate well to the terms "preventative" and "mitigating," respectively, used earlier in this report to differentiate protective systems that prevent contaminating materials (including hazmat) from being on the road surface, or mitigate the consequences given that they are present on the road surface. The German report emphasizes good alinements to control these (all the principles that apply to a smooth, safe ride).

Areas where protective systems should be used are clearly indicated when a spill could cause long-term damage to a potable water supply or a sensitive environmental area. In addition to good design and construction practices in general, measures must be taken for highways on dams and/or elevated areas. The side slopes should be constructed as shallow as possible. Barrier rails should to be incorporated along the median and shoulders.

For highways in low lying areas, the permissible thickness of natural soil left above groundwater depends upon the geological formulation and on hydrological conditions of the subsoil. The roadbed has to be planned in such a manner that a sufficiently thick upper layer of soil cover remains above the groundwater. There are no appropriate general thickness values known to the authors. Studies of specific materials and soil types should be made because research is needed on this subject. In cases where judgment concludes that a sufficient upper layer or soil cover does not exist, the subsoil has to be sealed up to a required thickness by constructing a watertight protection layer made of impervious material.[10] The German report recommends 23.6 in (60 cm).

Rainwater that drains from slopes should be collected in impervious ditches and channeled into controlled highway runoff facilities. The soil in the ditches and the soil areas between these and the roadway should be sealed with an impervious soil blanket at least 23.6 in (60 cm) thick. On bridges, pipes should be used to collect and channel runoff to properly designated receptors.

b. <u>Mitigation by containment procedure</u>: The remainder of this chapter will concentrate on physically containing or mitigating the consequences of hazmat spills. The chemical interactions of water and hazardous materials and mitigation by chemical reactions are beyond the scope of this report. Hazmat may be in the form of a solid, liquid, or highly volatile material or gas. The case of a solid on the ground is fairly easy as it involves only scooping up the substance and transporting it to a disposable area. However, this must be done by experienced response personnel in accordance with all existing regulations.

To contain hazardous vapors in the atmosphere is almost impossible, and stopping the leak as quickly as possible is the only logical approach. Again, officials in charge of coordinating State response should be consulted.

Many hazmats are heavier than water or soluble. In the case of soluble materials, the only practical approach would be containment by holding tanks of reservoirs of adequate capacity that can be isolated from regular storm drains should a spill occur. Grease trap sedimentation basins installed at the junction of secondary drainage network systems can effectively take care of removing substances that are heavier than water. Such a system is shown in figure 22.

Petroleum oils are the most likely hazmat to be spilled. Most petroleum oils float on water and are highly insoluble. These oils are easily separated. There are several different configurations of oil separators. A basic decision in sizing the basin is to decide on the amount of a hazmat spill during a rainstorm.

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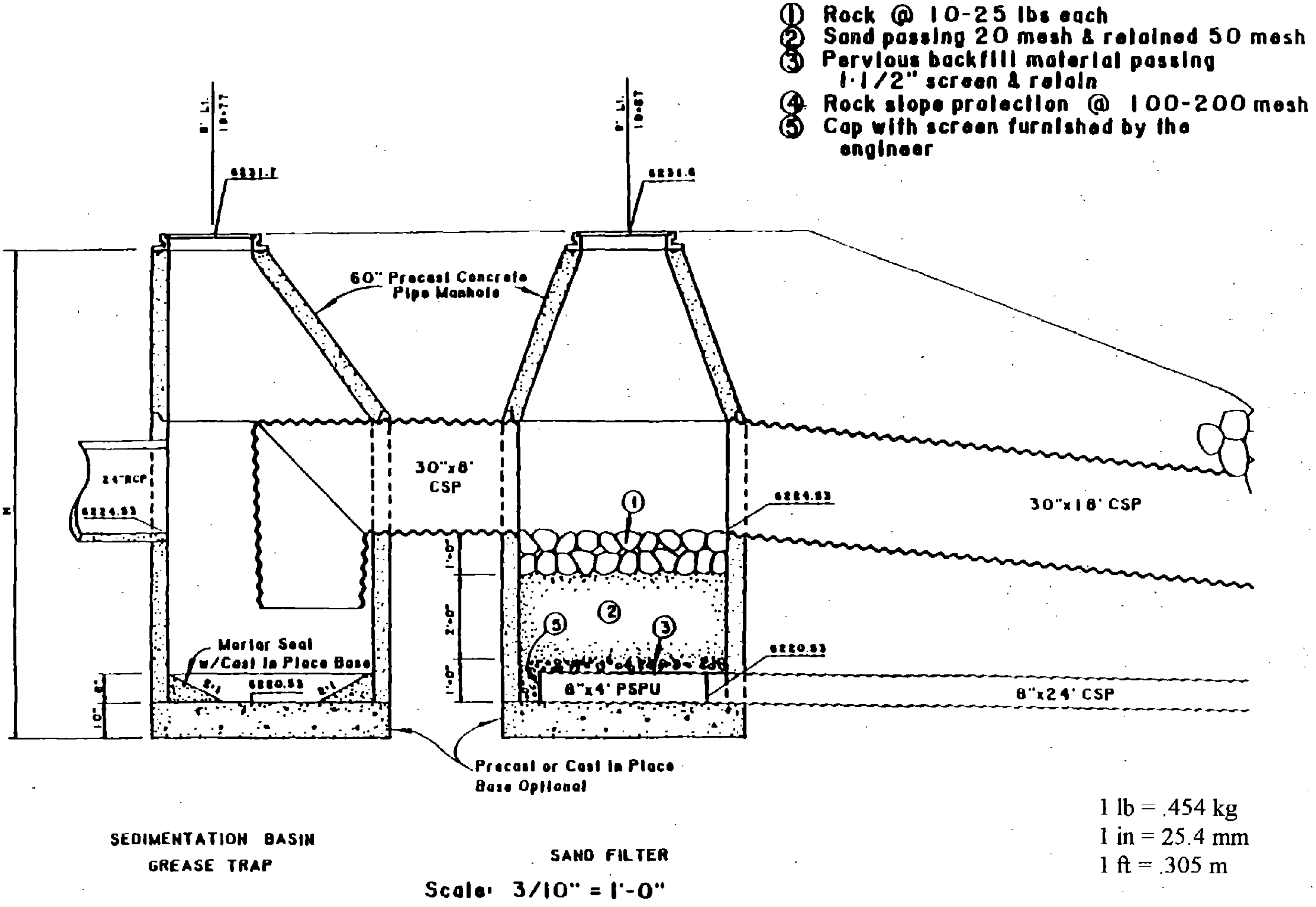
[10] The thickness needed would depend on the rate of perculation of the soil and how many days were considered safe before the infiltrating liquid reached the groundwater, a function of anticipated response time to correct the situation.



1 lb = .454 kg
1 in = 25.4 mm
1 ft = .305 m

Figure 22. Sedimentation basin with grease trap and sand filter.(53)

The sections of an oil separator are shown in figure 23. In regard to oil separators, the volume that maintains a given increase in velocity is used. In the case of a basin designed for retaining rain, the storage capacity needes is the water quantity that results from maximum difference between inflow and outflow.

The construction of a rain overflow in an urban area is related to case la of figure 24. Two possibilities of using the basin to retain a design rainfall are present in the case to retain oil: (1) construction of a submerged wall, or (2) a series connection of basin and oil separator. The latter case has the advantage that the oil separator is subject to a fixed maximum reduction in quantity of flow and thus could be designed smaller.

Also, it would be advantageous to have a good estimate of the amount of material spilled, considering the type of damage to the vehicle, and its capacity. No reliable data is available on spill quantities on U.S. highways. The German study concluded that less than one-half of the contents of a single tank compartment leaks out in the average incident (less than 500 gal (1892.5 L)). Research is needed to get a reliable figure for U.S. tank trucks.

When dealing with hazardous materials that are water soluble, oil separators and sedimentation basins, etc., are not effective. In such cases, the material has to be prevented from entering the water reservoir by providing drains that lead to a separate holding basin.

c. Example of an environmental protective system on bridges over waterways: An attempt was made to find examples where protective systems were installed in the United States specifically to mitigate hazmat liquid spills. Only one was found, in North Carolina, with minimal details available in its report.(54) Telephone contact was made with a designer, but no additional details were available. It appears to be a case where the designers knew the system was less than perfect but better than nothing. The biggest weakness of the system is having a manual shut-off valve.

The State decided that this project would be an ideal pilot project for the design and incorporation of pollution control measures on bridges over environmentally sensitive waters. The proposed bridge will be 30 ft (9.2 m) wide, with an estimated length of 300 ft (91.5 m), and of cored-slab, flat-deck concrete construction without weep holes, thus preventing bridge runoff from flowing directly into the river. Instead, runoff will be directed to two

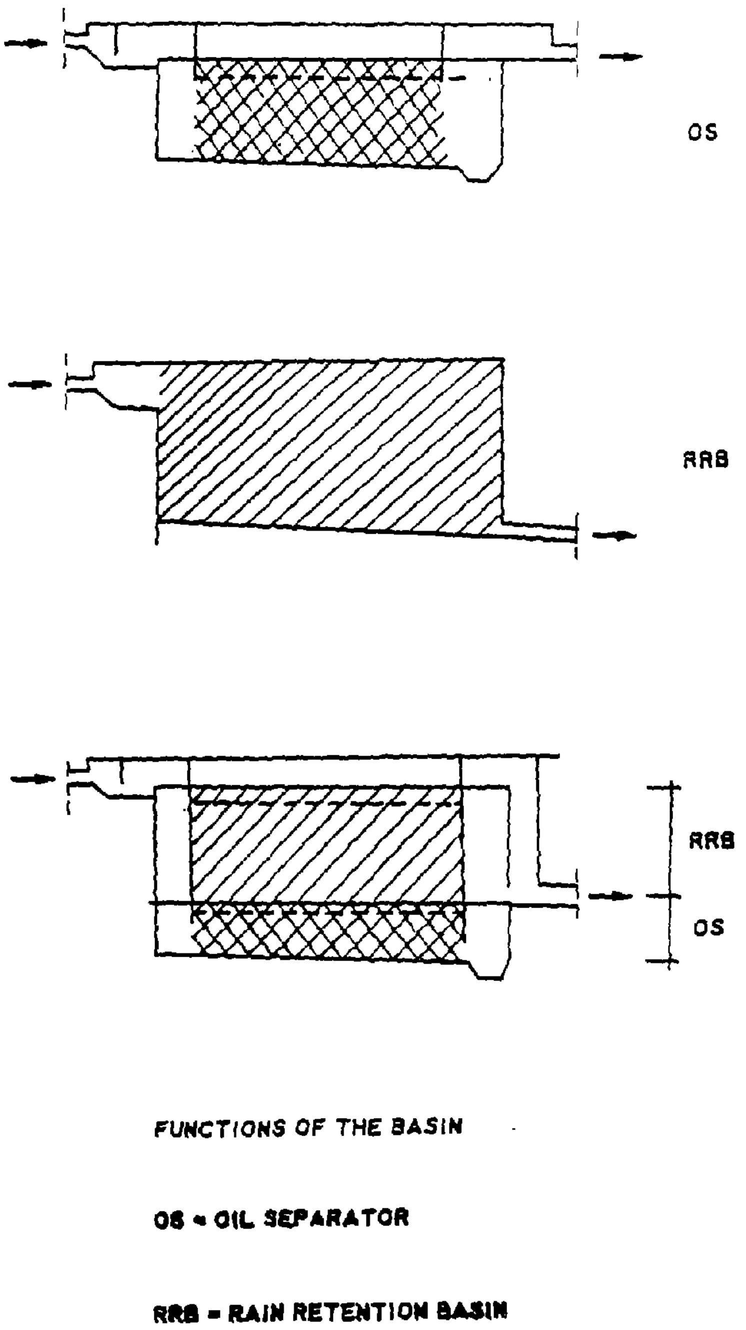
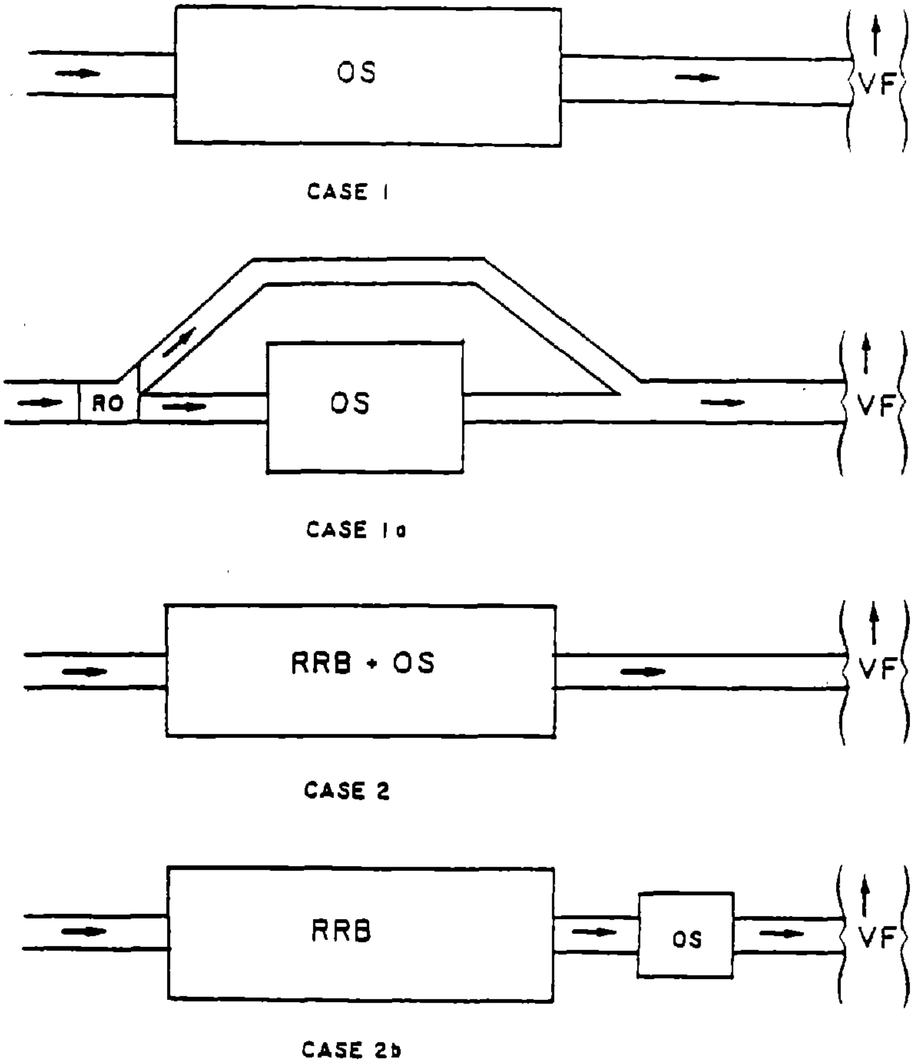


Figure 23. Sections of an oil separator.(36)



OS = OIL SEPARATOR

RRB = RAIN RETENTION BASIN

RO = RAIN OVERFLOW

VF = MAIN DRAINAGE

Figure 24. Special types of oil separators.[38]

sluice-gate controlled soil basins. The sluice gates will be normally open and must be shut manually if a spill occurs. It is assumed that somebody will be present at the scene who is knowledgeable about the system and would be able to shut the valves. If not, the system offers no protection.

The State has also adopted this system for installation in truck parking lots in highway rest areas. The use of the system appears to be more reasonable in rest areas. Rest areas are more likely than river crossings to have a knowledgable attendant on site who understands the system and can shut the sluice gate. For this reason, the system may be more effective at rest areas. However, the success of such a system depends upon response time of emergency responders or State personnel who understand the system.(54) If response time to shut the valve is within the spilled material outflow time (flow out of the soil basin), it will be effective; otherwise, it is useless.

4. Prevention and control of highway tunel fires(55)

a. Overview: As far as fires are concerned, highway tunnels are generally safer than open roads. There have been only two major tunnel fires in the United States, and only one resulting in fatalities.[11] Likewise, apparently only two incidents of major tunnel fires have been reported in the rest of the world. Because of this, a statistical basis for predicting the frequency of hazardous material accidents/fires in highway tunnels is very difficult to develop. The simplist recourse under such circumstances is to predict the highway tunnel accident/fire frequency based on the same statistical basis used to predict the open highway accident/fires of hazardous materials.

Highway tunnel fires can involve either the tunnel structure and systems or the vehicles that pass through it. However, the nonflammable nature of the materials involved suggests that all highway tunnel fires will continue to originate in vehicles and their fuel, cargo, and furnishings. In congested urban tunnels, small automobile fires are routine incidents, occurring as frequently as weekly and are generally extinguished without much difficulty. On the contrary, prevention and control of major tunnel fires is quite complicated.

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[11] In this chapter, "major" signifies that the fire was uncontrollable or spread throughout the entire tunnel or major portions of it.

b. Causes: Several reasons could be suggested for the number of accidents per-veh-mi apparently being lower in tunnels than on the open road:

- Tunnels are usually straight and gently curved.
- Intersections and interchanges usually are not present in tunnels.
- Generally, tunnels are supervised and well-lit.
- Traffic is often slow and congested, and this perhaps reduces the chances for high-speed relative motion between vehicles.
- Drivers are circumspect in tunnels.

Combinations of cargo and tunnel groups need to be subjected to quantitative risk assessments before the most cost-effective fire prevention and control strategy can be specified.

c. Risk analysis: The fire and explosion risk of a hazardous material tank truck in a high-way tunnel is a function of the frequency with which an incident may occur and the magnitude of such an incident. A risk analysis was performed with the help of a reference tunnel which is 33 ft (10.1 m) wide, 16 ft (4.89 m) high, and 1 mi (1.6 km) long with a horizontal tunnel bore.(57) The fire and hazardous cargo spill frequencies for the reference tunnel are predicted as:

- One cargo spill per 2,390,000 tunnel crossings.
- One cargo fire per 8,064,000 tunnel crossings.

Assuming that hazardous material tank truck crossings occur at the rate of 100 crossings per day (36,500 crossings per year), the hazardous material fire and spill frequencies are predicted as:

- One cargo spill occurring every 65 years.
- One cargo fire occurring every 221 years.

d. Prevention of accidents: The frequency of accidents in tunnels could be reduced considerably by prohibiting lane changing. Merely restricting of hazardous materials and placing controls on drivers' actions will be ineffective unless accompanied by vigorous enforcement actions such as:(55)

- Portal inspections to identify placarded vehicles carrying restricted materials or unplacarded vehicles suspected of doing so.

- Stationing tunnel personnel to observe and identify violators and to either issue citations at the scene or notify constant authority for their follow-up is essential if either restrictions or controls are to be complied with.

Traffic safety could be greatly enhanced by several roadway features and profiles, reducing the frequency of accidents and ignition sources. These include:(55)

- Avoiding sharp curves in the tunnel and its approaches. (The Caldecot fire started in a collision on a blind corner.)
- Avoiding transition points, such as exits or interchanges, in the tunnel or its portal. (Queens-Midtown and Deas Island tunnels report frequent accidents caused by sharp curves and interchanges near a portal.)
- Providing effective lighting at the portals and within tunnels. (The Colorado Department of Highway reports a reduction in accidents in several shorter tunnels near Idaho Springs after additional lights were installed.)
- Providing interstate-standard lanes and overhead clearances for better visibility and emergency access.

e. <u>Control of incidents</u>: When prevention attempts become unsuccessful and, subsequently, fire gets started, the next immediate step toward control is detection. In the past, personnel stationed in the tunnels to monitor traffic have detected numerous fires. Television cameras are an effective substitution for personnel. Doppler radar systems may prove to be effective in controlling the traffic flow. High technology systems obviously require the use of computers, and one may surmise that computer-based control of all tunnel systems would eventually become the norm.

The next step in effective control is making use of alarm systems. Rapid transmissions of alarms from fire scene to proper authorities enhances their effectiveness in this regard. Some of the systems include emergency telephones, which should be clearly marked, accompanied by simple operating instructions with care being taken to ensure that the caller's message can be understood in a noisy tunnel. Fire alarm pull boxes should be located beside each telephone.

Once the fire is detected and necessary alarms transmitted, a quick response in bringing limited control and available extinguishment systems into action is essential if minor fires are to be contained and if rescue efforts are to be successful. This requires a planning and training option and also a fire emergency plan, close liaison with local fire departments, and appropriate tunnel-owned equipment.

5. Overview of needs and resources of amerometric instrumentation at hazardous pill sites(56)

a. Background: This section is an introduction to spill sensors that can be used to monitor locations where the incidents would cause catastrophic consequences. Following sections present a listing and brief overview of appropriate types of sensors for site-specific incidents.

It should be noted that there is little or no history of their use in highway incident scenarios; thus, no literature or case studies can be cited. This is a new concept, and innovation must be used to adapt these types of detectors. Manufacturers and dealers with expertise in these areas should be contacted for the details of application to specific scenarios, as the specific adaptation is beyond the scope of this study.

The current state of the art of ambient chemical instrumentation and meterological sensors offers many possibilities for improving the ability of response teams to assess or predict the intensity and location of dangerous substances. These instruments are not normally used as permanent devices installed within highway systems, but they could be adapted for potential specific, high catastrophic scenarios where quick warning would mitigate consequences by saving lives through evacuation, etc.

b. Examples of available resources: A wide range of different sampling and detection techniques are available, both for monitoring of gases and aerosols for meteroldogical measurements. The following are some of the resources potentially available to support the air-monitoring needs of the emergency response teams:

(1) Grab samples. Instrumentations for grab samples can vary from substance-specific detector tubes to highly sophisticated interferometers and gas chromatographmass spectrometers. Draeger tubes, for example, are well suited for a first-on-the-scene responder or a phase-1 response team.

More sophisticated instruments such as portable infrared (IR) or portable gas chromatograph systems (GCS) or photoionization detectors offers more specificity and sensitivity of detection but are less portable and more complex to operate. For extremely toxic materials, more complex instrumentation such as IR interferometers; GCS with sensitive, specific detectors; and mass spectrometers can be used. These sophisticated instruments can be installed in vehicles to provide some portability, but only at a considerable expense and difficulty.

(2) Remote sensing. One problem facing the emergency response team when hazardous gases are released into the atmosphere is to define the size and concentration of the plume. Surveillance of the plume is needed as soon as possible after the accident until later periods when effects are residual from the contamination of soil and water. Definition of the plume is also critical when such actions as increasing the release rate or confining the material are contemplated. In addition, the plume may be laden with toxic aerosols or aerosols may form downwind. Remote sensing, because of wide area coverage, offers a way of defining these gas and aerosol plumes.

(3) Artificial tracers. Artificial, gaseous tracers can be injected into the hazardous spill at a known rate to provide at least four types of useful information:

- Definition of the distribution of toxic gases and their dispersion by acting as a surrogate for the gases of concern.
- Estimation of the actual concentration of the toxic gases, provided the rate of release of the toxic gases can be estimated.
- Estimation of the rate of release of the toxic gases, provided there are simultaneous ambient measurements of the tracer gas and the toxic gases at one or more representative locations.
- Real-time evaluation of atmospheric dispersion models, with the tracer data to provide an objective measure of confidence, the models can be used for real-time on-site contingency planning.

(4) Meteorological data. Meterological data are available from the National Weather Service; however, surface and upper air weather data, available by teletype, can be obtained at the accident site most easily or quickly by telephone or terminal access to one of several private companies that offer this service around the clock.

Microscale or local effects dominate the observed weather conditions at the accident site, particularly when dispersion conditions are poorest. Local meteorological measurements are a necessity. These should include wind measurements at multiple heights and different locations, particularly when the terrain is hilly or the area heavily forecasted. Temperature stratification near the ground is also important to assess air drainage patterns and the rate of diffusion of the toxic plume.

6. Remote sensing and special on-site techniques for detection of toxic substances(57)

a. Background: An accidental release of a material is usually a localized incident in which initial concentrations are highly variable in space and time. In later phases, the initial chemical or secondary products may be transported down-wind. In every late phase, long-term monitoring may be needed to study the residual effects.

Remote sensing is the process of deriving information about a phenomenon or object without direct access for sampling. In the case of an accidental release of a toxic substance, the phenomenon is a cloud of gas or aerosol not initially involved with the release. In such a case, remote sensing can be used to given real-time data on cloud structures so that the toxic release response can be better managed by the on-site team.

b. General characteristics of a remote sensor: The characteristics of an electromagnetic radiation at optical frequencies change while passing through or emanating from the region of a toxic cloud. The light may be natural in origin or from a source such as laser. Observations of natural and artificial light (laser) sources are termed passive and active remote sensing, respectively. Additionally, the systems can be range averaged or range resolved. Range-averaged methods give the average concentration of a gas along the line of sight. Range-resolved methods profile the gas cloud concentration over the range. Passive remote sensors give range-averaged results whereas certain laser radar (lidar) systems give range-resolved results.

c. Principles of operation of passive remote sensors: Passive sensing techniques involve measurement of infrared (IR), ultraviolet (UV), or visible radiation emanating from or through a toxic gas cloud. UV and visible radiation techniques are applicable during the day by aerosols (haze) and fog.

The absorption or emission spectrum is usually derived by:

- Using a diffraction grating.
- A Michelson interferometer.
- A filter in front of the lens.
- By comparing the spectrum to a reference measurement.

Of these, the Michelson interferometer is the most productive. EPA's ROSE (Remote Optical Spectrometer for Emissions) is an example of a Michelson interferometer. This particular instrument is designed to cover the 8- to 14-micron atmospheric window where many hazardous materials either absorb or emit.

d. Active systems: Active systems always use an artificial light source to probe the cloud of interest. Normally, this light source is a laser.

Lasers can be constructed by a variety of means to provide the spectral diversity that is so important to absorption measurements. In addition, pulse lasers can provide range information. Distance is determined by measuring the time it takes to travel from the transmitter to the target and back to the receiver located inside the transmitter. The target can be a convenient reflector, such as a building, the side of a hill, or the terrain.

e. Thermal sensing: Passive sensors operating in the IR spectral region have auxiliary benefits for the toxic spills management problem. Because they receive thermal radiation from a scene, they can be used to locate fires and other hot spots. Otherwise, a fire can be obscured from smoke and debris. Such systems are small, compact, and available from AGA Thermovision, Inframetrics, and Hughes Aircraft Inc.

f. Special on-site techniques: To tackle the problems of toxic gases, a trace gas can be used. Trace techniques applied to accidental toxic release problems can be used to infer two very important quantities. First, they can be used to determine the concentration of the toxic substance at a particular downwind distance. Second, they can be used to find the toxic substance source strength.

7. Non-remote sensing techniques[58]

a. Overview: The non-remote sensing field has a number of currently available instru-ments, including several commercial instruments using radiation absorption techniques: IR, UV, and visible mass spectrometry; gas chromatography; gas chromatography/mass spectrometry (GC/MS); and specific material chemical reactions and parameter measurement techniques (PH, conductivity, colorimetric indicators, gas and vapor detectors).

The GC/MS and dispersive IR analyzer show promise for near-term development. However, we believe the methods for detecting specific materials presently appear the most practical and broadly applicable for accident site use. These methods include specific colorimetric detector tubes, water analysis kits, gas and vapor detectors, and dosimeters. These types of detectors are most applicable to use by emergency responders evaluating an incident. They would have to be adapted for installation or as a permanent protection system warning device at a specific location. Their use would be limited to highly sensitive populations subjected to consequences of high catastrophic potential.

b. Specific techniques: The referenced report from which these non-remote sensing techniques were taken contain details of their use and application, albeit not in highway situations. The Volume II: Guidelines report of this study includes a more complete summary of those techniques that might be adaptable to highway systems with thorough research and development.

The techniques are:

- Calorimetric indicators.
- Water analysis kits.
- Gas and vapor detectors.
- Dosimeters, personal monitors and alarms.

VIII. SUMMARY OF ADDITIONAL MATERIAL CONTAINED IN VOLUME II: GUIDELINES

A. Philosophy

Supplementary information pertaining to this study was generally appropriate for appending to both this report and Volume II: Guidelines. To avoid duplication it will be appended to only volume II because it is more important to State personnel using the guidelines as a tool to assist in the process of deciding when, where and what physical, protective systems should be considered when designing new or reconstructed highways. For completeness, this chapter will list and briefly present an overview of material appended to volume II.

B. Specific Appendixes in Volume II

1. Appendix A: Procedures for Establishing Truck Accident Rates and Release Probabilities and Release Probabilities for Use in Routing Studies

It was stressed throughout this report that States should develop their own default values. Several procedures can be used to develop these default truck accident rates and incident probabilities to replace the general default values given in table 13. Estimates of truck accident rates and incident probabilities based on an agency's own data are preferred to the use of the default values in table 13.

It has also been emphasized that proper techniques and statistical analysis must be used when developing State-specified default values. Appendix A of volume II identifies the data required for an agency to develop these estimates and the data processing procedures that should be used.

2. Appendix B: Summary of the Dangerous Goods Route Screening Method for Canadian Municipalities

In the discussion of risk routing methods in chapter 2 of this volume and recommended revisions to the FHWA routing and risk procedures in chapter 3 of this volume, some of the features of the Canadian risk and routing methods were suggested as worthy of consideration for use by States. One such procedure was their route screening method.

The route screening method generates a short list of candidate routes for detailed study. Focusing on a few reasonable routes would reduce the commitment of funds by eliminating options with little chance of satisfying the need for safety. Appendix B of volume II presents the Canadian method to accomplish this screening.

3. Appendix C: Summary of Evacuation Distances of Selected Hazardous Materials

Appendix C of volume II presents a table that was developed in the course of this study by computerizing and summarizing tables given in the 1987 Emergency Response Guidebook for Hazardous Materials Incidents.(39) This appended table gives maximum, minimum and average values for all materials along with a summary of class 2 gases.

4. Appendix D: Evacuation Distances During Toxic Air Polution Incidents

The Emergency Response Unit of the Illinois Environmental Protection Agency (IEPA) has developed and successfully used calculations for evacuation distances during air pollution incidents with dispersion coefficients developed for three meterological weather stability classes. This information on their methodology supplments the evacuation distances suggested in the report and in appendix D of volume II. Information of this type is scarce in literature generally available to States' highway personnel. Appendix E of volume II also fits into this category.

5. Appendix E: Methodologies for Calculating Toxic Corridors

Calculating evacuation and/or impact distances or corridors for airborne toxic materials is difficult. Models are generally very complex.

Appendix E of volume II presents a relatively simple methodology developed by the United States Air Force Air Weather Services (AWS) generalized form of a diffusion prediction model for operational use. It should be useful for supplementing the information in this report and in appendixes C and D of volume II.

6. Appendix F: Measures Used by State Transportation Agencies to Mitigate Chemical Water Pollutants Related to Highway Facilities

Under a Highway Planning and Research (HP&R) study entitled, "Mitigation of Highway Related Chemical Water Quality Pollutants," Caltrans conducted a letter survey in 1978-79 of the 50 State transportation agencies to determine what mitigation measures were being used to remove chemical pollutants from various sources such as hazardous spills, constituents in pavement runoff water, leachates from mineral bearing soils, sandblasting old paint from bridges, etc. This material is summarized in appendix F of volume II insofar as it was relevant to this study.

7. Appendix G: Chicago Area Freeway Traffic Management Program--Its Mitigating Effect on Hazmat Incidents

It is stressed that whatever can be done in the area of facilitating prompt notification and response to hazmat incidents will greatly mitigate consequences and should be done. Several suggestions for designs to facilitate quick response were made. To compliment these physical improvements, a traffic management program should be considered.

The Illinois Department of Transportation (IDOT) operates a model freeway traffic management program in the Chicago area. This program helps maintain urban mobility while promoting motorist safety in Chicago area expressway traffic.

The program does not operate specifically to spot or mitigate hazardous materials incidents, but the fact of its existance is a great advantage in this regard. Appendix G of volume II discusses how this program is organized and how it operates.

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