Knowledge-Based Classification Scheme for Regulating the Flow of Hazardous Materials Through Tunnels and on Bridges

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Regulatory controls for handling hazardous material in tunnels and on bridges are extensive, detailed, and subject to constant changes. Local authorities responsible for tunnel and bridge facilities are concerned with developing facility restrictions for hazardous materials that will reduce the risk of death and injury without unnecessarily burdening commerce. The lack of expertise among tunnel personnel in general and the lack of a scientific basis on which to develop such regulations, however, have created problems for local tunnel authorities when they must update restrictions or create new ones for new materials introduced by industry. This paper describes the development of a prototype expert system to aid decision making about hazardous material safety in tunnel and bridge transportation. The regulatory process is modeled as a classification type of problem, which lends itself neatly to an expert system implementation. A heuristic problem solver, which is commonly used in solving classification problems, involves systematically matching the attributes of an unknown entity to a set of predefined solutions. For this study's application, the regulatory groupings inherent in existing tunnel regulations are the basis for the development of the solution space. The computer program developed uses knowledge that specifies the appropriate regulation applicable to a new commodity based on the material's physical and chemical properties.

Safety is a major concern for tunnel-bridge authorities. Local authorities are concerned with developing hazardous material restrictions to prevent such goods from causing injury, death, or property damages as they pass through the facilities. The objective of the regulations is to make shipping through the facilities safer by reducing, if not eliminating, the risk inherent in transporting hazardous products.

Hazardous material regulatory controls for tunnels and bridges are extensive, detailed, and subject to constant changes. Most existing tunnel-bridge rules and regulations have no provisions on how to deal with these changes; in some instances, they are entirely out of date. The lack of expertise among tunnel personnel in general and the lack of a scientific basis on which to develop such regulations, however, have created problems for local tunnel authorities when they must update restrictions or create new ones for materials being introduced by industry.

Local facility authorities often rely on the United States Department of Transportation (USDOT) Code of Federal Regulation Title 49 (49 CFR) when updating rules and regulations on the transportation of hazardous materials. Updating is done by adopting any changes made in 49 CFR. As of August 1985, all fifty states have adopted, completely or in part, the Federal Motor Carrier Safety (49 CFR Parts 390-399) and those portions about shipments on public highways (49 CFR Parts 171-178) for intrastate commerce (*1*). It is not surprising, however, for local authorities to feel uneasy about whether federal regulations provide for safety that is appropriate on a state level, since these federal regulations are made without consideration of special local circumstances. This is especially true for special facilities since hazardous materials present a greater risk when transported inside tunnels and on bridges than when they are shipped on the open road. This is reflected in existing tunnel-bridge safety regulations on transporting hazardous materials, which are generally more restrictive than those on open highways.

Risk assessment is one approach to aid decision making in regulatory control. Risk assessment provides a logical structure for studying possible hazard scenarios. This approach often reveals faults in current safety practice, the need to obtain more information about the problem, or the need for further study. Although risk assessment has effectively been used in several studies, regulatory procedures contain no specific legal mandate for its use. Currently, in evaluating inquiries, risk assessment can be used if desired (*2*). Most often, a regulatory decision, such as that for a permit or an exemption, is made without the benefit of risk assessment.

A major drawback of using risk assessment at the local level is the method's complexity. Few local jurisdictions have the expertise or the budget to use risk assessment's sophisticated mathematical techniques. Although computer packages and guidelines can provide a simple and rapid assessment of risk, many subjective evaluations and estimates must still be made in using them. Human expertise is still needed to run the program, interpret results, or estimate any gap in the database.

The complexity of risk assessment is compounded by the lack of high-quality data. Although hazardous materials agencies and organizations are aware of the importance of data collection and analysis, this area still needs improvement. The existence of gaps in the information database

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is one important reason for existing limits on the ability to predict risk in transportation safety.

The absence of data is more evident on the state and local levels. Although numerous hazardous materials databases exist at the federal level, the data they contain are too nonspecific to be useful for a particular state or locality. In its review of existing databases, the Office of Technology Assessment (OTA) reports that (*3*):

> Federal data collection activities are numerous and diverse, each providing modal transportation data of varying completeness . . . that no current federal resource could provide shipment information with the specificity desired by state and local jurisdiction.

Further, these databases are not easy to access. They do not use the same commodity identification codes and are not interactive. Although efforts for a coordinated spill reporting system are now being initiated at both the federal and local levels, their full implementation is at least a decade away (*4*).

Another problem facing the risk assessment practitioner is the evaluation of risk associated with toxic hazard. One part of an overall risk assessment where improvement is needed is in estimating the toxicity resulting from a toxic release. The main reason for the lack of precision here is the absence of any direct data for humans. For obvious reasons, direct tests on humans are not possible. Even in cases where deaths from toxic chemicals are known to have occurred, the lethal dosage is seldom known or available to estimate.

The prospect for modeling the hazardous materials regulatory problem is likely to be limited not only for the reasons cited but also because it is a new topic of research interest (*5*). Further, the number of materials involved is very great, making the approach difficult and time-consuming.

Subjective estimation is generally used to augment the limitations of risk assessment techniques. Subjective estimation is done by a panel of experts (*2*). These experts are assumed to be sufficiently familiar with the problems of concern and can meaningfully extrapolate their experience to the areas of interest.

Risk assessment techniques, such as statistical inference or fault tree modeling, provide the empirical information so that the subjective process of judging the relative safety of the various options can be performed on an informed basis. The major drawback of subjective estimation lies in forming the panel of experts. Experts are not readily available and are expensive to maintain. Maintaining a panel of experts at the local level would be too much of a drain on the budget of local jurisdictions.

Recent development in artificial intelligence (AI) opens new opportunities for addressing the problem. A study conducted by Virginia Polytechnic Institute and State University (VPI&SU), Department of Civil Engineering (*6*), to develop a single hazardous materials transportation safety regulations manual for Virginia's highway tunnels, bridges, and ferries, recognizes the dilemma of having the tunnel-bridge operators respond in a guessing manner to inquiries on hazardous material not listed in the manual. The study recommends an expert system implementation as the most appropriate way to resolve the issue. If expert knowledge is captured in a computer implementation form, expert advice is readily available and less expensive. This paper is a summary of the ongoing effort to build and develop an expert system application for tunnel and bridge operations.

Even though the prototype system does not incorporate all the situation-specific, problem-solving knowledge in tunnel-bridge regulatory control, the prototype developed provides a framework for further system evolution and development. Once fully developed, the system is expected to serve as a decision tool, not as a replacement for management decisions involved in the tunnel regulatory control of hazardous material.

BUILDING AN EXPERT SYSTEM

Building an expert system involves three basic tasks. These are discussed below.

1. Knowledge Acquisition: This aspect primarily deals with acquiring the necessary knowledge or "facts" about the domain or situation-specific problem-solving methods. The importance of knowledge acquisition cannot be overemphasized. The efficiency of the expert system depends on the acquired problem-solving knowledge.
2. Knowledge Representation: To be useful, the knowledge acquired (knowledge base) should be organized and structured in a computer-implementable form. Knowledge that is not adequately represented cannot be used (*7*).
3. Inference Mechanism: Inferencing is the process of generating alternate paths via a reasoning mechanism through the knowledge base to derive a conclusion (*8*). This involves selecting from the various pieces of knowledge in the system those few that, when combined, yield a conclusion or decision. To accomplish this task, the procedures or mechanism built into the system should search through the knowledge base in an efficient manner. If search is done at random, it will not be finished in a reasonable time.

The first two issues, task 1 and task 2, are pursued in this study. Task 3 is left for future work and is beyond the scope of the research objective. For this study's implementation, an expert system shell with a built-in inference engine is used.

System Goal

The objective of building the prototype expert system is to show that such a system provides a viable approach for real-time interactive regulatory control and to achieve a better understanding of what a tunnel-bridge consultative expert system should be capable of performing. Since the system developed is a research prototype to be used by the study group and not by tunnel-bridge personnel, the system developed allows some flexibility in such areas as degree of "user friendliness," extent of knowledge acquisition, and so forth. Nevertheless, features of the fully developed system, which are seen as essential for its eventual implementation, are defined to allow for a more realistic formation of the prototype system.

Developing a high-performance consultative system entails several demands. The foremost is to define the degree of abstraction of the fully developed system. The system must be useful to the personnel who will eventually use it. Usefulness implies competence, consistency, and ease of use.

The fully developed expert system is intended for use by technical staff or those responsible for regulation making to determine the specific quantity limitations of a substance. The system advises the user by suggesting regulatory actions appropriate for the hazardous cargo based on its characteristics. If advice is not reliable, the utility of the system is severely impaired.

The system's eventual implementation necessitates that the system be made familiar and friendly. The system must be easy to use and be understood by someone who is unfamiliar with computers. This is accomplished by:

- Designing the system around a simple rule syntax,
- Providing a "user friendly" support environment that simplifies the use of the system, and
- Making the system capable of explaining its action.

Another important consideration in building the system is the need to design the program to accommodate changes in the knowledge base. It is estimated that 1,000 new materials are added every year to the 19,000 separate hazardous materials in existence (*5*). An expert system designed in this area would require a continuous and systematic updating effort because it would have to contend with new substances each year. Furthermore, accumulation and codification of knowledge are important aspects in expert system development that make the program intelligent (*9*). Hence, knowledge should be structured to accept additional knowledge, as it becomes available, without existing knowledge having to be modified.

System Development Tool

The system developed is implemented using Insight 2+ (*10*). Insight 2+ is a system shell for developing expert systems. An expert system shell can be viewed as an expert system with all its basic components minus the knowledge base. An expert system shell provides the framework for building an expert system, in the same context as templates are built for accounting spreadsheet programs.

Use of an existing development tool or shell is based on the fact that there is no need to build from scratch at this point. The system developed in the study is a research prototype with two basic purposes: first, to show that artificial intelligence techniques can be effectively applied to the regulatory problem in question; and second, to develop an expert system framework for the problem that could eventually develop into a full system. Hence, an expert system shell is sufficient for the stated purpose of the study.

Insight 2+ has certain characteristics that are suitable for this study's implementation. It uses a simple yet versatile knowledge representation language called Production Rule Language (PRL). The basic construct of PRL is commonly known as the "IF-THEN" construct or, simply, production rule. The use of production rules results in a cause-and-effect structure for the knowledge base that is very similar to the way humans think. The domain knowledge expressed in a production rule format is easily accessible for evaluation and updating by human experts (*11*).

Another feature of Insight 2+ that serves the purpose of the system developed is its ease of use for unsophisticated users. Insight 2+ is totally menu-driven. All functions and fact acquisitions are accomplished through menu operations, with the selection made using function keys and keypad.

For a thorough discussion of the general structure and functions of Insight 2+, the reader can refer to INSIGHT 2+ reference manual (*10*).

Knowledge Source

Hayes-Roth et al. (*12*) classifies knowledge into two types: public and private. Public knowledge includes published literature that is available and accessible to anyone. Private knowledge refers to the expertise of individual experts in the specific field of the problem.

For this study, the major source of knowledge is public knowledge, such as chemical handbooks and current tunnel rules and regulations. Private knowledge is not considered, mainly because of the time and cost of acquiring it. Public knowledge is sufficient for the study's objective, which is to develop and evaluate an expert system for tunnel-bridge facilities that would be available to these facilities in the future. Public knowledge may have the disadvantage of being functional. It tells what, not why it was so. It is, nevertheless, a logical starting point for building the knowledge base.

PROBLEM-SOLVING KNOWLEDGE

The regulatory problem is characteristic of a class of well-structured problems commonly called classification. The solution or heuristic method (called knowledge in AI) used to solve a classification problem passes through easily identifiable phases of relating data from an unknown entity to a set of pre-enumerated solutions (*13*). Classification problems lend themselves neatly to expert system application. Many existing expert systems demonstrate successful applications of expert system techniques to these types of problems, among which are MYCIN (*14*), a diagnostic system, and EDAAS (*9*), an information analysis system.

In this section, the steps in developing the regulatory scheme for tunnel-bridge facilities are presented. The scheme is useful for finding an appropriate regulation for new commodities or for determining inconsistencies in the existing regulations when updated. It is the primary problem-solving component of the prototype knowledge-based system developed.

The overall scheme is based on a similar or close chemical relationship between hazardous materials. This approach, though heuristic in nature, circumvents the complexity and data constraints of a risk assessment methodology. The approach is rooted in using an existing system that assigns quantity limitations and packaging requirements to hazardous materials based on their harm potential. The following are the steps taken in developing the heuristic:

1. Selection of an existing system as point of reference.
2. Grouping the materials by their intrinsic properties and dispersive energy. Intrinsic properties (e.g., flammability, toxicity, reactivity) and dispersive energy (e.g., pressure, physical state, volatility) are dependent on the type of material shipped and reflect the relative harm potential of the substances.

Once the groupings (referred to here as "envelopes") are made, a comparative type of analysis is applied to determine the appropriate restriction. That is, properties of the unknown material are compared to the properties defining each of the envelopes.

Existing tunnel-bridge rules and regulations are logical starting points for the scheme illustrated. The restrictions imposed by these regulations reflect the degree of hazard or harm potential of the regulated material. They relate the acceptable quantity in tunnel facilities to the physical and chemical properties of the materials. As will become clear in the following example, tunnel-bridge rules and regulations have evolved through the years. The restrictions on hazardous materials currently regulated are not imposed in a random manner. Instead, certain criteria based on the materials' physical and chemical properties are followed.

Although it is debatable whether or not the restrictions reflect tolerable quantities in tunnel facilities, more than twenty years of implementation with good safety records attest to the reliability and effectiveness of these regulations (*6*). Because the restrictions have been enforced for so long, it is safe to assume that tunnel patrons have accepted or have learned to accept the restrictions.

Tunnel-bridge rules and regulations can be viewed as knowledge concerning the problem domain where experts are in agreement. A review of existing rules and regulations governing the transportation of hazardous materials through tunnels and bridges conducted in the VPI&SU study concludes that no major difference exists among them. The same restriction applies to a particular hazardous material, regardless of which one of the current regulations is referred.

Existing tunnel-bridge regulations are divided into the major hazard classes defined by the U.S. Department of Transportation (USDOT) (e.g., combustible liquids, compressed gases, etc. [*15*]). Each hazard class is further subdivided into the different notes that give the specific packaging and quantity restriction. These regulatory divisions form the basis for defining the individual envelopes.

The characteristics defining an envelope are determined by establishing commonality among the materials within the note and finding the difference with substances in other notes. These envelopes can be thought of as a set of baskets with unique characteristics defined by the physical and chemical properties of the materials inside it. If the properties of an unlisted material match the characteristics defining a particular basket, then the unlisted material belongs to that basket and should be subjected to the same restriction imposed on the basket. The assumption is that substances exhibiting similar characteristics will behave in the same manner, or will have the same severity of consequence when released under similar conditions.

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

The flammable hazard class is used as an example to show the regulatory methodology. Figure 1 gives the packaging and total quantity limitations for the flammable liquids based on the existing rules and regulations. By converting this figure according to the dispersive energy (i.e., pressure, temperature, state of the matter, etc.) and intrinsic properties (i.e., toxicity, flammability, etc.) of the materials under each note, the resulting chart (Figure 2) defines the envelopes for each of the notes.

Having established the envelopes' chart for each hazard class, the problem becomes one of finding to which envelope a hazardous material, based on its properties, belongs. From this, the total quantity limitations for a particular substance are easily determined.

EXPERT SYSTEM IMPLEMENTATION

With the domain knowledge to work on already defined, it should be represented in a computer-implementable form. Representation of knowledge in an expert system requires efficient structuring of the goals of the system and the supporting facts (*7*). The effectiveness of the knowledge base depends on the way the knowledge contained is structured. Careful organization of the facts and the relationship constituting the domain knowledge of application is necessary. Structured knowledge is interpreted accurately and used efficiently by the system in pursuit of the stated objectives or goals (*10*).

How the knowledge is organized, represented, and accessed to solve this study's problem is the topic of this section.

System Architecture

The general structure of the regulatory system developed follows the "blackboard" concept popularized in Hearsay

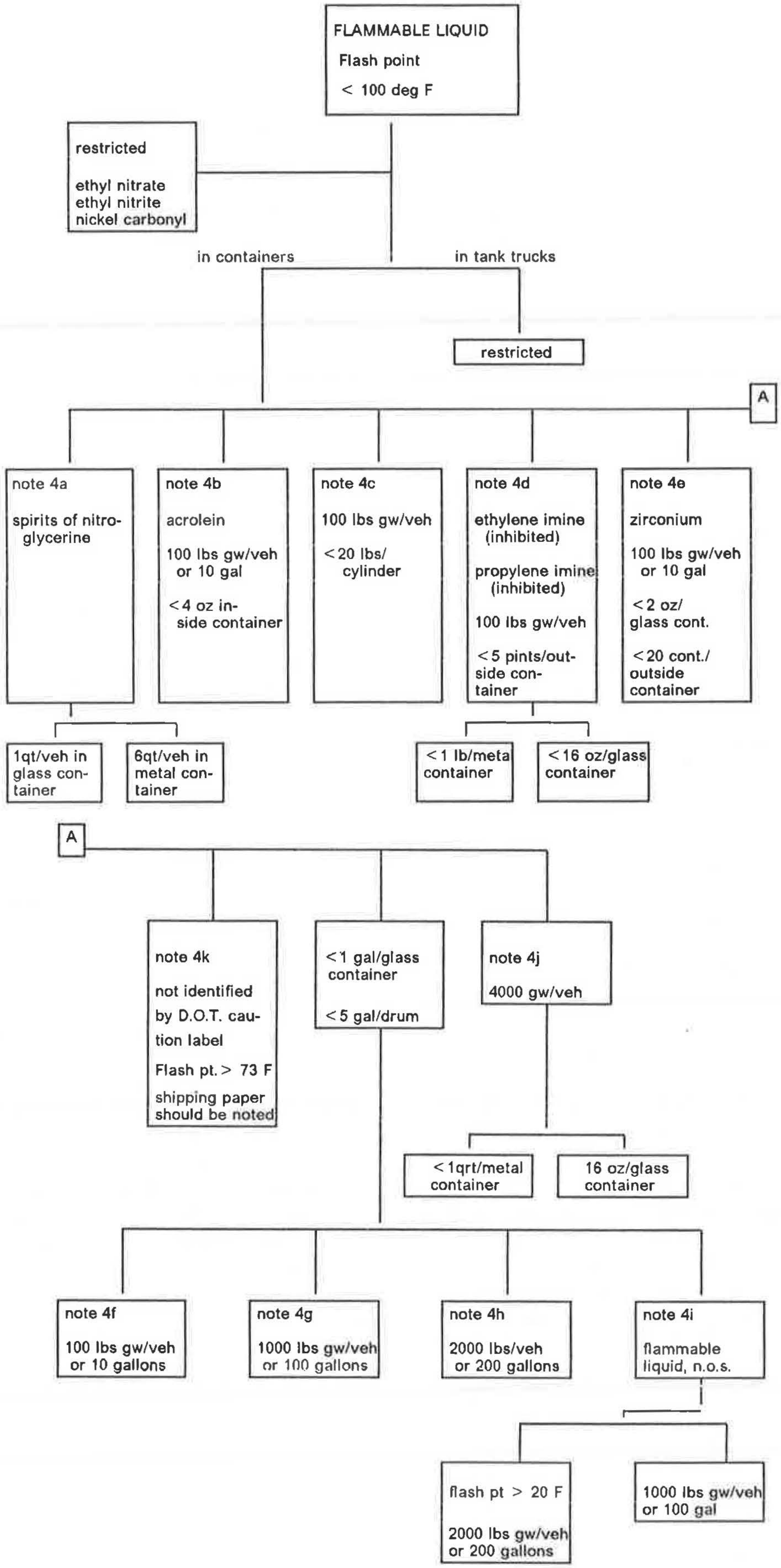

FIGURE 1 Rules and regulations chart for flammable liquids.

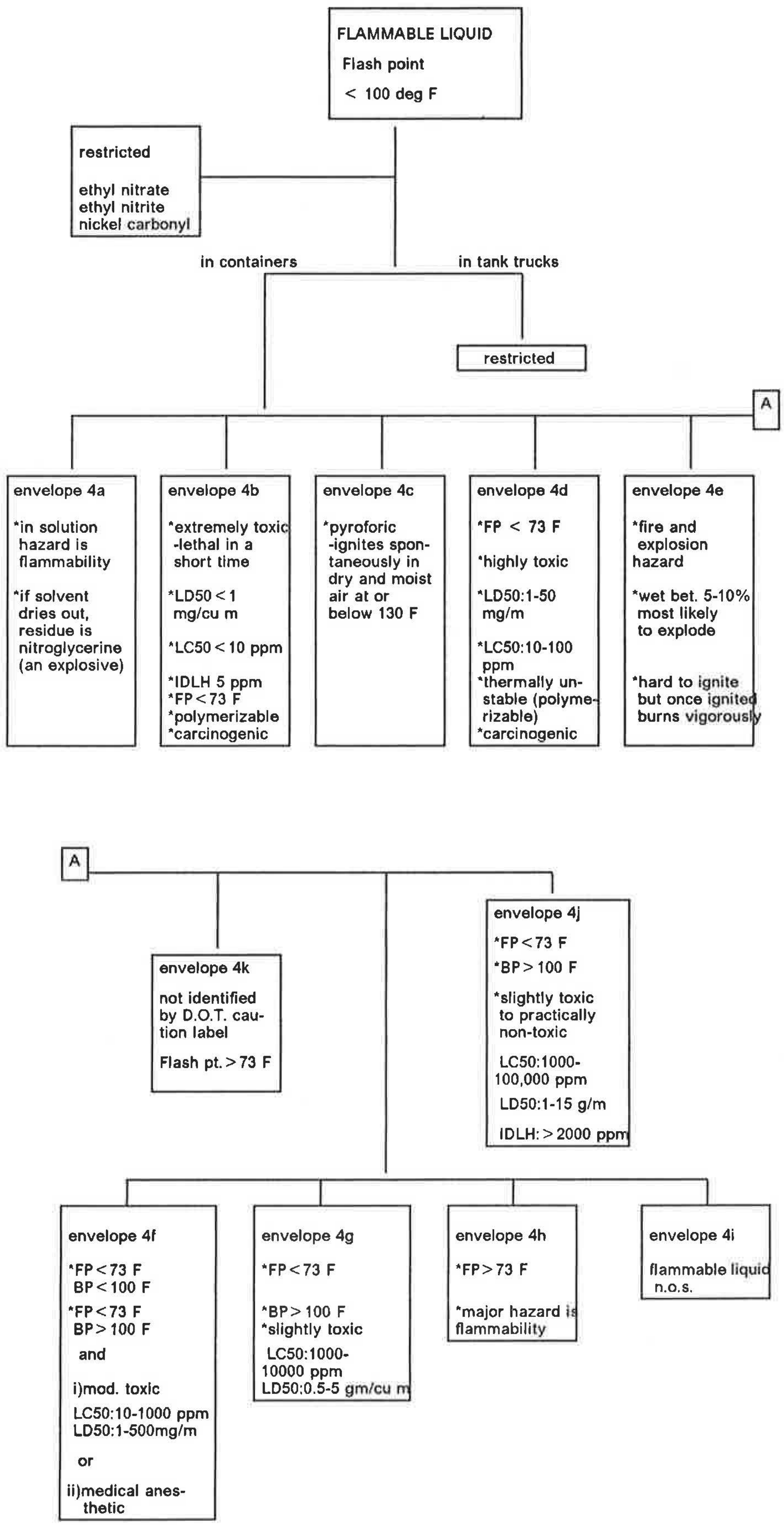

FIGURE 2 Characteristics defining the envelopes for flammable liquids.

II (*16*), a speech-understanding expert system. In blackboard architecture, the domain is partitioned into independent knowledge bases (KB), chained together via a control module. Each KB in a blackboard system structure has its own inference structure for solving a specific problem and communicates through a global database or working memory called blackboard. Inferences or conclusions from a KB are written on the blackboard. A control program analyzes the problem and transfers the control to the appropriate KB for execution.

The system architecture for this application is illustrated in Figure 3. The control module, the program controlling which KB is activated, is formulated as a rule-based program. Each KB is independent and represents a knowledge base for each of the hazard classes, into which the domain is partitioned.

One advantage of this type of architecture is the ease by which it can be modified to reflect the user's growing needs. Since the area of regulatory control for tunnel facilities is both large and constantly changing, it is necessary that the program be flexible and modifiable to accommodate new knowledge about the problem domain. Also, to justify the cost of developing the system, new KBs dealing with the other operations of the tunnel facility, such as management crisis, traffic control, monitoring, or scheduling, should be accommodated by the system.

Structuring the KBs in parallel allows flexibility and modifiability of the program. It enables KBs to be changed, added, or removed in an independent manner. Existing KBs can be enhanced as new knowledge is acquired without affecting the entire system. New KBs can easily be attached in parallel to the existing system, with minor changes in the control module. Next, the representation scheme used in organizing the knowledge within each KB is discussed.

Production Rules

The primary source of the domain of specific knowledge is a set of production rules, each with a condition-action type of relationship. The syntactic form of the production rule, as specified in Insight 2+ using PRL, must have a minimum of three components: the rule name, a supporting condition (premise), and a conclusion (action). An example of a PRL rule follows:

Rule criteria for flammable liquid
IF flash point is less than 100 degrees F
THEN evaluate as \ flammable liquid.

The rule name is "criteria for flammable liquid." The support condition of the rule is "Flash point is less than 100 degrees F." The conclusion of the rule is: "Evaluate as \ flammable liquid."

Using an "IF-THEN" construct allows each rule to be programmed to represent a single, modular piece of the domain knowledge, and with all the necessary context written explicitly in the premise. This representation is useful

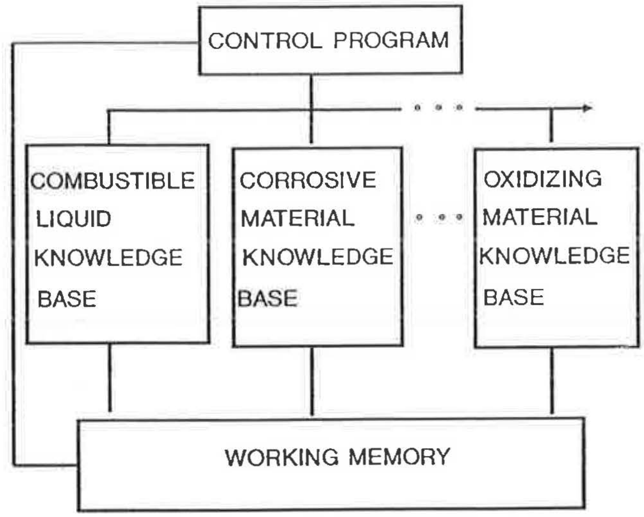

FIGURE 3 Expert system architecture for regulatory control.

when the system explains or gives reason for its action. Since the rules use a vocabulary of concepts common to the domain, they form, by themselves or in combination with other facts, a comprehensible statement of some knowledge about the domain.

The IF part of the rule may contain only facts. Hence, it is either true or false. The facts are usually expressed in the form "attribute = value" (i.e., flash point is less than 100 degrees F) or as a "property-present" condition that denotes the presence of a given property (i.e., material is explosive when dry).

The THEN either contains facts that are antecedents of other rules or an action. The actions are expressed through imperative verbs (i.e., regulation is note 4a) that are inferred if the supporting condition(s) is verified.

There are no limits to the number of antecedents that a rule can have. PRL allows as many supporting conditions as necessary to define a rule. Multiple antecedents are included, using the reserve words AND/OR. The same holds for the THEN part; rules can also have multiple conclusions.

The facts represented in the system can be partitioned into two types, namely:

- Hazard classes (flammable liquid, combustible liquid, poisons, etc.) and
- Physical and chemical properties (flash point, toxicity, volatility, etc.).

The partitioning can be expanded as the need arises or when new knowledge about the problem is acquired, including:

- Environmental factors (topography, weather);
- Population density in the vicinity and proximity of the facility;
- Facility preparedness (emergency response capability, sprinkler system, monitoring system); and
- Condition of transportation (quantity, packaging, etc.).

Similarly, actions can be of several sorts. The current implementation, however, is limited to the particular regulatory control. Other types of actions to extend the flexibility and usefulness of the system are:

- Traffic control and
- Management of critical events (fire, explosion, spill control, etc.).

The strategies built into the system for skillful inferencing of the knowledge contained in the rule base are described next. Such strategies are needed so that knowledge is used efficiently by the system during problem solving.

Control Structure

For the system developed, rules are invoked in a backward, unwinding scheme to produce a depth-first search of the goal tree. The choice of a backward chaining scheme is motivated by the type of application considered.

As seen in the discussion of the envelopes developed in the preceding section, it is clear that the process of identification is done by matching the characteristics of an unregulated hazardous material against the characteristics of the envelopes. As already mentioned, this type of heuristic search belongs to a class of well-structured problem solving called classification. The essential characteristic of the heuristic is that the problem solver selects from a set of pre-enumerated solutions. For this type of problem, a backward chaining is the most suitable inference mechanism to use.

A backward chain reasoning process starts with a goal to be established. In the pursuit of a goal, the system scans the knowledge base for all rules that can conclude that goal. These rules are invoked or retrieved for execution. The rule that does not have supporting condition(s) that are conclusions of other rules are verified first. The premise of each rule invoked is matched against the known facts or knowledge about the current session. The rules that have premises or IF portions verified, or matched the known facts, are executed or "fired." Its conclusion(s) becomes a known fact of the current session. This is illustrated in Figure 4.

The match-execute process continues until a goal is proven or disproved. If the goal is disproved, a new goal is pursued and the recursive pattern continues.

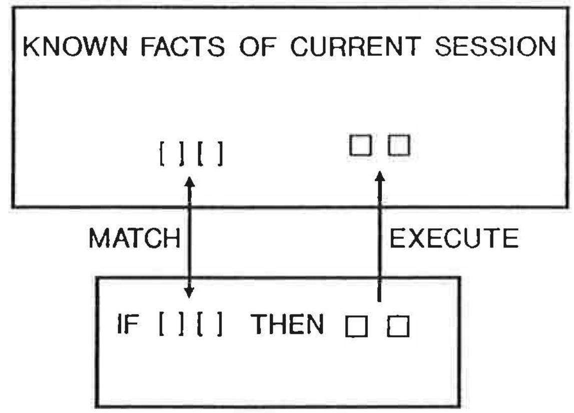

FIGURE 4 Match-execute process.

Sample System Session

To provide examples for the system's operation, an interactive session with the system is illustrated. The consultative system developed is fully menu-driven and uses the available support function in the expert shell for ease of use.

The program queries the user for facts to facilitate inferencing for the attainment of a particular goal. At any time within a knowledge-base session, the user can determine the current goal being pursued, find the reason why a particular query is posed, or ask for explanatory information to clarify a query. For this sample session, allylamine is taken as the unknown material with the following characteristics:

Hazard Class	:	Flammable Liquid
Flash Point	:	−4 deg F (−20 deg C)
Boiling Point	:	133.6 deg F (56.5 deg C)
Toxicity	:	LD50 = 106 mg/kg
		LC 50 = 286 ppm/4h
Others	:	Human irritant; no subsidiary hazard

The sample author-system interaction is shown in Figure 5. The bold text is the queries presented by the system, or the system's response to a user's query. The normal text and the underscored text are the user's responses, while the normal highlighted text is explanatory remarks from the author for a better insight of what is happening.

The session starts with a query from the control module. The goal of the control program is to determine the hazard class of the unknown material and activate the appropriate KB.

SUMMARY AND PLANS FOR FUTURE RESEARCH

This study shows that a consultative expert system to be accessed online is a viable approach to decision making in hazardous materials regulatory process for tunnel-bridge facilities. The study provides a useful framework for developing a rule-based system for representing the regulatory problem.

One limitation of the heuristic developed is that the criteria defining the envelopes are limited by the characteristics of the materials currently regulated. New commodities that are hazardous to society are constantly being developed and transported throughout the world. In this regard, the solution space can be expanded to accommodate these changes or new criteria may be added as they

Regulatory Screening Assistant for Hazardous Materials

What is :

The material's name

ALLYLAMINE

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

The function keys highlighted at any screen session are the available functions that the user can use. Function key F6 is the user's link to Insight 2+ reporting system. It gives the line of reasoning, current rule being verified, current goal being pursued, and other miscellaneous reports related to the session.

Regulatory Screening Assistant for Hazardous Materials

Can you identify the area of interest?

HAZARD CLASS is(are) RADIOACTIVE MATERIAL

HAZARD CLASS is(are) POISON

HAZARD CLASS is(are) COMPRESSED GAS

HAZARD CLASS is(are) FLAMMABLE LIQUID

HAZARD CLASS is(are) OTHER REGULATED MATERIAL

HAZARD CLASS is(are) FLAMMABLE SOLID

HAZARD CLASS is(are) CORROSIVE MATERIAL

HAZARD CLASS is(are) OXIDIZING MATERIAL

HAZARD CLASS is(are) COMBUSTIBLE LIQUID

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

The display now presented is a goal-selection menu. This is a list of possible conclusions that may be reached during the control module session. The system is asking if the user can narrow the list of possible conclusions. If the user is to select "UNKN" (function key 2), the system will proceed to evaluate the rules and continue to ask for information in an attempt to reach any of the above conclusions. At this point, **HAZARD CLASS is(are) FLAMMABLE LIQUID** ***is selected since the hazard class of hazardous materials is generally known and written in the shipping paper.***

ALLYLAMINE meets the definition of a flammable liquid

Press function key F2 to access knowledge base.

Control will activate KB for flammable liquid when function key F2 is pressed.

FIGURE 5 Sample author-system interaction.

Regulatory Screening Assistant for Flammable Liquids

What is the flash point of ALLYLAMINE in degree F?

-4

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

The flammable liquid KB is now activated. The goal of this KB is to determine the applicable regulation for the unknown material.

Regulatory Screening Assistant for Flammable Liquids

What is the boiling point of ALLYLAMINE in degree F at 1 atmosphere?

133.6

Regulatory Screening Assistant for Flammable Liquids

Select what describes :

TOXICITY

EXTREMELY TOXIC

HIGHLY TOXIC

MODERATELY TOXIC

SLIGHTLY TOXIC

PRACTICALLY NONTOXIC

HARMLESS

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

Again the user is presented with a list of choices to describe something which, in this case, is toxicity. Since the toxicity data given for ALLYLAMINE are numerical data, and not descriptive as presented by the system, there is a need for an explanatory information about the choices presented. To get explanatory information, Function key F5 is pressed.

Toxicity Classes

Descriptive Term	LD50 (wt/kg)	LC50 (ppm)
Extremely toxic	≤ 1 mg	< 10
Highly toxic	1-50 mg	10-100
Moderately toxic	50-500 mg	100-1000
Slightly toxic	0.5-5 g	1000-10000
Practically nontoxic	5-15 g	10000-100000
harmless	≥ 15 g	> 100000

FIGURE 5 *continued.*

LD50 (Lethal Dose fifty) signifies that about 50% of the animals given the specified dose by mouth will die. All LD50 values above are obtained using rats as the laboratory animal. If the route of administration is inhalation, the dose - LC50 (Lethal Concentration) - is expressed in parts per million (ppm).

The information given tells us that ALLYLAMINE is moderately toxic. Now, the user returns to the list and select moderately toxic.

Regulatory Screening Assistant for Flammable Liquids

Select what describes :

TOXICITY

EXTREMELY TOXIC

HIGHLY TOXIC

MODERATELY TOXIC

SLIGHTLY TOXIC

PRACTICALLY NONTOXIC

HARMLESS

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

NOTE 4f

ALLYLAMINE is restricted to:

1) a maximum quantity per vehicle of 10 gallons or 100 pounds gross weight, and;

2) such liquids are in one gallon capacity, or less in glass, earthenware, or polyethylene containers, or 5 gallon capacity or less metal drums.

The transport of empty containers last containing Allylamine has no restriction if the accompanying shipping papers state that the containers are drained and securely fastened.

Press Function Key 3 to restart the session

A match is determined and the applicable regulation is displayed.

FIGURE 5 *continued.*

are encountered. The heuristic developed in this study is useful enough to assist tunnel operators in decision making without the need for human experts. That is, only those materials that fail to find a match in the solution space require consultation with human experts. The recommendations given by the experts on these materials are then included in the database and, thus, improve the intelligence of the system.

The modularity of the system design provides ease for further development and enhancement of the expert system developed. This and other future research areas are discussed below.

1. One possible extension is to link the system to a hazardous material information system to further aid the decision process. One such information system is the Oil and Hazardous Material-Technical Data Systems.

2. Knowledge elicitation and codification is a continuing process. Hence, a subsystem should be developed so that knowledge is elicited from human experts through interaction with the system. Knowledge from human experts could greatly enhance the effectiveness of the envelopes.

3. The knowledge could be further enhanced by incorporating external programs such as simulation models, risk analysis, or fault tree modeling. Facts acquired from such models can be used by the system in its decision process.

4. As already mentioned, other KBs, such as management crisis and traffic control, can easily be attached to the system. Acquiring the knowledge on how tunnel-bridge operators and emergency response personnel react or respond to accidents, incidents, or traffic congestion inside tunnels and on bridges is the first step in developing the KBs for these domains.

5. The use of meta-level reasoning needs to be considered as rules accumulate. This is necessary to improve the efficiency of the search through the knowledge base. Metarules are strategic information imbedded in the rule base that suggests the best approach to attain the goal (7). They help or direct the inference engine search through the rule base efficiently.

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