Trends In U.S. Hazardous Materials Transportation Spills*

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This paper examines historical and spatial trends in hazardous materials transportation spills from 1971 to 1991. While the number of spills increased steadily during the 1970s, peaking in 1978–1979, there has been a decline in frequency since then largely due to modifications in reporting. Monetary damages have the opposite temporal pattern, with major increases recorded from 1982 onward. Death and injury statistics are more variable. Spatially, accidents are more prevalent in the Rust Belt extending from the Northeast corridor westward to the Great Lakes states, as well as in the Southeast. The greatest potential risk to the public is found in smaller, more densely populated industrial states such as New Jersey, Delaware, and Maryland. The spatial distribution, however, has not changed. Potential risk sources (e.g., chemical industry, number of hazardous waste facilities, number of railroad miles) are the best predictors of hazmat incident frequency. Mitigation efforts (statewide regulatory and/or management policies) also help explain the variability in hazmat incidents. **Key Words: hazardous materials, risk, transportation, accidents**.

More than 500,000 shipments of hazardous materials (hazmat) occur daily in the United States. Close to four billion tons of regulated hazardous waste move between states annually via truck, rail, air, and water carriers (Kenworthy 1993). Truck transport is the most dominant mode of transportation of hazmat materials in terms of both tonnage and vehicles, and poses a significant public risk from hazmat spills. In 1977, 327,000 trucks carried hazardous materials over 1.3 billion truck miles; this increased to 467,000 trucks totaling 1.6 billion truck miles in 1982. During this same time period there were more than 114,000 reported hazardous material accidents, an average of 31 accidents per day during the decade (Office of Technology Assessment 1986), or a mean annual accident rate of 1.25 accidents per 10,000 shipments. Data from a 1992 survey, however, show a drastic reduction in the number of hazmat truck carriers (down by 98% from a decade earlier to 10,500 vehicles) as well as a precipitous decline in cumulative hazmat truck miles (down 66% to 541 million miles) (U.S. Department of Commerce 1995).

This paper examines the historical and spatial patterns of hazmat incidents and considers three broad questions. First, how have the trends in hazmat spills changed during the last two decades? Second, what is the geographic variation in the pattern of incidents? Finally, what are the factors associated with hazmat shipments by rail versus truck and how does this vary regionally? We suggest that while truck transport still poses the greatest public risk of potential exposure to hazardous materials, the frequency or rate of risk has not significantly changed during the last 20 years. Instead, it is the spatial pattern of risk that has altered the risk burdens of the public in selected areas.

There are two definitional issues that require clarification. First, accidents involving hazmat shipments do not always involve an environmental release or spill of a hazardous material. However, by federal law all carriers are required to notify the U.S. Department of Transportation (DOT) of any accidents involving hazmat shipments. There are additional reporting requirements for accidents involving a hazmat release. USDOT regulations define a transportation-related incident or release as

> any unintentional release of a hazardous material during transportation, or during loading/unloading or temporary storage related to transportation. Every release, except for those from bulk water transporters and those motor carrier firms doing solely intrastate business, must be reported . . . . (OTA 1986, 67)

Second, the terms *risk* and *hazards* are often used interchangeably, yet there are subtle distinctions between them. Risk, *sensu stricto*, is the probability of occurrence of some event such as a hazmat incident. When we combine the risk with the magnitude and toxicity of the release,

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we get a measure of the potential population exposure to the risk. Hazard is a broader concept that not only includes the probability (risk) of an event happening and the potential exposure, but also includes the impact of that exposure on society or the environment (Cutter 1993). In other words, hazards include not only the risk, but the potential consequences of an event as well.

Background

Most of the research on transporting hazardous materials is case-study oriented and focuses on routing (Glickman and Sontag 1995; Harwood et al. 1993), risk analysis (List et al. 1991, Pijawka and Radwan 1985; Purdy 1993), regulation (Campbell and Langford 1991), emergency response (Hobeika et al. 1993), and pre- and post-disaster planning for hazardous material incidents (Sorenson and Rogers 1988; Rogers and Sorenson 1989; Quarantelli 1991; Beroggi and Wallace 1991; and Lepofsky et al. 1993). There are few studies that examine the historical and spatial context within which hazardous material incidents occur in the United States.

This paucity of research means there is little systematic knowledge on the quantity and type of hazardous materials being transported. With the exception of the Office of Technology Assessment report in 1986, there are few studies that examine the long-term trends in hazardous materials spills. While data on transportation accidents are available, spill incidents (e.g., releases of hazardous materials arising from accidents or human error), exposure (volume of hazardous material shipped), and consequence (population affected, damages, etc.) data are extremely limited. Moreover, mismatches between the available accident, spill incident, and exposure data severely restrict any national analyses of hazardous material transportation safety (Hobeika and Kim 1993), let alone interstate comparisons.

To partially address these data needs and to assuage public concern about the volume of hazardous materials shipped on the nation's railways and highways each day, Congress amended the Hazardous Materials Transportation Act of 1975. The Hazardous Materials Transportation Uniform Safety Act of 1990 (HMTUSA) contains provisions to improve public safety by improved tracking of information, addressing inconsistencies between state and local laws covering the transport of hazardous materials and requirements on highway routing, carrier registration, emergency response training, incident notification, motor carrier vehicle safety permits, placards and information provision, and criminal and civil enforcement measures.

Data Sources

Data for this analysis were provided by the Office of Hazardous Materials, U.S. Department of Transportation (USDOT), from their Hazardous Materials Information System (HMIS) database. Under federal law (CFR 49 Part 171.17), all transportation-related hazardous materials incidents or releases must be reported in writing to the USDOT within 15 days of their occurrence. Carriers are also required to make an immediate notification by phone to the National Response Center when a spill results in any of the following consequences: (1) a fatality; (2) serious injury necessitating hospitalization; (3) carrier or property damage in excess of $50,000; (4) fire, breakage, or contamination of shipments involving etiologic agents or radioactive materials; or (5) any situation the carrier judges as reportable (49 CFR 17.15) (OTA 1986, 67). Once reported, these incident/spill reports are compiled in a central repository, the Hazardous Materials Information System (HMIS).

Our data cover the period 1971–1991 and are geographically referenced by state. The data are further broken down into type of carrier (highway, rail, air, water). For each of these carriers we have statistics on number of incidents, number of major and minor injuries, number of deaths, and estimates of damages (in US$). Additional data include a summary of incidents by hazardous material class by year, including the number of incidents, major and minor injuries, deaths, and damages in US$. Unfortunately, this summary by hazard class does not contain any geographical breakdown, so we are unable to determine where the most dangerous incidents occur. Hard-copy tables from HMIS were provided for each year for each transportation mode. Making the data amenable for our spatial time series analyses required the reentry and reformatting of the hard-copy data, as well as inflation adjustment for dollar damage estimates.

These data are self-reported and are usually not verified by independent sources. The incident rate may also be underreported, with some estimates suggesting less than a 30–40% compliance rate (OTA 1986; Hobeika and Kim 1993). When using this database, two cautions are necessary. The magnitude of the spill may be underestimated (to minimize the severity of the event) or overestimated (to take advantage of insurance coverage). Because of the lack of independent verification of spill data, we have no way of knowing the accuracy of the damage estimates. Also, we know that the incident rate itself is an underestimate; thus both the temporal distribution and spatial distributions represent the most conservative or "low end" estimate of spills. Despite these caveats, HMIS continues to be the best source of national information on transportation-related hazmat incidents.

Temporal Trends

During our study period, more than 180,000 incidents occurred nationally, or about 8,880 per year on average. These incidents resulted in 17 deaths and 476 injuries per year, with an average of $9.8 million in damages per year based on 1987$ (Table 1). Highway carriers were the most frequent source of hazmat incidents, followed by rail carriers. In terms of actual injuries, water carrier incidents harmed people most often (38% of the time), followed by rail (15%), air (9%), and lastly highway carriers (4%). Mortality, on the other hand, was greatest with highway carriers. Mean damage estimates ranged from under $1,000 per truck or air carrier incident to more than $3,000 per water and rail carrier.

There is very little temporal variation in incident frequency for water, air, or rail carriers over the 21-year period (Fig. 1a). Highway incidents, however, are another story. The frequency of highway hazmat incidents steadily increased during the 1970s, peaked in 1978, and showed a decline until 1989 when a small upward trend emerged.

As might be expected, the yearly pattern of injuries and deaths is highly variable, especially for rail and truck carriers (Fig. 1c and 1d). There is a noticeable decline in highway and rail injuries beginning around 1981. Damage estimates are flat during the 1970s, rise precipitously beginning in 1982, especially for highway carriers, and continue to escalate for highway carriers during the remainder of the decade (Fig. 1b). For rail carriers the temporal pattern is similar, although there is considerable yearly fluctuation from 1984 onward. For water and air carriers, the damage estimates remained relatively constant.

Two factors contribute to the abrupt changes in the trend line for incidents and injuries: safety, including improved record keeping; and changes in reporting requirements. Consolidation in the transportation industry (fewer and more specialized carriers), increased safety training for personnel, and stricter safety and environmental regulations all contributed to a decline in hazmat incidents and injuries through the 1980s. For example, the Resource Conservation and Recovery Act of 1976 (RCRA) created a cradle-to-grave tracking system of hazardous materials, while the Emergency Planning and Community Right-to-Know Act of 1986 (SARA Title III) provided emergency notification and public access to information about chemicals that are stored, manufactured, or transported through their community. The 1975 Hazardous Materials Transportation Act included requirements for training of transport personnel, safety inspections of carriers, and civil and criminal penalties for violations.

The other factor was a change in reporting requirements. In 1981 a change in the reporting requirements eliminated the need to report battery spills and spills of less than five gallons of paint. Prior to this change, small paint and all battery spills were routinely entered in the database. As a consequence of this change in reporting requirements, the number of reported incidents to HMIS was reduced significantly

Table 1 *Transportation Incidents 1971-1991*

Carrier	Incidents (number)	Injuries (number)	Injury Rate per Incident	Damages ($ million)*	Deaths (number)
Air	2,961	276	9.3	1.79	1
Water	244	94	38.5	1.01	1
Highway	162,265	6,736	4.1	143.32	331
Rail	18,903	28,975	15.3	59.74	42
Total	184,373	10,003	5.4	205.86	375

* *Damage estimates were adjusted for inflation (1987$) using the* Economic Report of the President Transmitted to the Congress *(1994).*

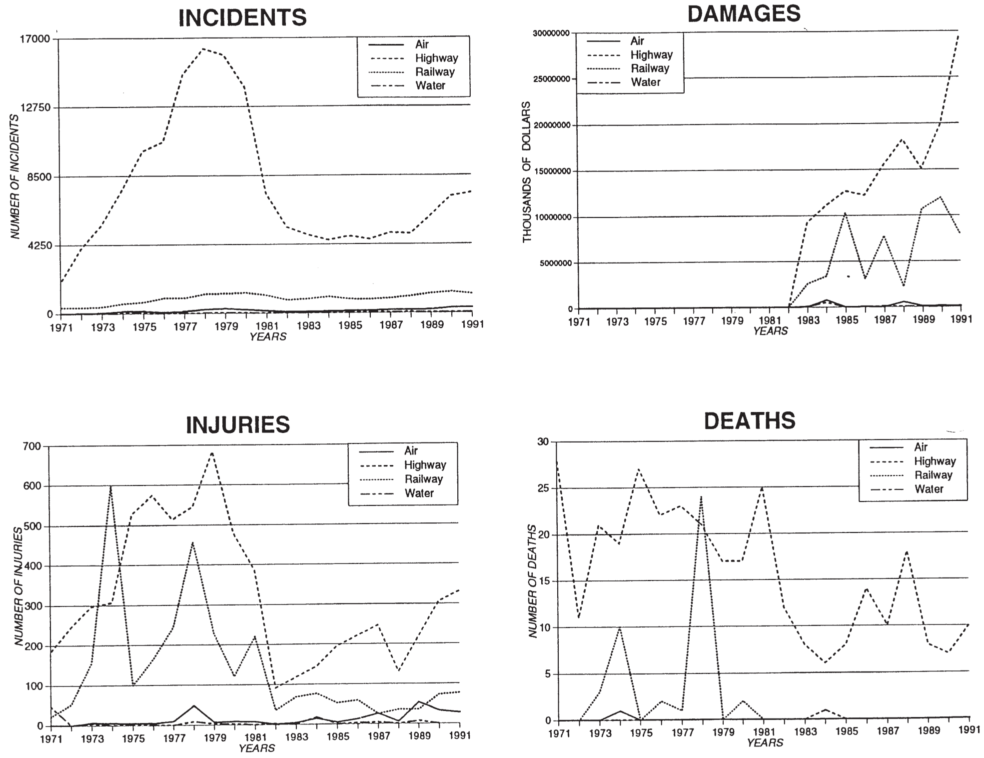


Figure 1: *Annual changes in hazardous materials incidents (a), damages (b), injuries (c), and deaths (d) by mode of release, 1971–1991.*

(OTA 1986). The flat line for rail and highway damages during the 1970s, for example, is reflective of the smaller spills with relatively little monetary impact. After 1981, the monetary damages increased significantly for highway and rail carriers.

Changes in Reporting

To test whether these reporting requirements altered the temporal distribution of spills, the two decades (1971–1980 and 1981–1991) were compared. It was important to ascertain whether the decadal difference was a result of some local factor such as regulation or policy changes in different states, or some global factor such as the "across-the-board" change in federal highway spill reporting requirements. A difference of means test was used to calculate the divergence between the 1971–1980 and 1981–1990 time periods. For railroad incidents, there was no statistically significant difference in the means per decade. On the other hand, the difference of means test for highway spills shows significant differences between the two decades.

We conducted a further test to see whether these decadal differences were simply a function of change in reporting requirements, or whether there were major differences in the frequency of incidents within each state during the two time periods. The independent samples *t*-test confirms differences potentially caused by changes in reporting requirements. The paired sample *t*-test (comparing states for each time period) shows a high correlation between highway carrier incidents for the 1970s and 1980s (r = .924, sign = .000). The average number of highway spills in the 1970s was almost twice as many as the following decade. The two-tail *t*-test indicated a statistically significant paired difference ($\alpha < .000$). The strong correlation implied a near-identical pattern of spatial variation across the two decades, whereas the statistically significant paired difference suggests a downward scaling by a constant. The railroad spills experienced a similar pattern, e.g., a strong correlation (.90) between the two decades and a constant increase from the 1970s to the 1980s.

Based on this analysis, we suggest that the 1970s were characterized by high probability/low consequence spills. While frequent, these small hazmat spills posed relatively little danger to the public. Regulations were changed in 1981, which reduced the frequency of small incidents, yet the spatial pattern remained identical. Thus, the significant difference between the decades simply reflects the elimination of these low consequence spills from the database and does not detract from the long-term trend in overall frequency or distribution of hazmat spills.

Characterizing Temporal Trends: High Probability/Low Consequence Events

As noted earlier, there was a reporting requirement change in 1981 that drastically altered the HMIS database. Until that time, both large and small releases were reported. This produced a hazmat spills database that overwhelmingly reflected frequent, yet small, releases, releases such as oil and gasoline spills that often posed relatively little harm to the public. When we examined the specific hazardous materials involved in these incidents, an interesting picture emerged. For example, the majority of spills (48%) involved flammable liquids such as alcohol, acrolein, or methylbutene (Table 2). Flammable and combustible liquids were also the most frequently carried hazmat, especially by trucks (292,300 trucks in 1992) (USDOC 1995). Corrosives were involved in one-third of the incidents. While there was an overall decline in all hazard classes between the two decades (1971–1980 and 1981–1991), the year-to-year patterns, as expected, were highly variable.

The decadal trends were most interesting. There were significant reductions in the more frequent incidents involving flammable liquids (frequent/low consequence releases) between the two decades. For example, in the 1970s, flammable liquids (oil and gasoline) accounted for more than half of all hazmat spills, while in the 1980s, this percentage dropped to around 40%. Corrosive spills (acids and acid wastes) also declined in actual frequency between the two decades, but made up a larger percentage of incidents during the 1980s (37% to 32%). On the other hand, the lower probability incidents (combustible liquids, oxidizers, and miscellaneous), presenting a greater risk to the public, actually increased during the 1980s. This initially supports our contention that the 1970s were characterized by frequent, smaller releases posing little threat to the public, spills we label high probability/low consequence (HP/LC).

Table 2 *International Hazard Classes and Frequency of Incidents*

		Number of Reports		
		Total	1971-1980	1981-1991
Class 1	Explosives	337	239	98
Class 2	Gases	6,708	3,454	3,254
	Flammable		1,946	1,482
	Nonflammable		1,449	1,697
	Poisonous		59	75
Class 3	Flammable liquids	91,905	59,896	32,036
Class 4	Flammable solids and combustible liquids	10,846	4,741	6,105
	Flammable solids		640	535
	Combustible liquids		4,101	5,570
Class 5	Oxidizers and organic peroxides	4,777	2,135	2,642
	Oxidizers		1,887	2,132
	Organic peroxides		248	510
Class 6	Poisonous and etiologic materials	7,718	4,656	3,062
	Poisonous		4,648	3,045
	Etiologic (infectious)		8	17
Class 7	Radioactive	835	604	231
Class 8	Corrosives	66,058	36,413	29,645
Class 9	Miscellaneous	2,975	405	2,570
	TOTALS*	192,159	112,516	79,643

Source: Data compiled by the authors from the USDOT HMIS database. Hazard classifications are from USDOT (1990).

** Totals add to more than the recorded number of incidents (n=184,373) because more than one hazardous material could have been released during a single accident.*

The 1980s also were dominated by HP/LC spills, yet there was more than a 10% increase in low probability/high consequence spills (LP/HC), particularly those involving combustible liquids and oxidizers such as methyl amyl ketone and chromic acid (used as solvents).

Spatial Variation

Pennsylvania has the greatest frequency of hazmat incidents (over 16,000), averaging about 800 per year, or slightly more than two per day during the two decades. The overwhelming majority of these involved highway accidents (Table 3). Ohio was next, with more than 11,000 highway accidents involving hazmat spills. One-third of all highway hazmat incidents occurred in only five states—Pennsylvania, Ohio, Illinois, California, and Texas. Texas had the most rail accidents involving hazardous materials (around 120 per year), followed by California and Illinois. Barge and ship incidents involving hazmat spills occurred most often in Louisiana, New Jersey, and Texas. These three states represent the location of almost half of all the water carrier incidents. Half of all the hazardous materials spills involving air carriers are also found in only three states: Tennessee (914), Ohio (464), and California (210) (Table 3).

Areal and Route Mile Density

To account for the effect of state size, the areal density of hazmat incidents were computed and mapped (Fig. 2). Regionally the pattern of hazmat spills is quite striking and is concentrated in two areas: the old industrial rust belt extending from the Northeast corridor to the Great Lakes states, and portions of the Southeast (Fig. 2). New Jersey has the highest density of hazmat spills (519/1,000 square miles), followed by Pennsylvania (375/1,000 square miles) and Ohio (292/1,000 square miles). The lowest hazmat spill rates are found in northern New England, the upper Great Plains, and Rocky Mountain/Great Basin states. There is very little spatial difference between the distribution of rail and highway incidents.

To further refine our understanding of the geography of hazmat incidents, we computed the expected frequency or incident rate in each state by taking into account the mileage of transportation routes for the nation (USDOT 1985) and each state. The total number of highway incidents for the 21-year record was then standardized by total number of truck route miles to produce a national mean incident rate per truck route mile of .897 incidents. This equates to an average of .0427 incidents per truck route mile per year. These procedures were replicated for railways, utilizing Class I operating railroad miles per state (Rand McNally 1988). For railroads, the national rate of hazardous materials spills is .117 incidents per Class I railroad mile for the 21-year period, or .0056 incidents per mile per year.

The spatial distribution of incidents per rail or highway route mile is found in Figure 3. As can be seen, the highest highway incident rate is found in the northeastern states, Wisconsin, Georgia, and Florida. For rail spills, the rate is highest in New Jersey and the Sun Belt states of Florida, Tennessee, Alabama, Louisiana, Texas, Arizona, and California.

Potential Population Exposure

The potential population at risk from hazmat spills, measured as the number of incidents per capita, alters the spatial pattern we determined for the area density and route density rate of spills (Fig. 4). The greatest potential exposure to people from highway hazmat spills occurs to residents in the Great Lakes states (especially Pennsylvania, Ohio, and Wisconsin). Other states with significant populations at risk include the Interstate 40 corridor in North Carolina, Tennessee, and Arkansas; Kansas; and Missouri. There are a number of outlier states (Wyoming and New Mexico) that have major east-west interstates, but relatively low populations. This accounts for the lower ranking on the rate per transportation mile, but a higher ranking on the population exposure measure.

In the case of rail transport, the states with the greatest population at risk are in the northern Rocky Mountains (Idaho, Wyoming, Montana), states with fewer people. Other states with significant populations at risk from rail spills include the more populated states of Illinois, Arkansas, Kansas, and Gulf Coast states such as Texas, Louisiana, Alabama, and Florida, all of which average more than one spill per 10,000 people.

Comparative Risk

Three different measures have been used to illustrate the spatial distribution of hazmat spills: areal density, incident frequency per transportation route mile, and per capita potential

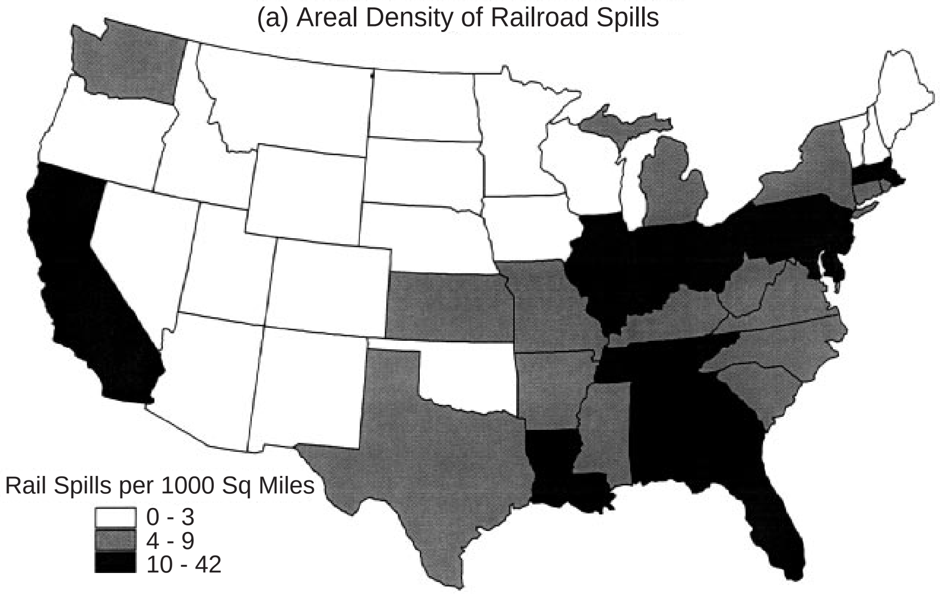
Table 3 *Spill Incidents from 1971 to 1991*

State	Air	Water	Rail	Highway	Total
Alabama	16	1	824	3,024	3,865
Alaska	50	10	32	92	184
Arizona	26	0	358	2,131	2,515
Arkansas	1	0	474	2,603	3,078
California	210	21	1,672	7,940	9,843
Colorado	65	0	141	2,578	2,784
Connecticut	12	0	36	1,158	1,206
Delaware	2	0	90	424	516
Florida	73	7	793	4,335	5,208
Georgia	32	4	720	6,004	6,760
Hawaii	27	1	0	40	68
Idaho	3	0	127	419	549
Illinois	110	0	1,547	9,243	10,900
Indiana	64	0	438	5,226	5,728
Iowa	6	0	195	2,790	2,991
Kansas	2	0	457	2,753	3,212
Kentucky	33	0	358	2,185	2,576
Louisiana	26	54	924	2,818	3,822
Maine	2	0	74	280	356
Maryland	24	23	132	2,779	2,958
Massachusetts	56	2	152	2,243	2,453
Michigan	62	0	638	5,740	6,440
Minnesota	40	0	157	3,160	3,357
Mississippi	0	0	178	1,958	2,136
Missouri	42	1	357	5,803	6,203
Montana	4	0	136	624	764
Nebraska	3	0	131	1,442	1,576
Nevada	11	0	54	395	460
New Hampshire	2	0	17	184	203
New Jersey	37	31	364	4,086	4,518
New Mexico	11	0	171	1,780	1,962
New York	159	9	345	7,317	7,830
North Carolina	25	1	487	6,732	7,245
North Dakota	3	0	43	203	249
Ohio	464	2	867	11,757	13,090
Oklahoma	21	0	105	1,642	1,768
Oregon	16	1	308	1,065	1,390
Pennsylvania	51	5	628	16,584	17,268
Rhode Island	1	0	6	291	298
South Carolina	10	5	234	2,702	2,951
South Dakota	0	0	8	309	317
Tennessee	914	2	501	6,033	7,450
Texas	153	29	2,527	7,620	10,329
Utah	18	0	60	1,348	1,426
Vermont	2	0	9	150	161
Virginia	16	19	321	3,728	4,084
Washington	36	15	289	1,912	2,252
West Virginia	1	0	186	1,159	1,346
Wisconsin	17	0	105	4,760	4,882
Wyoming	2	1	127	716	846
Total	2961	244	18,903	162,265	184,373

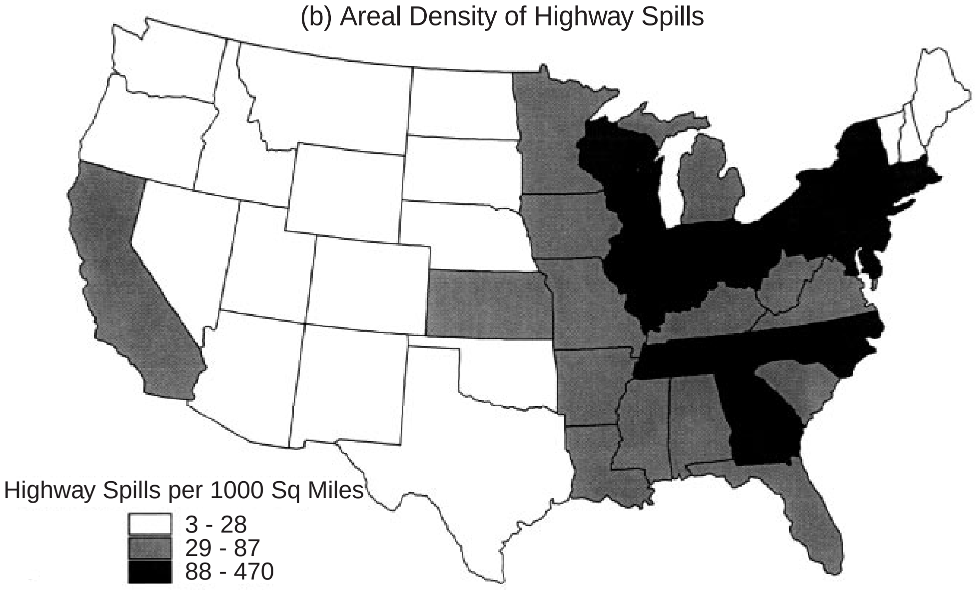
Source: Calculated by the authors from the USDOT HMIS database.

exposure. In the case of highway spills, the areal density and route mile rate is highest in the Northeast, yet due to the large population in that region, the individual potential for exposure is lessened. Only two states, Wisconsin and Pennsylvania, appeared in the highest class on all three maps (Figs. 2–4). Pennsylvania has the highest total number of incidents nationally, which partially explains its presence on each map. The rate of highway incidents in Pennsylvania is eight times greater than expected based solely on highway miles. The larger population of Pennsylvania theoretically should have lowered the per capita potential population at risk, but the extremely large number of incidents overshadows it. Wisconsin is more difficult to explain and may be partially a function of the sheer number of highway incidents (ranked thirteenth nationally) and its role as a transit state with major interstates and rail lines traversing it.

For rail incidents, the spatial density also is greatest in the Northeast. However, the population at risk and route density rate distributions are more dispersed. Only three states show up



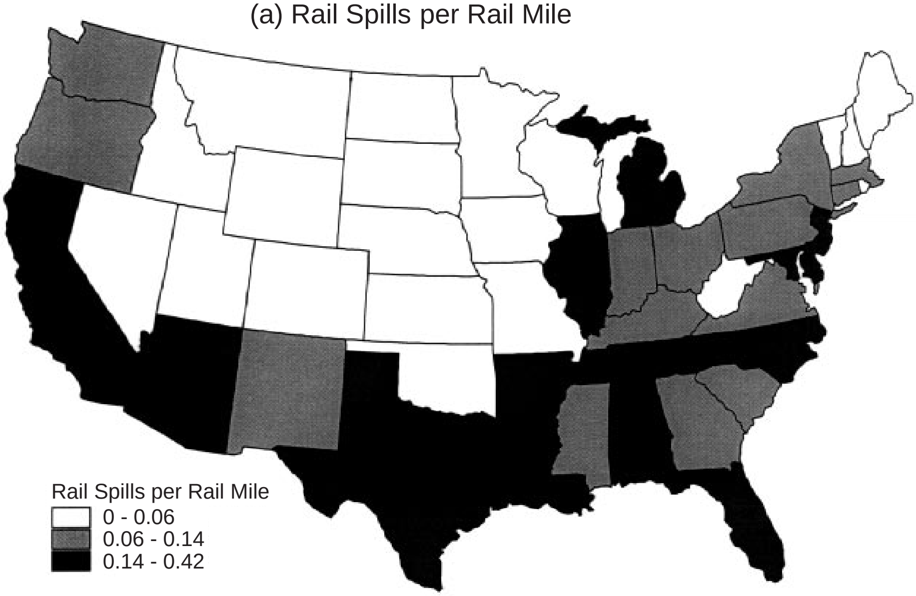
(a) Areal Density of Railroad Spills



(b) Areal Density of Highway Spills

Figure 2: *Areal density of hazardous materials spill incidents by state, 1971 to 1991 for (a) railroads and (b) highways. Incident data are reported in frequency per 1,000 square miles.*

(a) Rail Spills per Rail Mile



(b) Highway Spills per Highway Mile

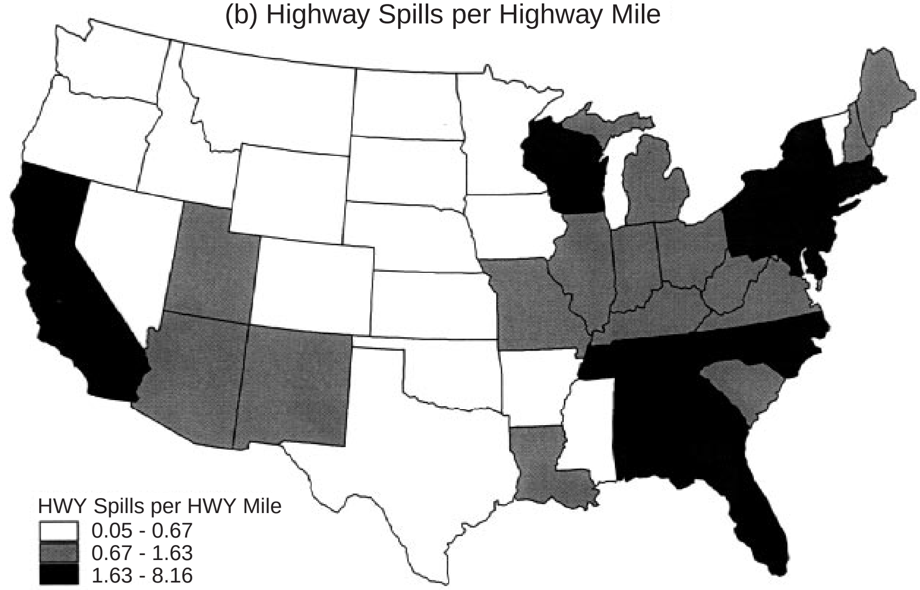
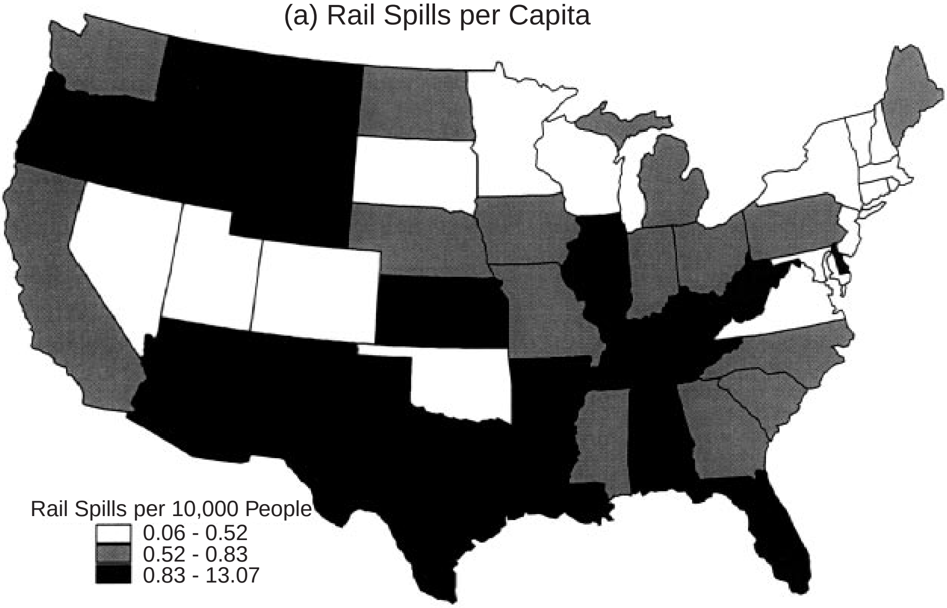


Figure 3: *Spill incidents by transportation mile, 1971 to 1991, for (a) railroads and (b) highways. Data are reported as the number of incidents per Class I railroad miles or truck route miles for each state.*

(a) Rail Spills per Capita



(b) Highway Spills per Capita

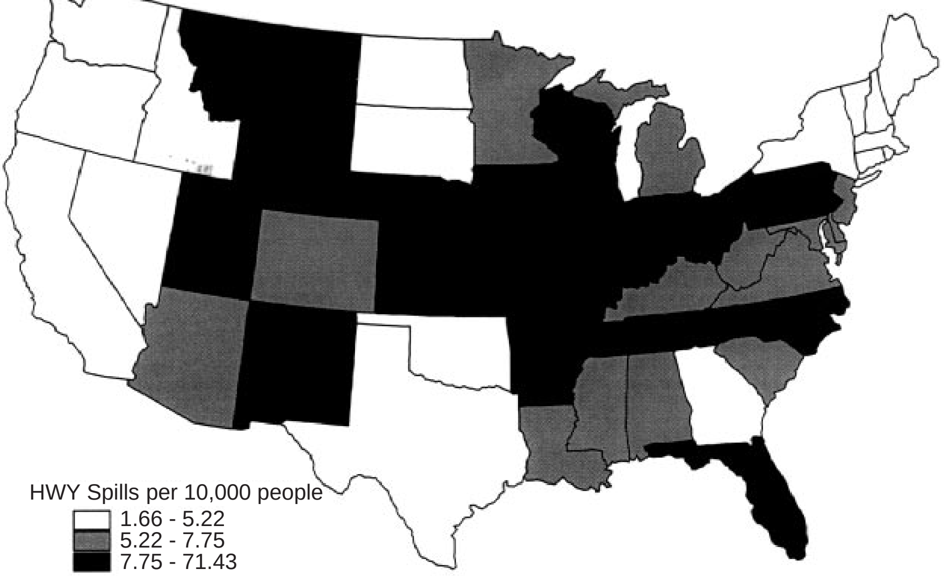


Figure 4: *Per capita spills, 1971 to 1991, for (a) railroads and (b) highways. Incident data are reported as the frequency per 10,000 people.*

in the highest category on all three maps (Figs. 2–4). These are Alabama, Florida, and Louisiana, states that are among the top seven nationally in terms of the total number of rail incidents. These states also have medium-sized populations. Finally, Louisiana and Florida have more than twice as many accidents as the number of rail miles would predict.

These regional patterns are not unexpected given that these states are often the primary producers of hazardous waste, mostly from industrial sources (OTA 1986; Cutter 1993). Moreover, there are more than 5,000 facilities nationwide that treat, store, dispose, or manage hazardous waste. These hazwaste facilities also are concentrated in the industrialized Northeast and the Great Lakes states, as well as in Texas and Louisiana (Cutter 1993). Routes to and from these generators to the hazmat disposal facilities traverse these same regions, as is also the case in the Southeast.

Contextual Explanations

As noted above, there are a number of contextual factors that give rise to risk. Another source of geographic variation in risk is the degree to which states adopt mitigation measures to reduce the impact of hazmat incidents. To examine these relationships, we undertook an analysis of the 1981–1991 hazmat spill data only, as risk and mitigation variables were difficult to acquire for the earlier decade. The specific variables used in the analysis are listed in Table 4. Risk sources include indicators such as rail miles, highway miles, hazardous waste sites, hazardous waste management facilities, and hazwaste tonnage generated. Potential exposure and mitigation indicators included population, metropolitan area population, per capita expenditures on environmental/natural resources, and per capita expenditures on hazardous waste. While not exhaustive, these variables can be viewed as providing a first approximation of the relative importance of risk and mitigation in understanding the spatial patterning of hazmat spills. All data were standardized to facilitate our analysis (Table 4). The dependent variable, number of hazmat incidents, was computed as the rate of occurrence per person per square mile. This was done to standardize state variability in area and population. The dependent variable thus represents the overall incident density by state.

Surprisingly, only four variables showed any statistically significant correlation with hazmat incident density. The per capita state income derived from the chemical industry has the highest positive correlation ($r = 0.789$, $\alpha < .000$) with hazmat spills (Table 5). This is followed by per capita number of RCRA sites ($r = 0.438$, $\alpha < .001$), per capita expenditures on hazardous waste management ($r = 0.388$, $\alpha < .008$), and railroad miles per square mile ($r = .280$, $\alpha < .049$). These results indicate that hazardous materials transportation spills are more prevalent in states with the following risk factors: large concentrations of chemical manufacturers (determined by personal income from the industry); a high density of RCRA facilities; and the number of railroad miles per square mile.

In examining the relative contributions of each independent variable, two risk variables again are important: per capita state income derived from the chemical industry and the density of RCRA facilities. However, it is noteworthy that the per capita waste staying in state and

Table 4 *Variables*

Dependent	
PSPILLS	Number of spills per 1,000,000 persons per 1,000 square miles
Independent	
PINCOME	Per capita personal income from the chemical industry
PRCRA	Number of hazardous waste sites regulated under RCRA/1,000 people
PSTAY	Per capita hazardous waste generated (lbs) and staying within the state
#POLICY	Number of different state policy initiatives on toxic waste
P$SPENT	Per capita expenditure on hazardous/solid waste management
PTXLBS	Per capita toxic waste produced (in lbs)
PRRMILE	Total number of Class I railroad miles per 1,000 square miles
PTRMILE	Total number of truck route miles per 1,000 square miles

Sources: World Resources Institute 1993; Hall and Kerr 1991; Rand McNally 1988; USDOT 1985.

Table 5 *Pearson Correlation Coefficients, 1981-1991*

VARIABLE	PSPILLS	BETA[1]
PRCRA	.438*	.523*
PTXLBS	-.105	
P$SPNT	.388*	
PSTAY	-.120	-.165*
PINCOME	.789*	.820*
PRRMILE	.280	
PTRMILE	.106	
#POLICY	.069	-.178*

** Statistically significant at p < .05.*
[1] Includes only those variables that were entered into the stepwise regression.

the number of policy initiatives both help to mitigate the impact of these two risk factors (Beta = -.165 and Beta = -.178, respectively).

In an examination of the residuals from the regression analysis, most of the states were predicted well within one standard deviation. There were some notable exceptions. The number of spills was substantially underpredicted in four states: Georgia, Maine, Maryland, and Rhode Island. The model predicted no spills for either Georgia or Maine, while it predicted two-thirds of the actual total for Maryland and one-third the actual for Rhode Island. Maine and Rhode Island have few RCRA generators, and derive very little of their per capita income from the chemical industry, the leading predictors of spill frequency. In addition, the decadal frequency of spills for both states is quite low. Georgia and Maryland, on the other hand, have a much higher incident density. These states do not have a large per capita investment in chemical industries; thus their incident density rate is primarily a function of their geographic positions as transit states, where hazmat materials traverse the state on the way to some other destination.

There were five states where the model substantially overpredicted the incident density of spills. These include Michigan, New Jersey, Texas, Pennsylvania, and Tennessee. These states have large chemical production complexes as well as a large number of RCRA facilities. It is interesting to note that the predicted incident density is considerably greater than the actual public exposure to hazmat spills in these chemically intensive states. Aside from these explanations of over- and underprediction, the relationship between incident density and predictor variables for these nine states may be a nonlinear one.

Discussion

Our empirical results illustrate a number of important findings. First, there has been a change in the temporal nature of hazmat spills during the last two decades. This change is primarily due to changes in reporting but is also characterized by a shift away from high probability/low consequence events in 1970s to slightly lower probability/higher consequence events in the 1980s. Not only have the modifications in the reporting requirements (small spills are no longer reported) eliminated recording of many of the small spills, but structural changes in the industry resulted in fewer carriers with potentially more toxic cargos, possibly contributing to more damages and injuries.

A second finding relates to the distribution of the spills and the potential population at risk. Our raw data show that Pennsylvania, Ohio, and Illinois had the highest number of overall incidents during the two decades. The greatest risk, measured as spills per transportation route mile, was to residents in smaller, more densely populated, industrialized states such as Delaware, Rhode Island, New Jersey, Maryland, New York, and Pennsylvania. The underlying industrial structure of the state was the greatest indicator of this relative risk. Nearly two-thirds of the variability in the incident density during the 1980s, for example, was explained by state dependence on the chemical industry (measured as per capita income derived from it). The number of hazwaste generators was also an important predictor. However, states with more hazmat policies mitigated the impact of these risk factors.

This paper points out a number of issues that require more attention before we can assess the nature, causes, and consequences of hazardous materials transport. For example, the Chemical Manufacturers Association (CMA), an industry trade group with 178 member companies, has adopted a national mitigation plan for the distribution of chemicals. Under the CMA's "Responsible Care's Distribution Code of Management Practices" approved in November 1990, each member company is supposed to have an ongoing chemical distribution safety program to reduce the risk of harm posed by the movement of chemicals. This code includes procedures for risk evaluation and management, carrier safety, chemical handling and safety, regulatory compliance review and training, and emergency preparedness (Ainsworth 1993). The CMA has also developed a partnership program with nonchemical manufacturers and carrier organizations (e.g., National Association of Chemical Distributors) to implement the distribution code. Action plans to reduce distributional risks are being implemented at 73% of CMA member companies (Cottrill 1995).

However laudatory, the CMA efforts are insufficient. More research is needed on the volume of traffic on the nation's highways and railways. These volumetric data will enable us to examine flow patterns more easily and truly derive an incident rate probability for all hazmat spills. We also need to quantify the rate of hazmat spills involving extremely hazardous substances, those substances that pose the greatest risk to human health. This can be done only with more detailed data from carrier manifests that list the chemical (CAS code) and quantity carried. Again, while these data are required under federal regulations, they are not kept in a systematic database to permit comparisons by any geographic region or specific route. Finally, this paper demonstrates the importance of considering both risk sources and mitigation efforts in understanding the distribution of hazmat spills. Mitigation efforts (e.g., environmental regulations, *in situ* management) can ameliorate the overall risk of hazmat spills as our data suggest. In addition to the critical data needs described above, the increased use of mitigation as a strategy for reducing risk is perhaps the most important public policy recommendation from this paper. ■

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Lead Contamination Adjacent to Roadways in Trujillo, Venezuela*

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This study analyzes the extent and pattern of lead contamination along roadways in Trujillo, Venezuela, using traffic counts and soil samples collected in the field. The normalized mean lead level for frontyard samples along major traffic arteries was 200 μgg^{-1} versus 0 μgg^{-1} for backyard samples. Furthermore, 55% of the frontyard lead levels were hazardous, versus 7% of the backyard samples. This suggests a strong relationship between traffic and soil lead content. However, a relationship between lead level spatial patterns and traffic volume patterns was not established, suggesting that factors beyond traffic volume, such as slope and erosion, play a significant role in contamination patterns. **Key Words: lead, soil, traffic volume.**

Introduction

This study examines the extent and pattern of lead contamination in soils in Trujillo, Venezuela. Assessing and understanding lead contamination in soils is necessary, given the associated negative health effects of such contamination. Although adults are at risk from high lead levels, fetuses, infants, children under the age of seven, and expectant mothers are most at risk (U.S. Department of Housing and Urban Development 1990). The risk is higher, in part, because children absorb a higher percentage of ingested lead than do adults. Health consequences associated with lead in children have been well documented (Joyce 1990; Martin 1991; Mushak 1992; Moehr et al. 1993) and include central nervous system disorders, attention span deficiencies, impaired hearing, reading and learning difficulties, mental retardation, seizures, delayed cognitive development, coma, and even death. Since almost 26% of the popu-

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