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DEVELOPMENT OF AN EXPERT SYSTEM FOR TRANSPORTATION OF HAZARDOUS AND RADIOACTIVE MATERIALS

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I. INTRODUCTION

Under the sponsorship of the U.S. Department of Energy's (DOE's) Transportation Management Division (EM-261), the Transportation Technologies Group at Oak Ridge National Laboratory (ORNL), has designed and developed an expert system prototype application of the hazardous materials transportation regulations. The objective of this task was to provide a proof-of-concept for developing a computerized expert system that will ensure straightforward, consistent, and error-free application of the hazardous materials transportation regulations. The expert system prototype entailed the analysis of what an expert in hazardous materials shipping information could/should do.

From the analysis of the different features required for the expert system prototype, it was concluded that the developmental efforts should be directed to a Windows™ 3.1 hypermedia environment. Hypermedia technology usually works as an interactive software system that gives personal computer users the ability to organize, manage, and present information in a number of formats—text, graphics, sound, and full-motion video.

II. DEVELOPMENT

The strategy to develop the expert system was to first, demonstrate the feasibility of developing an expert system prototype by developing modules to capture the knowledge of different areas of transportation and packaging; second, select an appropriate environment in which to deploy the expert system; third, analyze the feasibility of appending these different modules in one final full package; and fourth, develop the full-scale expert system.

A. Radioactive Materials Prototype Development

The initial prototype to demonstrate the feasibility of developing the expert system was based on a module for transporting and packaging radioactive material. Later, a module that included hazardous chemicals was developed.

The feasibility stage included (1) analysis of commercial software related to regulation access, (2) knowledge acquisition, and (3) development of the expert system prototype. The strategy to develop the latter subtask was to (a) develop modules to capture the knowledge of different areas of transportation and packaging and (b) analyze the feasibility of appending these different modules as one final full program. Two individual modules are used, one for transporting and packaging of radioactive materials and another for transporting and packaging hazardous chemical materials. The final product will integrate these two modules into an overall hazardous and radioactive materials system.

1. **Analysis of commercial programs.** The analysis of the commercially available software, RegScan™ and Environmental/Safety Library™, indicated that both packages, although very useful for navigating the pertinent regulations, are not particularly suitable for the determination of the type of packaging required for hazardous and radioactive material transportation; additional logic is needed. However, the regulations could be downloaded from these software systems and used as the source data base for the regulations that will be accessed by the expert system.

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2. Knowledge acquisition. The development of an expert system in any developmental stage requires a close relationship between the developer and the subject expert. Accordingly, the knowledge must flow from the expert to the developer[1] in a manner such that the latter can visualize the "branches and trunk" of the required knowledge "tree." Typically, the initial prototype is concerned with only a particular portion of the problem and does not provide the full range of ultimate solutions.

The U.S. Department of Transportation (DOT), the Nuclear Regulatory Commission (NRC), and the Environmental Protection Agency (EPA) have stringent regulations regarding the packaging of hazardous materials before these materials are shipped. For example, the DOT regulations specify types of packages (e.g., steel drum, plastic-lined wooden box, etc.) in which each hazardous material may be shipped; the shipper decides which one to use. However, selecting one of the allowed packages is not a simple task. To achieve this goal, the shipper must sift through hundreds of regulations, search large tables, and perform calculations, depending on the applicable regulations. Compounding this problem is the fact that the DOT and EPA require specific chemical names to identify the material being shipped.

Work has been done[2,3,4] to incorporate the transportation packaging knowledge base for radioactive materials into a logic diagram. This logic diagram represents the decision-making process that the user follows when evaluating the transport of radioactive materials. Anticipated HM-169A[5] regulatory changes have been included in the prototype; this effort required some changes to the original logic diagram. The logic diagram for radioactive materials transportation packaging is represented in Fig. 1, which represents the global logic diagram and illustrates the five different stages necessary to determine the type of packaging required for transporting a given radioactive material. Stage 1 of the logic diagram simply represents the data input required from the user. At this point, the user must answer if the material conforms with the definition of radioactive material. In addition, the user needs to supply information about the isotopes that comprise the radioactive material [i.e., how much activity per isotope, the form of the material (special or normal), and the physical state of the material (solid, liquid, or gas)]. Along with this information, stage 1 of the diagram contains enough data for the program to calculate the fraction of A_1 (if material is special form) or the fraction of A_2 (if material is normal form). Decisions will be based on the value of this fraction and will determine the path for the following stages of the logic diagram.

Stage 2 of the logic diagram determines whether the material to be transported is fissile, nonfissile, or fissile exempted. Stage 3 of the logic diagram determines if the material qualifies as limited quantity. Stage 4 determines, for a given material that has not qualified as limited quantity and has been declared as normal form, whether the material can be shipped as low specific activity (LSA) or surface-contaminated object (SCO). Once the system has determined that the total activity is less than $2A_1$ (as specified on page 47458 of Ref. 5), the user is in a position to answer whether the material could be shipped as LSA or SCO. Stage 5 of the logic diagram determines the type of package recommended for transportation of the radioactive material. Obviously, this generalized logic diagram illustrates only the concept behind each stage of the search. Each stage has its own intricate logic diagram to determine specific tasks.

3. Development of the prototype. The preliminary program to support the proof-of-concept process was developed using Prolog (Programming in Logic). This preliminary stage helped to decide that it was possible to develop such a program. At the same time, this preliminary prototype was an aid in recognizing the basic requirements for development and the required features of the program. The goal of the proof-of-concept stage was to secure funding for a proposal that would allow the development of a more structured and organized expert system. Details about this program are not considered to be crucial for the development of the final expert system and will not be presented here.

The basic requirements of the prototype development were that the expert system would run on the personal computer (PC) platform. It was clear that one requirement of the expert system is the ability to access the regulations from the commercial programs that update the regulations on regular basis. The friendliness of the user interface was another important requirement together with the ability to navigate throughout the regulations and display graphics and full-motion video information on the screen. The first concern of the knowledge engineer was to develop an interface between the user and all the specific program(s) that was transparent regarding the manipulations that are required to go from (a) one set of input data, to (b) calculation programs, to (c) decision-maker programs, etc. Thus, a straightforward system of a question-answer relationship between the computer and the user was highly desirable. Above all, the program had to provide an environment

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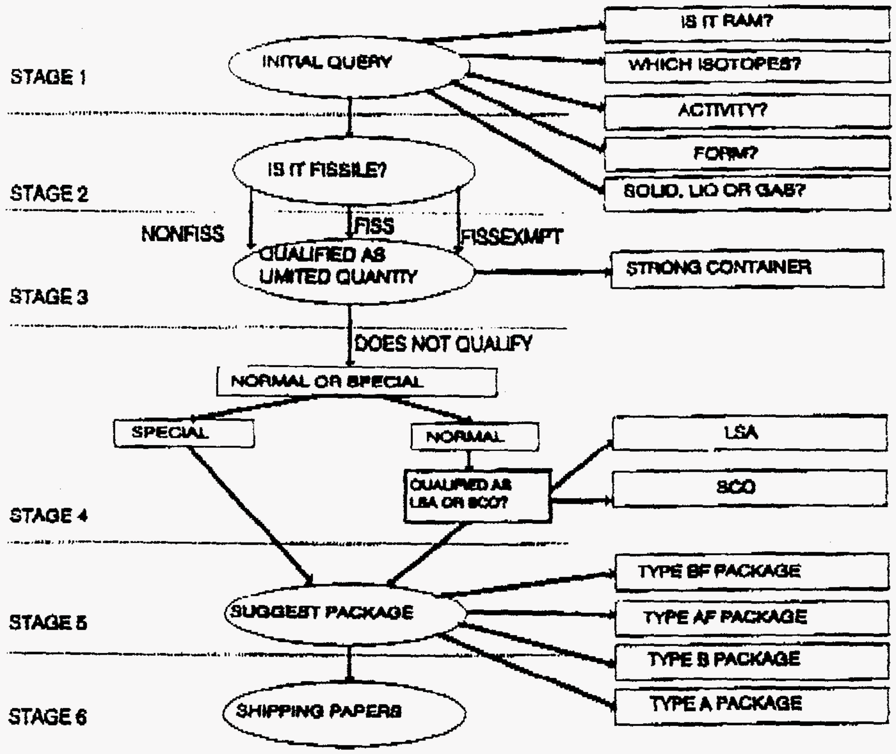

Fig. 1. Radioactive logic diagram.

wherein a rule-based system that represents the application of regulations can be implemented.

Other requirements, including access to several types of information sources, were suggested by the logic diagram. Behind every question asked of the user, there is a set of regulatory requirement(s) which may influence the answer given by the user. Thus, it was obvious that the user had to access the regulations in some cases before an answer could be given to the question. This feature provides the less knowledgeable user enough information to give an appropriate response. It is well-known that regulations normally refer to other regulations or parts of regulations, which in turn may refer to other regulations and so on. In such complex cases, the expert system not only needs to access regulations, but also it must be able to browse through them. Additional explanations about regulations, interpretation of regulations, or any other aspect of the decision mechanism to determine types of packages were required to be available in a form of video images or audio help. Consequently, multimedia elements such as text navigation, visual aids (whether as graphic or full-motion form), and mouse-driven interface elements were considered to be essential parts of the expert system.

To decide what software tool would be used to create the expert system prototype, five possible tools using five criteria were rated. These criteria were multimedia capabilities, rule-making capabilities, flexibility of the environment, user interface provided by each tool, data-handling capabilities of each tool, and ease of use of each tool. The following tools were rated: OWL™ Industries Guide™ (a multimedia document presenter), the C/C++ programming language (a general programming language), the Prolog programming language [a logic-based disk operating system (DOS) programming language], general expert system shells (tools used to create expert systems), and the Visual

Basic™ programming language (a general Windows programming language).

Ratings on these criteria suggested that Visual Basic was the best environment in which to create the expert system. Although a Prolog-based code had already been created during the proof-of-concept stage, and it was clear that putting the Prolog version together required little additional effort, multimedia features were difficult to obtain using only Prolog. Consequently, this option was abandoned. The solution found for the prototyping stage was to translate the Prolog code into Visual Basic code, which is a Windows application.

The prototype expert system that involves packaging of radioactive materials has been subjected to a review and validation process by experts in the matter. The logic of the system has been considered to be correct. Minor changes have been suggested: The program has been revised, and implementation of this module within the complete system has been undertaken. The demonstration of developing the expert system prototype has produced interesting results. It is possible to represent knowledge about radioactive material transportation packaging using a logic diagram that has been translated into a rule-based system. The mechanism to access updated regulatory information from RegScan™, a commercial program, has proven to be technically feasible and within the purview of the license agreement.

B. Hazardous Materials Module Development

The feasibility analysis of the hazardous materials module prototype is the next step in developing a global expert system to determine packages to transport radioactive and hazardous materials. After this, the consolidation of both modules comes out naturally.

1. Development of hazardous chemicals expert system prototype. The regulations concerning the transportation of hazardous materials are contained primarily in CFR 49 Parts 100–180. This is a two-volume set of over 1,100 pages. With such a mass of regulations to formulate into logic that could be programmed into a computer, the regulations were divided into pieces. Fortunately, the regulators have divided them into subparts that generally follow a logical grouping of the topics which they regulate. For example, the regulations that pertain to shipping papers are primarily in Subpart C; marking, in Subpart D; etc. Each of these subparts refer back to Subpart B, which is the hazardous material table (HMT). Therefore, the cornerstone of the regulations is the HMT. For this Phase-I proof-of-concept study, the primary focus was on determining the hazard class, the proper shipping name (PSN), and the authorized packaging.

The first step in determining the correct type of package is to determine the hazard class and the PSN for the material to be shipped. The materials that are regulated by DOT can be broken into two groups: those that are specifically listed in the HMT and those that are not specifically listed. For many hazardous chemicals, DOT has already determined the hazard class and given the chemical name as the PSN. For materials not specifically listed, DOT leaves it up to the shipper to determine which hazard class(es) the material meets and then to assign the most appropriate PSN according to rules in the regulations. The possible PSN's from the HMT were grouped as follows in descending order of priority of use:

1. Specific chemical names including mixtures and solutions of these chemicals. Examples: acetone, methanol, carbon disulfide, sodium cyanide
2. General chemical names. Examples: nitrates, octanes, acid, liquid thallium salt, solid
3. Functional descriptions. Examples: disinfectants, dispersant gas, cleaning solution, accumulators, adhesive, pesticide
4. General hazard class descriptions, n.o.s. Examples: flammable liquid, corrosive, poison
5. Environmentally hazardous substance, n.o.s. Examples: hazardous substance and reportable quantity (RQ), marine pollutant
6. Hazardous waste, n.o.s. Examples: EPA waste D008, EPA waste F006
7. Not regulated in transport.

The basis for these groupings and order of groups is derived from 49 CFR Part 172.101. Priority is in the order shown; namely, if a specific chemical name applies, it must be used when all specific limitations are met. For the chemicals that are specifically listed, the hazard class and packing group have already been determined by DOT.

If the chemical is not specifically listed, then information about the characteristics of the material must be known in order to classify the material before the PSN can be determined. In these cases, both the hazard class(es) and packing group(s) may need to be determined for proper classification. After the hazard class(es) and packing group(s) are determined, the general chemical group is checked to determine if the material qualifies as any of these PSNs. If not, then the functional-descriptions group is checked to see if the function of the material is listed. If the material does not fit any of the previous PSNs, then the appropriate choice from the general hazard class, n.o.s. is selected. If the material does not meet the definition of any of the DOT hazard classes it still might be regulated as indicated by its appearing in the HMT appendixes. Finally, if the material is classified as an EPA waste but doesn't meet the definition of any DOT hazard class or hazardous substance, then the PSN of hazardous waste, n.o.s. is selected.

Once a PSN is selected, the hazard class and packing group are checked to see that the material meets that PSN's assigned hazard class and packing group. If it does not, that PSN may not be used. This check is not needed for technically pure chemicals, but it is very important for mixtures and solutions, general chemical descriptions, and functional descriptions because the characteristics may have changed substantially from the pure chemical.

The conversion of the regulations to computer logic will be explained in the following paragraphs. Figure 2 represents the first stage of the logic diagram in which certain information about the shipment is needed throughout the system. The information defines which sections of the regulations are applicable to the shipment. For instance, if "**nonbulk**" is chosen, the system ignores the regulations that pertain only to bulk shipments. If "**aircraft**" is selected, then regulations for highway, rail, and water will be skipped. [It is recognized that multi-modal shipments need to be included in the scope of the final expert system.]

The second stage of the logic diagram deals with hazardous substances. The DOT also regulates hazardous substances (listed in appendix A to the HMT). This list is determined by the EPA. The Table of Marine Pollutants are also evaluated to determine if a material is also a marine pollutant. The third stage of the logic diagram determines the PSN, hazard class, and packing group using the approach described previously. All materials that meet the definition of a DOT hazard class will be assigned a name from here. Most materials that get past this section will either be unregulated or be a hazardous substance or hazardous waste which are regulated.

The fourth stage of the logic diagram deals with modes of transportation. Some materials are regulated only when they are transported by certain modes. If the transport mode selected is not a regulated mode, then the material is not regulated. Some PSNs are restricted to either domestic or international use. The logic in the middle of the diagram checks for such restrictions. The other stage of the logic diagram determines the authorized packaging for the shipment including the special provisions applicable to the shipment.

C. Appending Different Modules

The two prototype modules have been finalized and have incorporated the expertise for the transportation and packaging of radioactive and hazardous materials. Both modules can work separately, but from a practical point of view, the user would like to have them both together and be completely interactive. The system developed here promises to help transportation management not only with routine daily packaging duties but also, and more importantly, with those unusual cases requiring more regulatory information to stay in compliance.

III. VERIFICATION AND VALIDATION

The verification of the hazardous materials expert system (HaMTES) has been performed in two phases. In the first phase, the logic model was evaluated against the regulations by at least three experts. Then it was manually demonstrated that the model correctly performs the packaging-selection functions by comparing the operation of the HaMTES system with known shipments and packages. Model validation can be performed by a trained and an experienced traffic specialist using 49 CFR. Verification of the HaMTES system, the second phase of this activity, will test whether the system accurately represents the model.

The document that will be entered as the quality record includes the (1) verification plan, (2) verification reports, (3) logic diagram and hand determinations for the various tests, (4) examples used to verify the model, and (5) HaMTES users' manual.

IV. CONCLUSION

As previously mentioned, the DOT regulations determine the correct packaging for the transportation of hazardous materials. The logic involved in determining the correct package for a shipment has been successfully implemented as a decision tree, using the Revised Radioactive Materials Transportation Regulations as

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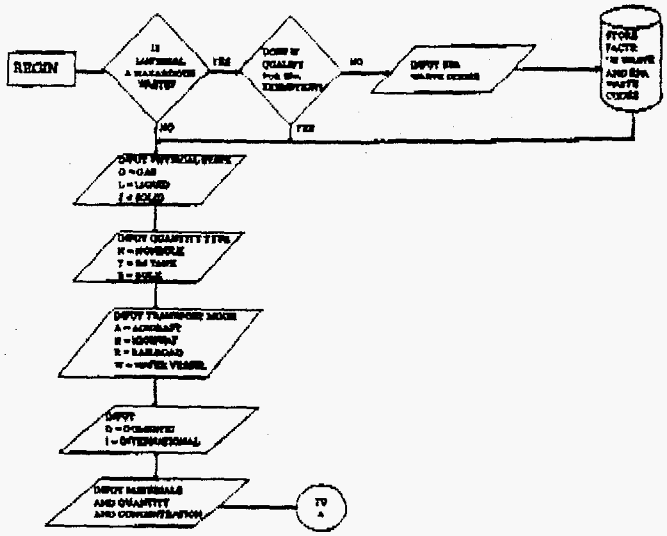

Fig. 2. Chemical hazardous material logic diagram.

proposed in HM-169A[5]. This work was performed in anticipation of the publication of the Final Rule HM-169A this year.

Some changes may have to be made when the Final Rule is published, but these changes are expected to be minor. Because HM-169A has not been finalized, this system *cannot* be used for actual shipments. There are substantial differences between the current regulation and the HM-169A proposed regulations; these differences could result in incorrect packaging if this system were used to prepare a shipment before HM-169A is finalized.

The development of both prototypes produced positive results in that it was concluded that the pertinent regulations can be translated into a logic diagram and that this logic diagram can be translated into a computer code. In addition, it was concluded that for presentation purposes, better memory utilization, and a larger portfolio of computer features, it was best to develop the hazardous materials modules completely in Windows 3.1. The language selected for developing the user interface and the rule-based system was Visual Basic.

A quality assurance plan has been developed and implemented for the validation and verification of the expert systems. The purpose of this verification plan is to establish specific responsibilities and methods for the validation and verification of the HaMTES in order to do quality work to support of the DOE Transportation Management Division (EM-261).

REFERENCES

1. J. J Ferrada, J. M. Holmes, "Developing Expert Systems", *Chemical Engineering Progress*, (April 1990).

2. A. Tarnuzzer, personal communication to R. R. Rawl, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1991.

3. R. Michelhaugh, Portsmouth Gaseous Diffusion Plant, personal communication to J. J. Ferrada, Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 1992.

4. J. J. Ferrada, V. M. Green, and R. R. Rawl, "Feasibility Study—Computerized Application of the Hazardous Material Regulations." ORNL/TM-12141, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September, 1992.

5. HM-169A, Federal Register, Vol. 54, No. 218, p. 47454, November, 1987.

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