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16. Abstract

While gasoline represents one-third of all hazardous materials transported in the country by trucks, the risk associated with gas transportation, as viewed by the private sector, is small. Public perceptions of risk are much greater due to lack of knowledge of probabilities and consequences of spills. Methods to improve knowledge available to the public on gasoline spills and methods to improve estimates of environmental damages from gasoline spills is presented. Generalization of methodologies to hazardous materials in general are discussed.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

PREFACE

Our society moves and stores increasingly larger amounts of hazardous materials each year. Public concerns about these increases and the possible effects of a hazardous material accident have also grown. Many hazardous materials are either fuels, fuel components, waste products from power plants or the inputs and outputs of industrial manufacturing processes. In addition, our society witnessed a stream of negative side effects accompanying the benefits of new technologies. These unpredicted costs include, to name only a few, the bioaccumulated effects of DDT on wildlife, the alleged effects of toxic wastes in the Love Canal, as well as a host of human carcinogens in our work places and dining rooms.

Growing along with the heightened public awareness of these costs, or risks, is the area of risk assessment. Risk assessment simply determines just how serious a hazard is and if society should be exposed to it (Slovic, 1979). The actors involved are very diverse. They include representatives of the public, environmental groups, scientists, engineers, and business people.

Risk management does not represent a panacea for all the world's problems and it probably never will come close to representing the variety of decision makers' special interests. However, risk management does offer some tools to the regulators, the standard setters, the legislators, the scientists and engineers, the business people and politicians (Sage, 1980). Decisions about new technologies will be made in the political arena and the public perception of risk can be affected by the views of risk held by the decision maker.

1.0 INTRODUCTION

Public concern about the movement and storage of hazardous materials is increasing (Royer, 1980). Generally the probabilities of occurrence are very low and the potential consequences very large. Investigating the views of risk from various segments of society by risk assessment procedures may prove to be of benefit to all involved.

1.1. The Focus

The unique aspect of this paper is to analyze whether management tools are available and appropriate for use on the problem of transporting hazardous material. This report focuses on the environmental risks rather than human safety risks or direct dollar losses associated with the highway transportation of gasoline. Gasoline was selected because:

1. gasoline provides 75 percent of the transportation energy consumed in the United States and thus benefits all of society (Rhoads, 1978);

2. one-third of all the hazardous materials transferred in this country by truck is gasoline (Rhoads, 1978);

3. there are indications that petroleum products and gasoline can cause considerable environmental damages (EPA, 1976; Malins, 1980);

Based on the gasoline case study, the report also presents some generalizations concerning risk assessment and the transportation of all hazardous materials.

2.0. THE RISKS ASSOCIATED WITH THE HIGHWAY TRANSPORTATION OF GASOLINE

2.1. How Large is the Problem?

Table 1 represents a summary of utilities and transportation (UTC) data that give a general picture of accidents involving hazardous materials in the State of Washington. These data are available starting in 1978.

Table 2 shows the oil spill complaint data collected by the Washington State Department of Ecology (DOE). The DOE summarizes spill response data from all of their regional offices and the U.S. Coast Guard. These data indicate the frequency of oil spills and their likely sources.

These data suggest the following about the transportation of hazardous material and gasoline in the State of Washington.

1. The private, currently unregulated carrier, is involved in a greater number of accidents than the common/contract carrier.

2. Driver error appears to cause more truck accidents than defective equipment.

3. Property damage due to hazardous materials accidents is very small in comparison to property loss associated with total traffic accidents.

4. Vehicle/vehicle accidents account for over 70% of the accidents reported.

5. Bulk tank type trucks are involved in most hazardous material accidents and 70% of the hazardous materials are liquid.

6. The DOE data show that of the spills reported across the State, very few come from highway accidents.

7. It appears that although accidents involving hazardous materials are occurring, they do not cause reportable damages to the environment. The relatively low property damage from hazardous material transportation (UTC) data seems to support this. It is conceivable and likely that small amounts of gasoline are being released during accidents and the spills are not reported to the DOE.

8. The frequency of an accident causing significant environmental damage due to gasoline is present but low.

Table 1

General Accident Statistics Involving the Transportation of Hazardous Materials in the State of Washington
(UTC, 1978 and 1979)

Category	1978 Heavy Truck	1978 (Total Traffic)	1979 Heavy Truck	1979 (Total Traffic)
Total Accidents	4,528	(116,923)	4,941	(118,686)
Total Fatalities	87	(1,006)	108	(1,032)
Total Injuries	1,838	(64,669)	1,907	(65,399)
Property Loss	$\$13.7\times10^6$	($\$5.49\times10^6$)	$\$18.1\times10^6$	($\$5.46\times10^6$)
Accidents/Death	52	(116.2)	45.8	(115)
Accidents/100×10^6 miles	80.3	(220)	83.3	(224.6)
Estimated Property Loss Involving Hazardous Materials	**$631,070**		**$821,105**	
Total Heavy Truck Accidents Involving:				
Private carrier	2,950	(62.7%	3,112	(59.7%)
Common/contract carrier	1,750	(37.5%)	2,103	(40.3%)
Hazardous Materials Accidents Involving:				
Private carrier	86	(74.1%)	121	(77.6%)
Common/contract carrier	30	(25.9%)	35	(22.4%)
Total Heavy Truck Accidents Caused By:				
Driver error[1]	2,608	(88%)	3,099	(77.6%)
Defective equipment	362	(12%)	397	(11.4%)
Hazardous Material Accidents Caused By:				
Driver error[1]	57	(90.5%)	96	(86.5%)
Defective equipment	6		15	
Post Accident Citations Issued to Truck Driver vs. Other Driver:				
Truck Driver	1,371		1,565	
Other Driver	944		945	
Accidents by Type[2]				
Vehicle hit vehicle	3,381	(74.7%)	3,702	(74.9%)
Vehicle hit object	570	(12.6%)	606	(12.3%)
Non Collision	456	(10%)	586	(11.8%)
Hazardous Material Accidents by Type of Truck:				
Solo with dry commodities	16	(13.8%)	22	(14.1%)
Solo with bulk tank	39	(33.6%)	56	(35.9%)
3-axle with 2-axle trailer-dry	3	(2.6%)	2	(1.3%)
3-axle with 2-axle trailer-tanker	14	(12.1%)	20	(12.8%)
Tractor and semi-trailer-dry	12	(10.3%)	23	(14.8%)
Tractor and semi-trailer-tanker	29	(25%)	32	(20.5%)
Tractor and 2 trailers -dry	0		0	
Tractor and 2 trailers -tanker	3	(2.6%)	1	(0.6%)

Notes: 1) Driver error includes inattention, fatigue, negligence, recklessness, driving while under the influence, following too close, over the center line, improper turn, and asleep.
2) Percentages are of total heavy truck accidents.

Table 2

Oil Spill Related Water Pollution
Incident Data Summary for the State of Washington
(DOE, 1979)

Category	1976		1977	
Total Number of Spills	774		616	
Cause, unknown	433	(56%)	396	(64%)
Cause, transport land vehicle	29	(4%)	12	(2%)
Cause, retail sales auto fuel	3	(<1%)	3	(<1%)
Spill by Material				
Oil, unknown	140	(18%)	150	(24%)
Oil, fuel, includes gasoline	357	(46%)	277	(45%)

The Oceanographic Institute of Washington (OIW) conducted a study on the probability of oil spills in the Columbia River Basin. Their results can be compared to gasoline spill probabilities assuming the volumes of gasoline transported are comparable to oil, and that the routes, drivers, and truck types are similar. Table 3 represents a breakdown of the sizes of oil spills occurring in the Columbia River Basin from 1973-1977. Table 4 shows the probability of spills of three sizes occurring in the Columbia River Basin and the national rate.

Table 3

Size and Frequency of Soil Spills in the Columbia River Basin
Study Area from 1973-1977 Due to Highway Bulk Transportation (OIW, 1978)

	0-99 Gallons		100-999 Gallons		1000-9999 Gallons		> 10,000 Gallons	
	Number	Volume	Number	Volume	Number	Volume	Number	Volume
Highway Liquid Bulk	12	428	8	2,265	12	40,062	0	0
Total	766	7793	90	22,711	31	92,881	2	66,100

Table 4

Spill Rates for
Bulk Oil Truck Carriers
Spill/Truck-Mile
(OIW, 1978)

Spill Size Gallons:	Columbia Basin	Nationwide
0-99	0.13×10^6	$.013 \times 10^6$
100-999	0.09×10^6	$.009 \times 10^6$
$\geq$ 1000	0.13×10^6	$.011 \times 10^6$

Rhoads (1978) conducted a study evaluating the nationwide human risk associated with the transportation of gasoline. Although it did not evaluate the environmental risk associated with gasoline transportation, the probability functions give some indication of the relative probabilities of gasoline truck accidents.

The study is based on a current nationwide accident rate of 2.5×10^{-6} per mile, and estimates that gasoline trucks will be involved in 1,781 accidents in 1980. It further estimates that 110 of the accidents will result in a release of at least 3,000 gallons of gasoline per spill and that one quarter of the spills will catch fire. The estimated number of fatalities in 1980 is 29. Table 5 from the Rhoads study (p. 1-4) indicates the relative risk to people from gasoline truck accidents.

Rhoads also evaluated the likelihood of the occurrence of a gasoline spill by street type. Spills will occur in the following street type locations:

rural highways, 68.9%
business areas on city streets, 6.2%
business areas on urban freeways, 16.4%
residential areas on city streets, 2.5%
residential areas on urban freeways, 6.3%

The overall probability of a spill is reported at 8.5×10^{-6} per shipment. This is based on an estimated 1.37×10^{12} shipments of gasoline nationwide. Rhoads also estimated that an accident producing 10 or more fatalities occurs at a rate of 2.2×10^{-2} per year or one accident in about 45 years.

Rhoads also performed a sensitivity analysis to determine the most important contributors to the risk. Tank wall failures from puncture, impact and abrasion produce 90% of the gasoline spills.

Table 5

Comparison of Gasoline Transportation Risks
with Individual Risk from Various Accidents and Natural Disasters
(Rhoads, 1978)

Accident Type	Total Fatalities	Individual Risk per Year
All Accidents	115,821	1 in 2,000
Motor Vehicle Accident	55,511	1 in 4,000
All Industrial Accidents[a]	14,100	1 in 6,000[b]
Falls	16,506	1 in 13,000
Drowning	7,152	1 in 29,000
Fires	6,503	1 in 32,000
Poisoning	5,335	1 in 40,000
Airplane Crashes	1,668	1 in 130,000
Railway Accidents	739	1 in 250,000
Lightning[c]	160	1 in 2,000,000
Tornadoes[d]	90	1 in 2,300,000
Gasoline Tank Truck Accidents	29	1 in 7,400,000

(a) U.S. Bureau of Census

(b) Only workers included in population at risk

(c) Accident Facts, 1973, National Safety Council, 1974

(d) Average value for several years, U.S. Bureau of Census

Other data sources are available that give an indication of the incidence of highway accidents and spills concerning gasoline. These data sources include:

1. Washington State Patrol (WSP) Accident Reports - general accident data, files are available for a fee.

2. Utilities and Transportation Commission (UTC) Hazardous Material Accident Reports.

3. State of Washington Department of Ecology (DOE) Spill Response Data.

4. Nationwide accident statistics are available from the Bureau of Motor Carrier Safety. Interstate carriers must report accidents causing greater than $2,000 in damages.

2.2. Adverse Impacts

Gasoline is a highly volatile inflammable fluid that, in an uncontrolled situation, can cause explosion, fire and have toxic effects on the environment. This section describes the environmental impacts, quantitative and qualitative, of a gasoline spill.

The volatile nature of gasoline and the potential to accumulate vapors can pose a threat of fire and explosion, unconfined, the volatility of gasoline is also a dispersal mechanism. The specific gravity of gasoline varies from 0.71-0.75 depending upon its grade and thus floats. Although by floating vaporization is promoted, it is also exposed to potential sources of ignition. The physical properties of gasoline are listed in Appendix B.

2.2.1. The Relative Hazard of Gasoline

Gasoline is not the most hazardous of the materials transported across the country. The Environmental Protection Agency developed a means of assessing the hazard of a spill based on both the characterisitcs of the hazardous material and the quantity spilled (Buckley, 1978). Each hazardous material is given a Relative Hazard Level (RHL) from 1 to 5. Gasoline has an RHL equal to 2, while a more toxic substance like Lacquer Thinner has

Figure 1
Relative Hazard Potential for Hazardous Materials
(after Buckley, 1978)

Hazard Potential (HP) Category	Relative Hazard Level of Material				
	1	2	3	4	5
1	7,500	2,500	500	40	5
2	19,000	6,500	1,300	130	13
3	38,000	12,500	2,500	250	25
4	75,000	25,000	5,000	500	50
5	150,000	50,000	10,000	1,000	100
6	380,000	125,000	25,000	2,500	250
7	750,000	250,000	50,000	5,000	500
8	1,500,000	500,000	100,000	10,000	1,000
9	3,800,000	1,250,000	250,000	25,000	2,500
10	>3,000,000	>1,250,000	>250,000	>25,000	>2,500

an RHL of 5. If a spill occurs it is possible by rising Figure 1 to determine the Relative Hazard Protential (HP) of the specific occurrence. Knowing the RHL for a substance and the quantity of material spilled in liters or kilograms, an HP can be determined.

By applying this approach to other hazardous materials, it is even possible to prioritize which hazardous materials, from a risk standpoint, are more dangerous than others. Clearly, the consequences of an accident involving liquid natural gas or chlorine gas have greater risk than a gasoline spill accident. An analysis of the maximum damage probable due to explosion is found in Rhoads (1978).

2.2.2. Lethal Effects

In contrast to petroleum, very little research has gone into the effects of gasoline spills on the environment. However, Quality Criteria for Water (EPA, 1976) lists lethal toxicity levels of 91 ppm for marine fin fish and 40-180 ppm for fresh water fin fish. The Water Quality Criteria 1972 specified that the 96 hour LC50 for *Salmo gairdneri* (rainbow trout) is 40 ppm. The mechanism of interference with these fish appears to be respiratory. Oils, for example, generally coat the epithelial surfaces of gills preventing oxygen transfer. In addition, some of the anti-knock additives like tetraethyl lead, tetra methyl lead, methyl ethyl lead or the anti-knock substitutes are also very toxic. The synergistic effects of these contaminants is not well-documented. Lead in sufficient concentrations can cause teratogenetic effects and also interfere with respiration. Lead will also accumulate in organisms and express some sublethal effects.

Gasoline will also effect other animal species but concentrations have not been documented. Clearly bird species are vulnerable. Toxic amounts of gasoline can be ingested by preening or due to bioaccumulation in the food chain. If the effect of oil is similar to that of gasoline, drowning can occur through loss of buoyancy, exposure, or loss of feather insulating capacity.

2.2.3. Sublethal Effects

There is very little in the literature about the sublethal effects of gasoline on aquatic organisms, except in the area of "tainting." Fish or water fowl exposed to gasoline tend to pick up abnormal flavors, odors, tastes or colors. Quality Criteria for Water (EPA, 1976) indicates that as little as 5 μgms/l of gasoline can impart "off-flavors" in fish. So gasoline can impact commercial fisheries even at sublethal concentrations.

2.2.4. Long-Term Effects on the Ecosystem

The duration and persistence of a spill on the ecosystem depends upon the specific physical and chemical properties of the gasoline involved as well as the size and quality of the receiving waters and the benthic-aquatic life present. The season of the year can also affect the magnitude of impacts, particularly where salmonid fish species are present. Generally gasoline will kill animal and plant species present but not damage the habitat permanently. Once the stream or water resource is clean of toxins, individuals from other nearby areas will start to reoccupy the vacant niches.

Secondary and tertiary effects are also probable, particularly if an entire subpopulation of fish, for example, is destroyed. Other predators further down the food chain will be forced to find other food sources or perish if other prey are not available. If an entire brood year is destroyed, there will be a gap in the fish production four or five years later when those fingerlings would have reproduced. In addition, the destruction of a wild strain of salmon on a small stream may permanently affect the population dynamics and genetic makeup of the whole species (Keeney, 1977). In addition, the breakdown products of gasoline may have harmful effects. The breakdown products of oil have been found to be toxic (Malins, 1980).

2.2.5. Two Gasoline Spill Case Studies

As was mentioned earlier, DOE is the state agency that has the responsibility of dealing with spill incidents. Two gasoline spills have recently occurred in the Puget Sound region. A review of the DOE reports provides an insight to the impacts of a gasoline spill.

The Scriber Creek spill occurred in April, 1973. An ARCO gas truck overturned releasing 3,400 gallons of gasoline to Scriber Creek. The resulting spill killed about 3,000 Coho fingerlings and 1000 Cutthroat trout along with an uncounted assortment of other game fish.

The DOE assessed the damages at $1,486.89 for the game species involved. Ultimately the sum was paid in full by the carriers' insurance company. The driver was not found to be negligent.

The Thornton Creek spill occurred in April, 1977. A leaky hose at a gas station caused the release of 300 gallons of gasoline to the storm drainage system and then to Thornton Creek. Ultimately gasoline vapors caught fire in the Creek and had to be extinguished by the fire department. This gasoline spill killed 15,000 Coho Salmon fry prior to dissipating in Lake Washington. One hundred percent of the salmonid population was killed 1.9 miles downstream of the spill site. For another 1.1 miles 50 percent of the salmonid species were killed. No other comments were made concerning other effects on the ecosystem. The DOE estimated the monetary value of the fish killed at $10,283.37. This amount was paid by the gas station operator and the oil company. The courts additionally fined the oil company $1,000 and the operator $500 for negligence.

In both of these spills, the DOE damage assessment focused on the salmonid fish species. The effects of a gasoline spill on other plant, animal species and habitat destruction were not evaluated. In spite of the fact that this damage assessment procedure underestimates total environmental damages, the DOE procedure is all that is currently available to quantify these damages. DOE's focus on salmon species reflects the commercial recreational and aesthetic value of a resource which is relatively sensitive to environmental disturbances (Keeney, 1977).

2.3. Some Alternative Risk Reduction Possibilities

Based on sections 2.1 and 2.2, it is possible to suggest some improvements to reduce the risks associated with the highway transportation of gasoline. These suggestions center on four areas: driver improvements, truck improvements, improvements of the emergency spill response teams, and routing. Section 3.4.3 discusses the strategies behind some of these alternatives.

2.3.1. The Driver

Since the driver was shown as the cause of over 85% of all hazardous material transportation accidents (highway), improved driver education could be a very significant step in reducing accidents. Special training for drivers of hazardous loads is also possible. In addition, spill prevention kits could be installed in truck cabs that could be used by the drivers to prevent either ignition of gasoline or prevent a spill from escaping down the storm drain.

An idea proposed by the UTC that would affect both drivers and truck is increased regulation of private carriers as well as contract carriers. Currently only common carriers are regulated yet approximately 60% of the accidents involve private carriers.

2.3.2. The Truck

Another approach to reduce risks focuses on tank improvements and increased truck safety inspections. Rhoads (1978) points out that 98% of the gasoline spills are due to puncture or abrasion holes in tank walls. Rhoads proposed either strengthening the tank walls or installing automatic fire protection systems to reduce the hazards. The automatic fire protection system might reduce the risk of explosion and fire but may not do much to mitigate environmental impacts of a spill. Improving tank wall strengths would require further benefit/cost analysis. Some other areas to improve truck safety include compartmentalizing the tanks, improving hatches and valves and decreasing the sizes of tanks.

2.3.3. Emergency Spill Response

The environmental impacts of gasoline and other hazardous material spills could be reduced by improving emergency response capabilities and preventing gasoline from reaching local water resources. Specialized training for local fire departments to handle hazardous material spills and clarifying governmental authority and responsibilities in spill responses would improve response effectiveness. In addition, local fire departments and response teams need to know a truck's contents if an accident occurs and what to do to neutralize the hazardous material. These situations could be improved by better hazardous materials labeling and access to neutralization information. It would also be possible to train drivers to cope with spills immediately after an accident by setting up temporary dams or foam plugs for tanks to contain a spill before it damages the environment.

2.3.4. Routing

The last approach to reducing environmental impacts of gasoline spills is by routing gasoline or other hazardous materials away from sensitive or unique environmental areas. The best routing procedure would specify alternative routes that would be as safe as the routes near sensitive areas. Another condition of routing is that large concentrations of trucks hauling hazardous materials should be avoided both spatially and temporally. Concentrating vehicles carrying hazardous materials would increase the magnitude of any losses in the event of an accident.

Environmentally sensitive areas could be identified based on their fragility, uniqueness and commercial wildlife values. A wild salmon run that produces large numbers of breeding fish would be an example of a resource that was fragile, unique and produced a commercially valuable product. The resources of an area could be prioritized and the most significant ones given routing protection.

2.4. The Public Agency Response

The transportation of gasoline as well as other hazardous materials has concerned public agencies at all three levels of government. Agency responses have taken the form of emergency response groups, regulation and planning.

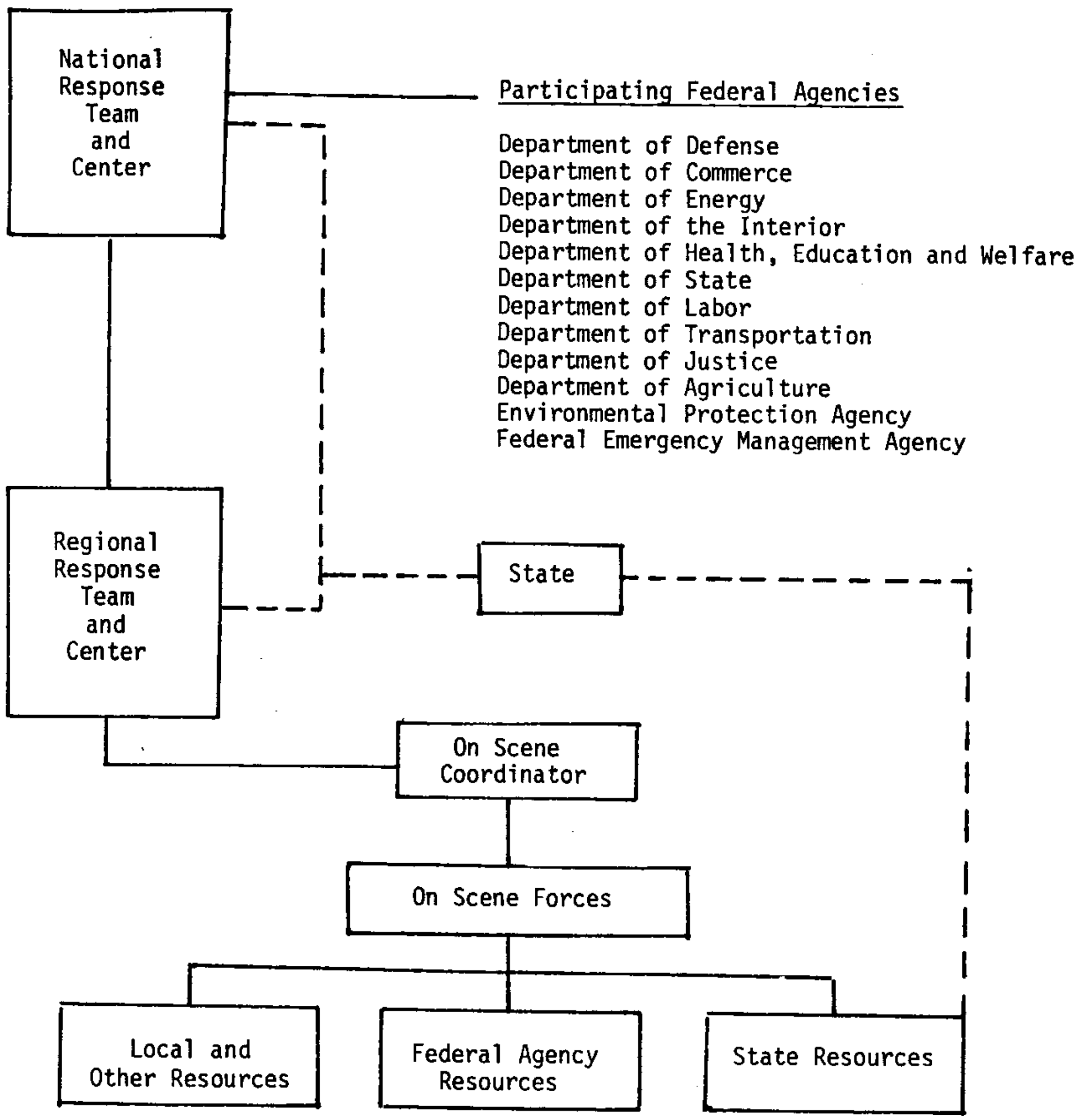
2.4.1. Emergency Spill Response Groups

Both a timely and proper response is essential to minimize the environmental damage and human hazards associated with a gasoline spill. Clean up and neutralization procedures should start as soon as is practicable to reduce the contact time with the environment. The response must also be appropriate to those aspects of the hazardous material that pose the greatest threat to the environment and man. Gasoline spills require controlling the potential for fire, explosion and its toxic properties.

Nationally both the Environmental Protection Agency and the Coast Guard are involved based on authority given them by the Clean Water Act (U.S. Federal Register, March 19, 1980). Their response is as a part of the National Response Team which follows the National Oil and Hazardous Substances Pollution Contingency Plan. The plan is an attempt to provide

Figure 2

Federal Contingency Plan for Emergency Spill Response (EPA, 1980)



national support and a coordinated response to any spill of hazardous material. Figure 2 shows how the federal government views the response teams working.

The RRT or regional response teams consist of regional representatives from various advisory agencies headed up by EPA. In the case of the State of Washington, EPA delegated the RRT authority to the Department of Ecology. The only significant exception occurs when a spill occurs along the coast, then the Coast Guard is in charge.

The State of Washington has its own Hazardous Materials Incident Contingency Plan in addition and complementary to the federal plan. This plan sets forth the responsibilities of the various state agencies and establishes a line of authority to provide coordination (Dept. of Emergency Services, 1980). The plan also specifies how local governments should respond in the event of a spill.

The primary response agency is the Washington State Patrol (WSP) which is generally first on the scene and provides immediate control and communication with the necessary coordinating agency. The Department of Ecology is the primary recovery agency that responds to any spills on land or water. It acts to reduce the effects of the spill and provide the on-the-scene coordinator (OSC). Both the WSP and DOE are the agencies directly involved at the spill site. Other State agencies can also be involved if required.

The DOE also assesses the environmental damages associated with any gasoline spill. This assessment is based on three components; property and environmental damages, a penalty up to $20,000 and clean up costs (Tracy, personal communication, 1980). Damages are based on the replacement costs of killed game fish and the contribution of the killed fish to the future fishery. In addition, a multi-state agency damage assessment team can assess a subjective value to the land impacted by a spill as well as land use impacts measured as sportman-days. The subjective analysis was not used in either gasoline spill assessment cited previously because habitat was not destroyed. Generally, DOE submits the total sum to the Washington State Attorney General's office and asks for full compensation. Sometimes, however, the original damage estimate is not collected due to negotiations with the defendent (Tracy, personal communication, 1980).

Two groups can be involved in the local response to gasoline spills, the local fire departments and the regional planning agency.

The Puget Sound Council of Governments is currently studying the local response capabilities and degree of coordination between the various response agencies. There are several problems shared by all emergency response personnel when they encounter a gasoline spill. These include:

1. The need to clarify governmental authority and responsibility. A coordinated response is needed to effectively minimize environmental damages. One single person is often not solely in charge of a spill response.

2. The need to identify a hazardous cargo so that the appropriate measures can be applied to the spill.

Joe Redden, of the National Fire Protection Association, listed several of the problems facing local fire departments when facing hazardous material incidents (Seattle Times, August 17, 1980):

1. Lack of uniform training program for the first responders;

2. Lack of cross training among agencies;

3. Lack of knowledge of new methods and techniques;

4. Lack of proper equipment;

5. Lack of standards for private cleanup companies;

6. Lack of access to adequate information at the scene;

7. Interagency overlap on federal, state and local levels.

2.4.2. Regulation and Planning

Regulation

The Materials Transportation Bureau of the United States Department of Transportation regulates the transportation of hazardous materials, including gasoline. In order to be hazardous, the substances must meet certain criteria for toxicity, flammability, combustability, or corrosiveness. Gasoline qualifies as a hazardous substance and is subject to special safety requirements (Ernst, personal communication, 1980). Regulations are issued by the Materials Transportation Bureau (DOT) in conjunction with the Federal Highway Administration, Federal Railroad Administration, the Federal Aviation Administration and the Office of Pipeline Safety (Oceanographic Institute of Washington, 1975). These regulations are found in Title 49, Code of Federal Regulations, Parts 100-199.

The State of Washington assumed enforcement responsibilities and generally adopted the DOT highway standards. These regulations concern primarily the preparation of material prior to shipment and the actual transportation conditions and storage. The two state agencies involved are Utilities and Transportation Commission and the State Patrol. The UTC has the power to write regulations and has adopted, fairly closely, the federal DOT guidelines. The Washington State Patrol does not write regulations but assists the UTC in enforcement. Both interstate and intra-state cargoes are subject to regulation in this regard. Only common carriers, not private carriers, are regulated at this time, however.

The major requirements for hazardous material transportation are as follows: (OJW, 1975) 49 CFS Parts 177-178.

1. Accident reporting procedures
2. Cargo tank certification
3. Shipping paper requirements
4. Tank inspection requirements every 2 and 5 years
5. Loading and unloading procedures
6. Specific requirments concerning each hazardous material
7. Procedures for responding to accidents
8. Specifications for cargo tank design
9. Limitations of route assignments
10. Minimum driver qualifications
11. Rules for attendance, surveillance and parking
12. General vehicle requirements

There are no special requirements for gasoline transport beyond those provided for flammable materials generally.

Planning

The majority of the planning work in the hazardous material field has centered on the federal government. Currently most state agencies are trying to define the problem (Ernst, personal communication, 1980). The design and maintenance of equipment, routes, facilities, policies, regulations and plans must keep pace with increased risks associated with increasing hazardous material and gasoline movements (Transportation Research Board, 1980).

Locally, the Puget Sound Council of Governments is conducting a planning study on the transportation of hazardous materials. That study focuses on four areas. These include (PSCOG, September, 1980):

1. Identify the types and amounts of hazardous material transported through the region by ship, rail, highway, air and pipeline.

2. Evaluate the roles, responsibilities and capabilities of agencies with hazardous material prevention and response.

3. Survey federal and state programs to determine if they are applicable in the Puget Sound region.

4. Develop some options for regional prevention and response plans based on the preceding three studies.

In association with this study, the federal DOT, Research and Special Programs Administration will fund a risk assessment project that will determine the relative safety of various routes in the Puget Sound area. It is hoped that this study will provide a standardized approach to risk assessment that will be applicable nationwide (Woodman, personal communication, 1980).

2.5. The Private Approach to Reduce Risk

Within the private sector, primarily two groups of companies are concerned about the financial risk of hauling gasoline on the highway, the insurance company and the gasoline hauler.

2.5.1. The Insurance Company Approach

Insurance companies are in the risk business. They pay casualty and liability damages when an accident occurs to their client. The insurance approach allows businesses to operate by spreading the risk from a client company to an insurance company. For that service the client company pays a premium.

To a great extent, the size of the premium represents the insurance company's view of risk. An important question then is, do insurance companies that insure trucking firms charge more to trucking clients that haul gasoline?

Premiums are fixed somewhat subjectively in the gasoline hauling business. Many factors, not just the risk of hauling gasoline come into play. The base premium rate is set nationally by the Insurance Services Organization, who keep national data on the actual losses for a particular class of motor hauler. Surcharges are then either added or subtracted from the base rate depending upon several factors. If gasoline is being hauled, a surcharge is added. The insurance company also evaluates past accident records of the company, the drivers, the safety and training programs adding or subtracting surcharges as necessary (Baldwin and Eliot, personal communication, 1980).

However, before an insurance company will even consider a trucking firm as a client, they will investigate the financial health of the business. The insurance company must first decide if they will even insure the trucking company. Or they may explain under what conditions they will insure a trucking firm. This is because insurance companies are also interested in minimizing their risk.

Frequently insurance companies have loss control sections that try to improve the safety precautions observed at a trucking firm. Some insurance companies encourage the further training of drivers to improve safety performance and lower overall risk (Baldwin, 1980). Mr. Baldwin, a local insurance representative and participant in the PSCOG study, indicates that the insurance company stands to gain a lot from improved driver training. In addition, he feels that decreased losses would have a ripple effect decreasing other forms of insurance like property damage, bodily injury liability, workmen's compensation, life insurance, medical insurance, and business interruption.

2.5.2. The Trucking Company

Trucking companies do not perceive the transportation of gasoline as a particularly risky job from a business sense. They do not make any extra profit from hauling gasoline in comparison to water. They haul gasoline because the demand for the service is there (Dillon, personal communication, 1980). As I noted earlier, truckers haul 1.14×10^{11} gallons of gasoline annually.

In regard to the high incidence of drivers as causes of accidents, the trucking industry trains all of their drivers. However, not all drivers that haul hazardous materials or gasoline receive special training (Dillon, personal communication, 1980). An exception to this would be trucking firms that haul only liquid bulk commodities (Simpson, personal communication, 1980).

Most trucking companies are insured, however, some do not carry insurance specific to the types of liabilities associated with hazardous material transportation risks. Generally, trucking companies are insured from $100,000 to $300,000 per occurrence. This appears in line with some of the damage assessments observed in the DOE damage reports for gasoline spills. The nature of the trucking industry also requires an umbrella policy sometimes called excess liability. This limit is set at one million dollars. These coverages suggest that in terms of environmental damages an insured trucking company is adequately covered.

2.6. Summary

The environmental risks associated with the highway transportation of gasoline have not been completely understood. There is a need for more data recording the environmental damages associated with a gasoline spill. Despite the problems associated with the DOE damage assessment procedures, the available data suggest relatively minor damages due to gasoline spills. Other hazardous materials may cause more damages.

There is also a need for risk assessment procedures on a regional basis that speak to the relatively high public perception of risk and transportation of hazardous materials.

Based on the data available and literature reviewed, environmental risk due to highway gasoline transportation can be reduced by improving driver training, truck safety improvements, more coordinated and prepared spill response teams and analysis of potential truck routes for safety.

3.0. ISSUES AND DISCUSSION

3.1. Definitions of Risk

The term risk is used in many ways and has many definitions. It is therefore useful to review several of these risk definitions and how they apply to the transportation of hazardous materials. Rowe (1977) classically defines risk as "the potential for realization of unwanted, negative consequences of an event" (p. 24). He explains that the cause can be single or multiple and emphasizes that risk does not occur under conditions of certainty. The two key components of the definition are "uncertainty" and "negative or unwanted consequences." Supplementing Rowes' classical definition, at least four working or applied definitions can be described based on the two components of probability and negative outcomes.

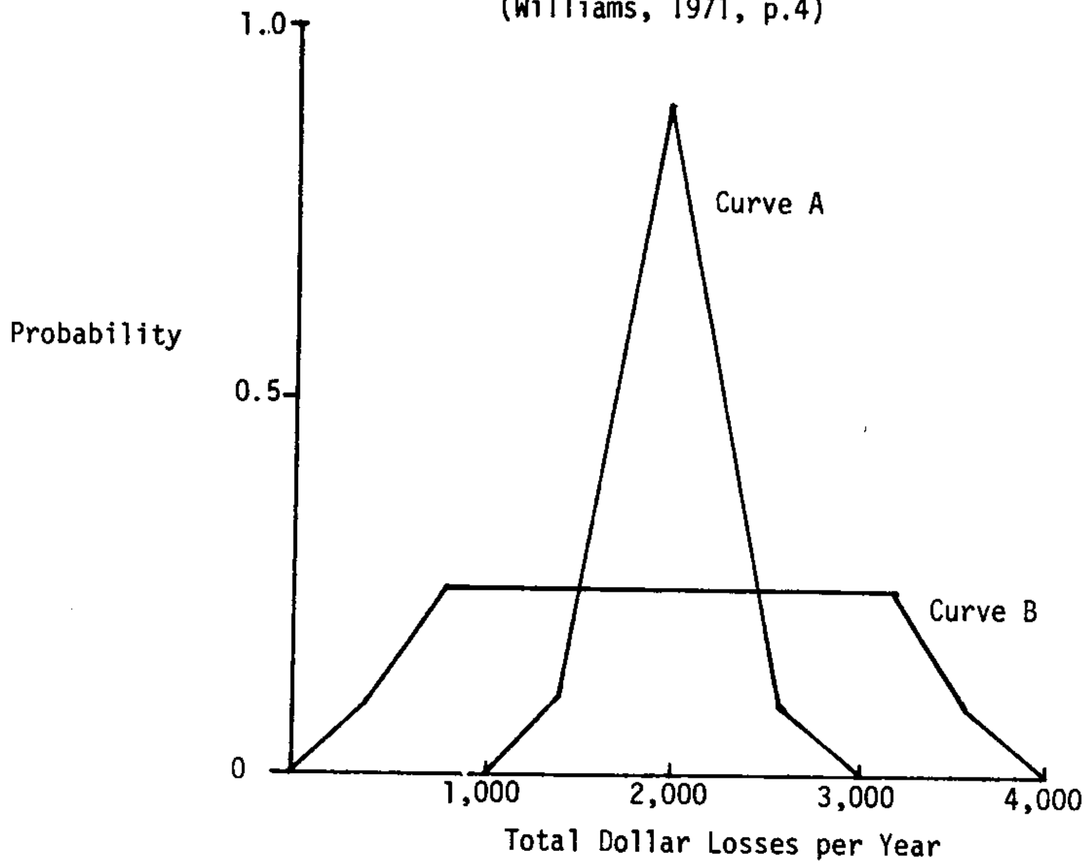
1. Risk can be defined as not knowing the outcomes of a particular action. In the case of hazardous material transportation, some people might find risk in not knowing all the environmental consequences of a spill. Using this definition, the environmental risk associated with some hazardous materials is greater than that of other materials. In reference to Figure 3, risk perceivers using this definition would not be able to describe the outcomes across the X axis.

2. Risk can also be defined as not knowing the probabilities associated with a known set of outcomes. This definition implies that if the probability of an occurrence is known with certainty, there is no risk. This approach is further complicated by another term, uncertainty, which can also be used to describe an outcome with an unknown probability (Sage, 1980). Sage (1980) notes that these two terms are often used interchangeably and that the literature is not very precise in this area. People using this definition would expend their effort to reduce risk by gathering data to clarify probability distributions. Thus, in reference to Figure 3, if the probability distribution function could be drawn, there would be no risk.

3. The private sector sometimes uses the third definition. Risk using this approach is a measure of the variation of possible outcomes. Thus, in Figure 3, probability distribution curve B represents more possible outcomes hence is riskier that curve A (Williams, 1971). The ability to predict one certain future carries less risk than knowing the probabilities of several.

Figure 3

Hypothetical Probability Distribution of
Total Dollar Losses per Year
(Williams, 1971, p.4)



4. The fourth definitional approach to risk focuses on the complexity of the issue. This approach states that even if you think you can describe risk by a series of outcomes and probabilities, there is a chance that you will not describe all of them due to the issue's complexity. These risk perceivers would say that the probability distribution function in Figure 3 does not describe the total risk picture.

In addition to these definition approaches, risk managers and decision makers use various adjectives to describe risk.

In terms of the transportation of hazardous materials, risk is unbounded and involuntary. The risk is unbounded because the exact magnitude of an accident is not readily determinable (Sill, personal communication, 1980). The risk is involuntary because the people or environment affected by an accident have not chosen to be affected. Voluntary risks are more readily accepted by the public due to their perception that the possible benefits are greater than the risk and costs (Sage, 1980).

When people don't believe they can control their exposure to risk, the amount of risk they are willing to accept decreases. Society attaches considerable significance to "involuntary" situations where decision makers are separated from those individuals affected by risk (Sage, 1980).

3.2. Risk Assessment Methodologies

This section will review two risk assessment methodologies: expected monetary value and fault tree analysis. In addition, this section contains a short description of decision principles and cost-risk-benefit analysis.

3.2.1. The Expected Value Model

If an estimate of probabilities and outcomes is available, decisions about any risky issue can be made using decision theory. Therefore, based on the previously described definitions of risk, a risk assessment using decision theory may or may not address all the perceptions of risk on a particular technical issue.

The expected monetary value model is most frequently used in conjunction with the transportation of hazardous materials. The basic formulation of risk, as measured by expected monetary value, is the product of the probability and the associated dollar losses of the outcome.

There are two complicating factors connected with the expected value approach to risk assessment, discounting and intangibles. Discounting comes into play if an accident probability is expressed over a period of time, say five years. The expected value must be discounted over time to account for the value of loss in the future. Valuing intangible environmental impacts can be controversial as well. For instance, people may value some components of the environment, like fish, in dramatically different ways. Fish to some people may be priceless, to others, "A dollar a pound." Other complicating valuing questions include the genetic value of a fish subpopulation, a unique habitat, wilderness or values for future generations. These questions go beyond the scope of this paper and have not been adequately addressed in the literature.

Two (EMV) models will be reviewed, one is capable of analyzing all modes of transportation, the second is applied specifically to the truck transportation of gasoline. Both could be applied on a state or regional basis if the data are available. Sufficient data are probably available on a national basis to apply either.

The federal DOT (1973) developed the following conceptual expected monetary value model so that it could be applied anywhere. The basic equation used in the model is as follows:

$$\text{Risk} = \sum_{j} \sum_{k} \sum_{l} L_{ijkl}D \cdot C_{ijkl}D$$

where i = alternative index, re. mode, route, material.

j = accident types, re. enroute , loading-unloading, leaks, or external causes.

k = severity class index

l = loss category index, re. property damage, bodily injury or death.

LijklD = the likelihood of an accident due to kind j, resulting in severity class K, and causing loss l.

DijklD = cost of an accident due to kind j resulting in severity class K and causing loss l.

A total loss figure is used to compare variables in the transportation application. So total transportation costs equal the cost of normal transportation via alternative i and the total risk associated with that alternative.

The DOT (1973) approach evaluated one or more hazardous materials and evaluates the whole transportation picture from loading at port of entry to unloading at the final destination, and considers a wide range of consequences from human health and safety to environmental impact. Given the required data, it could be applied to gasoline transportation.

The second expected value model was used by Rhoads (1978) to assess the risks of the truck transportation of gasoline. Rhoads used the following equation to estimate the expected number of fatalities:

$$\text{Risk} = (AF_{R_i} \times P_{R_i}) \times \sum(C_{E_{iq}} \times P_{E_q})$$

where AF_{R_i} = is the product of the amount of material per shipment times the amount of material lost in an i^{th} release accident.

P_{R_i} = is the probability that the accident and spill will occur during transit

$C_{E_{iq}}$ = represents the consequences of the spill. The q subscript reflects a certain weather condition and population exposure at the time of the spill. In this case measured as fatalities.

P_{E_q} = is the probability of encountering the particular set of weather conditions and population exposure.

The first expression ($AF_{R_i} \times P_{R_i}$) represents the probability that the release or spill-accident of a certain size will occur. Rhoads uses the second expression to reflect the consequences of a gasoline spill under the probabilistically weighted weather and population distribution (p. 3-3). This second term is measured not in dollars but in fatalities. The incidense of probability of fatalities is then compared to other risks. The results are shown in Table 5.

3.2.2. Fault Tree Analysis

Fault tree analysis, developed by the aerospace industry in the sixties, is a technique to identify design deficiencies (Rhoads, 1980).

The fault tree approach assumes a failure and then reveals component failure probabilities that contribute to the overall system failure (Rhoads, 1980). Generally only basic system components are evaluated because frequently the data are not available for more detailed analysis. When applying a fault tree to the gasoline transportation by truck, a spill that damages the environment is assumed and then the events leading up to that spill are evaluated. Rhoads (1978) used a fault tree analysis in conjunction with the expected value model described in section 3.2.2. It is used to describe how spills occur and at what probability or the R_i subscript. Rhoads noted that the particular data necessary for the fault tree was not readily available and that the probabilities were determined by a "reasoning process."

This analysis was used to show that the failure of tank walls accounted for 39% of all gasoline spills. Coupled with a sensitivity analysis, Rhoads (1978) showed that improvements in tanks or fire suppression systems would decrease fatalities. No cost analysis was perfomed to determine which was the most cost effective.

3.2.3. Risk Benefit and Cost Benefit Analysis

Frequently the term cost-benefit analysis or risk-benefit analysis is encountered in conjunction with risk assessment. The distinction is not always clear in the literature. Risk-benefit refers to a category of cost benefit analysis where risks are an important component of the costs. Generally risk benefit analysis is used to compare alternative plans, like alternative routes for gasoline transportation. Cost-benefit analysis is generally used to determine if a particular project should be built. This can be an optimizing process where the best "scale of activity" is determined (Taylor, personal communication, 1979).

3.2.4. Decision Principles

When decisions are required under certainty, you know the outcomes and probability, the preferred alternative is the one with the minimum dollar loss associated with it. Unfortunately, in the case of the transportation of hazardous materials, lack of data requires subjective probabilities.

When evaluating a probabilistic risk, it is important to specify a decision principle. Briefly they include (From DOT, 1973):

A. Pessimism or worst case analysis. The condition that causes the highest cost for each alternative is assumed to occur. The minimum of these maximums is then selected.

B. Optimism or best case analysis. The condition that causes the lowest cost for each alternative is assumed to occur. The minimum of these minimums is selected.

C. Coefficient of Optimism. The decision maker multiplies the minimum cost of an alternative under the best condition, by a coefficient and the maximum cost of the same alternative, under the worst condition by one minus the coefficient. These two products are summed and alternatives are then compared.

D. Regret Principle. The basis for the regret principle is that in hindsight, the regret for selecting any alternative is minimum. The decision maker forms a regret matrix by finding the difference between the minimum cost of the best alternative and the cost of each alternative under the same condition. The alternative with the minimum maximum regret for all conditions is selected. This is probably the most reasonable principle when dealing with hazardous material transportation.

E. Criterion of Rationality. The principle assumes that the probability of occurrence of all conditions is equal, thus the probability of an accident occurring equals the probability of non-occurrence and a decision is made solely on cost.

F. Dominance. Any alternative that shows a higher or equal cost for both conditions than another alternative is said to be dominated and not selected.

G. Maximum Cost Levels. These can be set for normal and/or accident costs and alternatives that exceed those costs are eliminated.

3.3. Perceptions of Risk

Given the four definitions of risk, described in section 3.1, the perspectives of decision makers in relationship to those definitions is important.

Section 2 showed that the environmental outcomes from a gasoline spill include, but are not limited to, tainting and sublethal effects, lethal effects, possibly habitat destruction and an assortment of secondary effects.

In addition, the probabilities associated with these outcomes may be available but have not been compiled. It is also clear that the environmental outcomes and probabilities of other hazardous materials spills have not been completely described. Section 2 also points out that the public perception, based on newspaper articles and Mayor Royer's comments, of the risks of hazardous material transportation is considerable. In contrast, the private sector (as represented by local insurance companies and some trucking firms) perceives the risk of highway transportation as decreasing. Why?

The public's concern for hazardous material transportation may be based on any or all four definitions or approaches to risk. The public is not aware of all the consequences, particularly environmentally, or the associated probabilities, and is confronted with a very complex distribution and transportation system. In addition, the public may perceive the subjective probabilities associated with hazardous materials of greater consequence than other risks which have objective probabilities. This idea is described by Ashby, 1980.

The private sector, on the other hand, deals primarily with dollar damages (that do not reflect externalities) and is also aware and understands the complexity of the distribution and transportation system. This does not imply that the private sector does not perceive any risk, because insurance companies are constantly working to reduce the risks from a dollar loss standpoint and to know the probabilities and losses well enough to set premiums to make a profit.

The PSCOG study is a very good opportunity to clarify to the public the outcomes, the probabilities, and the complexities of the problem. By including the private sector, the PSCOG study gets direct access to volumes and types of materials, routes of transportation and exposes the private sector to some of the public perceptions of risk as well.

Beyond the definitions of risk, people and societies perceive risk in different ways. The many factors that affect whether someone is risk averse, a risk taker, or prefers some risks over others, are beyond the scope of this paper. However, there are methods to clarify perceptions of risk. These perceptions of risk can also be incorporated into the decision theory models described briefly in Section 3.2 with the concept of utility.

The utility theory approach incorporates the subjective value of the decision maker into the risk assessment and results in a non-linear relationship between utility measures and dollars. Expected utility is the product of the probability of occurrence and the utility of that outcome. This approach prescribes what should happen in the view of the decision maker not what has occurred in dollar terms historically in the past (Kenney, 1976). In other words, the utility value representing a hazardous material spill might be larger than the historically measured dollar damages associated with hazardous material spills.

Defining the utility of various negative outcomes that confront a society can be very complex. Sage (1980) lists five broad categories of techniques that could be used to determine utility functions. They include (p. 432-3):

1. Ranking. Ordering the levels of alternatives and attributes from the most preferred to the least.

2. Category methods. Classifying the worth of alternative outcomes and attribute levels into a fixed number of discrete categories.

3. Direct methods. The direct assignment of numerical worths to alternatives and associated outcomes and attributes.

4. Gamble methods. Constructing wagers, then varying outcomes or probabilities of event outcomes until the decision maker is indifferent between the wager and an alternative sure thing.

5. Indifference methods. The joint assessment of two attributes by constructing a plane of possible combination of attribute levels and determining indifference points and curves on the plane.

3.4. Public Versus Private Strategies

Within the public and private sectors, risk managers deal with the transportation of hazardous materials, including gasoline, using different management strategies. The strategies reflect the definitions of risk assumed and the respective goals of the risk manager. One general and three specific comparisons can be made. These strategies will vary depending upon the type of hazardous material being transported and on the region or nation affected.

Generally, the public and private sector view risk associated with the transportation of hazardous materials differently. The acceptability of risk in the private sector relates to the perceived return on investment. If the anticipated return is low, private decision makers tend to avoid the risk (Sage, 1980). The public sector is more interested in "output" or a broader set of consequences of a technology as opposed to profit maximization. Government tends to assume a stronger role in situations where probability and outcome data are scarce, the uncertainty high and possible liability great (Zinn, 1980).

Based on the four definitions of risk, it is not hard to understand why the public perception and strategies for risk may be different than the private sectors. The private sector sees the risk as small, because as section 2.0 illustrated, the dollar loss is low and so is the probability. Losses are either in fatalities with some unspecified dollar value or a property loss value.

The DOT is still investigating the magnitude of the risk and is funding several research projects (Transportation Research Board, 1980, see Appendix C). The public agency concern about the risk of hazardous material transportation has also led to legislative proposals at both the state and federal levels for more regulation (UTC and McClelland, personal communication, 1980).

3.4.1. Perception Versus Expected Value Approach

The public, based on media coverage and Mayor Royer's speech, is concerned about hazardous materials transportation, which may not be reflected in the expected value model. There is risk using all four definitions of risk associated with hazardous material transportation; the public may be using any or all. The DOT uses the expected value approach and focuses on human safety. The strategy of using the expected value model may, in fact, describe risk in relationship to other risks, but the assessment must be accepted by the public. If the expected values used in the model approach by DOT reflects the public and private perceptions of risk, the strategy of using expected value models will be successful. The DOT hopes that by generating a state-of-the-art expected value model, they can test solutions for improving safety, like specifying routes and changing truck designs.

If the public is concerned about complexity and other unspecified environmental effects, the intangibles, the expected value approach will not address the public's perception of risk.

3.4.2. Insurance and Regulatory Strategies

Insurance companies and regulatory agencies have different views and strategies to deal with the risk associated with the transportation of hazardous materials. The regulatory approach aims at reducing societal externalities of hazardous material transportation, while the insurance company is interested in controlling dollar losses.

The insurance company approach is based on previous records of dollar losses associated with hazardous material transportation. If environmental damages are well described by DOE's damage assessment procedure, the insurance approach will handle the risk and cover the losses. There is little evidence that insurance companies are doing a bad job of covering hazardous material transportation, the limits of liability seem to cover the potential damages.

If the historical damages reported have not reflected the actual losses, the insurance approach will not adequately cover the risk. For example, how much money will it take to replace the last wild run of salmon in a three county area? Obviously the values in society differ, but the historical costs probably don't reflect its unique value.

Regulators are often faced with conflicting goals of improving transportation (DOT) and protecting the environment (EPA and DOE). Their regulation strategy is aimed at protecting the "people" from private companies that would externalize their costs. They make sure that companies are not running trucks that are unsafe and may threaten the public with involuntary risks. In other words, trading public safety and cost for corporate profit.

3.4.3. Fail-Safe and Safe-Fail Strategies

The third area of comparison focuses on different strategies for solutions, the fail-safe and safe-fail approach. Solutions to perceived risks can work towards preventing a failure or towards minimizing the negative effects when one occurs.

The fail-safe approach evaluates a system with the view of improving these components of the system with the highest probability of failure. A useful tool in this approach is the fault tree analysis. In the Rhoads (1978) study, proposals were developed to reduce tank puncture and the danger due to gasoline spills by strengthening the tanks or installing fire prevention units. The improvements proposed by the fail-safe approach must be evaluated with the overall benefits of the technology. In terms of hazardous material transportation, it would be difficult to justify the cost of retrofitting all gasoline trucks with stronger tanks. A benefit/cost analysis can then be used to say yes or no to a particular improvement.

The safe-fail approach assumes that some component of the system will fail and that potential solutions should focus on averting or minimizing the consequences. Some of the proposed solutions described earlier that fit this approach are: improvements in response teams, routing hazardous materials away from environmentally sensitive areas and limiting the size loads of hazardous materials transported by truck.

Improvements in driver training could fit in either strategy. Since driver error is a major cause of heavy truck accidents (UTC, 1980), improving driver skills should decrease the number of accidents and spills, the fail-safe approach. Drivers could also be educated to stop leaks with foam plugging devices (Mitchell, 1973) or portable dams and follow the safe-fail approach.

These strategies are not used exclusively by either private or public sector. Improvements are being considered from each stragegy in both the public and the private sector.

SUMMARY

Clearly the volumes of gasoline and other hazardous materials being transported in this country are increasing as is the public awareness of the associated risk (Transportation Research Board, 1980). It is also apparent that accidents involving gasoline and other hazardous materials will accompany the benefits associated with the use of these materials.

The societal risks associated with the highway transportation of gasoline and other hazardous materials has not been completely described. Rhoads (1978) assessed the human risks from the highway transportation of gasoline and compared those probabilities to other risks encountered in our society. Rhoads used both an expected value model and fault tree analysis. Up to this point few studies have looked at the environmental effects of spills, or looked at the risks on a regional basis. Similarly, few comparative studies on other hazardous materials have been conducted.

This report shows a need for improved statistically valid data. Data is particularly short in the area of specifying possible environmental damages or outcomes associated with a hazardous material spill. The current assessment data comes primarily from the DOE. The DOE procedure has not focused on environmental effects beyond commercially valuable fish species except when habitat is destroyed. In spite of the fact that the assessment procedure has problems defining the value of the natural system in non-human, non-economic terms, the DOE procedure is all that is available to predict environmental damages at this time.

In terms of risk management of hazardous material transportation, the responsibilities are well distributed. Insurance companies monitor risk for the private sector on a monetary basis. The public sector responsibility is broken up into transportation responsibilities and environmental impacts. The bulk of risk estimation is conducted by the federal DOT using expected value models which they are striving to improve. Environmental impacts of hazardous materials are handled by a safe-fail strategy that emphasizes emergency spill response teams.

The private sector perceives the risk of hazardous material transportation as relatively small and to some decreasing, however, if local newapaper and politicians reflect the public perception, the risk is significant or

even increasing. Some insight into this difference is based on the proposed applied definitions of risk. The public and to some extent public agencies may perceive risk due to:

1. A lack of clear understanding of the consequences of a spill;

2. A lack of understanding of the probabilities of a spill;

3. A view that the entire system is too complex to understand and that an unforseen disaster may occur.

4. A view that the consequences being evaluated may not include all of the intangibles or externalities properly;

while the private sector appears to feel that the probabilities and outcomes are adequately covered by insurance companies and current regulations

From the public agency viewpoint several recommendations can be made to reduce risk. Clearly more work is needed to clarify these public perceptions of risk. An expected utility approach may prove useful in this regard. The current PSCOG study is an opportunity to clarify and describe these risks by bringing in all those institutions, public and private, that share the responsibility for transporting hazardous materials. Continuing efforts by DOT to improve transportation of hazardous materials should include a better assessment of the potential environmental impacts. The Department of Ecology (DOE) now handles the environmental damages associated with spills on a reaction basis. Although the historical impacts associated with gasoline spills appear to be relatively small, other hazardous materials spills can have more far-reaching impacts, and should be comparatively evaluated, while the private sector appears to feel that the probabilities and outcomes are adequately covered by insurance companies and current regulations.

Routing may be another significant step to reduce hazardous material transportation risks. According to Rhoads, 68 percent of accidents occur on rural highways where the possible environmental damage is the greatest. If environmentally sensitive areas can be identified and prioritized, hazardous material routes could be specified to avoid those areas. The cost-benefit of this strategy depends upon the relative sizes and numbers of hazardous materials spilled by source. The DOE data suggest that most of the spills do not come from highway accidents but from "unknown" sources. The source question needs to be clarified if routing is a cost-effective alternative.

Risk assessments can supply more information to decision makers and the public, which may or may not help them make better decisions about transporting hazardous materials. Some level of risk will be carried when any amount of hazardous materials are transported. The acceptable level of risk concerning the transportation of hazardous materials, including gasoline, will be set in the public arena regardless of the risk assessment methodologies.

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APPENDIX A

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Mr. Nick Russo Utilities Transportation Commission	regulations	753-6427
Captain Hart State Patrol	accident statistics	753-6554
Mr. Lord U.S. Dept. of Transportation	National DOT policy	(206) 426-5980
M. Bammert Insurance Commissioner Offices	insurance rates	752-7300
Mr. Biodine Insurance Services Organization	insurance rates	(212)487-4946
Mr. Bill Baldwin Insurance Associates	insurance	882-1183
Mr. John Elliot Aetna Super. Tech. Serv.	insurance	223-1800
Pete Padone PSCOG	local study	464-6250
Dave Teeter PSCOG	local study	464-6250
Mr. Bodin Marsh McClennan, Inc.	insurance	223-1240
Dick Johnson Washington State DOT	research	764-4289
Mr. Jack Seims Seattle Fire Department	accident statistics	625-4091
Mr. Dave Payton Fed. Emergency Mgmt. Agency		481-8800

Person Contacted	Area	Phone Number
Mr. Landsback Unigard Insurance	insurance	292-1234
Mr. Jim Steele Unigard insurance	insurance	292-1234
Betty McClelland Hazard Committee Olympia	Washington State legislative approach	753-6780
Mr. Ernst Washington DOT	research and DOT's role	753-6030
Coast Guard Officer	spill response data	442-5233
Mr. Dick Bruno Seattle Police Dept.	accident statistics	625-2347
Mr. Davison King County Police	accident statistics	344-7608
Mr. Craig Baker Washington State DOE	response statistics	885-1900
Mr. Frank Dillon	trucking perspective	882-1183
Mr.Howard Flint Federal Emergency Mgmt. Agency	response groups	481-8800
Mr. Elvin Sill, DOT	federal research	(202) 426-4823
Mr. H. Tracy Department of Ecology	damage assessment	753-6880
Mr. Al Simpson Inland Transport Co.	trucking perspective	767-3605
Mr. Simon Prensley, DOT	federal research	(617) 494-2076
Mrs. Donna Woodman, DOT	federal research	(617) 494-2076
Mr. Joe Johnson Seattle Fire Department		625-4077

APPENDIX B

Properties of Gasoline
(Rhoads, Appendix B, 1978)

Refiners process gasoline by distillation and cracking or reforming longer molecules. Gasoline's chemical composition varies with the grade but generally ranges from 5 to 10 carbon atoms per molecule. The hydrocarbon molecules consist of paraffins (saturated hydrocarbons), olefins (unsaturated hydrocarbons) and aromatic and napthanic rings. In addition tetraethyl lead or similar antiknock compounds are added.

The type of crude oil used during processing affects the chemical and physical properties of gasoline. Table B-1 lists some of the ranges of gasoline's physical properties.

Table B-1

Physical Properties of Gasoline

Boiling point	100°-400°F
Specific gravity	0.71-0.75
Vapor density (Air = 1.0)	3.4
Average molecular weight	102
Flash temperature (100 octane)	-36°F
Flammability limits	1.4-7.6%
Open pool burning rate	4 mm/min
Reid Vapor Pressure (100°F)	9.5-13.5 psi
Evaporation rate (80°F)	$\sim 2 \times 10^{-4}$ g/cm^2·sec

APPENDIX C

THE TEN MOST CRITICAL ISSUES IN HAZARDOUS MATERIAL TRANSPORTATION

The Transportation Research Board (1980) recently assessed the research needs in the area of hazardous material transportation. The TRB described these needs to help planners and guide research in the most important areas. The following is a brief summary list of those ten critical needs:

Regulations

Issue 1. There is a need for harmonious international, federal, state and local hazardous material regulatory controls. Conflicts exist between various regulatory levels that place undue burdens on commerce.

Issue 2. There is a need to reduce the complexity of DOT's hazardous material regulation and convert them from detailed specifications to performance based criteria.

A Coordinated Systems Approach

Issue 3. There is a need for a national strategy to improve the hazardous material transportation system.

Issue 4. There is a need to train shippers, drivers, and emergency response personnel.

Issue 5. There is a need for a single national response system to provide coordination and expertise during an emergency.

Issue 6. There is a need for an integrated transportation administration system among federal and state agencies.

Data and Data Applications

Issue 7. There is a need for comprehensive data system for the flow of hazardous material by quantity, class, route, and mode. There is a general lack of knowledge about quantity and type of material being transported in this country. One of the major goals of the PSCOG's study was to identify and quantify hazardous materials by location in the Puget Sound region.

Issue 8. There is a need to determine the state-of-the-art in hazardous material cost benefit-risk analysis and see if it is practical.

Legal Responsibilities

Issue 9. There is a need to clarify the legal responsibilities of government and private agencies involved in hazardous material transportation.

Public Awareness

Issue 10. There is a need to communicate to the public the relative safety of hazardous material transportation.