Hazardous Materials Transportation Rules and Regulations at Bridge-Tunnel Facilities

BAHRAM JAMEI, ANTOINE G. HOBEIKA, AND DENNIS L. PRICE

Hazardous materials are transported every hour of every day through major and vital transportation facilities such as bridges and tunnels. The problem of identification, classification, regulation, and control of these toxic substances during transportation is one of tremendous magnitude and significance. Development of rules and regulations for shipment of hazardous materials through special facilities such as bridges and tunnels was the main objective of a study performed under contract for the Virginia Department of Transportation. During the conduct of this project many tasks were undertaken to produce a single manual of rules and regulations for bridge-tunnel facilities in the Commonwealth of Virginia. This paper is a summary of that study, and it concentrates on the details of the analytical framework that was used to generate a set of criteria by which regulations for new and unlisted substances could be developed in the existing manuals. For example, the methodology of developed rules and regulations for the flammable liquids hazard class is discussed to provide an overview of the entire analytical technique.

Hazardous materials are transported every hour of every day through vital transportation facilities such as bridges and tunnels. According to a recent report published by the Office of Technology Assessment (OTA), more than 60 percent of all hazardous materials shipments are made by trucks (containers, flat beds, and tanks) (*1*). A study by Price and Schmidt in 1978 at Virginia Tech disclosed that approximately 13 percent of all trucks in Virginia carried hazardous materials and 240 highway accidents involving hazardous materials could be expected in Virginia in a ten-year period (*2*).

The enormous damage to human health and the environment that can be caused by a single truck accident carrying hazardous materials is of great concern. Even though such incidents are relatively infrequent, shipment of such materials must be safely regulated in order to reduce harmful consequences.

A way to reduce the risks involved with the transportation of hazardous materials is to develop and deploy the proper regulations, information systems, container safety, enforcement, and training for emergency response personnel. This could be accomplished by providing more uniformity in federal, state, and local regulations and enforcement procedures and by encouraging coordination and cooperation among all levels of government agencies.

Department of Civil Engineering & Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Va. 24061.

Availability of more information about the transportation of hazardous materials would improve public knowledge in this matter. In addition, better government coordination in setting container regulations, including operational and procedural guidelines, is needed. Most important, a national strategy to provide training for emergency response and enforcement personnel is necessary at the state and local levels.

Lack of industries' familiarity and compliance with federal regulations of hazardous materials and inadequate government surveillance resulted in the passage of the Hazardous Materials Transportation Act (HMTA) of 1975. The basic intent of the law was to improve regulations and enforcement activities by allowing the Secretary of Transportation to set regulations applicable to all modes of transport. The most important existing federal regulations governing the transportation of hazardous materials are documented in Title 49 Code of Federal Regulations (49 CFR), parts 100 through 199.

The code consists of extensive specifications for containers, hazardous communication requirements such as vehicle placarding, and operating procedures for each mode of transport. Even though many states have adopted 49 CFR wholly or in part, in some cases states have developed their own regulations. This is true specifically for bridge and tunnel facilities throughout the United States, as documented in *A Summary of Highway Facilities Where Hazardous Materials Are Restricted* (*3*). Local jurisdictions and state governments controlling these facilities are concerned with developing regulations regarding the maximum quantity of hazardous materials per vehicle that they should allow to go through these vital bridges and tunnels without producing unreasonable risk to human health and the environment, as well as risk of damage to property in case of an incident involving such vehicles. State regulations concerning shipment of hazardous materials could be more restrictive than such federal regulations but not to the extent that they unreasonably burden interstate commerce.

RESEARCH OBJECTIVES

This paper contains a summary of the analytical framework that was developed as part of a study to produce a single hazardous materials regulation manual for bridge-tunnel facilities in the Commonwealth of Virginia. The emphasis was on a comprehensive assessment of existing regulations and on developing a set of criteria by which the shipment of new and unlisted hazardous materials through bridge-tunnel facilities could be regulated and controlled.

In the process of developing such a manual, the following tasks were performed:

- Task 1—review of literature related to existing hazardous materials' regulations and their development process;
- Task 2—review of hazardous materials' regulations on board ferry vessels;
- Task 3—inventory of tunnel facilities using a detailed questionnaire form and site visits by project team;
- Task 4—gathering of information about the hazardous materials flow through the facilities by conducting special surveys of carrier companies and industries, in addition to placarding trucks stopping at inspection stations;
- Task 5—development of a regulatory methodology based on the performance and safety records of existing regulations;
- Task 6—utilization of different hazardous materials rating schemes to disaggregate those substances that justify further regulatory investigations;
- Task 7—development of a technical regulatory process sensitive to the chemical properties of hazardous materials;
- Task 8—discussion of substances that needed regulatory modifications using expert systems;
- Task 9—evaluation of traffic conditions in and around the tunnels under emergencies; and
- Task 10—preparation and development of the manual.

This paper concentrates, however, on the results of tasks 5, 6, and 7 and briefly refers only when necessary to the findings of other tasks performed within this study.

DEVELOPMENT OF A REGULATORY FRAMEWORK

Findings of a literature review for the study revealed that all of the existing regulations for shipment of hazardous materials through bridge-tunnel facilities are similar. Furthermore, there is a lack of scientific methodologies leading to the development of such regulations. Weaknesses in these methodologies exist in determining the joint probabilities of an accident occurring in a tunnel or on a bridge that could lead to a chemical spill, and then evaluating the consequences and effects of such a spill in a specific environment to determine the tolerable risks and eventually using these findings to develop appropriate regulations.

The review concentrated basically on existing regulations on hazardous materials via five tunnel and bridge facilities in different states. These five facilities are (1) Big Walker and East River Mountain Tunnels (BW), (2) Chesapeake Bay Bridge and Tunnel (CB), (3) New York and New Jersey Port Authority tunnels and bridges (NY/NJ), (4) Maryland toll facilities tunnels and bridges (MD), and (5) Triborough Bridge and Tunnel Authority (TBTA) of New York.

In developing a basis for comparing existing regulations among the five different facilities, the regulations of TBTA were selected as the point of reference or framework for the analysis, as well as for development of the Hazardous Materials Tunnel and Bridge (HMTB) data file. There were several reasons for selecting TBTA regulations as the study base. First, the regulations were the most current of those of the five facilities analyzed. Second, the regulations of TBTA appeared to be more comprehensive than those of the other facilities (that is, they contained more material listings or descriptions), and they conformed most closely to the structure of the Hazardous Materials Table in 49 CFR, part 172.101. Third, the TBTA regulations contained the United Nations (UN) hazard identification (ID) number for each commodity, an added dimension in terms of commodity description.

Therefore, the current bridge-tunnel regulations were used as a starting point for developing such a regulatory framework. The basic reasons for utilizing existing regulations were:

1. The regulations were established and were widely accepted. The safety records of the bridge-tunnel facilities during the past twenty-five years indicated that the regulations have been performing reasonably well in preventing catastrophic disasters.
2. The transportation industries have been using these regulations for a long time, as the survey indicated. A substantial change in the regulations would have resulted in additional costs to shippers, a disturbance to their existing procedures, and the need to retrain their employees.
3. The weight limitations imposed on hazardous materials in the current regulations reflected the degree of hazard each substance holds.

Next, this study designed an approach to separate those hazardous materials that are subject to inconsistencies in the current regulations. That is, the effort was made to seek out those hazardous materials within a hazard class that have similar chemical properties and produce the same harm potentials, yet were given two different maximum allowable quantities per vehicle in the regulations. Those materials treated inconsistently were identified by the following procedure:

1. A list of highly dangerous substances was produced by utilizing the rating system of hazardous materials of major organizations and by consulting individual authorities on chemical substances.
2. Existing regulations for the preceding list of hazardous materials were studied closely to determine if any discrepancies exist. Such materials were then marked for further investigation regarding their unequal regulatory treatment.
3. Existing regulations for those substances in item 2 and certain other hazardous materials (whether new or

needing regulations) were analyzed to determine whether new regulations should be established or whether the current rules should be followed.

Basically there are two general approaches for selecting questionable substances discussed above: (1) a comparative approach and (2) a risk analysis system approach. The comparative approach relies on performance of existing regulations. It selects for further investigation only those substances that do not have the same regulations of allowable quantity per vehicle weight limitations, even though they do have chemical properties and characteristics similar to those of other substances in their class. This approach could also be used to determine the regulations for those substances that, for regulatory purposes, are either new or have been recommended by major organizations and experts as being highly dangerous and requiring further regulatory investigation.

The alternative strategy would have been to perform a risk analysis approach for every one of the substances and then produce a matrix of harm versus various scenarios and events that might occur in case of an incident involving release of the hazardous material. The outcome of this latter approach would then have been a risk analysis and cost-effectiveness measure for any specific rules and regulations concerning a substance. Unfortunately, because of time and money constraints, this approach is not feasible for this study. Besides, the data needed to implement such a study are not available, and the models necessary to conduct the analysis would have to be designed from scratch for tunnel operations. Therefore, it is not possible to conduct this approach in a year, as required by contract for this study.

Hazardous materials are classified in existing regulations according to their chemical properties and harm potentials. Even within a specific hazard class, such as flammable liquids or poisons, further divisions exist that carry their own specific characteristics by type of packaging, maximum allowable quantity per vehicle, and per package weights.

The effort was made in this study to characterize these regulatory divisions (here called "envelopes") within each hazard class by a set of chemical, physical, environmental, and other properties of the substances originally forming these divisions. The basic idea is that substances in each envelope within a general hazard class behave the same or have similar severity of harm when released and therefore should have a consistent and uniform set of regulations. The next step would be to extract substances that, based on their chemical properties and other characteristics, were placed in an inappropriate envelope. These substances and any other new or questionable hazardous materials could then be assigned to the appropriate envelopes by considering their chemical properties and matching them with the right envelope in the corresponding hazard class.

The flow chart in Figure 1 illustrates the entire process of selecting questionable substances and the steps involved in developing the regulatory methodology.

HAZARDOUS MATERIALS RATING SCHEMES

Hazardous materials ranking or classification systems are usually grouped into two major categories: classification systems established for regulatory purposes and classification systems used to facilitate emergency response in case of an incident.

Classification systems may categorize materials by specification of the hazard or degree of hazard associated with handling, transportation, disposal, or incident involving release of the substance. Currently, no single system incorporates the degree of hazard, corrective action, transportation limitation, storage, and handling of containers. One major reason for the lack of a unified system is that a single system may be impractical or too complicated from all the possible usage viewpoints.

For the purpose of the study and in order to address both regulatory and emergency response aspects of the existing schemes, six major classification systems were selected as described below:

1. International Maritime Organization Rating System (IMO). The system establishes criteria on harm mechanisms resulting from continuous discharges into the sea from stationary outfalls that could affect the marine environment (*4*).
2. National Fire Protection Association Rating System (NFPA). The system provides simple, readily recognizable, and easily understood markings that will give, at a glance, a general idea of the inherent hazards of any material and the order of severity of these hazards as they relate to fire prevention, exposure, and controls (*5*).
3. Glickman and Waddington Hazard Rating System. The system determines relative hazards based on the premise that if the contents of a hazardous material shipment are very dangerous and if the container is likely to release a large quantity of its contents in an accident, then the hazard rating for that shipment should be high (*6*).
4. N. Irving Sax's Toxicity Rating System (Sax's). The Sax's rating system basically addresses the issue of toxicity and its relative hazards (*7*).
5. National Academy of Sciences Rating System (NAS). The fire, health, water pollution, and reactivity hazards of bulk water transportation of industrial chemicals are evaluated (*8*).
6. United Nations Packaging System (UN). The system divides the hazardous materials of all classes other than class 1 (explosives), 2 (gases), 6.2 (infectious substances), and 7 (radioactive materials) into three main packaging groups according to the degree of danger they present.

These three packaging groups are as follows:

- Packaging group I—hazardous materials with great danger;
- Packaging group II—hazardous materials with medium danger; and
- Packaging group III—hazardous materials with minor danger (*9*).

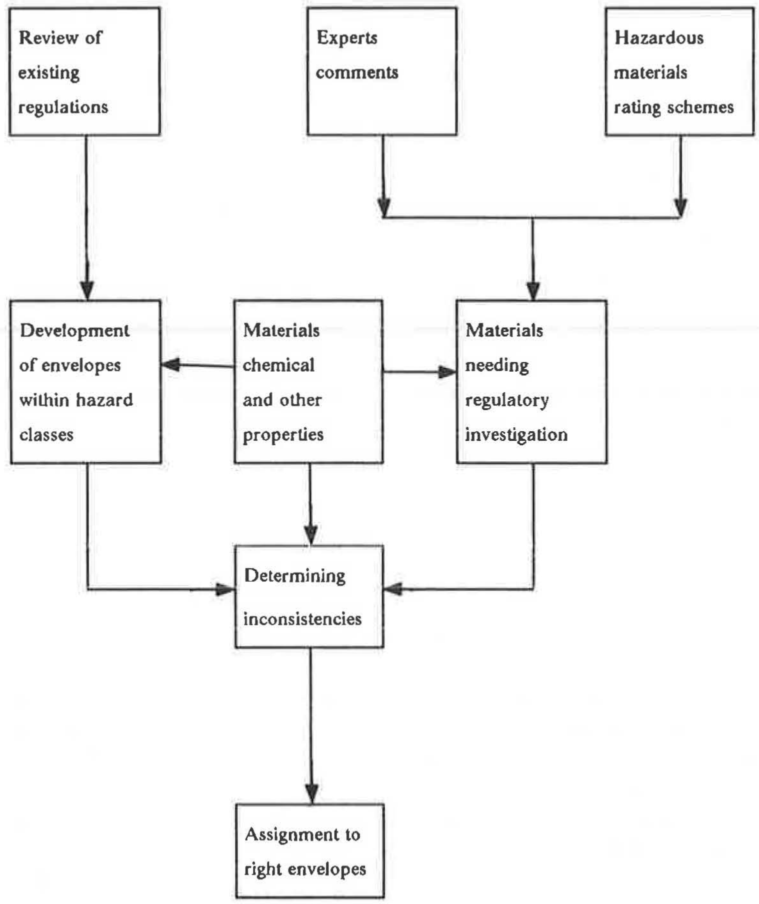

FIGURE 1 Framework of analysis.

Based on the preceding rating schemes and the expertise of many individuals, more than 700 substances were selected for investigation regarding their regulations for shipment via tunnels and bridges. In the next section of this paper, the analytical framework that was used to develop regulatory methodology is explained. Also, as an example, the methodology for flammable liquids hazard class is given in a more detailed format.

DEVELOPMENT OF TECHNICAL REGULATORY METHODOLOGY

In all of the reviewed regulatory sources, each hazardous material class, such as flammable liquids or poisons, had a different set of rules and regulations. Within a specific hazard class, further divisions defined the material's specific characteristics in terms of type of packaging, maximum allowable quantity per vehicle, and per package weights. The study characterized these regulatory divisions ("envelopes") within each hazard class by a set of chemical, physical, environmental, and other properties of the substances originally forming these divisions. Since substances in each envelope within a general hazard class behave the same or have similar severity of harm when released, the substances in each envelope should have a uniform set of regulations. The next step, as stated earlier, was to extract substances that, based on their chemical properties and other characteristics, were placed in an inappropriate envelope. These substances and any other new or questionable hazardous materials could then be assigned to the appropriate envelopes through a consideration of their chemical properties and by matching them with the right envelope in their corresponding hazard class.

It should be noted that the envelopes formed served only as an aid to arriving at a decision. Other relevant characteristics that are unique to a particular hazardous material were considered in determining the final restrictions.

V. C. Marshall (*10*) lists five principal factors that govern severity of consequence of spillage:

1. Intrinsic properties: flammability, toxicity, instability;
2. Dispersive energy: pressure, temperature, state of the matter, volatility;
3. Quantity present;
4. Environmental factors: topography and weather; and
5. Population density in the vicinity and proximity of property.

Factors 4 and 5 can be considered constant or unchanging. These factors are independent of the hazardous materials present. The other three factors are dependent on the type of material present and provide an indication of the harm potential of the material. Of these, the quantity present is one factor that can be controlled through regulation. The regulated amount will largely depend on the properties of the substance. The harm potential of a hazardous material can be effectively reduced to a tolerable magnitude by reducing the quantity present.

Harm potential is a function of the intrinsic property and dispersive energy of the material. By defining envelopes or grouping for each hazard class based on their harm potential, with environmental conditions and population density assumed constant, the severity of consequences becomes a function solely of quantity present. Analyzing these envelopes based on probable tunnel incident scenarios will give an estimate of the magnitude of harm for each envelope. From this, quantity limitation can be assigned for each envelope.

Analyzing tunnel incident scenarios and assigning the appropriate quantity limitation using risk analysis, simulation, or an impact matrix are too rigorous to be justified at the present time, even if the data necessary to do so existed. A rigorous approach would require a detailed study in the probability of release as a function of the transportation environment, traffic densities, container design, stowage, and the various factors that can influence the magnitude and occurrence of a breach in the containment system. A rigorous approach would be as prohibitively costly as it is difficult. Such an approach is too complex and highly theoretical; it would require, in most cases, data that simply do not exist.

To circumvent these methodological and data constraints, an alternative approach was devised. The approach is rooted in using an existing system that assigns quantities to hazardous materials that reflect their harm potential. The current tunnel-bridge regulations were a good starting point for such a scheme.

The flammable liquid hazard class is used here as an example to illustrate the regulatory methodology. Figure 2 gives the packaging and total quantity restrictions for the flammable liquids based on existing regulations. By converting this figure according to the dispersive energy and intrinsic properties of the materials under each note, the resulting chart (Figure 3) was developed. The chart defines the envelopes for each note with the corresponding packaging and quantity limitation. Having established these decision trees for each hazard class, the problem became one of finding to which envelope a hazardous material, based on its properties, would belong. From this, the packaging and total quantity limitations for a particular substance were easily determined.

In determining the envelopes for flammable liquids, susceptibility to burning was the basic criterion used. The range of the flammability limits and the amount of vapor produced by a flammable liquid at normal conditions give an indication of its susceptibility to burning or explosion. It is a well-known fact that gasoline, for example, does not burn; the vapors of gasoline burn. This was one of the major reasons for forming a common grouping for flammable liquids based on their characteristics, such as flash point, which is the temperature at which enough vapors are generated to momentarily support combustion and volatility. As shown in Figure 2, flammable liquids in tank vehicles are restricted. For those flammable liquids in containers, the weight limitations are either 100 pounds gross weight per vehicle (notes b through f) or greater (notes g through j). Three flammable liquids, namely, ethyl nitrate, ethyl nitrite, and nickel carbonyl, are totally restricted from passage.

The amount of vapor produced by a liquid at any temperature (volatility) is directly related to its vapor pressure and its boiling point. In general, the lower the boiling point and the higher the vapor pressure, the more hazardous the flammable liquid is. For flammable liquids with similar flash points, the one with the lower boiling point is considered the most hazardous. This is reflected in the National Fire Protection Association (NFPA) class rating given for flammable liquids; that rating is adopted here in forming the envelopes for this hazard class. Briefly, the NFPA system separates flammable liquids into three classes.

Class	*Flash Point*	*Boiling Point*
1A	Below 73 F (23 C)	Below 100 F (38 C)
1B	Below 73 F (23 C)	At or above 100 F (38 C)
1C	At or above 73 F (23 C) and below 100 F (38 C)	

Other factors that further separate the individual envelopes for this hazard class are toxicity, explosivity, ease of ignition, and burning rate.

The various combinations of the preceding characteristics defining each envelope are shown in Figure 3. As used here, explosivity refers to the immediate or instantaneous explosion hazard of materials that burn at an explosive rate. Explosion caused by the ignition of a flammable vapor cloud is not considered an immediate explosion hazard. Toxicity is defined in terms of lethal dose fifty (LD50) and lethal concentration fifty (LC50). To be consistent, only LD50 and LC50 values for rats as test animals were used.

One example of the changes made is the substance ethyl methyl ether, originally referred to in notes g, j, and k in Figure 3. After the chemical properties of the substance were reviewed, it was determined that the substance should belong to note f, with maximum gross weight per vehicle of 100 pounds.

The commodity table of the developed manual contains close to 2,700 substances, in comparison with 1,300 substances for the current Chesapeake Bay bridge-tunnel District manual and 650 substances for the Big Walker and East River mountain tunnels. There were also 56 new commodities in the table that had to be regulated. The hazardous material regulations for 69 substances had to be tightened based on new regulatory process. And finally, the regulations for 22 hazardous materials were relaxed. These numbers were obtained using the CFR 49, Table 172.101, as a reference base.

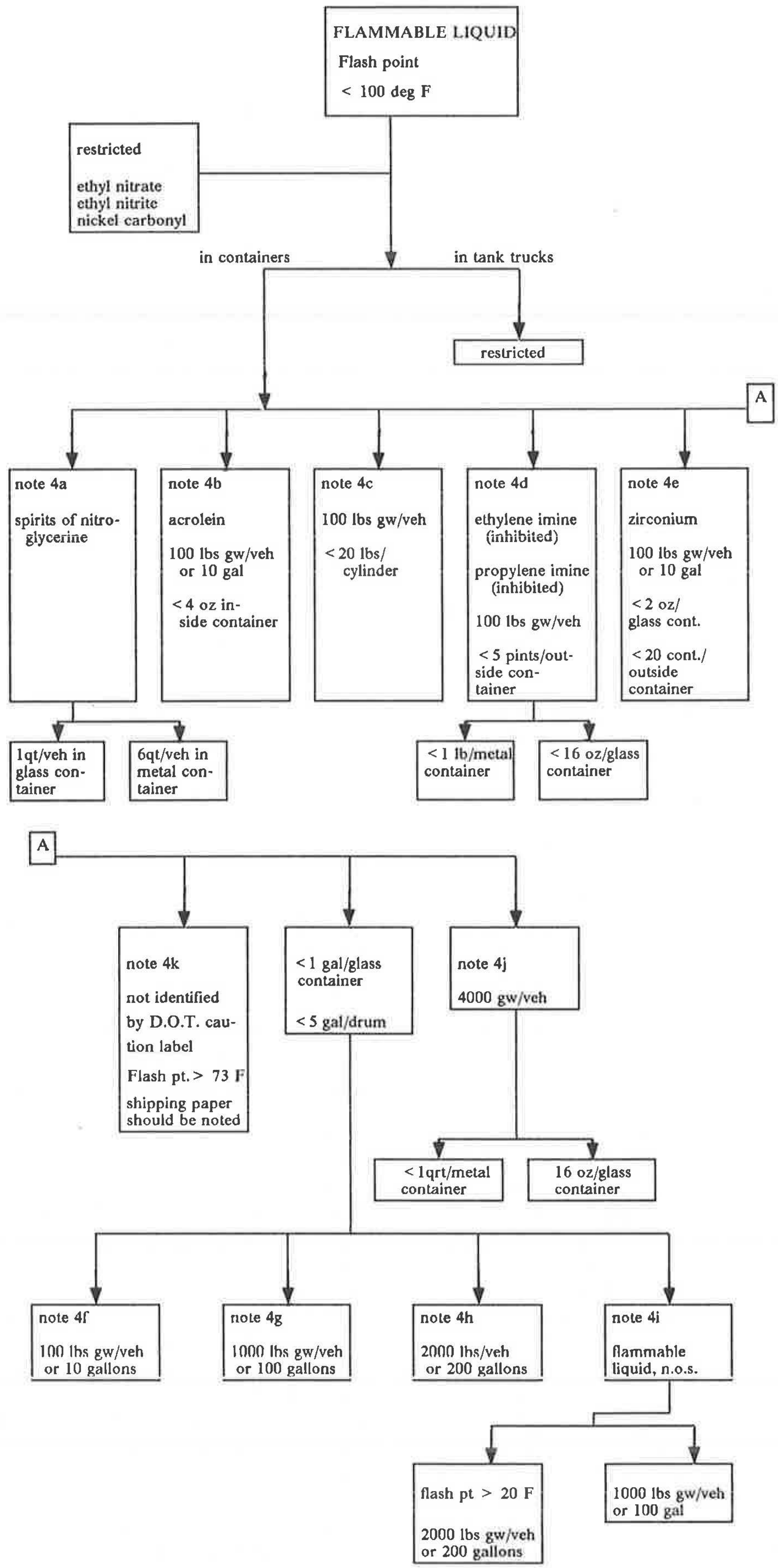

FIGURE 2 Rules and regulations chart for flammable liquids.

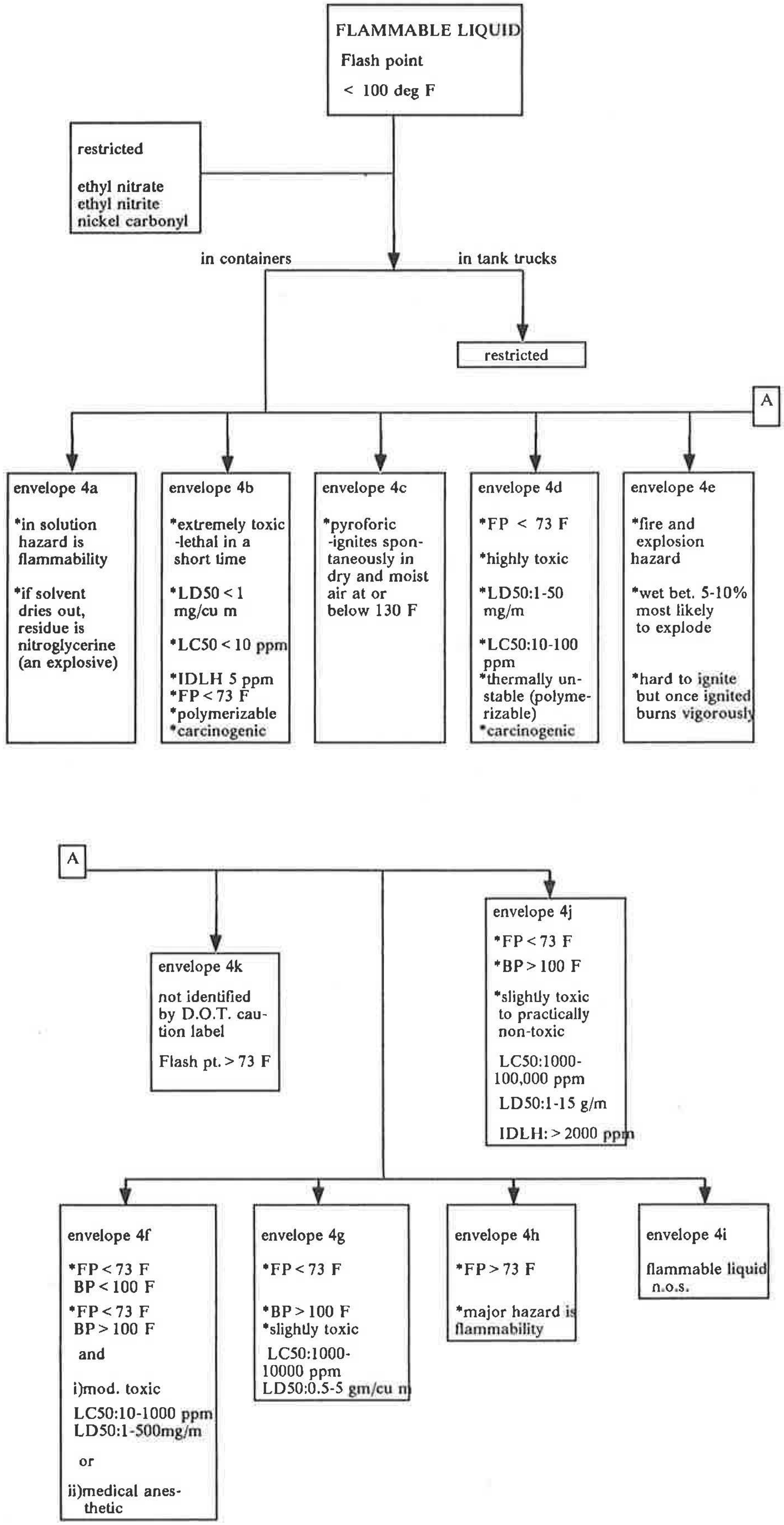

FIGURE 3 Characteristics defining the envelope for flammable liquids.

CONCLUSIONS AND RECOMMENDATIONS

The rules and regulations for transport of hazardous materials are presented in a manual that defines the weight limitations per vehicle and per package for a given material in each hazard class permitted to go through the bridge-tunnel facilities. The manual also contains the basis for regulations, general definitions, traffic rules and regulations, and toll schedules.

It is important to mention that the developed methodology should be updated regularly to respond to changes in federal and state regulations. Also, it is suggested that the state departments and the bridge-tunnel operators remain in continuing contact with the carriers and the industries involved in shipping hazardous materials to obtain necessary feedback about the workability of the rules and regulations adopted and to assist the operators in enforcing these rules.

The dilemma of having the tunnel operators respond in a guessing fashion to inquiries on hazardous materials not listed in the manual needs to be solved. A computer program using a knowledge-based expert system that identifies the appropriate regulations for an unlisted substance is being developed at Virginia Tech. The program, in a simplified manner, asks the user to identify some characteristics of the substance and then displays the regulatory notes that govern its passage through the bridge-tunnel facility. This artificial intelligence computer program will aid in updating and identifying the regulations for any new commodities that are introduced by industries. The program could be used by technical staff or those responsible for making regulations to determine the specific quantity limitations of a substance for shipment.

ACKNOWLEDGMENT

The project team wishes to thank the staff of the Virginia Department of Transportation for their interest and support throughout the conduct of the study. The team wishes to extend special recognition to the members of the Task Force Committee and several federal, state, and local governments for their assistance and guidance.

REFERENCES

1. *Transportation of Hazardous Materials*. OTA-SET-304. U.S. Congress, Office of Technology Assessment, July 1986.
2. D. L. Price and W. Schmidt. *Multi Model Hazardous Materials Transportation in Virginia*, September 1981.
3. *A Summary of Highway Facilities Where Hazardous Materials Are Restricted*. U.S. Department of Transportation, Federal Highway Administration, January 1977.
4. *Composite List of Hazard Profiles of Substances Carried by Ships*. SET 7SR. International Maritime Organization, London, January 1986.
5. *National Fire Codes, 1984*, Vols. 2 and 7. National Fire Protection Association, Batterymarch Park, Mass., 1984.
6. T. S. Glickman and T. R. Waddington. *Rating the Hazard of Hazardous Materials Shipment*. Presented at 1986 Hazardous Materials Spills Conference, St. Louis, Mo., May 5–8, 1986, pp. 478–489.
7. N. I. Sax. *Dangerous Properties of Industrial Materials*, 6th ed. Von Nostrand Reinhold Co., New York, 1984.
8. *Chemical Hazard Response Information System (CHRIS)*. U.S. Coast Guard, Government Printing Office, Washington, D.C., 1984.
9. *Transport of Dangerous Goods: Recommendations of the Committee of Experts on the Transport of Dangerous Goods*, 4th rev. ed. United Nations, New York, 1986.
10. V. C. Marshall. *Assessment of Hazard and Risk in Hazardous Material Spills Handbook*. McGraw-Hill Co., New York, 1982, Section 5.

Publication of this paper sponsored by Committee on Transportation of Hazardous Materials.