Knowledge Acquisition, Representation, and Knowledge Base Development of Intelligent Traffic Evaluator for Prompt Incident Diagnosis

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Incident-related congestion on freeways costs the United States billions of dollars a year in loss of productivity, property damage, and personal injuries. Congestion on rural freeways is even worse than that on urban freeways because the resources needed for appropriate incident responses are not always nearby and high-tech equipment, such as closed-circuit televisions, is not available to detect and verify the incidents. Furthermore, incident responses are based only on the judgment of a patrol officer at the scene. Unfortunately, highly experienced officers may not always be available for managing such a situation. A relatively inexperienced officer may overreact or, with even more detrimental results, fail to call for sufficient response. Thus, to provide quick and suitable responses, an expert system for incident management (IM) is needed. The INtelligent TRaffic Evaluator for Prompt Incident Diagnosis (INTREPID) is being developed as a knowledge-based IM system to help a dispatcher manage an incident with the proper responses. INTREPID is part of the Advanced Rural Traffic Management Systems, which is a component of the Intelligent Vehicle Highway System. Unlike other systems, users can directly enter key information gathered from eyewitnesses to obtain prompt responses from the proper agencies and request the proper equipment without delay. The development of INTREPID is discussed and includes the following steps: (*a*) knowledge acquisition, including interviewing and literature searching, (*b*) knowledge representation, which involves the development of a decision tree, and (*c*) knowledge base development in a multimedia environment.

Traffic delays on urban, suburban, and rural highways throughout the United States have become a significant problem. The delays, which impede mobility and increase travel costs for road users, may be caused by recurrent or non-recurrent incidents. Recurrent incidents are events that always happen around the same time and place, such as traffic congestion during a peak period. Non-recurrent incidents, such as traffic accidents, are random events that can happen at any time and any place. Traffic accidents alone cost $70 billion annually (*1*). The toll is especially high in rural areas where the collision speeds are higher, increasing the likelihood of fatalities. Approximately 57 percent of fatal accidents occur in rural areas (*2*).

Congestion directly causes both inefficient movement of traffic and poor quality of environment. Its consequences cost the nation approximately $100 billion annually in loss of productivity (*1*). More specifically, each year the congestion amounts to more than two billion vehicle-hours of delay, more than 7 billion L of wasted fuel, and almost $16 billion in user costs. The FHWA predicts that by the year 2005 incidents will cause 70 percent of all urban freeway congestion, with a road users' cost of $35 billion (*3*).

Substantial research has been conducted to enhance incident management (IM) techniques. The conventional techniques range from reliance on eyewitness reports and IM agencies to the use of automatic incident detection systems and central control operators. Many of the techniques are inefficient, even the automated systems have high false alarm rates due to deficient incident detection algorithms. However, the detection problems are not significant if the technology of two-way communications is widely spread. The IM problems that still need to be worked out include the accuracy of incident verification and the application of appropriate responses.

The INtelligent TRaffic Evaluator for Prompt Incident Diagnosis (INTREPID) was proposed to speed up the IM decision making process and provide suitable responses. The functions of INTREPID are: (*a*) promptly verifying the nature of incidents and (*b*) applying appropriate IM strategies quickly to alleviate traffic delays. INTREPID, which employs expert system techniques to fulfill its goals, was developed as a knowledge-based system using an expert system shell and a multimedia technique. By combining these applications, the development of an intelligent traffic management system as part of the Intelligent Vehicle Highway System (IVHS) can be expected eventually to lessen congestion problems and reduce unnecessary costs to the nation.

The stages of developing INTREPID, namely, knowledge acquisition, knowledge representation, and knowledge base development, are discussed, and an illustration of a consultation process is presented.

KNOWLEDGE ACQUISITION

In the knowledge acquisition process, information is obtained through interviews and literature searches. Interviews were conducted with experts from the Ohio State Highway Patrol (OSHP) and the Ohio Department of Transportation (ODOT). The criteria for the selection of experts are discussed in the next section.

Criteria for Selecting an Expert

Because the selection of an expert is a difficult task in the development of a traffic management system, the following guidelines were established:

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• Experts may be provided by related organizations, such as OSHP and ODOT. This implies that they have a significant expertise within the area of interest. For example, they must have extensive experience in managing incidents at the incident site or building an IM system.
• The expert should have an excellent record and be recognized as superior to others performing the same task.
• Experts need to be available and willing to participate throughout the system development processes.

After several meetings with OSHP and ODOT individuals who deal with freeway incident management in the state of Ohio, two experts in the following fields of expertise were selected:

• From the field of operations, OSHP's Lieutenant Harold E. Nease was selected by his organization and colleagues as a prominent incident manager whose proficiency is outstanding.
• From the field of traffic engineering, ODOT's George E. Saylor, whose expertise is in congestion management.

The following sections discuss the process of knowledge acquisition, which was separated into four phases: preliminary, intermediate, advanced, and organizational. The interviews during these phases were conducted by knowledge elicitors, who in the preliminary phase reviewed the relevant literature, selected domain experts, and gathered general information concerning the impact of incidents, IM strategies, current IM plans, and equipment needed in IM. The present Ohio freeway IM was found to have many shortcomings, including the unnecessary repetition of incident verification processes (causing errors during the information collecting processes) and assigning complete responsibility to only one officer.

In the intermediate phase, more specific information was requested from the experts concerning the type and nature of incidents, and the protocol in handling incidents. The questions used in the interview were divided into two groups: antecedent and consequence. They were formulated to facilitate the establishment of If-Then statements. For example, the case of an overturned truck that blocks all travel lanes and causes personal injury can be formulated as follows:

Antecedent: If (Type of Incident is Major) AND (Personal Injury is Yes) AND (Lane Blockage is All) AND (Fire is No).
Consequence: Then Action 1 and Action 2.

Action 1 may involve dispatching a patrol vehicle to the scene, dispatching an emergency medical services (EMS) team to the scene, or dispatching a Type C tow truck to the scene. Action 2 might involve notifying ODOT for possible rerouting and calling a radio station to broadcast the incident information. The questions were prepared by reconstructing all of the non-recurrent incidents that occurred on Ohio rural freeways I-70 East during the past several years. Each scenario that was developed helped elicit the experts' knowledge in handling real-life incidents.

In the advanced phase, the consistency of the information acquired in the intermediate phase was checked and If-Then statements were formulated. If conflicting information was found in the acquired knowledge due to misunderstandings or different thought processes, clarification was sought. Most of the conflicts were related to the procedure for managing an incident, which was not a difficult task to correct.

The fourth phase, organizational, focused on the creation of the knowledge structure. Having completed the formulation of all If-Then statements and having arranged the flow of thought processes, all the If-Then statements were rewritten using Level5 Object language, which is similar to standard English. The statements were then stored in the INTREPID knowledge base.

Experts' Criteria for Incident Classification

In this research, freeway incidents on I-70 East between Columbus and Zanesville, Ohio, were classified as minor or major, based on the judgment of the experts. This classification is useful because minor and major incidents call for different responses. In addition, this division allows for easy maintenance of the knowledge base.

Minor Incidents

In general, a minor incident involves a vehicle that has had a flat tire, run out of gas, stalled, overheated, or been involved in a fender-bender even if the vehicle is located on the shoulder and poses no hazard. According to the experts, any incident that does not involve a blocked travel lane, personal injury, fire, spilled hazardous material, or an area considered dangerous, is minor and requires no urgent response. An incident that involves one or more of those situations is regarded as a major incident. However, any minor incident that occurs in a hazardous area should be considered an urgent minor incident.

Management of Non-urgent Minor Incidents

As stated, a non-urgent minor incident does not involve personal injury, fire, or travel lane blockage. Such an incident is investigated by a patrol officer to determine its causes. The owner of the involved vehicle is notified and ordered to remove it as soon as possible. The involved vehicle is allowed to remain in a safe area on the highway for 48 hr before further action is taken. The common practice for OSHP is that any vehicle left at the incident scene for more than 48 hr is to be towed at the owner's expense.

Management of Urgent Minor Incidents

An urgent minor incident is one that occurs on the shoulder of a hill, a sharp curve, a bridge, or an on-off ramp. Such an incident must be cleared promptly to avoid severe consequences. For example, a vehicle stalled on a sharp curve, even on the shoulder lane, may cause a sudden slow-down in approaching traffic and could lead to a head-on collision. After a minor incident has been detected and deemed urgent, a patrol officer must secure the area with emergency markers.

Minor Incidents

Major incidents on rural freeways are similar to major incidents on urban freeways in that both have the potential for severe consequences. For example, an overturned truck on a freeway that has already caused a delay in existing traffic, may cause a secondary accident due to an unexpected stop or a stop-and-go situation. Without the proper IM system, such a situation may lead to the unnecessary loss of life and property.

Although it is easy to recognize a major incident, it is quite difficult to make a decision about managing it. For investigating officers, a major incident differs from a minor one in that it is multijurisdictional. Faulty communication about the incident can endanger a responding crew or motorists. This problem may be caused by misjudgment or the inconsistent management techniques of an inexperienced patrol officer. The following section proposes guidelines for recognizing a major incident and applying the proper management techniques to resolve it.

According to experts, a major accident is classified as a major incident if it consists of the following elements.

1. It may involve personal injury, usually the result of a serious collision or an overturned vehicle.
2. It tends to block one or more travel lanes.
3. It sometimes involves a fire, requiring the response of a fire unit.
4. Such an incident always draws the attention of motorists, which may result in a secondary accident and further block travel lanes.

Acts of nature and hazardous material spills may also be involved in major incidents. Ice, flooding, or fog on a roadway, strong winds, or a landslide, can create a negative impact on traffic. The results may include roadway closure, multiple-car accidents, and traffic rerouting, which can lead to delays, loss of productivity, waste of fuel, and more. Similarly, a hazardous material spill can complicate travel for motorists. However, this study is limited to major accidents. The system currently used to manage major accidents on I-70 East is described in the following sections.

Management of Major Incidents

Unlike minor incidents, major incidents are harder to manage and require several responding agencies and management techniques.

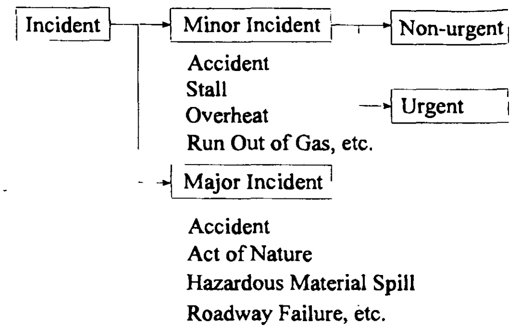

FIGURE 1 Two principle types of non-recurrent incidents.

Incident clearance takes longer and more types of equipment are needed since vehicles cannot be removed from the scene as easily as they can in a minor incident. Thus, the IM for major incidents is a complex task that demands great effort from every responding agency. If the agencies and equipment needed for response and clearance are known, over- and under-responses can be avoided.

Major incidents on I-70 East often receive less-than-proper responses because of difficulties with verification and inadequate response systems. The present system, therefore, requires revision.

KNOWLEDGE REPRESENTATION

The process of knowledge representation involves the use of a decision tree to represent the knowledge acquired from experts. The decision tree presents the structure of knowledge in a way that is relatively easy to view and understand. It is simple, so that one can directly check the consistency of acquired knowledge. Finally, it is helpful for developing the knowledge base and maintaining operations.

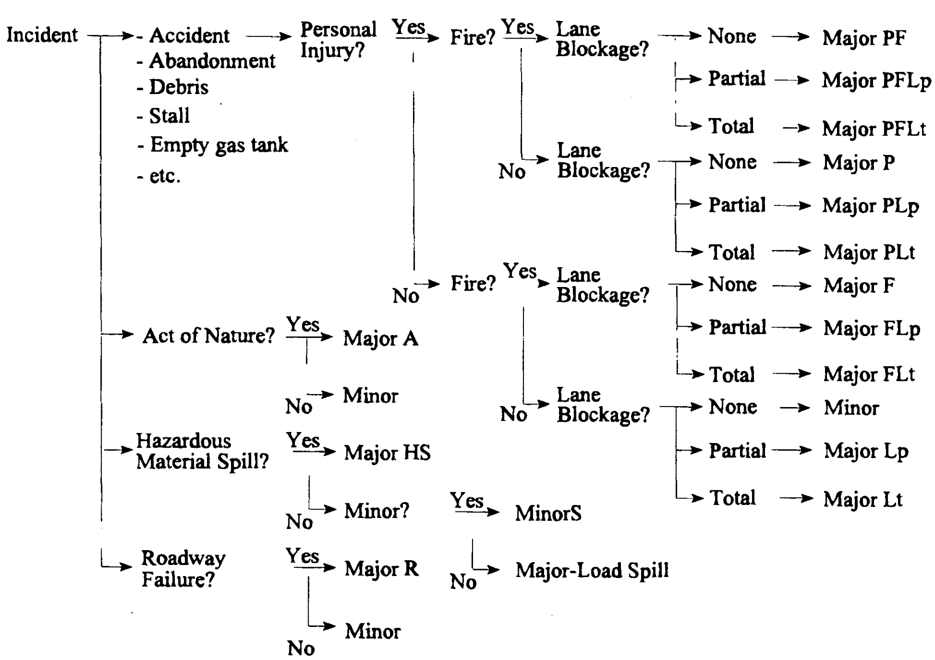

FIGURE 2 A decision tree used in the development of knowledge representation.

For the purposes of system development, incidents have been classified into two principal groups, minor (both urgent and non-urgent) and major. These two groups are shown in Figure 1. Figure 2 represents all possible causes of incidents on I-70 East. The tree consists of several nodes, such as accident, act of nature, hazardous material spill, and so on. Each node represents a question that requires input from users. For example, "Personal Injury?" represents the question "Is there any personal injury?" If the answer is "Yes," the tree leads the decision to "MajorP," which indicates that an accident involves a personal injury. The other branches will be explained in the following sections. In Figure 2 of the decision tree, nodes arise at either major or minor incidents. The development of the decision tree is continued until conclusions are reached.

Representation of Minor Incidents

The minor incident branch of the tree is shown in Figure 3. The tree proceeds with the question, "Hazardous Area?" If the answer is "Yes," an incident is considered an urgent minor incident. Otherwise, it is regarded as a non-urgent minor incident. In the following sections, the representation of the acquired knowledge on both non-urgent and urgent minor incidents is discussed.

Representation of Non-urgent Minor Incidents

When a hazardous area variable is "No," the flow of a decision tree follows the non-urgent minor incident branch, shown in Figure 3. After the type of minor incident is identified, the responses from the vehicle owner from the variable "Immediately Respond" must be obtained. In both urgent and non-urgent minor incidents, if the variable "Immediate Respond" is "Yes," the tree will reach its end node, which is a set of response actions or recommendations from the system. Otherwise, the tree, which represents additional branches of non-urgent minor incidents, continues further.

The tree provides specific response actions, such as MNUAB000 and MNUAB001. MNUABxxx is a file name containing a series of suitable responses that constitute recommendations for each incident. As an example, MNUAB001, which represents a response file for a non-urgent minor incident, recommends several actions, including dispatching a patrol vehicle to the scene, notifying the vehicle owner to remove the vehicle within 48 hr, and so on.

Further actions and a continued branch of this tree are shown in the lower part of Figure 3, which charts the characteristics of the rest of the non-urgent minor incidents. The type of vehicle and the severity of damage ("Towable?" and "Position?") are two other variables given in the tree.

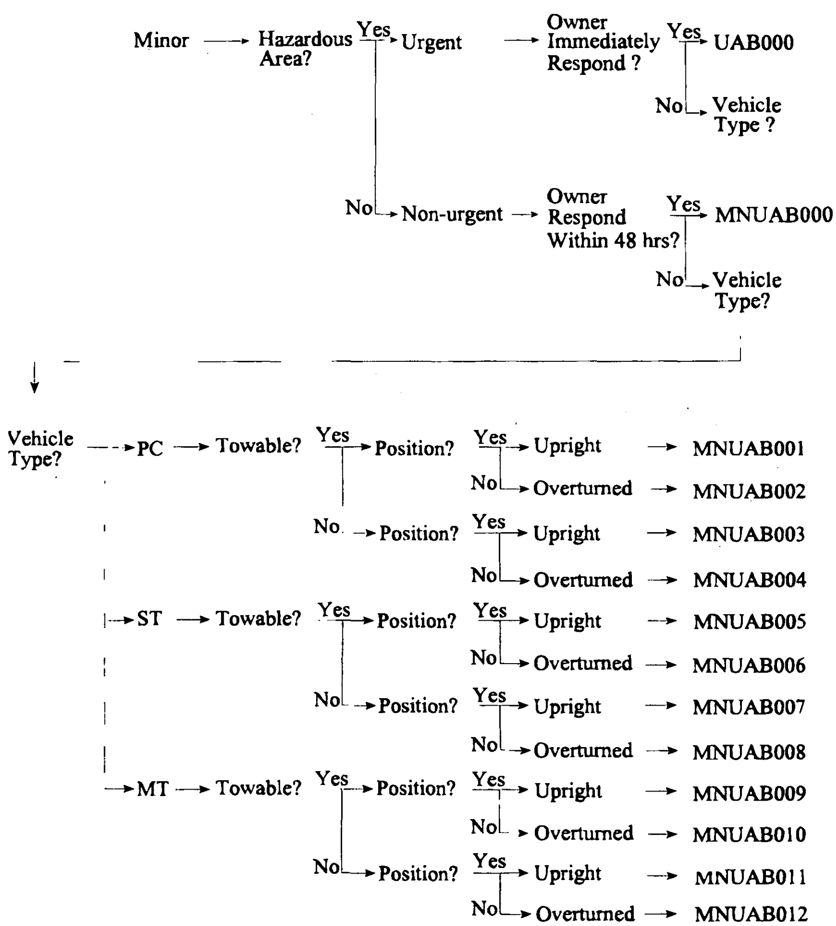

FIGURE 3 A minor incident branch of the decision tree with urgent and non-urgent minor incident and the continuation of a non-urgent minor incident branch of the decision tree.

Representation of Urgent Minor Incidents

The urgent minor incident branch is similar to a non-urgent minor incident branch of the decision tree, except for some differences in the details of responses, as shown in Figure 4. According to the experts, the urgent minor incident must be cleared as soon as possible for urgent responses. UAB001, an example of an end node, consists of the actions that should be taken in response to an urgent minor incident; those actions may include dispatching a patrol vehicle to the scene or dispatching a tow truck to remove the involved vehicle to a safe area, etc.

Representation of Major Incidents

In Figure 2, if the variable "Personal Injury" is "Yes," the next two variables, "Fire" and "Lane Blockage," must be identified. If the identification of these variables is "No," the tree will be classified in Figure 3 as a minor incident. Otherwise, the incident is classified as major. If the identification of those three variables is "Yes," this expanded portion is displayed in the upper branch of the tree. Otherwise it will be shown in the following branches of the decision tree.

In this study, MajorP is an incident that involves personal injury, and, as a branch of the tree indicates, it may be accompanied by other variables, such as "Fire," "Lane Blockage," and "Through Traffic." The variable "Lane Blockage" can be none, partial, or total, which indicates whether the lane is blocked by involved vehicles, spilled loads, accident debris, or injured persons. In Figure 2, "No Lane Blockage" would mean that the involved vehicles did not block a travel lane when an eyewitness reported the incident. "Partial" would mean that some travel lanes were obstructed but others were still open to traffic. Finally, "Total Blockage" would mean that all travel lanes were blocked by the incident. However, total blockage does not always mean that through traffic is impossible.

After the variables "Fire" and "Lane Blockage" are defined, the next variable to be evaluated is "Through Traffic" (Figure 5). If the variable "Through Traffic" is "Yes," this implies that through traffic is possible. Traffic may be diverted to any open lane or around the incident scene in the area adjacent to the shoulder lane without any potential danger to motorists. If the answer is "No," travel lanes may be totally closed due to hazardous material spills, load spills, removal of injured persons, lane blockage, geographical constraints, and so on. This expanded branch is shown in Figure 5, in which the variable "Time of Day" will be evaluated. The continuation of each branch of the tree is denoted by a circled letter.

In Figure 5, the time of day is divided into several intervals, midnight to 05:00 a.m., 05:00 a.m. to 08:00 a.m. and so on. After the time of day is known, the type of vehicles involved in the incident must be determined. In the development of INTREPID, vehicles are assigned to three major groups: passenger car, single-unit truck, or multiple-unit truck. Each type of vehicle requires different equipment for the clearance processes. After the type of vehicle has been identified, its position is then requested. The position is important for incident clearance, especially if the vehicle is a truck, which can be removed from the scene only when it is upright. If overturned, it must be made upright before removal from the scene.

The lower part of Figure 5 records the degree of vehicle damage, which may fall into one of three categories: functional, nonfunctional, or disabled. After inquiring about the vehicle's position, the tree then addresses the possibility of a load spill. If the condition of "Load Spill" is "Yes," the magnitude of delay is increased. If a load spill is involved, its type (e.g., sludge, live stock, construction material, etc) must be determined. By identifying the type of cargo spill, the proper agencies and equipment can be dispatched in a shorter period of time. This part of the extended decision tree is shown in Figure 6. If there is no load spill, the tree will reach its end node, which is MJP-000, or conclusion of the problem. In the lower part of Figure 6, if the variable "Owner Immediately Respond" is "Yes," the tree will reach its end node: MJP-MI00. If the variable is recorded as "No," the type of cargo spill must be provided, as shown in Figure 6. If the load spill represents a minor incident, the tree is constructed as shown in Figure 7, which is the continuation of Figure 2.

MJP-xxxx is a file of response activities, recommendations, or conclusions about the proper type of equipment needed for a par-

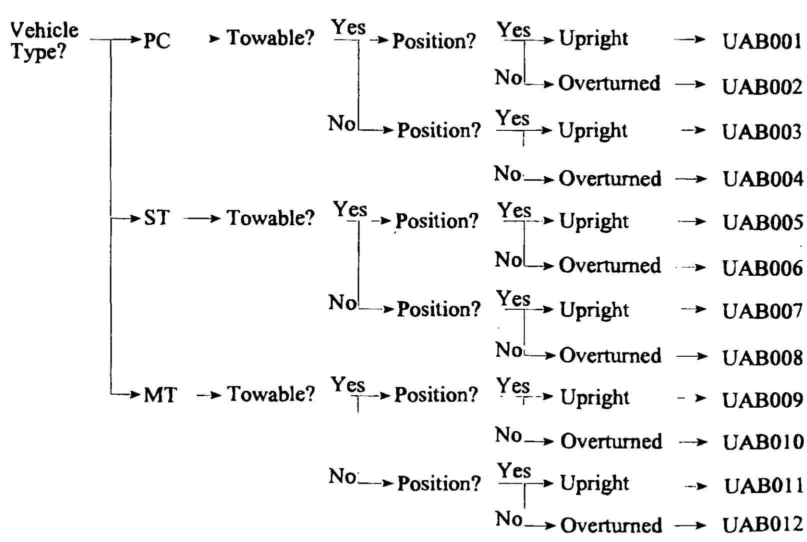

FIGURE 4 The continuation of an urgent minor incident branch of the decision tree.

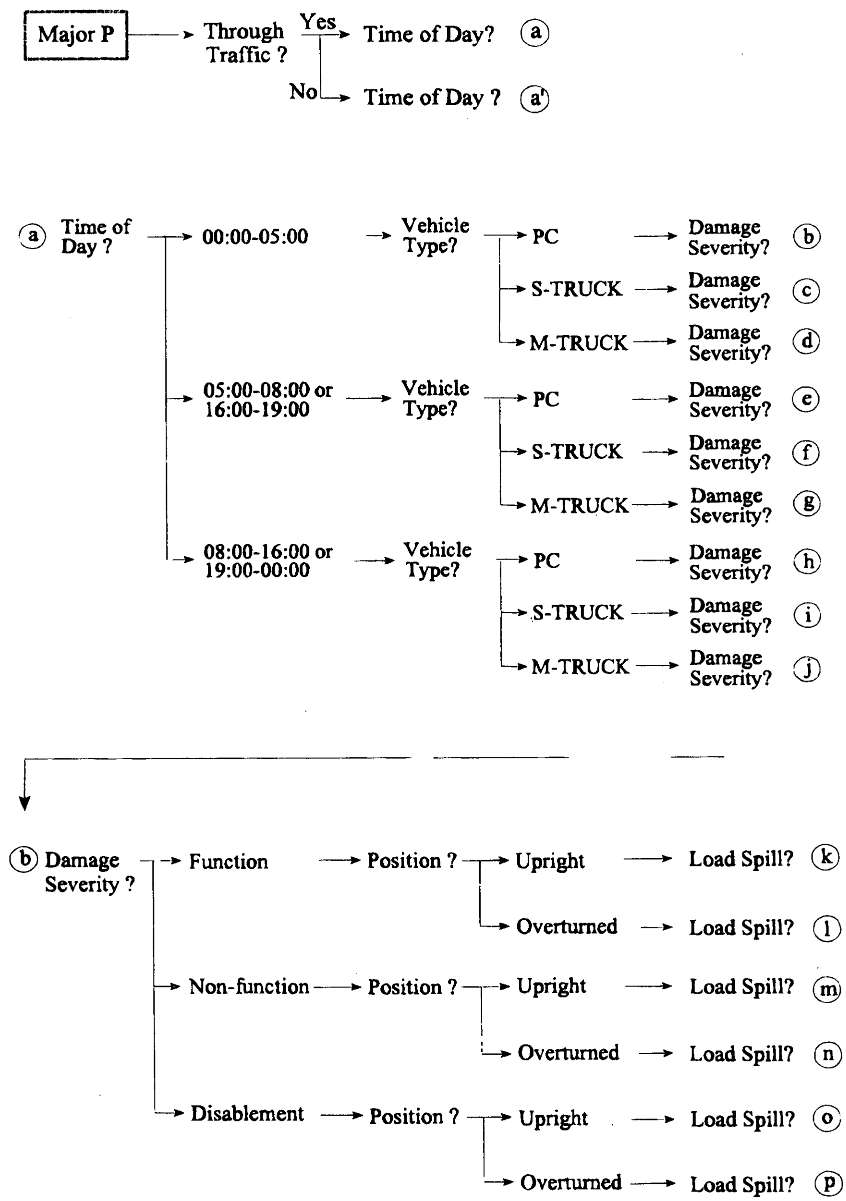

FIGURE 5 The decision tree of a major accident ("majorP") and continuation.

ticular major incident. Details of the recommendations are provided under each file name. Recommendations for addressing a particular problem can be accessed after the user has provided all requested information. Other branches of a major accident will not be mentioned in this discussion. In general, decision trees for other major incidents are similar, with some minor modifications.

THE KNOWLEDGE BASE DEVELOPMENT

The knowledge representation introduced in the previous section was used in constructing the knowledge base of INTREPID. In the following sections, the processes of knowledge base development and system implementation are explained.

Knowledge Base of INTREPID

Figure 8 shows the system architecture of INTREPID. We have selected Level5 Object (*4,5*) as the expert system shell. INTREPID was divided into two main portions: main program and supporting facility. The main program, which is developed using the expert system shell, consists of the first four components mentioned in the previous section. The first component, knowledge base, contains the knowledge acquired from the experts and is represented in the form of production rules. The second component, the inference engine, serves as the inference and control mechanism of INTREPID. The next component, the user interface, enables user-friendly fact entering or input, and controls and formats all output or end results for the user. This component also provides the user

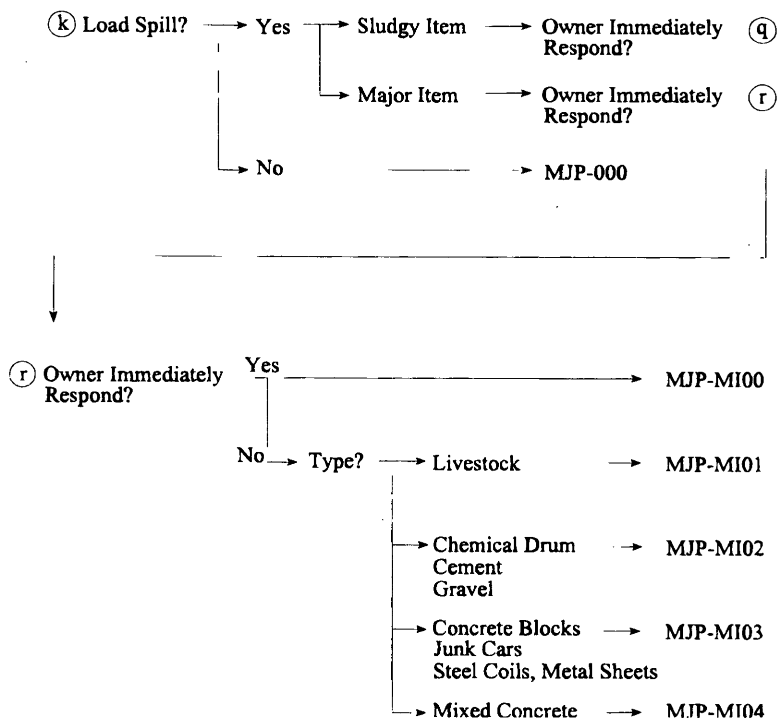

FIGURE 6 The continuation of the decision tree of load spill and the major item spill.

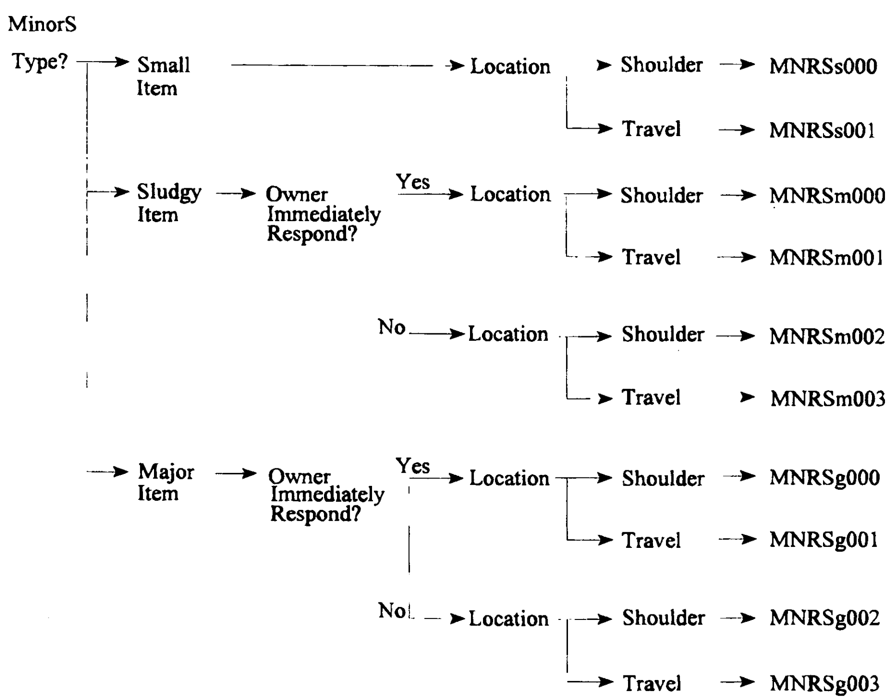

FIGURE 7 The continuation of the decision tree of major load spill.

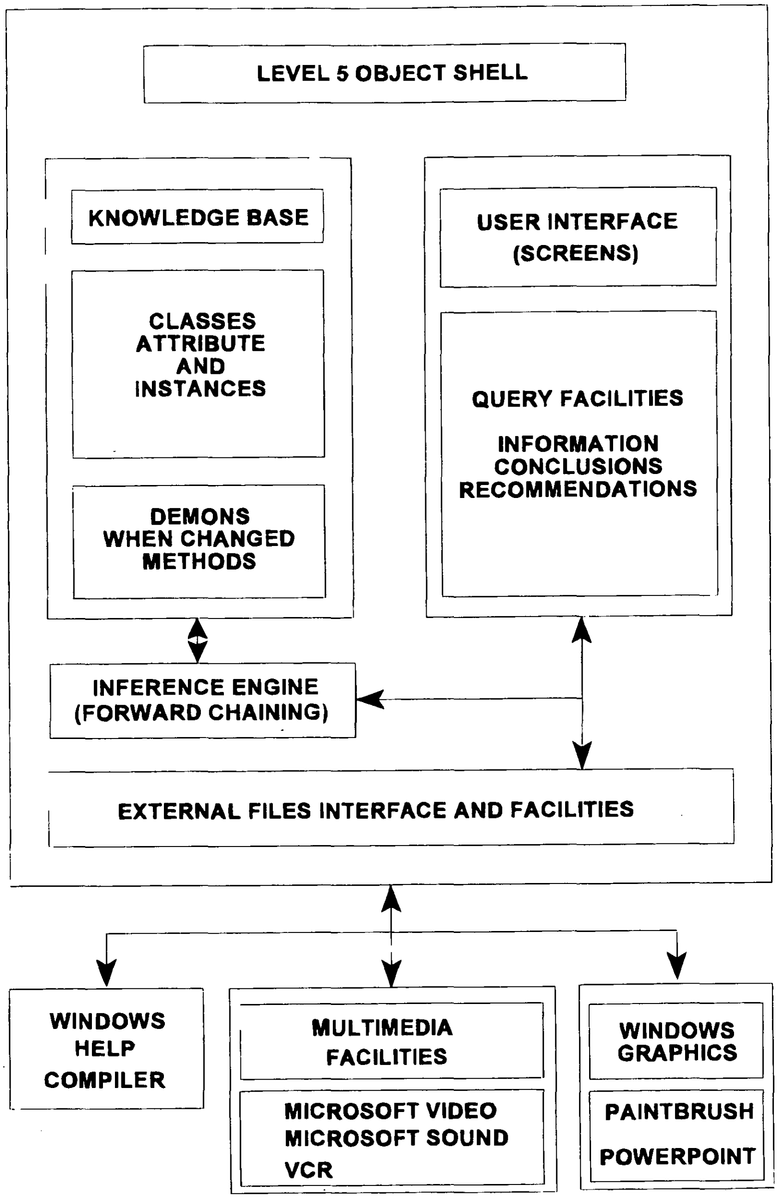

FIGURE 8 The architecture of INTREPID.

with an explanation facility. The fourth component, the external file interface, helps enhance the ability of INTREPID to interface with external computer programming, such as graphic, multi-media, and text files.

An example of INTREPID's screens and a user's consultation process are shown in Figures 9 to 13. The first screen (Figure 9) welcomes users to INTREPID and ask them to define the project route number and location. Figure 10 show users the incident management screen. Selecting "Abandonment" triggers the screen shown in Figure 11. The user then must provide the type of vehicle and the numbers and types of damaged vehicles. After the user inputs this information, the screen shown in Figure 12, which is a conclusion screen, will appear. Figure 12 gives all the necessary information in IM, such as the type and number of responding agencies and the type of equipment needed. Figures 13 shows a typical multi-media component in INTREPID, used for a demonstration purpose.

SUMMARY AND CONCLUSION

In an effort to reduce incident-related congestion, INTREPID has been developed as a comprehensive knowledge-based IM system. It is designed to assist a dispatcher in diagnosing incidents and initiating quick and appropriate responses on the rural freeway I-70 from Columbus to Zanesville, Ohio. Unlike other systems, INTREPID offers recommendations based on key information provided by users.

Knowledge acquisition and knowledge representation were the first two tasks undertaken in INTREPID's development. During the knowledge acquisition process a knowledge elicitor obtained key information to develop INTREPID's control screen and knowledge base. In addition, experts from OSHP and ODOT with experience managing minor and major incidents at the scene and developing the IM system in Ohio, participated in the study. Many incident

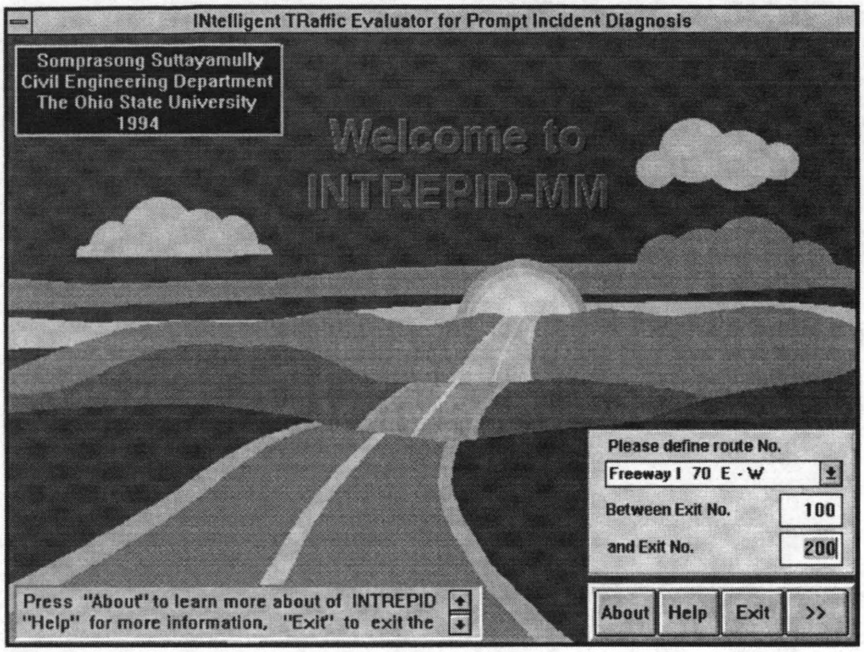

FIGURE 9 INTREPID's welcome screen.

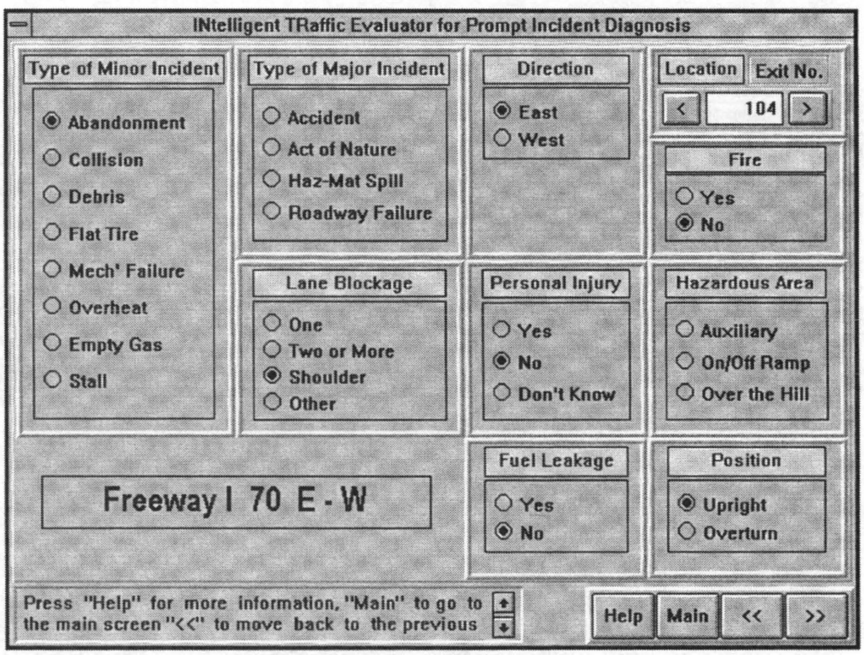

FIGURE 10 The incident management main screen.

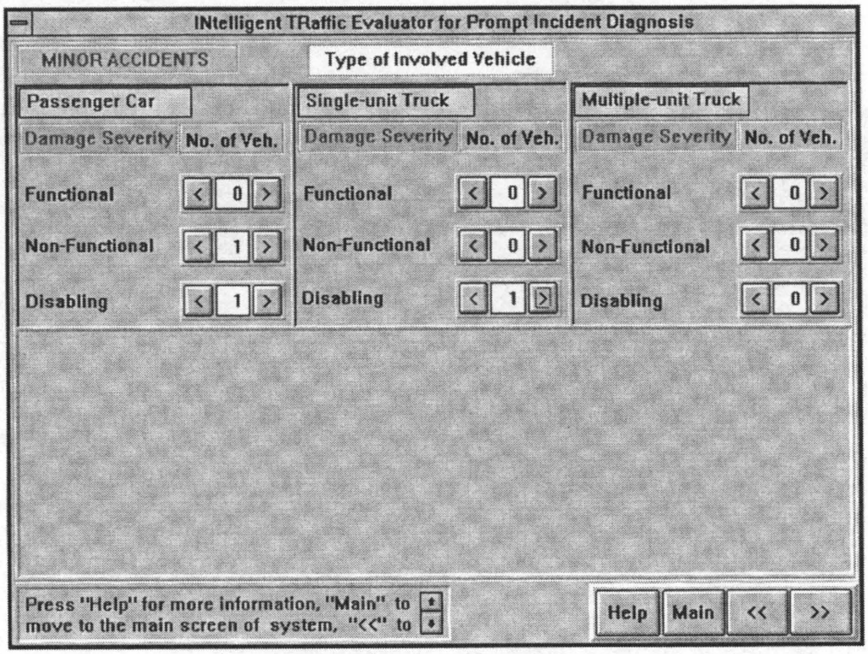

FIGURE 11 The severity assessment screen of minor incident.

cases were reconstructed to cross-check the consistency of the acquired knowledge. Furthermore, dispatchers, the potential users of INTREPID, were also interviewed to help the knowledge engineer build a user-friendly intelligent system.

The acquired knowledge of INTREPID was represented in a decision tree that is easily understood and transformed into production rules. The tree helps the knowledge engineer maintain the knowledge base, which makes INTREPID a robust system. With the decision tree, the knowledge engineer can easily construct the knowledge base and complete the development of a limited, simple-to-use INTREPID. However, like other intelligent systems, much still needs to be done in the refinement of INTREPID's knowledge base.

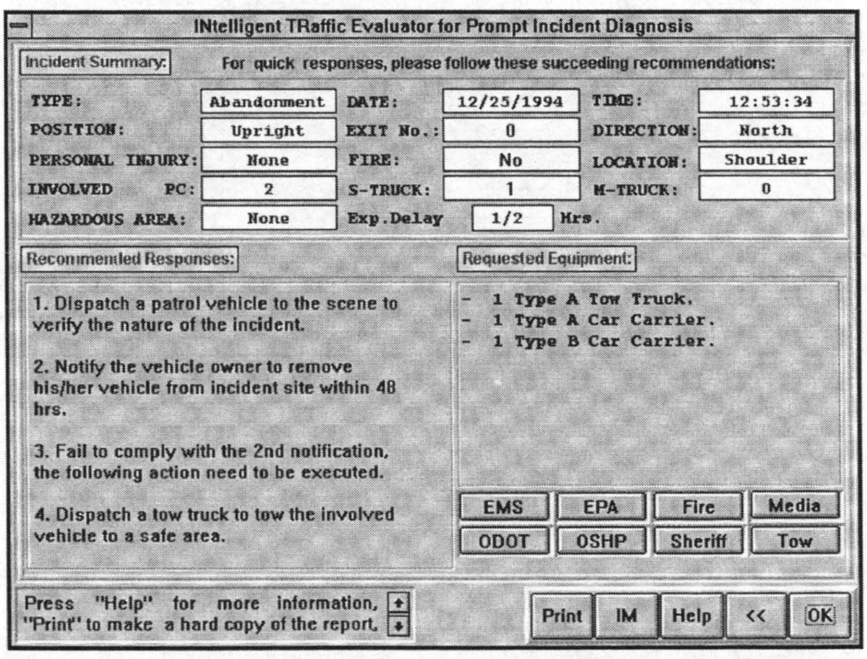

FIGURE 12 A recommendation screen of INTREPID.

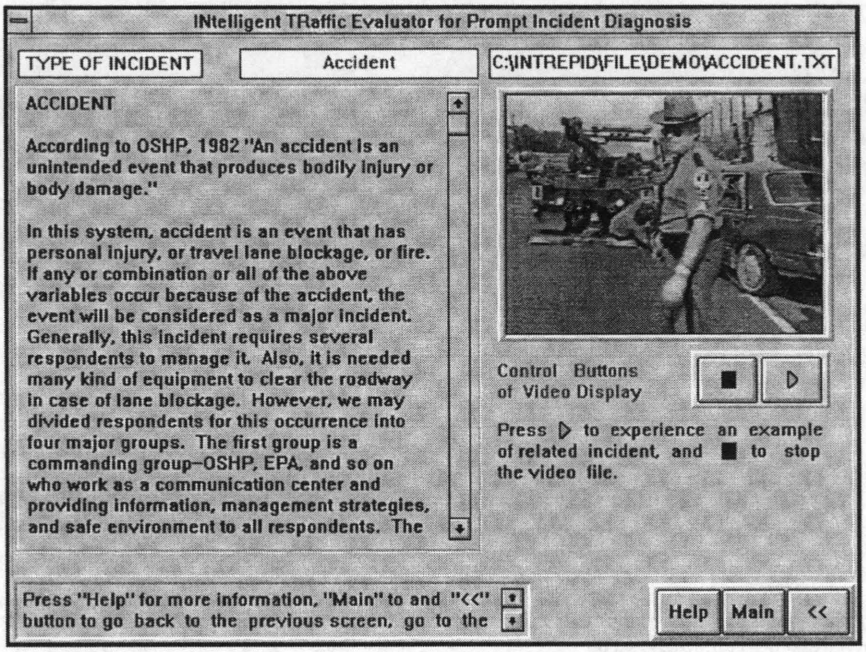

FIGURE 13 A multi-media component of INTREPID.

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