Assessing the Risk of Hazardous Materials Flows: Implications for Incidence Response and Enforcement Training

ROGER R. STOUGH and JEFFREY HOFFMAN

ABSTRACT

Several factors affect the risk created by hazardous material (hazmat) in transit, including at least the probability of an accident involving a hazmat load, the probability of a spill given that an accident has occurred, and exposure level. In this paper, the focus is on estimating the exposure factor on highways in the heavily industrialized northwest corridor of Indiana. Exposure is defined as the frequency of hazmat loads per time period. Analysis indicates that exposure is highest between 6:00 a.m. and 6:00 p.m. and that it is highly correlated with volume of total truck traffic. Flammable liquids (58.4 percent) and corrosives (26.3 percent) are the most frequent types of loads. Most loads passing through the study area originate outside Indiana, in Illinois and Michigan. Analysis of safety indicators reveals that driver qualification was the least satisfactory and that appropriate placarding was lacking in 20 percent of the hazmat loads. The results suggest that officers should be deployed most intensively during the daytime to enhance enforcement efforts and that officer training efforts should focus on placard recognition and incident response training--especially regarding flammable liquids and corrosives. A significant effort should be made to develop cooperation and coordination among enforcement officials in Indiana, Michigan, and Illinois. Driver training should be designed to improve qualifications and particularly to increase knowledge about the nature of loads. The results and recommendations generalize most directly to heavily industrialized areas located close to or overlapping multiple state boundaries.

Technology has become the "major source of hazard for modern society" (1). Strong agreement exists on this regardless of whether one's ideological perspective is econocentric (2) or technocentric (3,4). Technological hazards may be viewed as threats to human life and property created by modern production and consumption processes (5). For the most part, hazards arise from materials that are created to satisfy modern consumption demands and their residuals. As a consequence, management of hazard from technological sources has become the focus of public policy initiatives at all levels of government (6). In particular, policy development has focused on the management of hazards from these materials at their origin, during their transport, and at their disposal. In this paper, attention is focused on the management of risk arising from the transportation of hazardous materials on Interstate and state highways. Risk as differentiated from hazard may be viewed as the probability that a particular material in a given context will lead to a specific life- or property-threatening consequence during a given period of time (1). Analyses reported in this paper are based on field data collected in the northwest corridor of Indiana.

Although public policy developments such as the revision of the Code of Federal Regulations (C.F.R.) in 1981 regarding the transportation of hazardous materials (sec 49 C.F.R., Parts 100-177, October 1981) and adoption of the manifest tracing system mandated by the Resource Conservation and Recovery Act have occurred in an effort to manage transportation-related risks, numerous problems still exist. In several recent analyses (7-12), the following have been identified as continuing major problems: (a) unclear terminology, (b) regulatory fragmentation at each level of government as well as across different levels, (c) confusing regulations, (d) inadequate training of emergency response forces, (e) inadequate risk assessment methods for judging the value of regulations, and (f) unreliability of federal and state inspections. Each of these problems stems in part from a lack of reliable and complete information about what is being shipped, where it is being shipped, and by whom.

The purposes of this paper are to

1. Develop, analyze, and test a procedure (using data collected in the northwest corridor of Indiana) for determining the nature and level of hazardous materials in transit on the nation's Interstate and state highways;
2. Determine how the nature and level of hazardous materials on Interstate and state highways vary with time of day and with state of origin;
3. Determine the level of safety of loads; and
4. Draw implications for the training of enforcement personnel and incident response forces from the analysis.

R.R. Stough, School of Public and Environmental Affairs, Indiana University, 801 W. Michigan St., Indianapolis, Ind. 46223. J. Hoffman, Indiana Department of Natural Resources, 304 State Office Building, 100 N. Senate, Indianapolis, Ind. 46204.

RISK, EXPOSURE, AND MATERIALS HAZARDS

Ultimately, concern is with the social costs and benefits associated with hazardous materials and their transport. Although society has viewed the benefits as outweighing the costs, recent policy developments (discussed in the preceding section) suggest that a desire exists to increase the benefit-to-cost (b/c) ratio through more careful management of hazardous materials. However, such interpretations are based largely on qualitative observation. Ideally, it would be desirable to be able to at least quantify the social costs of hazardous materials and their transport, that is, the cost in terms of damage to life and property. The key to improving cost estimates lies in the ability to accurately estimate risk from hazardous materials. A discussion of risk is undertaken next to demonstrate that the nature and quantity of hazardous materials in transit are critically important components of risk and, therefore, of cost.

A general model for estimating the risk of transport-related hazardous materials incidents was developed in Indianapolis in 1983. In this model risk is defined as

$$R = A/Ep(S/A) \quad (1)$$

where

- R = risk of hazmat incident in transportation;
- A = expected number of transportation accidents involving hazardous materials within a definable period of time;
- E = exposure to risk, or some measure of the total amount of hazardous materials being transported (e.g., number of hazmat-laden trucks); and
- p(S/A) = probability of a hazardous materials spill, given that a transportation accident has occurred.

One problem with this model is that it appears to suggest that risk is inversely proportional to exposure. This apparent problem disappears when it is noted that A is probably an increasing function of exposure above some threshold.

Several problems exist in the implementation of this and similar models, not the least of which is data availability. As noted, the primary focus in this study is the determination of the nature of hazardous materials in transit. In the context of the model, this purpose is to estimate the exposure variable E.

Two attempts to measure exposure have been identified. The first, by Price et al. (13), involved systematic sampling of truck traffic in 1977 at numerous locations throughout Virginia. The sample data indicated that almost 13 percent of all loads involved hazardous materials and about 10 percent carried amounts sufficient to require placarding. A later study by the city of Indianapolis (14) involved the estimation of exposure by systematically recording placard numbers (United Nations/North American Classification Number, or UN/NA number) on vehicles observed at selected points of high truck traffic flows in the region. The data were used to estimate that 7.1 percent of all loads sampled were carrying hazardous materials and that the majority of these loads were flammable liquids. The study also forecast that the majority of hazardous incidents in the region would occur on city and county streets and roads.

Some problems exist with each of these approaches. In the Price et al. study, those conducting the field sampling received no or limited instruction on the identification of hazardous materials. Furthermore, after the 1981 revisions in the C.F.R. regarding the transport of hazardous materials, a clearer defintion of what constituted hazardous material in transit existed. In short, these qualifications may explain in part why the percent of hazardous loads in the Virginia study was noticeably higher than the more recent Indianapolis study.

The city of Indianapolis study is also subject to a number of qualifications. First, the sampling locations in this study appeared to have overrepresented local streets and roads, thereby calling into question the forecast that the majority of hazmat incidents would occur on city and county streets and roads. The authors of this study readily acknowledge additional problems with the methodology, including the following: (a) sampling procedures employed systematic yet less than full scientific sampling protocol; (b) the use of placards to identify hazardous loads--some types of loads need not be placarded because of the quantity of the load or its packaging and some loads are not placarded that should be; (c) the observer may not have observed some placards; and (d) some placarded trucks did not have UN/NA numbers, which made it difficult or impossible in those cases to determine the nature of the material being transported.

The Indianapolis study is the only recent (since the 1981 revision of the C.F.R.) attempt to empirically estimate exposure to hazardous materials while in transit. Given that several problems exist with earlier methodologies, there is a need to improve the measurement methodology if hazardous materials risk on highways is to be more accurately estimated.

DATA COLLECTION METHODOLOGY

A plan to collect information on hazardous materials transported on highways was developed by the Indiana State Police during fall 1983. This plan tried to address the shortcomings of the earlier studies. A key feature of the plan involved the utilization of state police officers who had recently completed a 40-hr U.S. Department of Transportation hazmat highway transportation regulation course to collect hazardous materials data as part of truck weigh scale operations. As the plan evolved, the northwest part of Indiana was selected for initial implementation. The primary reason that this region was selected stemmed from the availability of trained personnel there.

The northwest part of Indiana is heavily industrialized and is adjacent to the Chicago-Cook County metropolitan complex. Major U.S. and Interstate routes traverse this region: US 20, US 30, US 41, I-65, I-94, and I-90 (Indiana Toll Road). Data collection sites were identified and used on all routes except the Indiana Toll Road (see Figure 1). Two of the routes (US 20 and I-65) have permanent weigh scale stations. Inspection sites were set up on the other routes at places where trucks could be safely pulled off the traveled portion of the highway and inspected. These sites were operated in much the same manner as portable weigh scale stations. Each of the five routes had one location where inspections were made.

Hazmat data were collected during 1-hr periods at each site for traffic in both directions. At the beginning of the study period (October 1-30, 1983), a systematic sample of 1-hr periods on weekdays between 4:00 a.m. and 10:00 p.m. was selected for each route. Sample days varied from a minimum of 3 (which resulted as a consequence of personnel shortages) to

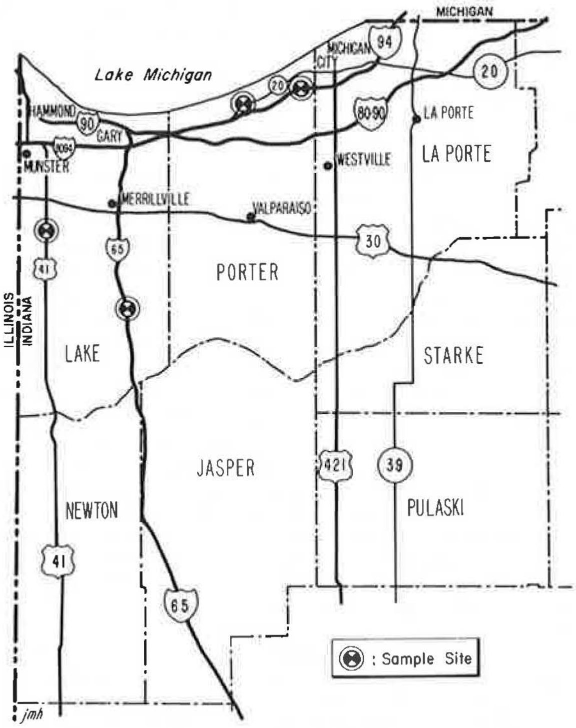


FIGURE 1 Map of Indiana's northwest corridor: sample locations of hazardous materials.

TABLE 1 Sample Hours by Time of Day

Hour	No. of Sample Hours
4 a.m.	4
7 a.m.	14
9 a.m.	8
10 a.m.	2
11 a.m.	2
12 noon	14
2 p.m.	4
3 p.m.	2
4 p.m.	2
5 p.m.	4
10 p.m.	4
All times	60

a maximum of 11 at the different sites. In total, there were 60 sample hours at all 5 sites. The data in Table 1 indicate that the majority of sample hours occurred between 6:00 a.m. and 6:00 p.m.

During each sample hour, all truck vehicles passing the sample point (regardless of direction) were inspected. Sample periods were set at 1 hr to reduce site-avoidance behavior arising from truckers talking on citizens band radios or coffee house conversations. Each inspection included identification of type of commodity, total weigh and/or quantity, container type, number of containers, and origin and destination (state). For loads identified as hazardous (from their shipping papers), the hazard class, UN/NA number, was determined. In addition, through a physical inspection of the truck, its contents and shipping papers, a credentials check, and a short questioning period with the driver, a determination was made of apparent violations of existing laws and those that were soon to be enacted in areas that were considered to be integral to effective enforcement of the laws. These included:

- Driver training and qualifications,
- Placarding,
- Shipping papers, and
- Vehicle and equipment condition.

In general, the criteria used to determine apparent violations were based on existing laws in Indiana used to enforce motor carrier safety (I.C. 8-2-7 and 49 C.F.R., Parts 390, 391, 392, 395, 396, and 397) as well as those that were not Indiana law at the time but were contained in 49 C.F.R., Parts 171, 172, 173, 177, and 178, pertaining to transportation of hazardous materials.

For each of the four enforcement areas just listed, a rating of either satisfactory or unsatisfactory was made of apparent violations or deficiencies. Table 2 gives a description of the criteria used to determine an unsatisfactory rating in each of the four areas. Assessment of drivers' qualifications included licensing and limits on driving time as well as the evaluation of their knowledge, emergency procedures, and awareness of the CHEMTREC hotline and how to use it. Some drivers expressed no knowledge or concern of their load's nature: they were hauling cargoes based solely on a numerical assignment of a trailer at the dispatch location.

TABLE 2 Load Safety: Criteria for Unsatisfactory Rating

Enforcement Area	Criteria	Rating
Driver training	Proper license Knowledge of CHEMTREC hotline Any training on HAZMAT received Driving hours within limits Knowledge of load substance	3 of 5 unsatisfactory = unsatisfactory driver training
Placarding	Placard present Empty load--proper placard present Proper placard for load	2 of 3 unsatisfactory = unsatisfactory placarding
Shipping papers	Present with load Entire load manifested Adequate load description	2 of 3 unsatisfactory = unsatisfactory shipping papers
Vehicle condition	Brakes Tires Proper registration Lights Load security Proper weight	1 of 5 unsatisfactory = unsatisfactory vehicle condition

Placarding was checked to determine if the load indicated was the load specified in the shipping papers or if the load should have been placarded and was not. Some trucks although empty are required to be placarded. These loads were noted when detected.

Determining if a load is adequately placarded is complicated because of the complexity of federal laws. Not all loads may be required to be placarded even though they are carrying hazardous cargo because of quantity or packaging of the cargo or both. In addition, when more than one hazardous material is present in a single load, complex and at times apparently contradictory regulations must be interpreted to determine the correct placarding.

Shipping papers were inspected for presence or absence of hazardous materials and, as noted previously, compared with the C.F.R. to determine appropriate placarding. The origin and destination of the load were also determined by these documents.

Vehicle condition was evaluated in the same manner as that used for any vehicle required to stop at roadside inspection or permanent weigh scale locations. This was probably the easiest of the four inspection activities to accurately evaluate.

ANALYSIS AND RESULTS

During the study month (October 1983), 12,321 loads were inspected at the five sample locations. Of these, 687 or 5.6 percent were hazardous loads. This figure is somewhat less than the 7.1 percent observed in the city of Indianapolis study (14) and considerably less than that observed in the Price et al. study (13). Some variation was observed in the percentage of hazardous loads at different times: the high was 6.0 percent between 7:00 a.m. and 11:00 a.m.; the low was observed during late evening (10:00 p.m.--4.3 percent) and during the early morning (4:00 a.m.--4.8 percent).

The overall pattern of hazardous and nonhazardous loads is similar, as shown in Figure 2. Beginning early in the morning (probably about 6:00 a.m. to 7:00 a.m.), traffic density increases and peaks at about 10 a.m. Density drops off significantly during the next hour but subsequently increases at noon and reaches a second high at 3:00 p.m. (hazardous loads are at a plateau from noon through 3:00 p.m.). A second low-density period occurs at 4:00 p.m. Density increases, however, at 5:00 p.m. and appears to gradually decline from that time until early the following day (6:00 a.m. to 7:00 a.m.). These findings suggest that the apparent high truck density perceived by automobile travelers during the night does not hold for the authors' sample locations.

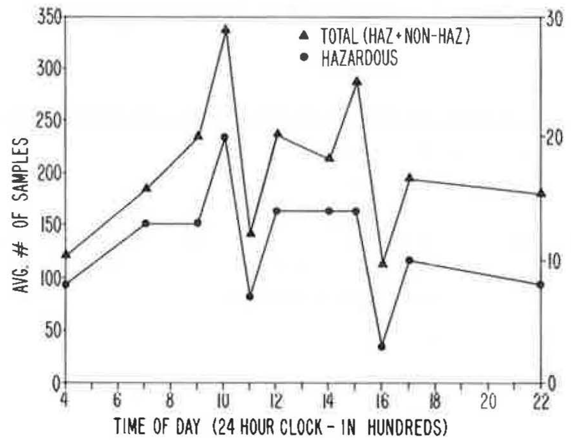


FIGURE 2 Average number of loads per sample hour.

Data presented in Table 3 indicate that 58.4 percent of all loads are flammable liquids. The next largest class is corrosives at 26.3 percent. Other types of hazardous loads comprise a small percentage of all loads. This pattern is characteristic of all sample times. However, during the 4:00 a.m. sample period, the percent of loads for oxidizing and poisonous substances was found to be slightly higher during the early morning.

TABLE 3 Percentage of Hazardous Loads by Hazardous Class and by Time

	Time				
Class	4:00 a.m.	7:00-11:00 a.m.	12:00-3:00 p.m.	10:00 p.m.	All times
Explosives	0.0	0.6	0.3	0.0	0.4
Gases	0.0	3.1	9.4	3.2	5.8
Flammable liquids	39.1	62.5	54.5	67.7	58.4
Flammable solids	0.0	1.2	0.7	0.0	0.9
Oxidizing substances	4.3	2.2	1.6	3.2	1.9
Poisonous substances	4.3	0.6	2.9	0.0	1.7
Radioactive substances	0.0	0.9	1.3	0.0	1.0
Corrosives	47.8	24.8	26.8	22.6	26.3
Other	4.3	4.0	2.9	3.2	5.5
All classes (n)	23	323	310	31	687

Data given in Table 4 show relationships between the origin and destination of hazardous loads. Most loads originated in Illinois, Indiana, and Michigan. Illinois was the largest source (39.9 percent), which reflects the mass of the Chicago-Cook County metropolitan industrial complex. Kentucky, Ohio, and Wisconsin are sources of relatively small percentages of loads. Almost 40 percent (266) of all loads (667) are destined for Indiana: 43.6 percent of these loads come from Indiana but almost 30 percent come from Illinois and 30.3 percent originate in Michigan. In summary, both origin and destination of hazardous materials at the sample sites are dominated by three states: Illinois, Indiana, and Michigan. Perhaps the most surprising aspect of these findings is the relatively minor role Ohio plays as an origin or destination. However, this may be due to no sampling taking place along the Indiana Toll Road (I-90), which serves as the most direct link with Ohio.

Data on driver qualification, vehicle condition, shipping papers, and placarding are summarized in Figure 3. Overall, driver qualification is observed as the least satisfactory of the four indicators of safety. This is particularly disturbing in the case of the high-danger explosives and classes of radioactive substances. Although the number of cases for these classes was small (three in the case of explosives), it would be hoped that driver qualifications for these types of cargo would be impeccable.

Appropriate placarding was lacking for about 20 percent of all loads. Clearly, a need exists for greater enforcement in this area. There is probably also a need for more education as well as regulation recodification to reduce the complexity involved in determining the appropriate placarding.

Generally, vehicle condition is the strongest of the four safety indicators. More than 95 percent of all inspected vehicles were judged to be in satisfactory condition. It is important to note that no unsatisfactory vehicles were found for loads such as explosives and radioactive substances.

The overall or average safety conditions found for all loads are almost identical to those observed for the categories of high-density hazardous flammable liquids and corrosives. Almost 85 percent of all hazardous loads are of these two types. The results suggest that any plan to improve safety for these hazardous categories should focus on placarding, driver qualifications (training and education), and vehicle condition.

TRAINING AND ENFORCEMENT GUIDELINES

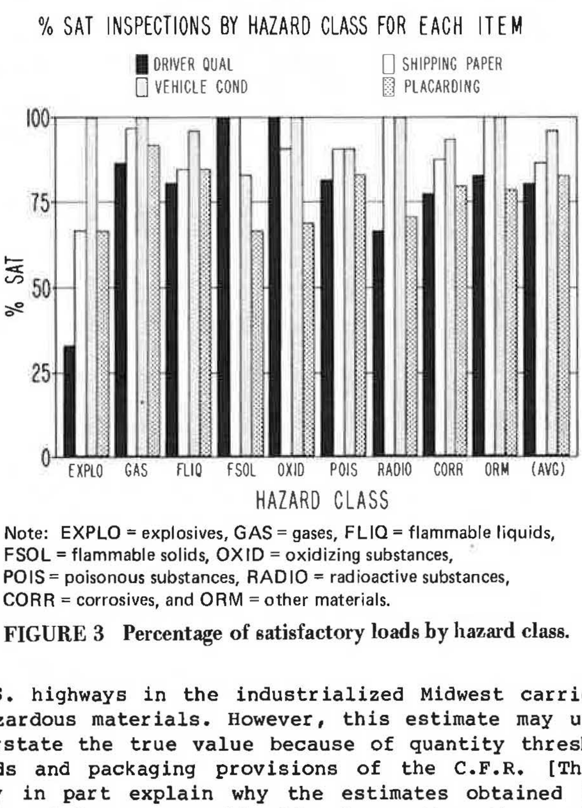
In the initial part of this paper, exposure to a hazmat spill was identified as one of the key factors contributing to risk and therefore to the social cost of hazardous material transport. Exposure was defined in terms of a surrogate variable--amount of hazardous material being transported. The analysis identified a number of empirical regularities regarding this variable, including regularities in the way the number of hazardous loads vary with time of day, type of hazardous material, origin and destination, and safeness of the load. The implications of these findings for enforcement and incident response are discussed in the following paragraphs.

The northwest Indiana study suggests that about 1 in every 17 trucks operating on Interstate and other

TABLE 4 Origin and Destination of Hazardous Materials Loads

Origin	Destination Illinois	Indiana	Kentucky	Michigan	Ohio	Wisconsin	Other	Total
Illinois								
Number	8	79	14	80	37	1	47	266
Percent	3.0	29.7	5.3	30.1	13.9	0.4	17.7	100.1[a]
Indiana								
Number	27	116	0	10	2	1	10	166
Percent	16.3	69.9	0.0	6.0	1.2	0.6	6.0	100.0
Kentucky								
Number	7	4	0	0	0	2	2	15
Percent	46.7	26.7	0.0	0.0	0.0	13.3	13.3	100.0
Michigan								
Number	56	54	9	1	8	0	8	136
Percent	41.1	39.7	6.6	0.7	5.9	0.0	5.9	99.9[a]
Ohio								
Number	7	2	0	1	0	2	6	18
Percent	38.9	11.1	0.0	5.6	0.0	11.1	33.3	100.0
Wisconsin								
Number	1	2	2	3	1	0	8	17
Percent	5.9	11.8	11.8	17.6	5.9	0.0	47.1	100.1[a]
Other								
Number	21	9	1	5	4	5	4	49
Percent	42.8	18.3	2.0	10.2	8.2	10.2	8.2	99.9[a]
Total								
Number	127	266	26	100	52	11	845	667
Percent	19.0	39.9	3.9	15.0	7.8	1.7	12.7	100.0

[a]Totals may not sum to 100.0 percent because of rounding.



Note: EXPLO = explosives, GAS = gases, FLIQ = flammable liquids, FSOL = flammable solids, OXID = oxidizing substances, POIS = poisonous substances, RADIO = radioactive substances, CORR = corrosives, and ORM = other materials.

FIGURE 3 Percentage of satisfactory loads by hazard class.

U.S. highways in the industrialized Midwest carries hazardous materials. However, this estimate may understate the true value because of quantity thresholds and packaging provisions of the C.F.R. [This may in part explain why the estimates obtained in this study are considerably lower than those obtained by Price et al. (13) in 1982.] Nevertheless, it is reasonable to conclude that hazardous loads as defined by the C.F.R. comprise a relatively small proportion of all loads--probably not more than 7 to 8 percent. Enforcement and incident response training and management must begin with an awareness of this statistic. Moreover, the results of this study strongly suggest that the proportion of hazardous loads does not vary much with time of day, which implies that the need for enforcement and incident management will vary directly with traffic volume.

The northwest Indiana study shows that (a) traffic density is highest during the period 6:00 a.m. to 6:00 p.m. and (b) during this period, peak-volume periods are observed between 7:00 a.m. and 10:00 a.m. and between 12:00 and 3:00 p.m. Consequently, training efforts should make enforcement and incidence response planners and personnel aware that demands are likely to be greater during these daytime periods. Forces should be deployed more intensively during the daytime; this is consistent with current general deployment practice.

Two of the hazardous materials classes (flammable liquids and corrosives) were found to represent almost 85 percent of all loads. Consequently, hazardous loads may be viewed as falling into two broad groups: frequent hazmat loads and rare hazmat loads. To demonstrate this, it need only be noted that 1 in 36 trucks on the highway transports flammable liquids, whereas 1 in about 4,000 trucks carries explosives.

If it is assumed that the probability of an accident involving a hazardous cargo spill is invariant with the type of material, then the majority of enforcement and incident training effort should address the transportation of flammable liquids and corrosives. This conclusion is further supported when it is considered that regulations for the transport of many of the other categories (e.g., explosives and radioactive substances) are more stringent, thereby making their transit presumably even safer. The reason that regulations for the transit of these types of materials are more stringent is because the social costs of incidents involving explosives or radioactive substances are likely to be much higher.

The origin and destination analysis showed that northwest Indiana is a net receiver of hazardous materials from other states. Most of the externally generated hazardous materials received by Indiana from other states come from Illinois and Michigan. Consequently, training should make enforcement and incident response planners and personnel aware of this. Moreover, training efforts should include familiarization with hazmat enforcement and incident response procedures and training in these adjacent states.

It was interesting to find that the condition of vehicles is the strongest overall safety feature. This is not unexpected because many problems with vehicles are readily observable; furthermore, these are areas of routine enforcement for the state police.

In contrast to vehicle condition, problems with appropriate placarding are widespread. Transporters fail to correctly placard vehicles about 20 percent of the time. A need therefore exists for better education of appropriate placarding for shippers. A need also apparently exists to rewrite some of the placarding guidelines and regulations because their complexity probably contributes to inappropriate placarding or the failure to use placards to identify loads that require them. Significant effort should focus not only on developing a more significant placard education program for shippers but also on a placard enforcement program. Emergency response efforts begin with identification.

The overall safety findings in the northwest study showed that driver qualification is the weakest safety category. Attempts to reduce driver qualification problems should begin with an education program designed to make drivers and shippers more aware of the nature of the load they are carrying, the appropriate response if a leak or spill is detected, and knowledge of the CHEMTREC hotline telephone number. Licensing guidelines that include these points should be developed and implemented.

Finally, it is important to note how this study and its findings might be generalized. First, the data collection methodology is an improvement over earlier ones used to measure exposure. The study was designed to preserve most aspects of scientific sampling protocol and used highly trained state police officers to collect field data. One problem with the procedure occurred when absences or higher priority work necessitated foregoing data collection, which resulted in an unevenness in sample sizes at the five sample locations. In the future, this problem could be overcome simply by oversampling at different locations and times.

The data collected and analyzed in this study were obtained in one of the most heavily industrialized and heavily populated areas of the United States. Such areas are known to be both large-scale producers and consumers of hazardous materials and, as a consequence, are characterized by high levels of hazardous materials in transit. The findings of this study are, therefore, most directly generalizable to areas with similar characteristics.

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