103

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 103

RISK ASSESSMENT PROCESSES FOR HAZARDOUS MATERIALS TRANSPORTATION

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RISK ASSESSMENT PROCESSES FOR HAZARDOUS MATERIALS TRANSPORTATION

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest to decision makers responsible for reducing the risks associated with transportation of hazardous materials. Detailed information is presented on estimation of risk as part of a mitigation strategy to reduce community vulnerability.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

In addition to making use of regulations provided by federal, state, and regional authorities, local jurisdictions must analyze risks from transportation disasters as part of an overall strategy for coping with accidents involving hazardous material transport. This report of the Transportation Research Board includes information on procedures to identify the degree of risk and the community's ability to cope with transportation of hazardous materials.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

RISK ASSESSMENT PROCESSES FOR HAZARDOUS MATERIALS TRANSPORTATION

SUMMARY

Hazardous cargo shipments, as well as their attendant risks, are increasing in both volume and variety of materials shipped. The scope of these risks, and mechanisms for coping with them, must be addressed in a formal structure. Risk assessment is a major component of this structure.

This synthesis provides an overview of the use of risk assessment with regard to transporting hazardous materials (including hazardous wastes). Although the synthesis addresses risk assessment for use in rule making, it focuses on the needs, and means, to prevent, reduce, mitigate, and respond to hazardous material transport risks from the perspective of local jurisdictions.

These transportation risks can be viewed from three different perspectives—that of shippers, federal and state regulators, and communities. The first is that of the shippers, transporters, and receivers of hazardous cargos, in both industry and government. These organizations are primarily interested in maintaining the throughput of hazardous materials in terms of timely shipment and costs. Although safety is good business, in extreme situations throughput predominates over safety, making total self-regulation by the transport industry questionable at best. As a result, federal regulatory agencies are required to administer control over the safe transport of hazardous goods. The Department of Transportation, the Environmental Protection Agency, and, to some extent, the Department of Energy have various responsibilities for regulating hazardous cargo transport. These agencies have a national view of the problem and must strike a balance between maintenance of throughput and safety. This is often true of state agencies, as well, in terms of overall state perspectives.

When incidents do occur, they normally occur in local jurisdictions—towns, cities, counties—that have the primary responsibility for mitigating these incidents and exercising emergency response procedures. Accidents involving hazardous cargo transport can be catastrophic events. While such events are rare, they can devastate communities having minimal resources or where a substantial portion of their total population is at risk. What is often merely a statistic at the national level is an identifiable, meaningful risk at the local level. At these levels, sound planning to minimize risks must address specific populations and communities at risk by specific modes of transport.

The development of a strategy for dealing with transportation disasters at the operational level can be separated into three steps:

1. Identify and estimate the risks from hazardous cargos;
2. Delineate actions to prevent and reduce risks;
3. Develop mitigation strategies to reduce vulnerability to risks.

One of the major problems encountered in regulating hazardous material transport is the plethora of regulations that, as a whole, appear to make little or no sense. Each individual rule making has been based on its own set of criteria, which is usually different from all others. Federal regulators, states, localities, shippers, and industry have all complained of this problem. It has been suggested that the use of risk assessment, as a basis for rule making, might result in a more logical and flexible rationale for establishing regulations. As far as can be ascertained, no rule making in the hazardous transport area, to date, has formally used risk criteria in its establishment.

The benefit of risk analysis is that it can establish a rational basis for flexible, cost-effective regulations. However, the application of risk assessment and analysis is not without problems, of which there are two major kinds: (a) the implication that explicit levels of "acceptable risk" must be established; and (b) the extreme difficulty in measuring actual levels of risk before, during, and after application. The wide range of uncertainty, in both the value judgments about risk levels, and the difficulty of measurement, make risk analysis a less-than-precise science. This synthesis discusses a number of approaches to the application of risk analysis and reviews existing studies.

Applying any form of analysis for rational decision making at the local community level is limited by available resources, such as funds and trained personnel. Kansas State University, under a contract with the Department of Transportation, has developed a method that enables communities to make extensive studies of the risks of hazardous material transport. This approach, while strongly supported in concept, still requires the commitment of considerable resources. As a result, a reduced-level "scoping approach" is recommended as a more realistic approach for initial screening by a community.

This scoping approach analyzes the problem in a manner similar to that of the Kansas State model but focuses on only three key commodities: gasoline, chlorine, and anhydrous ammonia. These 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. All communities have gasoline service stations, many communities us chlorine for water purification, and farming communities need ammonia for fertilizer. The analysis evaluates sources and transport corridors for these commodities; identifies high traffic and poor transport conditions that may indicate potential problems; identifies and develops alternative strategies, if warranted; and evaluates the current level and needs for emergency response readiness. Once the problems (if any) involved with the use of these commodities have been explored, then other commodities with high hazard potential can be examined (as far as resources allow) on an incremental case-by-case basis. In the meantime, there is some assurance that the major threats will have been investigated.

Although the scoping analysis is presented in form, it has not yet been developed for immediate application by local communities. Further development of the approach must include its documentation for direct use and testing in a number of local communities.

To investigate these risks, a community has several sources from which to draw in terms of expertise: federal, state, and regional authorities; industrial groups and specific businesses; consultants and academia; and, the community's own local resources. The roles of these professionals are addressed in the body of the report.

The resources devoted to accomplishing the risk analysis must be proportionate to both the degree of risk involved and the resources available to the community. In any case, a community should have some idea of its vulnerability and its ability to cope.

Given limited resources, the Kansas State model is recommended as a means of dealing with the problem of identifying the degree of risk and the community's ability to cope. If resources are too limited to carry out the prescribed analysis in total, a shortcut analysis, using the three commodities cited above, can be undertaken with minimal time and effort. These analyses, however, must be more than just scoring systems to identify the degree of risk—they must identify specific high risk and high vulnerability conditions and allow alternatives to be considered.

Unless a community has gone through the process of risk analysis (perhaps using the three base commodities as a minimum), there is no rational basis for establishing regulations restricting throughput of hazardous materials transport. Only after an analysis has been made and specific risks have been identified, which are substantially higher than those of the three base commodities, should banning throughput be considered. In these cases, alternative routes, special traffic procedures, and notification and traffic control approaches should be considered before banning the shipments of hazardous materials. There must be a clear and present danger before a community acts restrictively.

A community has responsibility for its own health and safety over and above that provided by federal and state authorities. It can only carry out this responsibility if it knows the scope of its problem, if it can act to prevent such incidents from occurring, and, if it can provide the means to cope effectively with such accidents when they do occur. With minimal resources, a community can rate itself either by using the Kansas State model or the simplified version suggested herein.

Three specific recommendations are made as a result of this study:

1. A study is needed to define the benefits, problems, and costs of using risk analysis criteria for decision making in establishing federal, state, and local rules and regulations for hazardous material transport.
2. A further, formal delineation of the scoping analysis, examples of implementation, and wide dissemination of its application, should be undertaken. In formalizing the scoping analysis, methods must be developed to specify the minimum quantities for consideration.
3. Studies should be undertaken to analytically address the relative risks of intermodal hazardous material transport.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

OBJECTIVES

This document seeks to provide an overview of the use of risk assessment in hazardous materials transport, including hazardous wastes. While it addresses the problem of risk assessment for use in rule making, the document focuses on the needs and means to prevent, reduce, mitigate, and respond to hazardous material transport risks from the perspective of local jurisdictions.

BACKGROUND

"The Department of Transportation (DOT) estimates that more than 250,000 shipments of hazardous materials move daily through the nation's transportation systems, and that an estimated 200 billion ton-miles of hazardous materials are shipped annually in the United States. These shipments originate from more than 100,000 locations within the 50 states, and more than 2 million persons are involved in the handling of these shipments" (*1*). The number of accidents and the resulting deaths and injuries from transporting hazardous materials increased during the period 1971–1979, as illustrated in Figure 1. The volume of transport and the number of ton-miles are also increasing, but the data bases that presently exist are inadequate to determine these.

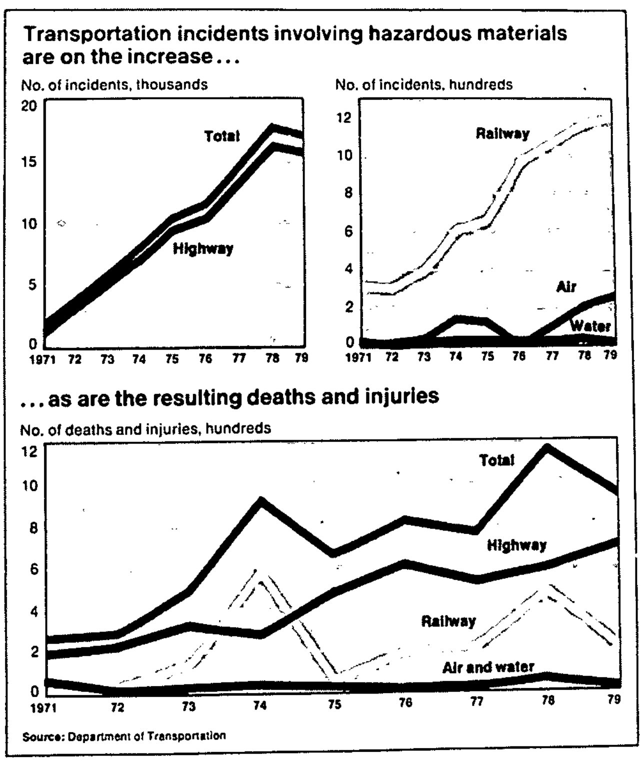

FIGURE 1 Transportation incidents involving hazardous materials (*2*).

> Experience indicates that most hazardous material shipments are transported safely, and DOT's accident data indicate that the overall transportation safety record for hazardous materials is good. Fewer than 400 shipments annually are involved in accidents which result in injuries or loss of life. However, when involved in transportation accidents, some commodities and types of shipments have the potential for causing enormous losses of life and property, and investigations of these accidents have established that addditional safety precautions must be implemented in order to minimize or avert these losses. From 1977 through 1979, nearly 80 percent of the fatalities involved only five specific commodities in three commodity groups—flammable liquids, pressurized liquified gases, and corrosive liquids.
>
> During 1980, after enhanced thermal and tank-head protection was added to most railroad tank cars that transport liquified petroleum gases, liquified petroleum gases were no longer a major cause of fatalities. Almost 80 percent of the fatalities in 1980 were caused by flammable and combustible liquids. On the other hand, the nature of many hazardous material shipments is such that a single catastrophic event could reverse these statistics overnight (*1*).

During the period 1971 through 1980, more than 111,000 accidents involving hazardous materials were reported (Table 1a), resulting in a total of 248 fatalities (Table 1b), 6,873 injuries (Table 1c), and approximately $120 million in property damage (Table 1d). Highway accidents accounted for 90 percent of the total, and railroads 8 percent of the total. The average number of fatalities during this period was 25 persons per year. Eighty percent of these were attributable to highway shipments and 18 percent to railroads. Injury (Table 1c) and property damage data (Table 1d) show a similar concentration with respect to highways and railroads.

An incident is any reported occurrence or event—from a small box falling off a truck to a large accident. Mixed cargo trucks often carry miscellaneous small packages, making them more prone to incident reporting in comparison to bulk carriers on both highway and railway. There are differing definitions of accidents for highway and rail transport and the data for these are not directly comparable to existing data bases.

These transportation risks can be viewed from three different perspectives, that of shippers, federal and state regulators, and communities. The first is that of the shippers, transporters, and receivers of hazardous cargos, in both industry and government. These organizations are primarily interested in maintaining the throughput of hazardous materials in terms of timely shipment and costs. Nevertheless, safety is good business for these organizations because, among other things, accidents decrease throughput and initiate high costs that are due to product loss, emergency response, cleanup, and liability claims. Moreover, the protection of the general public and workers is a felt responsibility of these organizations; at least, up to a point. On balance, the primary objective is to transport hazardous cargos between source and destination. In extreme situations, however,

TABLE 1

SUMMARY STATISTICS ON HAZARDOUS MATERIALS TRANSPORTATION INCIDENTS

(a) Incidents by Mode and Reporting Year

MODE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	TOTAL
Air	4	33	49	157	152	90	130	231	284	233	1,363
Highway (for hire)	1,552	3,558	5,048	7,251	8,988	10,223	13,000	15,983	15,355	14,042	95,000
Highway (private)	224	342	419	361	903	549	1,250	565	623	442	5,678
Railway	343	333	409	616	676	982	1,500	1,191	1,215	1,327	8,592
Water	11	9	12	26	32	13	50	47	34	42	276
Freight Fowarder	0	0	0	2	6	11	20	5	2	1	47
Other	121	53	65	15	12	21	0	0	11	28	326
TOTALS	2,255	4,328	6,002	8,428	10,769	11,889	15,950	18,022	17,524	16,115	111,282

(b) Deaths by Mode and Reporting Year

MODE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	TOTAL
Air	0	0	0	4	0	0	0	0	0	0	4
Highway (for hire)	18	6	11	14	7	12	14	14	12	13	121
Highway (private)	5	6	7	4	20	4	17	6	6	4	79
Railway	0	0	3	10	0	2	1	26	0	2	44
Water	0	0	0	0	0	0	0	0	0	0	0
Freight Forwarder	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0
TOTALS	23	12	21	32	27	18	32	46	18	19	248

(c) Injuries by Mode and Reporting Year

MODE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	TOTAL
Air	0	0	6	5	4	4	9	43	13	8	92
Highway (for hire)	122	192	297	243	395	568	447	536	608	425	3,833
Highway (private)	60	49	38	38	92	49	60	58	89	53	586
Railway	21	53	152	596	96	198	233	482	228	129	2,188
Water	48	0	3	17	2	1	0	10	1	1	83
Freight Forwarder	0	0	0	4	15	0	0	1	0	1	21
Other	2	0	13	0	51	0	0	0	2	2	70
TOTALS	253	294	509	903	655	820	749	1,130	941	619	6,873

(d) Damages by Mode and Reporting Year ($)

MODE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	TOTAL
Air	0	2,853	5,104	4,511,708	9,159	20,512	28,686	6,834	30,312	12,486	4,627,654
Highway (for hire)	3,118,508	3,587,379	2,604,163	3,849,176	3,028,405	3,617,548	4,272,106	7,440,533	5,372,736	4,343,739	41,234,293
Highway (private)	1,661,475	2,701,366	1,713,815	924,980	2,574,211	2,057,017	4,356,545	3,819,373	3,552,533	2,979,889	26,341,204
Railway	1,491,745	1,549,358	3,021,685	11,965,143	1,481,995	2,294,633	7,815,243	6,848,354	5,781,500	2,834,030	45,083,696
Water	201,052	1,252,095	8,009	20,117	6,331	5,270	18,258	17,912	30,364	507,427	2,066,835
Freight Forwarder	0	0	0	0	3,345	405	351	180	0	100	4,361
Other	136,005	223,925	14,439	13,035	182	3,788	9,700	0	5,100	29,365	435,539
TOTALS	6,608,785	9,316,976	7,367,215	21,284,159	7,103,628	7,999,173	16,500,889	18,133,176	14,772,545	10,707,036	119,793,582

this objective predominates over safety, making total self-regulation by the transport industry questionable at best.

As a result, federal regulatory agencies are required to administer control over the safe transport of hazardous goods. The DOT, the Environmental Protection Agency (EPA), and, to some extent, the Department of Energy (DOE) have various responsibilities for regulating hazardous cargo transport. These agencies have a national view of the problem and must strike a balance between maintenance of throughput and safety. This is often true of state agencies, as well, in terms of overall state perspectives.

When incidents do occur, they normally occur in local jurisdictions—town, city, county—that have the primary responsibility for mitigating these incidents and exercising emergency response procedures. Accidents involving the transport of hazardous cargos can be catastrophic events. While such events are rare, they can devastate communities with minimal resources or where a substantial portion of their total population is at risk. What is often merely a statistic at the national level is an identifiable, meaningful risk at the local level.

STRATEGIES FOR RISK REDUCTION

In developing strategies to prevent or mitigate major disasters resulting from hazardous cargos, it is important to recognize wide variations in application at local, regional, and state levels. At these levels, sound planning to minimize risks must address specific populations and communities at risk by specific modes of transport.

The development of a strategy for dealing with transportation disasters at the operational level can be separated into three aspects:

1. Identification and estimation of risks from hazardous cargos;
2. Actions for prevention and reduction of risks; and
3. Mitigation strategies to reduce vulnerability to risks.

The concept of community vulnerability, as expressed by Garbor and Griffith (*3*), uses the term *risk* to

> denote the threat of hazards which chemical agents, *per se*, pose for a community, independent of community-wide measures or preparations to reduce the probability of an occurrence or to mitigate the impact of an incident already underway.
>
> The term "vulnerability," on the other hand, will be used here to indicate the status of a community as a totality. Vulnerability, therefore, will refer to the threat to which a community is exposed, taking into account not only the properties of the chemical agents involved, but also the ecological situation of the community and the general state of emergency preparedness at any given point in time. Community planners should generally concern themselves with the question of vulnerability as this refers to a community's overall sensitivity, given the existing level of threat and its coping ability. Given the numerous sources of hazards and the potential magnitude of incidents in these communities, the risk posed by chemical agents may be so severe in extreme cases as to virtually neutralize community planning efforts. In such cases, the focus of planners should primarily concern the risk factor (the hazardous products themselves) and the prevention of such a threat, rather than upon community-related coping measures.

Figure 2 illustrates the basis for some general conditions of community vulnerability; however, it should be realized that vulnerability depends on all three aspects, and actions to reduce vulnerability must be consistent at each level.

IDENTIFICATION AND ESTIMATION OF RISKS

The identification of risks in a community is probably one of the most difficult aspects of vulnerability analysis. This effort encompasses identifying all hazardous materials that may be produced, received, stored in, and transported through the community. Because there are thousands of hazardous chemicals, many routes, and several different transport modes, complete identification is virtually impossible. It is proposed in subsequent sections of this synthesis that several subsets of the most hazardous materials may provide a less complete, but sufficient, and more practical scope of such studies, at least, for obtaining an initial measure of a community's vulnerability.

Risk (hazard)	Preparedness: High	Preparedness: Low
High	Moderately high (wide range)	High
Low	Low	Moderately low (wide range)

FIGURE 2 Community vulnerability (*3*).

Once particular chemicals are identified, the possible exposure involving populations within affected neighborhoods or transit routes must be addressed. The kind and extent of threat (e.g., explosion, fire, toxic or corrosive exposure, etc.), the geographic and demographic patterns, and the mode of propagation of the events leading to an occurrence during a potential disaster are examples of the variables that must be considered in a risk estimate. Although such estimates may be complex, a subset of generic conditions may be used to identify potential high-risk conditions.

ACTIONS FOR PREVENTION AND REDUCTION OF RISKS

Once a risk is identified, steps may be taken to reduce the probability of an event leading to a potential disaster, as well as to reduce the impact of the event should it occur. This can include increased regulation of industry and industrial processes, alteration of routes, modification and special precautions during transit, and even prohibiting the use of certain routes in regard to specific hazardous materials. These actions are aimed at preventing events from occurring by decreasing the likelihood of their occurrence through reduction of accident causes, exposure to accidents, and exposure to populations and property as a result of accidents.

MITIGATION STRATEGIES TO REDUCE COMMUNITY VULNERABILITY

After an accident occurs, communities have means to mitigate the consequences of the event; such as containing toxic chemicals and fumes, preventing ignition, or extinguishing fires after they begin. During these periods, use of shelters, evacuations, and prophylaxis measures can mitigate the effects of the accident on the population.

A community's capabilities to conduct mitigation strategies depend on the community's ability to respond to accidents, to take knowledgeable action, and to control the movement of its population. This ability depends on both available resources and trained personnel at all levels. Because many communities may be too small to have adequate resources of their own, the use of regional organizations for emergency response and training may be desirable.

Considerable effort has already been expended to deal with these problems by federal and state authorities, industry, academia, and the communities themselves. These efforts provide a basis for the development of useful methods for community-vulnerability assessment.

DEFINITIONS

Before the discussion of risks, some definitions are in order. The following definitions are used here specifically for transportation of hazardous cargos.

Hazard—The severity of harm relative to a commodity itself occurring from unwanted exposure to the commodity.

Exposure—An activity that results in proximity in space and time to a hazard.

Risk—A function of the degree of magnitude of the consequence of an accident (hazard) *and* its probability of occurrence (degree of exposure and likelihood of occurrence).

Vulnerability—A function of the estimated risk *and* the ability to cope with consequences should they occur.

Absolute Risk—A determination of the probability of occurrence of specified consequences based on measured data or models (e.g., a fatality rate per year per mile).

Relative Risk—A measure of the difference in probability of occurrence and/or consequence magnitude between a given risk situation and some other risk situation used as a baseline (e.g., risk of gasoline transport is higher than that of shipping coal on a unit basis).

Comparative Risk—Comparing the probabilities and consequences of alternative situations (e.g., two alternative transportation routes).

CHAPTER TWO

STATE OF THE ART

Past and present efforts in risk analysis and risk management are described separately for each of the three major areas addressed in the preceding chapter, namely, identification, reduction, and mitigation. Considerable effort has been expended in the past for studies that address hazardous cargo transport, most of which address the general transport problem. Nevertheless, some effort has been appropriately directed at providing states and communities with useful guidance.

IDENTIFICATION AND ESTIMATES OF RISKS

Efforts in this area address the cargos themselves and their possible impact resulting from transportation accidents; source-route-destination safety for road, rail, waterway, and air systems; and safety design in vehicles, vessels, and aircraft.

Cargo Hazard Determination

Substantial work has been done to provide means of identifying and classifying hazardous cargos. Classification of cargos has occurred at both the national and international levels and eight classes have been established by the United Nations (*4*).

Class Number	UN Class Name
1	Explosives
2	Gases
3	Flammable and Combustible Liquids
4	Flammable Solids
5	Oxidizers and Organic Peroxides
6	Poisons
7	Radioactive Materials
8	Corrosives

In addition, EPA uses four criteria for classifying hazardous wastes: ignitability, corrosivity, toxicity, and reactivity (*5*). For each of these, a quantitative specification is stated for which test methods are available. DOT uses 16 such classifications and publishes extensive lists of regulated hazardous materials in the Code of Federal Regulations, Title 49, Sections 172.101 and 172.102 (49 CFR 172.101 and 49 CFR 172.102). These lists indicate the hazard class, identification number, label requirements, and packaging and shipping requirements for various transportation modes. However, the criteria for including a hazardous material consider the level of hazard of the commodity itself, not the actual risk of shipments. Thus, for purposes of risk management, some means is required to estimate the relative level of hazard for these substances and the potential for accidents during shipment.

The relative level of hazard provides a means of using criteria, such as those prepared by EPA, to order different substances by their hazardous proportions without taking into account other risk parameters such as vehicle, volume, traffic level, route, and demographic and geographic parameters.

Risk Indices

One of the earliest attempts to develop a risk index was undertaken by Danahy and Gathy (1973) (*6*) for the marine transportation of hazardous materials. Three indices were developed: a cargo hazard index, a vessel safety index, and a port hazard index, where the first provided a measure of the toxicity and/or flammability of the cargo and the measures of impact of accidents as a result of particular materials. A National Research Council Panel on the Equivalent Safety Concept of the Committee on Maritime Hazardous Materials is currently attempting to provide a more in-depth set of indices for this purpose. The objective is to provide a means to rank numerically all hazardous materials in terms of their toxicity, flammability, and area of impact should an accident occur. Earlier efforts include a Battelle Memorial Institute study (*7*) undertaken for EPA that defined a priority ranking system for water soluble substances based on their properties, quantities shipped annually, and probabilities for spillage.

Perhaps the most extensive and recent attempt to develop risk indices for mitigation of community vulnerability is that of Russell et al. at Kansas State University (*8*). This document attempts to cover all three phases mentioned above, not just identification of risks.

ACTIONS FOR PREVENTION AND REDUCTION OF RISKS

Methods to prevent and reduce risk must decrease either the cause or the exposure to risk. Prevention involves improvements in vehicle design and storage facilities, regulation of traffic flow to minimize exposure to hazardous substances, and, in extreme cases, removal of the cause by prohibitions on the transport and storage of specific materials.

Technical Design to Prevent Accident Propagation

Means to mitigate the consequence of traffic accidents involving hazardous materials are used throughout the transportation industry. Thermal and tank-head protection for railroad tank cars and low-center-of-gravity designs for tanker trucks are examples of design aids. Regulations for these designs are under the purview of the Department of Transportation for all forms of transportation. Storage facility design is a different matter because these designs depend on local and state building, fire, and safety codes and may, of necessity, be of local concern where such codes do not exist or are improperly enforced.

Regulation of Traffic Flow to Minimize Exposure

Explosive and flammable cargos have been restricted from tunnels and other similar corridors for several decades, so the idea of regulating the flow of hazardous material traffic is not new. The objective is to minimize exposure to vulnerable facilities and large or captive populations. The solution is not a simple one since rerouting may increase travel distance over lower-grade routes. Glickman (*9, 10*) has conducted several studies on railroad rerouting that bear out this problem. Another example is the use of accident-prone, two-lane U.S. Route 30 over the Allegheny mountains in Pennsylvania as an alternative route for the heavily traveled Pennsylvania Turnpike with its tunnels and high-density traffic. Rerouting must include risk and consequence estimates for alternative routes. Peat, Marwick, Mitchell & Co. (*11, 12*) have developed a set of criteria for this purpose.

Transport Prohibitions

Local and state authorities have the responsibility to protect the health and safety of their constituents. The federal government is responsible for public safety, as well as ensuring the unburdened conduct of commerce. Congress has designated the DOT Secretary as the responsible decision-making authority for hazardous material transport through Section 104 of the Hazardous Materials Transportation Act, Public Law 93-633 (49 USC 1803):

> Upon a finding by the Secretary, in his discretion, that the transportation of a particular quantity and form of material in commerce may pose an unreasonable risk to health and safety or property, he shall designate such quantity and form of material or group or class of such materials as a hazardous material. The materials so designated may include, but are not limited to, explosives, radioactive materials, etiologic agents, flammable liquids or solids, combustible liquids or solids, poisons, oxidizing or corrosive materials, and compressed gases.

Thus, in the protection of safety, local authorities can conflict with unburdened commerce requirements (at the federal level) when prohibiting the transport of hazardous materials through local and state jurisdictions. Section 112 of the Hazardous Materials Transportation Act (49 USC 1811) deals with federal preemption of states

> (a) GENERAL.—Except as provided in subsection (b) of this section, any requirement, of a State or political subdivision thereof, which is inconsistent with any requirement set forth in this title, or in a regulation issued under this title, is preempted.
>
> (b) STATE LAWS.—Any requirement, of a State or political subdivision thereof, which is not consistent with any requirement set forth in this title, or in a regulation issued under this title, is not preempted if, upon application of an appropriate State agency, the Secretary determines, in accordance with procedures to be prescribed by regulation, that such requirement (1) affords an equal or greater level of protection to the public than is afforded by the requirements of this title or of regulations issued under this title and (2) does not unreasonably burden commerce. . . .

In February 1982, United States District Court for the Southern District of New York permanently enjoined the U.S. DOT from enforcing its regulations governing shipment of radioactive materials, thereby opening up the preemption rule to challenge. In addition, states that have been designated as having "State routing agencies" under 49 CFR 177.825 are delegated powers to reroute highway transportation, if necessary, in order to minimize overall risk to the public.

MITIGATION STRATEGIES TO REDUCE COMMUNITY VULNERABILITY

Emergency preparedness for minimizing the consequences of accidents after they occur is a major approach in minimizing community vulnerability. The Federal Emergency Management Agency (FEMA) has major oversight responsibilities for planning activities for emergency response at the federal level and works directly with state and regional authorities for emergency response readiness and planning activities. All federal agencies having responsibilities in the transportation of materials provide varying degrees of assistance to mitigate accidents after they occur. Depending on the nature of the material and transport mechanisms, the following agencies may be involved: DOT, EPA, Nuclear Regulatory Commission (NRC), DOE, and FEMA. In addition, state and regional agencies, ports, and industry (CHEMTREC, shippers, producers, etc.) have facilities to aid in post-accident mitigation. However, in all cases, the responsibility for, and coordination of, emergency response activities involves local authorities, elected and appointed officials, police, fire, public works, etc. Thus the burden falls on local authorities who must be prepared for, and able to implement, emergency response.

Considerable material is available in regard to emergency response for hazardous materials in general cases (*8, 13*) as well as for specific transport modes, for example, railroads (*14, 15*). The problem facing a community is determining its needs for emergency response and then training personnel to deal with hazardous material accidents. In many cases resources and training are coordinated and shared at the regional and state levels. Thus, the scope of the problem, the need for emergency response, and the means for obtaining resources for planning must be determined by local authorities.

RISK ANALYSIS IN REGULATION OF HAZARDOUS MATERIAL TRANSPORT

One of the major problems in regulation of hazardous material transport is the plethora of regulations that seem to make little or no sense as a whole. Each individual rule making has been based on its own set of criteria, which is usually different from all others. This complaint has been expressed by federal regulators, states, localities, shippers, and industry. It has been suggested the use of risk analysis as a basis for rule making might result in a more logical and flexible rationale for establishing regulations. To date, no rule making in the hazardous transport area, as far as can be ascertained, has formally used risk criteria in its establishment. The following section presents some benefits and difficulties in the use and implementation of risk analysis as a basis for federal, state, and local rule making.

Benefits of Risk Analysis

Risk analysis can provide a performance base for the safety of hazardous material transport independent of specific situations, commodities, and modes of transport. This safety performance base can provide the connecting rationale for all regulations, and the costs of obtaining increments of risk reductions provide cost-effectiveness measures, whereby resources can be applied in an orderly manner.

Given a risk performance set of criteria, flexibility in obtaining that performance, via alternative solutions and designs, becomes feasible, and the process in which such decisions are made are open, visible, and rational.

Problems in Implementation

There are two major problems in implementation; namely: (a) the implication that explicit levels of "acceptable risk" must be established; and (b) the extreme difficulty in measuring actual levels of risk before, during, and after application. The wide range of uncertainty, in both the value judgments about risk levels and the difficulty of measurement, make risk analysis a less than precise science. Acknowledging these limitations at the outset, there are means to apply risk analysis that can overcome these difficulties to a great extent.

Approaches for Surpassing Difficulties in Applying Risk Criteria

Given risk analysis capability, the level of risk (within limits of uncertainty) inherent in any rule can be ascertained, revealing the level of risk implied by the standard. In fact, a review of such standards for automobile safety devices, such as seat belts, indicated a level of cost-effectiveness of risk reduction of about $250,000 per health effect in 1975 (*16*). In this sense, the point of ignoring the establishment of acceptable risk levels is moot.

Setting such levels is more difficult, and there are a variety of methods to set such standards (*17*). Only one preliminary approach is suggested here—that is, to review existing rules and regulations to determine the levels of risk revealed by each rule making. Those cases that are significantly higher or lower than the average levels might then provide insight as to how acceptable risk criteria might be formulated.

Measuring risk directly is extremely difficult, especially for rare events that happen so seldom (or never have happened) that no data can be acquired. Thus, one has to depend on "models" of risk to establish a surrogate criterion. The surrogate is a parameter that can be measured in terms of performance and compliance. The model relating the surrogate to risk becomes a formal vehicle for converting surrogate performance to risk performance, and such models must be formally specified. Depending on the available data and capable analysis, such models can be rather good estimators of actual risk, although the actual relationship cannot be empirically established. Carefully selected margins of safety can be used to take into account uncertainties that are due to measurement and to the impact of exposure to risk. The cost of margins of safety must be understood and made explicit. The surrogate, which is directly measurable, becomes the basis for standard setting.

It is important to consider the use of risk assessment techniques in rule making. Studies are needed to determine how best to apply these techniques prior to their use.

CHAPTER THREE

REVIEW OF PRESENT PRACTICE

OVERVIEW OF PRESENT PRACTICE

In Volume II of their report, Russell et al. (*8*) provide a rather complete review and summary of existing methods and studies used to estimate the risks of hazardous materials transport. Their summary has been used, to some extent, to present the following overview of present practices. The methods reviewed are classified by use in four distinct categories: (a) enumerative indices, (b) regression models, (c) network and distribution models, and (d) probabilistic risk assessment models.

Enumerative Indices

These models count the number of conditions that exist in order to develop a risk rating score. For example, Garbor and Griffith's model (*3*) counts the number of chemical plants, storage facilities, and their proximity to population, modes of transport, and types of threats. Weights are assigned to the different parameters and the weighted count forms a risk index. The Kansas State model [Russell et al. (*8*)] works on the same enumeration principle, but uses prepared tables to convert traffic counts, route mileage, placard counts, and form of threat, to indices for use in determining a risk index with a three-level risk precision of low, medium, and high. The same type of index is generated for emergency response preparedness.

The difficulty with these models is their lack of precision, which can result in suppressing the identification of particular high-risk situations in the aggregation process leading to an index. Conversely, they are relatively easy to use in terms of data acquisition and computation requirements from a small community's perspective. They can provide an excellent overview of the communities' average vulnerability but do not help identify particular locations or situations of unusually high risk or specific means to reduce these risks.

Regression Models

Regression models attempt to use measurable parameters (such as average daily traffic, number of heavy volume intersections, number of signals, type of road or railroad, road or rail condition) in order to develop a value for the probability of an accident per million vehicle miles, or some other similar probabilistic form, for a specific vehicle type. The probability is combined with a consequence valuation by determining the population density of those at risk. The Peat, Marwick, Mitchell model (*11, 12*), for example, uses this approach.

These methods are route specific since the data come from specific routes that are generally independent of the type of cargo. The regression equation uses actual data for its variables; however, constants for equations are either set arbitrarily (as weights) or are correlated with actual conditions and accident history for specific routes. Although the latter approach seems most appropriate to determine the average number of accidents expected over a given route, it does not account for the magnitude of the consequences of an accident. For rare events, historic data regarding a specific route, or even national averages, will not usually reflect the actual potential for large accidents.

These methods seem more applicable to the risk of specific shipments over alternative routes than providing a community with guidance on either the overall risk or specific risk problems. The approach can provide guidance on alternative route selection.

Network and Distribution Models

Network and distribution models are based on the development of a network of routes and transportation links with particular characteristics. Using historic nationwide data (or specific data sources), accident rates for different links and modes are determined; some models utilize population density (e.g., the Princeton (*18*) and Transportation Systems Center (*19*) models).

Because these data use national data bases, they primarily assess either national or regional transportation risks for a given mode of transport, and, in some cases, by class of commodity. One particular distribution model, by Williams and Sheldon (*20*) uses an optimal (shortest) path determination algorithm, with link factors based on a risk/cost weight, in which the weights are based on conditional probability and consequence products. This makes it similar to probabilistic relative risk assessment models. These models are best suited for routing rather than risk identification.

Probabilistic Risk Assessment Models

Probabilistic risk assessment models use the conditional probability of an accident and the magnitude of its consequence as the two parameters. These models differ in: (a) how they combine the two parameters to arrive at risk; (b) the level of detail for data acquisition; and (c) the methods of obtaining data and model parameters.

Risk Definition

The National Academy of Sciences Panel on Risk Analysis and Hazard Evaluation (*21*) uses the conditional probability of an accident causing some loss as its definition of risk. The Williams and Sheldon model (*20*), the Battelle models (*22, 23*), and the USC models (*24*) all use expected value of risk, that is, they use the product of conditional probability and consequence magnitude as their definition of risk.

Level of Detail

Some models start with the shipment of a particular material by a specified mode over a set 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 [e.g., IRAS (*25, 26*) and Illinois model (*27*)]. This is an example of a "bottom-up" approach as one goes from the smallest risk component, which is aggregated upward, to an overall risk. Other models start at much higher levels of detail, using aggregated data to obtain expected risk values.

Sources of Data

Some models use fault-tree analysis to develop probabilities, such as PNL (*22, 23*), whereas others, for example, use average accident rates by mode and vehicle. Dispersion models for population exposure [e.g., Garrick et al. (*28*)] and simulations to determine spill behavior are but two of many approaches tried to develop the magnitude of consequences.

The objective of bottom-up risk approaches is to develop an absolute risk estimate of a transportation route, problem, or complex of routes. The problem with these approaches is the multiplicative build-up of errors and the uncertainties in dealing with rare events.

DIFFICULTIES IN CARRYING OUT ABSOLUTE RISK ASSESSMENTS

Bottom-Up Risk Estimates

The difficulties in carrying out a bottom-up risk assessment to obtain an estimate of absolute risk are immense. At the finest grain, an analysis of this type must consider the risks of each single shipment of a cargo along a specified route by a specified mode of transport, and then add these to obtain the risk of the total traffic in hazardous materials in the area of concern. Usually, routes are broken into segments and for every i^{th} segment for trip j, the fine-grain risk for that segment and trip, R_{ij}, is given by the following formula:

$$R_{ij} = P_{1ij} \times P_{2ijk} \times P_{3ijmn} \times P_{4ijp} \times P_{5ijp} \times P_{6ij} \times P_{7ijq} \times N_{ij} \quad \text{(Eq. 1)}$$

where:

P_{1ij} = Probability of an incident in mode segment i based on road (rail, waterway) type and conditions, traffic levels, traffic hazards, congestion, and vehicle type. This is usually based on historic data for similar conditions or obtained through regression models.

P_{2ijk} = Probability of an incident resulting in an accident of severity class k. Historic data can be used in some cases, but only actual tests combined with models can be used for rare events.

P_{3ijmn} = Probability of release of cargo type, m, in an amount of spill of a size class n.

P_{4ijp} = Probability of release spreading by pathway p, e.g., air plume, water release, etc.

P_{5ijp} = Probability of ignition for a flammable or explosive material via the pathway p.

P_{6ij} = Probability of wind direction for an air release.

P_{7ijq} = Probability of damage to an area receiving the spill and the probabilities that an exposed person will die or be injured.

N_{ij} = Number of people exposed.

These probabilities have been shown as independent probabilities for illustration. They could better be represented as conditional probabilities. However, the fine-grain risk estimate is derived from a large number of probabilities multiplicatively related. This means that errors in each term are also related multiplicatively, resulting in very high levels of error propagation. Because expected values of risk are measures of central tendency, they do not, by themselves, reflect error ranges. Therefore, any risk analysis of this type must make error calculations and show how these errors propagate. In many cases, the error ranges are usually so large that absolute risk estimates are meaningless, especially when rare event probabilities are involved.

Of course, the overall risk is obtained by summing all route segments and all trips.

$$R = \sum_i \sum_j R_{ij} \quad \text{(Eq. 2)}$$

Here the errors are only additive; however, unless a detailed risk analysis is carried out, there is no way to tell if the errors add systematically or randomly offset each other.

Top-Down Risk Estimates

The opposite approach is the top-down approach, which uses aggregate historic data as a basis for estimating particular situations. The aggregate data base is analyzed by regression and correlation techniques that attempt to find cause and effect relationships that can then be used to provide overall values for P_1 through P_7 as described above. In the absence of historic data, models are used to explain these cause and effect relationships. In some cases, the models are testable, such as the explosion potential of liquified natural gas spills. These models are less difficult to use, but they are only as good as the data base or the models used. Many models, especially for rare events, are not directly testable.

Table 2 illustrates the steps that must be carried out in a top-down estimate of absolute risk. The first two major entries characterize the cargo and transport requirements; the third and fourth entries indicate the type of historic information needed and the requirements for rare event analysis, respectively. These entries are the risk parameters. The fifth entry combines the previous cases that are required to conduct specific analyses.

Depending on whether the risk estimation is for the nation, a region, state, city, port, small community, or for a more specific location, there are major difficulties involved in obtaining data for use on an absolute basis. The resultant uncertainties make any but very generic analyses suspect. More practical analyses have then focused on relative risk estimates for specific situations.

TABLE 2

ELEMENTS OF A TOP-DOWN ABSOLUTE RISK ESTIMATE

1. Development of Source Terms
    - A. Identification of Materials Transported
    - B. Determination of Threat Class
        - 1) Explosive
        - 2) Corrosive
        - 3) Others
    - C. Vehicular Mode
        - 1) Mode of Transport
        - 2) Class of Vehicle
    - D. Amount of Material Transported by Each Vehicle Type
        - 1) Single Cargos
        - 2) Mixed Cargos
2. Development of Traffic Patterns
    - A. Amount of Traffic of Each Type for Each Cargo
    - B. Actual Routes
        - 1) Length of Route over Each Class of Route
        - 2) Route Traffic Problems
        - 3) Population Corridors
        - 4) Source and Storage Problems
3. Historic Risk Data
    - A. Number of Accidents for Each Type of Transport
        - 1) Vehicle Class
        - 2) Route Class
    - B. Consequences of Accidents for Each of Above by Cargo Class
        - 1) Single Fatalities
        - 2) Multiple Fatalities
        - 3) Injuries
        - 4) Property Damage
        - 5) Inconveniences
    - C. Calculation Of Average Accident Rates
4. Analysis of Rare Events
    - A. Use of Models to Evaluate Accident Sequences
        - 1) Plausible Sequences
        - 2) Identification of Minimal Margins of Safety
        - 3) Event-tree/Fault-tree Analyses
    - B. Evaluation of the Models
        - 1) Consequences
        - 2) Probabilities
        - 3) Analysis of Degree of Conservatism
        - 4) Error and Sensitivity Analyses
5. Combining the Historic and Actual Cases to Make a Risk Determination
    - A. Estimate of the Levels of Risk For Each Case
    - B. Identification of High-Risk Situations
    - C. Risk Summaries

RELATIVE RISK ESTIMATES

Relative risk estimates make comparisons among risks; they are not concerned with absolute risks in detail, but only with a general relationship between historic risk information and actual occurrences. The use of ranks and indices to rate the hazards of materials, such as those of Danahy and Gathy (*6*), is an example of this type of approach. A more simplified relative risk approach is the kind undertaken by Russell et al. (*8*) (Kansas State model) where nominal scales are used as counting measures for specific situations. These approaches do not estimate absolute risks but can be very useful for problem identification.

Kansas State Model (*8*)

This model consists of 14 steps for making such risk assessments in which the first 11 involve a risk assessment and the last 3 involve evaluation of emergency response capability and selection of a response plan. This document provides detailed guidance, with tables and forms, for carrying out such an analysis, and all community planners would do well to have this material available to them.

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

Step 2. *Conduct a Manufacturing and Storage Establishment Survey*—Identify all sources and repositories of hazardous materials within the community.

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

Step 4. *Plot One-Mile Route Segment Corridors*—Use maps to plot population corridors for all traffic routes.

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

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

Step 7. *Determine Risk Subfactors*—Determine 12-hour average density of traffic based on traffic counts and distance, and adjust by placard counts (for hazardous materials carriers) and vehicle type (use supplied tables).

Step 8. *Determine Risk Factor*—Convert step 7 to a risk factor, using the appropriate table.

Step 9. *Determine Consequence Subfactors*—Take population density and environmental conditions into account to determine possible range of consequences. Determine manufacturing and storage indices and employee exposure factors.

Step 10. *Determine Consequence Factor*—Sum values of step 9.

Step 11. *Determine Risk Index*—Convert indices above into a high, medium, or low risk level.

Steps 12–14. *Emergency Response Capability Evaluation*

This approach is limited by the resources required to carry out the total process and the lack of means to identify specific problem areas for further consideration. Step 7 is particularly difficult because placarding only covers a portion of actual hazardous material shipments. On the other hand, it does provide a community with a reasonable, although imprecise, overview of its vulnerability to risk. If this vulnerability is high, then further studies will be necessary.

RESPONSIBILITIES FOR CONDUCTING RISK ANALYSES OF HAZARDOUS MATERIAL TRANSPORT

At the national level, DOT issues statistics for each mode of transportation, such as highway, railway, maritime, airline, and pipeline. The National Transportation Safety Board (NTSB) summarizes these analyses and publishes reports of these summaries, as well as the actions taken to correct deficiencies. The DOT Materials Transportation Bureau (MTB) is primarily responsible for regulating the transport of hazardous materials, as well as conducting research in the risk analysis area. In addition, the Coast Guard and the Federal Highway and Federal Railroad Administrations are also integrally involved in safety programs. All conduct safety analyses as well. (Safety analyses differ from risk analyses only in scope. The former are concerned with specific operating conditions and are often applied after incidents take place as corrective action. Risk analyses are generally made on a broad planning basis before events occur.) The EPA is responsible for hazardous wastes under the Resource Conservation and Recovery Act but generally its requirements for transportation coincide with DOT regulations.

At the state level, several states (including California, Rhode Island, Washington, and Texas) (*29*) have developed their own method for classifying hazardous materials and wastes by degree of hazard and/or by degree of containment and destruction. This attempt at classification is similar to that of Danahy and Gathy (*6*).

In addition, several ports, namely the Port of Long Beach and the Central Puget Sound Region, have undertaken comprehensive risk analysis studies of hazardous material transport. Many other ports have conducted studies of specific commodities, such as for liquified natural gas vessels. These studies have included extensive development of environmental impact statements (*30, 31*) and many risk analysis studies of the problem (*32*).

CHAPTER FOUR

FRAMEWORK FOR ADDRESSING THE PROBLEM: SCOPING ANALYSIS

It is not possible for a small community to undertake a complete risk analysis of hazardous material transport where comprehensive assessments have not been done at federal and state levels. The resources involved are extensive and beyond that of most communities. A community undertaking an analysis will have to consider at least three things: (a) an overview of the community's vulnerability; (b) identification of high risk situations and problems; and (c) alternatives to deal with the identified risks. Russell et al. (*8*) uses indices, a form of relative risk analysis, rather than an absolute risk analysis, as a means of determining community vulnerability. Even this approach involves extensive resources and neither identifies special problems nor alternative actions. What is needed is a rapidly applied low resource approach to determine whether a community has an overall problem and to identify specific high-risk situations. Such a scoping approach is proposed here.

This scoping approach analyzes the problem in a manner similar to that of Russell et al. (*8*) but only for three key commodities: gasoline, chlorine, and anhydrous ammonia. These 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.

All communities have gasoline service stations, many communities use chlorine for water purification, and farming communities need ammonia for fertilizer.* This analysis will serve to evaluate sources and transport corridors for these commodities, identify high-traffic and poor-transport conditions that may indicate potential problems, identify and develop alternative strategies if warranted, and evaluate the current level and needs for emergency response readiness. Once the problems (if any) involved with the use of these commodities have been explored, then other commodities with high hazard potential can be examined, as far as resources allow, on an incremental case-by-case basis. In the meantime, there is some assurance that the major threats will have been investigated.

The initial step is to demonstrate the importance of these three commodities in relation to established purposes, and then to provide some background on them. Figure 3 profiles the number of fatalities for the five highest commodities involved in highway hazardous material accidents during 1971–1981. Gasoline is the highest source (45 percent) of the total number of fatalities, with anhydrous ammonia the third highest source of fatalities (6 percent of the total) for this period. Figure 4 profiles injuries, with gasoline first (5 percent of total injuries), anhydrous ammonia second (approximately 5 percent of the total), and chlorine seventh (about 2 percent of the total). Figure 5 compares these commodities for highway and railway injuries for 1980–1981. Highway injuries dominate in all cases, except for sulfuric acid. Further details concerning these three commodities are given in the Appendix.

Table 3 summarizes the characteristics of the three hazardous materials and provides identification numbers for them. It is proposed that these three commodities be used as specific cases for analysis following the method of Russell et al. (*8*) but with several modifications. Once this analysis is made and evaluated other commodities can be considered without expending large numbers of resources to acquire additional information. In other words, one can sharpshoot rather than try a shotgun approach.

To demonstrate what such an analysis might encompass, the steps involved are given. These steps are not to be considered definitive but are used to provide a framework for further discussion and development.

Using the steps established by Russell et al. (see Chapter 3) as a point of departure, an initial scoping analysis could be performed as follows:

Step 1. *Obtain Maps and Available Photographs*—Use these as a basis for location of sources and traffic corridors.

*Liquid petroleum gas (LPG) is a similar commodity and is both flammable and toxic. Moreover, it is rapidly dispersed when released. Should a community not have one of the three base commodities transported through or within it, LPG would be a good substitute.

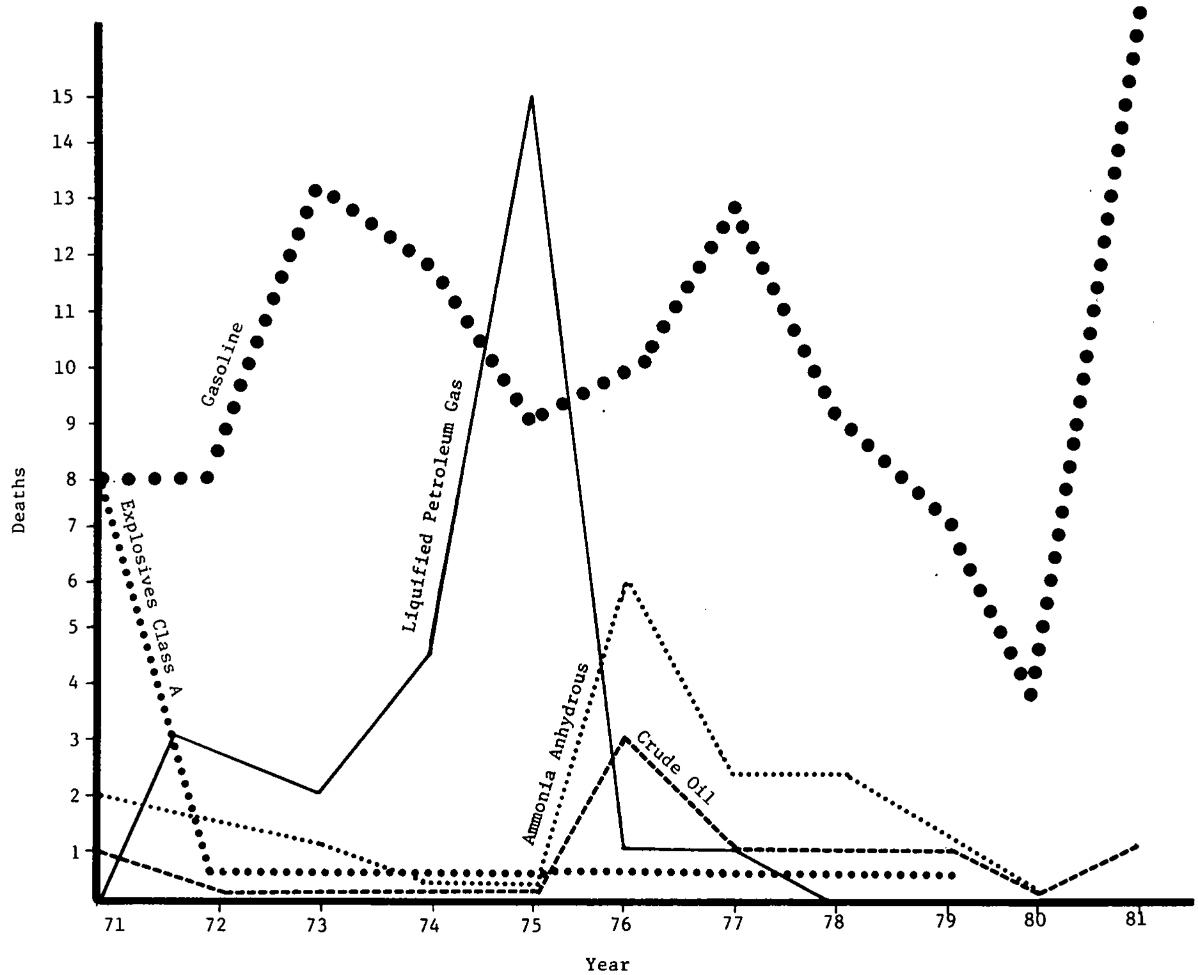

FIGURE 3 Deaths: five highest commodities—highway.

Step 2. *Conduct a Survey of Users or Suppliers*—Every service station and storage facility using gasoline should be identified. Frequency of shipments, the time of and route for these shipments, the amount stored and shipped, and the identity of the transporters can then be ascertained. Because transporters will most likely have multiple deliveries, routes and schedules can also be obtained. Chlorine is usually shipped to, and stored at, water-treatment plants. Thus, the quantities and traffic patterns for chlorine should be readily available. Other users or suppliers of chlorine must also be identified. Questionnaires or telephone surveys may provide this information for chlorine as well as ammonia. Some thought as to quantities of these materials, which might be small enough not to be considered in the analysis (minimum quantities), is necessary here. There remains an open question as to the basis for establishing such levels.

Step 3. *Obtain Traffic Data*—The initial source of traffic data would be to contact gasoline stations, water-treatment departments, and fertilizer manufacturers within specified communities to determine their shipment patterns for incoming materials, as well as identification of individual shippers and carriers. The carriers could then provide data for route, vehicle, cargo, and shipment frequency. A placard count survey on major routes may be necessary to identify through traffic, although this will not ensure that all shipments are identified. Although it is necessary to identify only the three commodities of interest, it may be possible to note all placards without expending additional resources. This could be helpful after the first commodities are evaluated. Small communities might use volunteers for such counting. Unless there is heavy barge traffic, only highway and railroad traffic should be considered. Russell et al. (*8*) provide forms for this purpose.

Step 4. *Plot One-Mile Route Segments*—Use maps showing corridors. Show traffic rates, type and condition of road or railway, as well as population density and use type. Population

TABLE 3

PROPERTIES OF GASOLINE, CHLORINE, AND AMMONIA

Commodity*	Identification #	Label
Gasoline	UN 1203	Flammable Liquid
Chlorine	UN 1017	Poison Gas, Oxidizer
Anhydrous Ammonia	UN 1005	Poison Gas

*See Appendix for further characterization.

estimates involving these three commodities can be made by counting homes and businesses within specified corridors, and averaging the number of occupants during working and non-working hours. Only roadside corridors (at the minimum), perhaps one block in width, need be considered. Full half-mile segments are not necessary for gasoline, but may be important for chlorine and ammonia plume releases.

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

Step 6. *Conduct Traffic Surveys*—Conduct traffic surveys where data were not available in step 3, particularly for highways.

Step 7. *Identify Conditions with Minimal Margins of Safety*—At this point, the scoping analysis departs from that of Russell et al. The purpose here is to use a relative risk approach to identify those situations that have the lowest margins of safety in terms of risks to people and property. The analysis must proceed from dichotomous views—that of the corridors and that of the vehicles and their cargos.

The corridor analysis for these three commodities includes the amount of total traffic, hazardous material traffic, time profiles, class and conditions of roadways and railways, intersections and grade crossings (and control and warning for these), zoning and population levels along the corridors, and any unusual patterns of use, such as bridges, tunnels, bypasses, short cuts, etc., which channel traffic. The object is to locate route segments that have higher than average hazardous cargo traffic and/or unusual congestion, or roadway or railway hazards, in conjunction with traffic flow. Once these are located, then demographic patterns can be established for each case in order to locate those having high potential for exposure as a result of an accident.

The vehicle and cargo analysis addresses the type and condition of vehicles, their total route, and the amount and type of cargo and its method of stowage. The objective is to locate a combination of vehicle type, condition, cargo, and particular route having marginal capability in comparison with similar conditions.

When completed, the two analyses are combined to determine whether or not marginal vehicle situations occur in corridors with minimal margins of safety. These combinational conditions should be addressed first, followed by remaining vehicle or corridor problems.

Step 8. *Identify Possible Alternative Routes*—For corridor problems, identification of alternative routes for cargos must be undertaken. Two kinds of routes must be considered: (a) bypasses for through traffic and (b) alternatives for sources and destinations within the community.

Step 9. *Analyze Alternative Routes to Determine If These Minimize Risk*—There are a number of factors to be considered and traded off in this analysis:

a. Longer route length versus better road or rail class and less exposure to people and property;

b. Elimination of congestion versus longer length of travel; and

c. Selective routing by cargo, vehicle type, etc., versus longer routes and needs for enforcement.

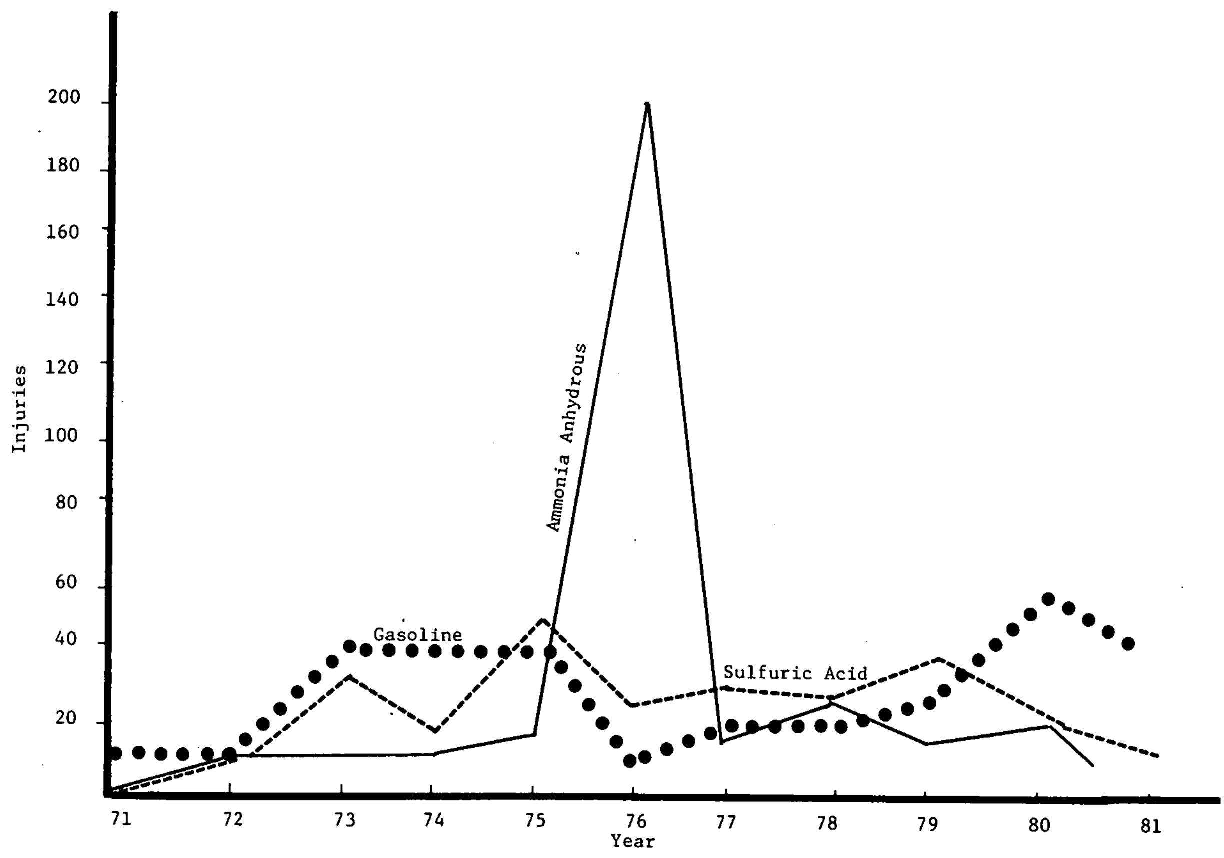

FIGURE 4 Injuries: three highest commodities—highway.

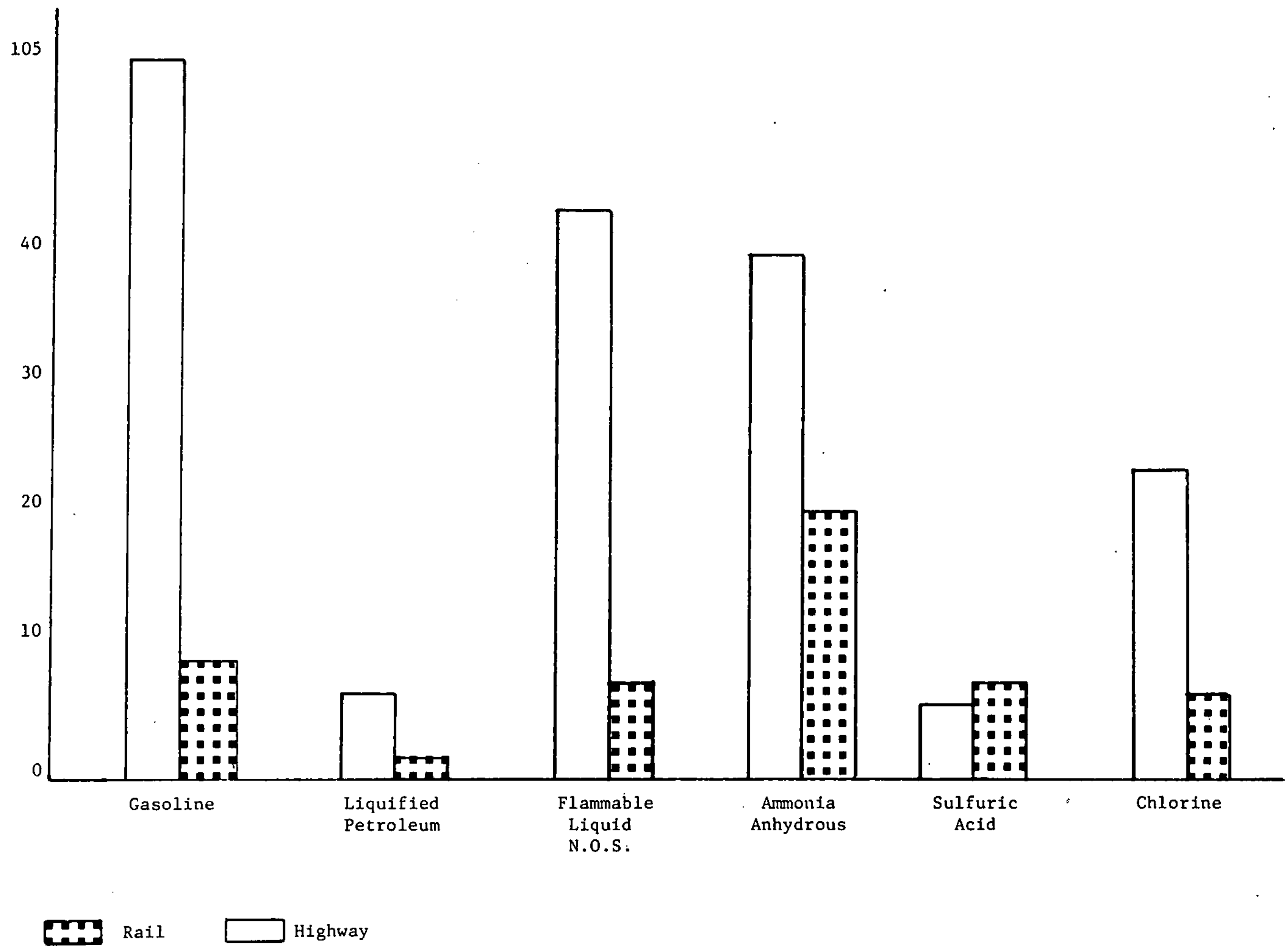

FIGURE 5 Injuries by highway and rail 1980–1981.

The alternative routes must lower overall risk to people and property if they are to be effectively implemented.

Step 10. *Prohibition of Cargos*—Because these three cargos are necessary to conduct community business, there is no incentive to restrict the flow of these cargos on any total basis. However, route restrictions, with designated alternative routes and vehicle restrictions that conform to federal and state laws, are desirable if the overall risks are lower and traffic flow can be maintained.

Step 11. *Determine Level of Community Emergency Response Capability for Dealing with Accidents from the Three Cargos of Interest*—Determining the emergency response capability of a community will, of course, depend on the community's own capability; however, coordination of, and support for, training for emergency response at both state and regional levels is also extremely important. Russell et al. have developed a questionnaire (*8*, pp. 30–31) that is effective in assessing the emergency response preparedness in a community. However, its initial use should be aimed primarily at how well the community is prepared to respond to the three specified cargos. Other sources of emergency response information include Gabor and Griffith (*3*), Rockwell International Guide and Checklist (*33*), Zajic and Himmelman (*13*), DOT Emergency Action Guide (*34*), National Fire Protection Association Guides (*35*), and DOT Emergency Response Guidebook (*4*). The analysis of emergency response capability for handling these three cargos will also provide insight into a community's ability to respond to any emergency.

The scoping analysis outlined above is based on the idea that the transport of these three cargos, which represent the majority of severe hazardous material accidents, is necessary to the conduct of everyday life in the community. Additionally, while the risk of transporting these cargos can be reduced, some level of risk will also remain. Once a community is able to cope with the risks from these cargos, it can then assess similar situations involving more hazardous cargos.

Once additional cargos and traffic patterns are identified, the analysis is the same, namely, to determine corridor and cargo route conditions with lower margins of safety on a relative basis to those developed for the three base cargos. Prohibition should be considered only for those cases in which the margin of safety and the size of possible consequences are much larger than those for the base case. All means of risk reduction should be considered before restricting traffic flow of specific materials.

Insofar as possible, the scoping analysis should be a cooperative process involving all jurisdictions that control transportation facilities in the area being studied.

CHAPTER FIVE

ALTERNATIVE APPROACHES TO ADDRESSING THE PROBLEM

A formal risk analysis regarding the transport of hazardous materials to determine absolute risk levels from a bottom-up approach is difficult to make. Such an analysis will have wide ranges of uncertainty, especially for rare events resulting in large consequences. The outline of the components of such an analysis (Eq. 1) illustrates the problem of dealing with many variables with wide ranges of uncertainty. For a top-down approach, a substantial amount of data are available at the national level for calculating risks of frequent events where the consequences are very small (see Table 1). However, a few large, rare events can distort this information, as indicated in Figure 3 by the sharp peak in fatalities from anhydrous ammonia in 1976. In the top-down approach, aggregated data from different sources with varying degrees of error, completeness, and precision must be combined. For example, converting historic accident data to other indices, such as accidents per ton-mile via a particular transport mode, requires that the accident data be used as the numerator of the index and that the number of ton-miles of each type of cargo by mode be used as the denominator. This index can have wide ranges of error since the numerator and denominator are derived from different sources with different error characteristics. In addition, rare events, which have not yet occurred, will not be reflected in historic data. Modeling techniques, such as decision models and event/fault tree analysis, can be used in these cases to provide analytical estimates of risk. The validity of models that cannot be empirically verified (because the events are so rare) are always suspect to some extent.

When top-down and bottom-up analyses are used in concert to make relative risk analyses, the usefulness of the results increase substantially. Resulting analyses can be used to rank and order the sources of risk and the means of mitigating them. Identification of the major sources of risk becomes very important since this knowledge can provide strategic approaches to identify and cope with such risks. Searching for, and identifying, inadequate margins of safety in traffic corridors and route patterns, in comparison with normal margins of safety, is one such strategic approach. Looking for similarity among factors causing risks, in order to discover underlying causes, is another strategy. The comparison of risks with benchmarks and other similar risks in society is yet another. In general, these analyses are best carried out at the national or regional level rather than at the local level. However, these types of analyses have been conducted for specific situations; for example, specific transportation corridors, port facilities, and for specific projects in the form of environmental impact assessments and related studies.

Another type of relative-risk study is the comparative analysis of alternative routes. Glickman has made analytic studies of alternative routes for both railway and highway traffic (*9, 10*), and many of the methods discussed above, such as Russell et al. (*8*) and Peat, Marwick, Mitchell & Co. (*11, 12*) are directly applicable to this purpose. In general, all of these analyses are for alternative routes within a single mode of transport. As far as is known, there have been no analytical studies concerning intermodal routing. Such routing has been discussed, however, such as the EPA's suggestion that barges, as an alternative to trucks, be used for transporting radioactive wastes from Brookhaven National Laboratories through New York City. Usually, this type of analysis must be conducted by the shipper or national or state agencies concerned with specific hazardous materials.

The resources required for these studies, in terms of money and trained personnel, is high and may well be beyond the capability of a small community. The approach used by Russell et al. is aimed at shortcutting the formal risk analysis and provides a scoring method to evaluate overall community vulnerability. Even this approach requires resources and trained personnel. Moreover, it does identify specific problem conditions. The scoping analysis proposed here would provide, when further delineated, a low cost means of determining whether a community is vulnerable, whether specific problems exist, and what might be done about it. If a major problem does exist, then the Russell et al. (*8*) approach or a formal risk analysis could be undertaken.

CHAPTER SIX

ROLE OF THE FEDERAL GOVERNMENT, STATES, AND LOCALITIES IN RISK AND VULNERABILITY ASSESSMENT

OVERVIEW

Organizations at all levels of government either address or need to address the three steps of risk identification, risk reduction, and emergency response preparedness for hazardous materials transport (HMT) to, from, and through their jurisdictions. The legal, technical, and procedural requirements differ among the various levels of government as exemplified in Table 4, which lists these categories and their respective requirements for both government and industry. A more detailed discussion of these roles follows.

LEGAL ISSUES IN HAZARDOUS MATERIALS TRANSPORT

Identification

The federal government provides the most widely accepted guidelines for identifying transported hazardous materials through laws requiring labeling and placarding, as well as container and vehicle design specification. The most comprehensive federal regulations pertaining to hazardous material transportation are contained in Title 49 of the Code of Federal Regulations, which covers issues such as general requirements for packaging and shipping, container specifications, pipeline standards, and rules pertaining to carriage of hazardous materials by specific mode (air, rail, etc.). Procedures for reporting hazardous material transportation accidents are also described in Title 49. EPA requirements under the Resource Recovery and Conservation Act include identification, record keeping, and assignment of responsibility for hazardous material wastes, but are congruent with Title 49 for transportation.

Many states have adopted Title 49, in whole or in part, as the foundation of their HMT policies. The most common problems encountered are mislabeling of materials, interpretation of search and seizure clauses, implementation of hazardous material inspection functions, and development of guidelines for the removal of unsafe products (this final issue is generally more consumer-protection oriented than it is a response to HMT). Several states have implemented regulations designed to identify potential HMT risks, such as Oregon's requirement that railroads handling hazardous material shipments notify the state of same, and Connecticut's requirement that records be kept of all fuel handled and transported. State HMT identification laws appear to be the exception. There is evidence that many states are becoming more active in the identification, record keeping, and licensing of radioactive materials and the transporation and storage of hazardous waste.

Reduction

Most states rely on federal regulations regarding hazardous material traffic and routing restrictions in conjunction with Article 1, Section 8 of the United States Constitution, which designates the federal government as the exclusive promulgator of laws pertaining to interstate commerce. However, New York City's enactment of laws restricting the movement of radioactive materials is currently upheld (at least temporarily) by the federal courts. Other cities and states may consider similar action depending on the court's decision (*8*, pp. 3–44). In Michigan, for example, the Director of the State Department of Transportation is permitted to formulate rules pertaining to the transportation of hazardous materials although, presumably, the rules are bound by federal prerogative.

States and localities generally confine HMT risk reduction efforts to the enforcement of transportation and safety laws. The California Highway Patrol for example, is charged with ensuring the safe operation of hazardous material carriers, including the handling and disposing of hazardous wastes. A New Mexico law allows police to escort carriers of transported hazardous materials.

Several localities have restricted the flow of hazardous materials (e.g., New York, mentioned above, and a community law enacted in New Jersey that sets a maximum speed limit for trains transporting hazardous materials through the community (*8*). Most state and local traffic control efforts, however, are restricted to general vehicle and operator specifications and requirements.

Emergency Preparedness

The federal government assumes primary responsibility for severe HMT emergencies (such as nationally declared disasters) and provides coordination of safety efforts for less severe emergencies. However, precise role delineation, at state and local levels, as well, is one of the most vexing issues concerning HMT emergency response. For instance, California has delegated 17 agencies as having responsibilities for HMT emergency response (*8*). Some states, such as Arizona, authorize the governor to exercise emergency powers regarding state cases, and, yet, authorize mayors similar powers in regard to local emergencies. Thus, without a clear definition as to what constitutes a state versus a local emergency, as well as a definitive guideline concerning gubernatorial or mayoral jurisdiction with regard to such emergencies, remedies may only aggravate the chain-of-command problems.

For any accident within a community, the local, responsible official becomes the decision-making authority and other levels of government are only brought in for assistance on request. The need for assigning responsibility to a single local official and a chain of command for action at the local level is imperative before the occurrence of incidents. Coordination with state, federal, and industrial organizations that can provide assistance is necessary to ensure smooth working procedures when incidents actually occur.

TABLE 4

LEVEL OF GOVERNMENT AND HAZARDOUS MATERIALS TRANSPORTATION REQUIREMENTS

Hazardous Transportation Requirements	Level of Responsibility								
	Federal	State	Regional	Ports	Cities	Urban Communities (Small)	Suburban Communities	Rural Communities	Industry
Legal									
Designation	I								
Labelling & Placarding	I								
Transit Rules	R	R	r	r	r	r	r	r	
Traffic Control	R →	R	R	R	R	R	R	R	
Throughput Maintenance	X								
Technical									
Vehicle & Container Design	I,R								I,R
Traffic Routing Studies	I,R	I,R	i,r	i,r	i,r	i,r	i,r	i,r	i,r
Emergency Response Techniques	M	M	m	m	m	m	m	m	m
Risk Analysis	I	i	i	i	i	i	i	i	i
Procedures									
Budgets	X	X	X						
Training	M	M	m	m	m	m	m	m	m
Communication	m	m	m	m	m	m	m	m	m
Coordination	M	M	m						
Management				M	M	M	M	M	M

Key:

I = Identification
R = Risk Reduction
M = Mitigation
X = Other

Upper Case = Required
Lower Case = Optional
→ = By Formal Delegation

TECHNICAL ISSUES IN HAZARDOUS MATERIAL TRANSPORTATION

Identification

Identification of technical issues pertaining to the transportation of hazardous materials takes two basic forms: risk assessment, which concentrates on a determination of the likelihood of an event; and traffic and routing studies, which examine traffic corridors with the aim of identifying accident-prone route segments.

At the federal level, where DOT keeps statistics on accident frequency for all modes of transportation, many agencies under DOT maintain independent routing and traffic records pertaining to their particular interests (e.g., the Federal Railroad Administration). Traffic and routing information is crucial to the more formalized risk identification process of risk analysis that, until recently, was largely undertaken by private industry and the federal government—particularly the Departments of Energy and Defense. Additionally, state legislatures and other more localized decision-making bodies have increasingly turned toward risk analysis, such as Washington's commissioning of a risk analysis of their oil transportation system (Oceanographic Institute of Washington, 1972), and numerous assessments of port facilities dealing with the marine transportation of hazardous cargos. While risk analysis methodology is becoming more accessible, smaller communities are utilizing it as a tool for the identification of HMT risks (Kansas State Model applied to St. Marys and Manhattan, Kansas) within their jurisdictions.

Reduction

The DOT has primary responsibility for regulations pertaining to the design of HMT carriers, and works in conjunction with industry to develop HMT safety standards. Such standards include thermal and tank-head protection to railroad tank cars and low center of gravity designs for tanker trucks (as mentioned earlier). Designs for storage facilities are generally subject to state and local building and fire codes.

In addition to carrier and storage design, information generated from traffic and routing studies is applied to dangerous route segments where risk reduction mechanisms include upgrading railroad crossings, highway intersections, physical roadway conditions, and alternative routing patterns.

Emergency Preparedness

Technical issues in HMT emergency response are closely linked with procedural issues, although the technical emphasis is on equipment and technique, where procedural issues involve use of equipment and command and control functions.

With the exception of technical training and large scale emergencies, the federal government's role in technical emergency preparedness is largely to advise or to provide expert assistance. In some cases (e.g., the U. S. Energy Research and Development Administration's Interagency Radiological Assistance Plan, EPA, and FEMA), the federal government supplies technical response teams.

Some industries involved with the Chemical Transportation Emergency Center (CHEMTREC) are prepared to provide emergency assistance teams for specific HMT emergencies. Both the Chlorine Emergency Plan (CHLOREP) and the Pesticides Safety Team Network, operating through CHEMTREC, are designed to provide emergency technical personnel in the case of chlorine- or pesticide-related emergencies. Many of the larger petroleum companies have developed rapid response teams although they are manufacturer specific as opposed to industry wide.

In addition to technical emergency preparedness, as represented by emergency response and communication equipment, state and local authorities receive training for HMT emergency response from the federal government (FEMA, EPA), the private sector (Colorado Training Institute, the American Red Cross), or from the state agencies themselves.

PROCEDURAL ISSUES IN HAZARDOUS MATERIALS TRANSPORTATION

As previously mentioned, procedural issues in hazardous material transportation are largely confined to emergency response. In addition to budgetary concerns, primary emergency response procedures involve the need for a defined chain of command as well as command and control (communications) capability.

At the federal level, emergency coordination and technical information is available through a variety of agencies including DOT, EPA, FEMA, the Coast Guard, the Army, and others. Although FEMA was, in part, created to develop a comprehensive national emergency response network, that goal has yet to be realized.

Few states have clarified HMT emergency response chains of command below the federal level. However, for those that have, the preferred chain appears to be the state police or local fire chief assuming a communication and control role, with more specialized agencies involved in the emergency. Ultimate responsibility often rests with state governors or, in more localized incidents, with mayors, or their equivalent.

While only a few states require cities and rural communities to develop HMT emergency plans, a growing number of communities have begun to develop such plans on their own and have begun to identify responsible personnel. In general, as noted by Russell et al. (*8*), "laws on (communication and leadership) are so varied they defy categorization."

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Cities and local communities are currently vulnerable to multiple-fatality accidents resulting from incidents involving the transportation of hazardous materials. This is evident from statistics covering three widely used commodities: gasoline, chlorine, and anhydrous ammonia. There is much that the community can do to minimize the risk of accidents and to reduce vulnerability. Such efforts can be categorized under three headings: risk identification, risk reduction, and risk mitigation.

To investigate these risks, a community has several sources to draw from in terms of expertise: federal, state, and regional authorities; industrial groups and specific businesses; consultants and academia; and its own local resources. The resources devoted to accomplishing the risk analysis must be proportionate to both the degree of risk involved and the resources available to the community. In any case, a community should have some idea of its vulnerability and its ability to cope.

Given limited resources, the methodology developed by Russell et al. (*8*) at Kansas State is recommended as a means of dealing with the problem of identifying the degree of risk and the community's ability to cope. Even if resources are too limited to carry out the total analysis as prescribed, a shortcut analysis, using the three commodities cited above, can be undertaken with minimal time and effort. These analyses, however, must be more than just scoring systems to identify the degree of risk; they must aid in identifying specific high-risk and high-vulnerability conditions and allow alternatives to be considered.

Risk reduction occurs through the removal of hazardous traffic problems, through alternative routing techniques, and through controlling hazardous material flow. Alternative routes must balance the distance, condition of roadways (or railways), traffic hazards, and populations at risk in order to ensure a net risk reduction. In the case where risks are very high, controlling (including the banning of) the flow of transport should be considered. However, the commodities involved must be considerably more toxic or explosive than the three base commodities. The base commodities represent shipments necessary to the economic health of all communities. Restricting the transport of these commodities could result in higher risks to the community (e.g., impure water from lack of chlorine). Nevertheless, a community can reduce its risks and vulnerability by controlling traffic, eliminating unusual hazardous conditions, and developing emergency response preparedness. Such actions will reduce the total risk of hazardous material transport, not just of the base commodities. Once the base commodities have been addressed other hazardous materials, which have the potential for multiple-fatality accidents, can be addressed.

Unless a community has gone through the process of risk analysis (perhaps using the three base commodities as a minimum), there is no rational basis for establishing regulations restricting throughput of hazardous materials transport. Only after an analysis has been made, and specific risks have been identified (which are substantially higher than those of the three base commodities), should banning throughput be considered. In these cases, alternative routes, special traffic procedures, and notification and traffic control approaches should be considered before considering the banning of hazardous materials shipments. There must be a clear and present danger before a community acts restrictively.

A community has responsibility for its own health and safety over and above that provided by federal and state authorities. It can only carry out this responsibility if it knows the scope of its problem, if it can act to prevent such incidents from occurring, and, if it can provide the means of coping effectively with such accidents when they do occur. With minimal resources, a community can rate itself by using either the Kansas State model or the simplified version recommended here. Local communities are urged to do so.

RECOMMENDATIONS

1. A study is needed to define the benefits, problems, and costs of using risk analysis criteria for decision making in establishing federal, state, and local rules and regulations of hazardous material transport.
2. A further, formal delineation of the scoping analysis, examples of implementation including demonstration and evaluation, and wide dissemination of its application, should be undertaken. In formalizing the scoping analysis methods must be developed to specify the minimum quantities for consideration.
3. Studies should be undertaken to address analytically the relative risks of intermodal hazardous material transport.

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APPENDIX

PROPERTIES OF AMMONIA, CHLORINE, AND GASOLINE

Ammonia, Anhydrous:

- Emits irritating gas, causes skin irritation and burns
- Threshold limit = 50 ppm over 8-hour exposure period

Physical characteristics:
Auto ignition = 646°C
Vapor pressure (TORR/°C) = 10 atm/25.7
Boiling point = 33.4°C
Vapor density (g/L) = 0.6
Very water soluble

Health hazard rating: severe; short exposure may cause serious injury

Flammability: minor; material must be pre-heated to ignite

Reactivity: None; stable when exposed to fire

Ammonia, Anhydrous: 1971-1982 (DOT)

Highway: 177 incidents reported

Results:
Deaths: 14
Injuries: 325
Damages: $442,000
Vehicle accidents: 24
Evacuations: 2

Breakdown of all "Accidents"

Deaths: 5 -- 35% of total
Injuries: 145 -- 47% of total
Damages: $195,000 -- 44% of total
13% of all incidents

Rail: 570 incidents reported

Results:
Deaths: 3
Injuries: 172
Damages: $1,080,000
Derailments: 48
Evacuations: 8

Breakdown of all "Derailments"
Deaths: 3 -- 100% of total
Injuries: 79 -- 45% of total
Damages: $942,000 -- 87% of total
8% of all incidents

Chlorine:

- Emits irritating gas, causes skin irritation and burns, explosive under certain conditions, oxidizing substance (reacts with reducing agents)

- Threshold limit = 1 ppm over 8-hour exposure period

Physical characteristics:
Vapor pressure (TORR/^{o}C) = 3.66/0
Boiling point = 34.5^{o}C
Vapor density (g/L) = 2.49
Semi-soluble in water

Health hazard rating: severe; short expsoure may cause serious injury

Flammability: none; material does not burn

Reactivity: minor; unstable at high temperature or presure and may react with water

Chlorine: 1971-1982 (DOT)

Highway: 37 incidents reported
Results
Deaths: 0
Injuries: 162
Damages: $50,000
Accidents: 2
Evacuations: 0

Breakdown of "Accidents"
Death: 0
Injuries: 0
Damages: $3,800 = 7% of total
6% of all incidents

Rail: 84 incidents reported
Results
Deaths: 11
Injuries: 248
Damages: $2,192,000
Derailments: 19
Evacuations: 3

Breakdown of "Derailments"
Deaths: 8 -- 72% of total
Injuries: 171 -- 68% of total
Damages: $1,101,000 -- 50% of total
22% of all incidents

Gasoline

- Flammable, emits toxic gas or vapor, causes skin irritation or burns, explosive under certain conditions.

Physical characteristics:
Flash point = $-40^{\circ}C$
Auto ignition = $257^{\circ}C$
Vapor density (g/L) = 3.0
Insoluble in water

Health hazard rating: minor

Flammability: severe; material ignites at normal temperature

Reactivity: none; stable when exposed to fire

Gasoline: 1971-1982 (DOT)

Highway: 8,762 incidents reported
Results
Deaths: 128
Injuries: 365
Damages: $35,351,000
Accidents: 1,174
Evacuations: 0

Breakdown of "Accidents"
Deaths: 68 -- 53% of total
Injuries: 123 -- 33% of total
Damages: $18,751,000 -- 53% of total
13% of all incidents

Rail: 89 incidents reported
Results
Deaths: 0
Injuries: 0
Damages: $168,000
Derailments: 18
Evaculations: 1

Breakdown of "Derailments"
Deaths: 0
Injuries: 0
Damages: $151,000 -- 90% of total
20% of total incidents

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