Structuring Expert Systems and Other Computerized Models in Transportation

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A thorough analysis is presented of how expert systems and existing simulation, evaluation, and optimization models in traffic and transportation engineering can be combined. The problems and shortcomings of the currently available computerized models are discussed, and potential applications of expert systems in curtailing these shortcomings are analyzed. Different taxonomies and configurations of how expert systems and other computerized models may be combined are shown, and the advantages and disadvantages of each configuration are stated. Finally, an application problem in transportation issues dealing with disaster evacuation and response planning is presented. It is concluded that expert systems and other computerized models work best when combined together to create intelligent computer programs.

For the past 20 years, the U.S. Department of Transportation through the Federal Highway Administration (FHWA) has sponsored a number of computerized models in traffic and transportation engineering (*1*). These powerful models, though useful, have had significant limitations:

- User cost—most models were originally designed for mainframe computers whose costs impaired the effectiveness of these programs.
- User access—turnaround times were often lengthy, sharply reducing the productivity of the professional. Furthermore, since traffic and transportation models are data intensive, their use often mandated onerous input-preparation efforts.
- Interpretation of results—model output takes the form of extensive statistical tabulations. Skill, insight and considerable knowledge on the part of the user are needed in order to extract those results which can provide a basis for decision-making.
- Models are evaluators—these models do not directly offer guidance for the decision maker. It is necessary for the skilled professional to execute these models repetitively, within the context of a well-designed experiment, in order to assess the relative benefits of candidate solutions and to select the best approach.
- Design models—models such as TRANSYT (*2*), MAXBAND (*3*), and PASSER (*4*) do provide results that can be used for improving traffic performance directly. They must be used by the traffic professional, are subject to similar user access difficulties, and are limited to components of a corridor system.

For these reasons, these evaluation and design tools have not fulfilled their potential. There have been some recent developments, however, which are ameliorating these shortcomings:

- These models have been "ported" to personal computers (PCs), thus providing improved access to the planning community. Moreover, PCs are becoming faster, less costly, and are now equipped with adequate memory.
- User-interactive input interfaces have been developed and combined with data base management systems (DBMSs). These greatly ease the input preparation activity, allowing technicians to replace engineers for this effort. Furthermore, the DBMS greatly reduces the extent of this effort.
- A user output interface is currently under development for the NETSIM (*5*) model, using interactive computer graphics (ICG) for PCs and workstations. This "Fifth Generation" technology, which requires no familiarity with computers on the part of the user, will greatly reduce the effort and cost associated with analyzing the model results.

While these recent advances represent significant improvements that enhance the appeal (and, hopefully, usage) of these models, they lack the ability to provide the decision maker with a direct response to his needs. Furthermore, there remains the need for highly skilled professional engineers to interpret the results and translate them into design or policy decisions. Finally, there is presently no organized and readily accessible inventory of current knowledge and experience which can be used to guide the decision-maker.

POTENTIAL ARTIFICIAL INTELLIGENCE APPLICATIONS

Advances in artificial intelligence (AI) offer the potential for solving or ameliorating these shortcomings and producing a new generation of traffic and transportation management tools. One of the major strengths of AI is that it can process knowledge, judgment, and opinion for application to such areas as game playing, theorem proving, general problem solving, robotics, natural language comprehension, and expert problem solving.

Some potential applications that employ artificial intelligence techniques might improve the limitations of current traffic and transportation management methodologies and evaluation models. These techniques can provide:

- Knowledge bases;
- Intelligence interfaces;

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- Knowledge-based traffic and transportation management decision systems; and
- Real-time traffic management tools.

A "knowledge base" contains *facts*, or *rules* that use these facts as a basis for decision making. The core of all expert systems (ESs) is a knowledge base that contains information describing a specified "domain."

An "intelligence interface" can further relieve the user from tedious chores of data preparation, input-output, and model interfacing, and possibly help the user select appropriate analytical models for a given problem. For any particular traffic management strategy, the "intelligence interface" can (1) check the data requirement and data availability, (2) assist with data preparation if necessary, (3) do retrieval and preparation if data from the knowledge base is available, and (4) suggest analytical models appropriate to the problem.

The lack of determinacy (i.e., closed-form solutions) in many traffic management problems is beyond the capabilities of present algorithmic traffic management tools. Knowledge-based ESs offer a new approach for analyzing and solving nondeterministic problems for the highway corridor transportation manager. Such an ES would include an explanation module, knowledge acquisition module, context (also called workspace), knowledge base, and inference machine.

Traffic management experts can store their knowledge about any particular implementation of traffic management strategy to the *knowledge base* using the *knowledge acquisition module*. This information can be divided into two classes: (1) the factual or causal knowledge of the traffic management, and (2) the empirical associations, rules, or experiences. The knowledge base can also contain long-term historical traffic data, as well as network information. All information in the knowledge base is organized so that it may be effectively utilized by the other components of the system.

The *context* contains all the information that describes the problem currently being solved, including both problem data and solution status. The user can get access to the context through the explanation module. The traffic problem data may be divided into facts provided by the user and those derived or implied by the problem. The use of knowledge-based transportation management decision ES begins with the user entering some known facts about the problem (e.g., traffic corridor network configuration, traffic data, and other related information).

The *inference engine* is the knowledge processor. It operates on facts contained in the knowledge base and in the context, utilizing rules in the knowledge base to deduce new facts, which then can be used for subsequent inferences. The objective of the inference engine is to arrive at a global conclusion (goal), and the process continues until either the problem is solved and the context is transformed into the desired goal state, or when there are no more rules remaining to be invoked.

Many ES inference engines can deal with imprecise or incomplete knowledge. Associated with the data may be "certainty measures" indicating a level of confidence in the data. Rules are conditionally invoked, based on the certainty of the premise. The inference mechanism can then propagate certainty about the inferences along with results of the inferences.

The *explanation module* provides the traffic management decision ES with the capability to explain its reasoning and problem-solving strategy to the user. At any point the user may interrupt the system and inquire what it is doing and why it is pursuing the current line of reasoning. In addition, the system can explain how any fact was deduced and how knowledge was applied.

The *knowledge acquisition module* is provided to facilitate the knowledge input process. The information in the knowledge base is in rigid format, and the translation of knowledge obtained from experts to the required internal format may be tedious. Although it is desired that eventually the human expert be able to enter knowledge directly into the system, this goal is currently not achieved.

In addition, a *user interface* can be added. The user accesses the system through a friendly interface, often using a problem-oriented subset of English or computer graphics. The interface provides capabilities for the user to monitor the performance of the system, volunteer information, request explanations, and redirect the problem-solving approach used by the expert system.

With a knowledge-based traffic management decision system, even an inexperienced traffic manager can sit down in front of a terminal and state his goal for a certain traffic highway corridor. The manager will then enter some facts about the highway corridor under consideration, such as peak-hour traffic volume, highway arterial configurations, and other relevant information. Then the ES would recommend feasible transportation management strategies and the necessary procedures and additional resources required to implement the suggested management strategies. The solutions suggested by the traffic management decision system are deduced from knowledge obtained from a variety of experts, based on experiences from both successful and ill-fated previous similar projects.

AI techniques may also be useful in real-time traffic control. For example, current computerized urban signal control systems are based on the ideas of either minimizing vehicular delays or queues at signalized intersections or maximizing the progression band width of arterial signals. These ideas work well for an undersaturated network but not for congested networks. Currently, some researchers think that two simple principles—(1) keep intersections clear of spillback vehicles, and (2) give right-of-way to the direction in which traffic can move—might work better for congested networks. The ES type of program is ideal for either this simple system or a decidedly more complex rule-based system. In addition, traffic diversion and simulation capabilities can be added. The traffic manager can then have a real-time traffic management decision tool which will suggest traffic congestion or incident diversion schemes. This type of system can aid the traffic manager in making human decisions that require the exercise of certain models, only much faster. Such an ES was developed recently in France (*6*).

Finally, there are advantages to developing application programs in ES style. For a good conventional application program, it is a major undertaking to establish all the causal relationships, algorithms, or rules. The rules within a good conventional application program must be complete, unique, and correct. The program developer has the responsibility to insure that these three criteria are met. Due to the complexity of the transportation congestion problem, it is almost impossible to attain these three criteria. This makes conventional program development expensive. Additional costs are incurred when programs are updated, because major code modifications are generally required in order to accommodate new rules and locate the affected rules. For an ES program, it would be much easier to add more or change existing capabilities. New traffic control measures, such as incident diversion, demand/time-of-day tolls, on-board vehicle guidance system, and roadside two-way communication system, might be more easily incorporated into an existing ES program. The new traffic control measure would be first translated into appropriate rules, and then the new rules would be added to the existing rules. No algorithmic logic would need to be restructured and no existing code would need to be modified.

EXPERT SYSTEMS AND SIMULATION

Researchers and practitioners in the field of simulation and those in AI have had to face similar problems in creating models of complex and sometimes partially understood systems. To a large extent, solutions have been developed independently in each area, leading to techniques and software tools that differ markedly in terminology but often overlap in terms of concepts. The recent stress on knowledge representation in AI has emphasized a common ground, modeling of reality, but each group maintains a slightly different emphasis: dynamic behavior for simulationists, and logical inference for AI workers.

The purposes of simulation models and of ESs are similar: to provide a computer model that aids decision making. Their methods are similar in that they are both based on modular representations of physical systems and on "inference mechanisms" that drive these representations.

An inference mechanism, as opposed to user-programmed control structure, works with any number of modules, and these modules can (in theory at least) be presented in any order and are entirely independent of other modules. For instance, the inference mechanism of an event-based simulation is independent of the number of events and their order within the simulation. The inference mechanism, for simulation models, includes next-event-scheduling algorithms and interval-scanning procedures. For an ES, the inference mechanisms include backward and/or forward chaining with some form of uncertainty updating.

There are differences between these two disciplines:

- Simulation applications involve an iterative process wherein a model is designed, inputs are specified, an experiment is executed, the results are analyzed, a new run is designed, executed and analyzed, etc., until sufficient insight is gained to render a decision. In ES, on the other hand, the modeler constructs a knowledge base; the user defines the goal and lets the computer work to identify the decision rules.
- In simulation models, the data base is integrated with the program logic. For ES, the knowledge base is distinct from the inference engine that controls the logical flow.
- The data base for simulation models is generally numeric and formally structured. In an ES, the knowledge base is symbolic and represents facts, rules, judgment, and experience (i.e., heuristic knowledge) about a narrow problem area.
- Simulation employs algorithms; ES employs symbolic inference.
- Simulation languages are procedural or imperative (FORTRAN, GPSS, SIMSCRIPT). ES may use shells (OPS5, ROSIE, Expert-Ease) that, in turn, are usually written in functional or descriptive languages (LISP, PROLOG).

It has been well documented that knowledge acquisition is slow and costly due to the need for large amounts of knowledge. Simulation models, properly applied and integrated with information provided by experts, offer the potential for expanding the traffic engineering and transportation planning knowledge base *and* affecting important savings in cost and in time. The next section explores approaches that can both exploit the similarities between simulation and ES and accommodate their differences.

Structuring an Expert System Simulation Environment

Figure 1 shows a taxonomy for combining simulation and expert systems. Perhaps the most obvious way in which the two can be combined is by embedding an expert system within a simulation model as in (a), or vice versa as in (b). It is arguable that many simulation models already use knowledge, as opposed to data. For instance, a queue priority rule is knowledge. It may be pertinent to keep such rules in a knowledge base, rather than embedded in code. It may be necessary to embed a simulation within an ES for two reasons. First, the ES may need to run a simulation to obtain some results for the user. Second, and more important, the ES may use one or more time-dependent variables, and thus needs a simulation to update their values. This situation has occurred in some real-time military applications, where the system needs to know the position of ships, aircraft, etc.

Simulations and ESs that are designed, developed, and implemented as separate software, in parallel, may interact. A simulation model could interrogate an ES, as in (c). This may be useful where a simulation is developed for a complex system, and an ES already exists for part of the decision making within that system. The simulation can then access this, rather than mimic or encode the decision rules. ESs that execute and use the results from simulations, as in (d), are of increasing interest to knowledge engineers. Rather than test an ES on a user or a real environment, the ES can be tested on a simulation. Not only is development time reduced, but also testing can be more comprehensive. Further, if the simulation is a valid model, then an ES that adequately controls or responds to the simulation is, perhaps, valid itself. Application domains where this approach may be useful include real-time control, where an ES developed to ultimately control the process can be tested on a continuous simulation of that process.

Whereas in (a) through (d) the user of the main tool does not have direct access to the other, in many instances both an expert system and a simulation will be used together to do some task, as in (e). Each may well share some data; in effect, the simulation and ES will cooperate in the task. Given the

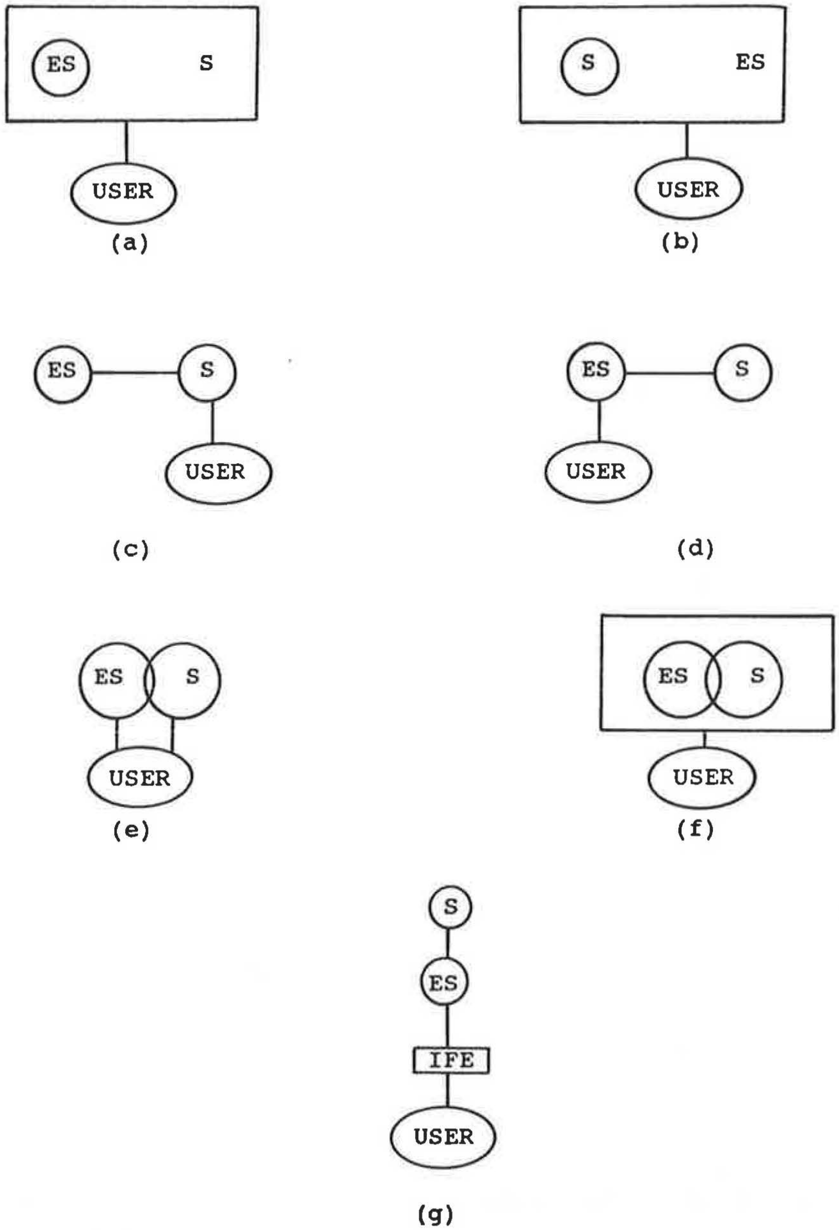

FIGURE 1 Taxonomy for combining expert systems (ES) and simulation (S).

increasing trend to hand over simulation models to users who may be inexperienced simulation users, there is a growing need to support the use, and guard against the misuse, of such models.

The cooperative simulation and ES may be surrounded by a larger piece of software, as in (f). Each may be part of a simulation environment or part of a large decision support system used directly by decision makers. New tools based on both simulation and knowledge-based methods fall into this category, for example, as does the Rule Oriented Simulation System (ROSS) developed by the Rand Corporation (*7*).

One of the most important application areas for knowledge-based methods is intelligent front ends (IFEs) or user interfaces (g). This generates the necessary instructions or code to use the package following a dialogue with the user and interprets and explains results from the package. Simulation programs, including TRAF (*8*), perform some of the functions of IFEs, although they do not actually execute the simulation and interpret the results. Useful intelligence for an ESSE would include:

- Dialogue handling (a natural language interface or at least user-directed free format input);
- Some model of the user, so that the system adjusts its requirements of the user, given evidence that the user is inexperienced, experienced, or whatever; and
- A model of the target package, so that some decisions can be taken by the IFE rather than referred to the user.

In considering how simulation and ESs can be combined, the above taxonomy is useful. For evaluating the pros and cons of different simulation/expert system configurations, several philosophies must be considered:

- The ES employs the simulation model to generate results that are added to the knowledge base, as required to respond to a user's needs, in the event this additional data is required. Here, the simulation model is executed as a precursor activity, prior to the interactive session between user and ES.
- The ES and simulation model are "cooperative," in that both may be executed during the session. Depending on the taxonomy selected, the user may communicate directly with the simulation model, *or* the ES will determine the need for the simulation model, prepare its input stream and execute it to generate the required "knowledge." In the latter case, the simulation model is transparent to the user who communicates only with the ES or IFE.

Note that the software system can be designed to accommodate both approaches, depending on the skills and objectives of the user. For example, macroscopic simulation models may be employed "on-line," while microscopic models used "off-line" to augment the knowledge base.

Integration of Expert Systems and Other Computerized Models

Expert systems may also be combined with other computerized evaluation or optimization models. An example of this type of integration in traffic engineering is the design of an expert system and the required interface to complement the existing intersection design models such as EVIPAS (*9*). Seven potential engineering design cases for the integration of expert systems and other computerized models are depicted in Figure 2 and discussed below.

In Case I, the engineering model controls the user interface. The graphics package (if separate from the model) and the ES shell are both run in a background mode and the user would not directly interact with them. There is one consistent interface. If the chosen model is very robust, easy to maintain, and has a built-in graphics package that is user friendly, then the expert system should run in background mode behind the model. However, the model must be able to handle graphics. The 80386 machines have a batch mode capability. The model must be multitasking, able to run itself (for hours as required), and still be available to the user for other tasks.

In Case II, the graphics package (if separate from the engineering model) controls the user interface. The model and the ES shell run in background mode, and the user would not directly interact with them. This case would be most appropriate if the desired model were very unfriendly to a casual user and had no acceptable built-in graphics capability. Again, there is one consistent interface. If the graphics package integrates well with model and ES, this may be the most appropriate user interface. However, the graphics package must be able to handle text and draw tables of output from the model.

In Case III, the ES shell controls the user interface. The graphics package (if separate from the model) and the engineering model run in background mode, and the user would not directly interact with them. There is one consistent interface, but experience has shown that it is often necessary to disable the ES tool graphics capability, and coding must be done in a graphics tool. Typically, expert systems have problems in the graphics (other than simple business charts) presentation area.

In Case IV, the graphics package and ES jointly participate as the user interface. Only the engineering model runs in background mode, and the user would not directly interact with it. This arrangement offers the user potentially better control over the graphics and ES. However, the user also has two separate interfaces to handle. Only if the ES can control the model and all text from the graphics package will an acceptable solution of a text and a graphics format be presented to the user.

In Case V, the ES shell and engineering model jointly control the user interface. Only the graphics package runs in background mode, and the user would not directly interact

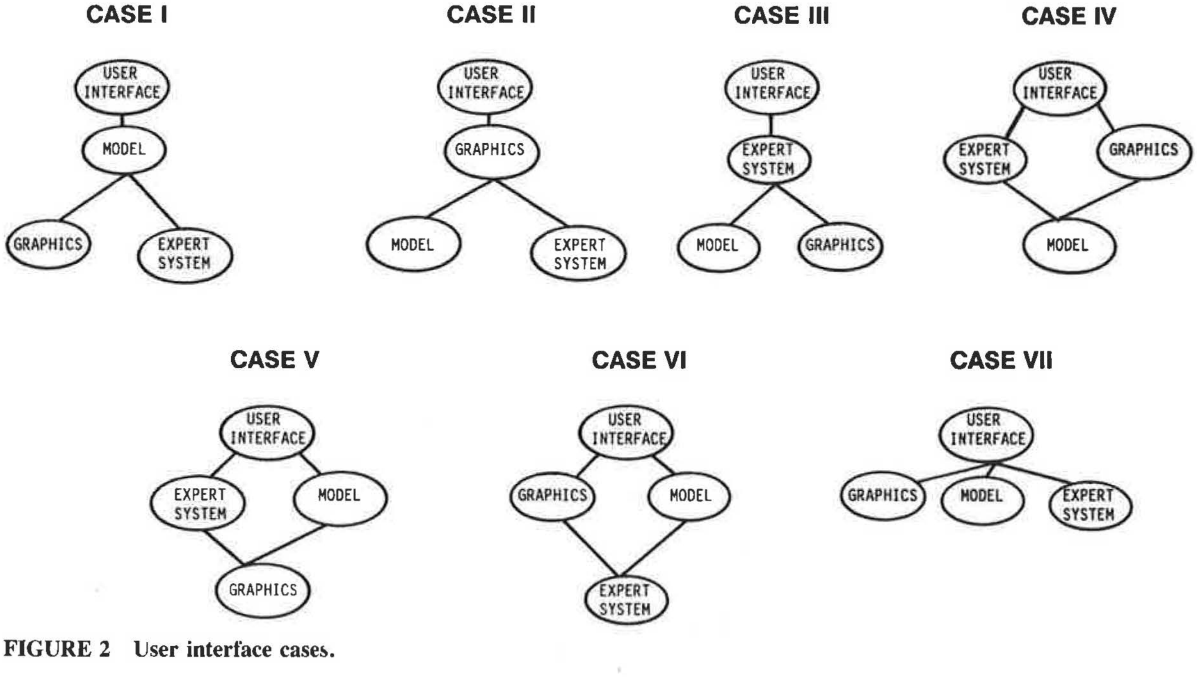

FIGURE 2 User interface cases.

with it. The user has potentially better control over the ES and model, but still has two separate text interfaces to handle. This option assumes that the model or the ES can completely control the graphics package. That assumption is valid only if the graphics package is built into the model.

In Case VI, the graphics package and engineering model jointly control the user interface. Only the ES shell runs in background mode, and the user would not directly interact with it. This offers the user potentially better control over the graphics and engineering model. The user still has two separate interfaces to handle. However, if the graphics package and model are built together then this reduces to Case I.

In Case VII, the graphics package, engineering model, and ES shell all directly interact as the user interface. None of the system components run in background mode. A very knowledgeable user will be able to most freely interact with the system, but the user must contend with three separate interfaces. For example, "Help" may be ^H, Fl, or H, depending on the environment. The user presentation would be very choppy, because the screens would all be different. Based upon the ability of the three separate packages to run together and the potential confusion to the practicing traffic engineer user, this may not be a viable option.

In the next section, an application problem—disaster evacuation and response planning—is described, the shortcomings of the existing simulation models in this area are discussed, and ways in which expert systems can be combined with existing models are analyzed.

APPLICATION

The state-of-the-art method and technique for dealing with highway network evacuation under disaster is to apply the available computer simulation and evaluation models (*10*). Some of the most popular models that are in use are: Network Emergency Evacuation (NETVAC) simulation model (*11*), EVAC PLAN PACK (*12*), and the Dynamic Network Evacuation (DYNEV) and its derivative IDYNEV computer models (*13*). These models, in general, have been designed to simulate the traffic flow and estimate the vehicular traffic evacuation time around a nuclear power plant in case of radioactive leaks similar to the Three Mile Island accident.

The state-of-the-art in evacuation modeling is IDYNEV (*14*). Table 1 summarizes the measures of effectiveness output by IDYNEV and also presents the input data required for simulation. The measures of effectiveness output data are provided for each network link and are also aggregated over the entire network.

TABLE 1 MEASURES OF EFFECTIVENESS OUTPUT BY IDYNEV (*14*)

Measure	Units
Travel	Vehicles miles and vehicle trips
Moving Time	Vehicle minutes
Delay Time	Vehicle minutes
Efficiency: moving time/ total travel time	Percent
Mean travel time per vehicle	Seconds
Mean delay per vehicle	Seconds
Mean delay per vehicle mile	Seconds/mile
Mean speed	Miles/hour
Mean occupancy	Vehicles
Mean saturation	Percent
Vehicle stops	Percent

The input data required for IDYNEV are summarized below:

- Topology of the roadway system.
- Geometries of each roadway component.
- Channelization of traffic on each roadway component.
- Motorist behavior that, in aggregate, determines the operational performance of vehicles in the system.
- Specification of the traffic control devices and their operational characteristics.
- Traffic volumes entering and leaving the roadway system.
- Traffic composition

Limitations of Current Procedures

Radwan et al. (*10*) have reviewed the aforementioned models and note several important features that the existing models lack. Among the deficiencies are:

- Since most of the models have been designed and tested for nuclear power plant accidents, they lack the capability of handling different disaster types, particularly natural ones.
- The shelter areas are defined as anything beyond the hazard area boundary lines, with no capacity constraint.
- The evacuation routes are treated solely on the traffic flow conditions, with no risk factors attached to them that can be influenced by the available evacuation time, the direction of disaster propagation, and the route topography. (IDYNEV is an exception; it takes into account time and route topography.)
- The models are not capable of testing different population density strategies.
- The models cannot be used for future land use management planning.

Another potential problem of applying the current models is the lack of communication between emergency management professionals and transportation professionals, which has resulted in an incomplete integration of resources. Transportation professionals usually lack the knowledge and experience of emergency management, and emergency management professionals often lack the expertise of running the simulation models and interpreting the output results.

Expert Systems Applications

The concept of a knowledge-based expert system (KBES) can be applied in conjunction with the current simulation models (in this case IDYNEV) to curtail some of the deficiencies described in the last section. A complete technical description of how a suitable ES can be built to interface with the IDYNEV model has been presented elsewhere (*15*). In brief, the different disastrous events are presented in a frame-based representation format in the ES, as shown in Figure 3, and the expertise of how to control traffic during each event is presented as a rule-based format. The decision-making process for dealing with the specific emergency event starts at the "appropriate actions to be taken" slot (shown in Figure 3). The slot contains appropriate heuristic knowledge in the form of rules in dealing with specific disasters.

This process is accomplished by (1) going through the frame; (2) having the frame automatically revise the local network (the If-Added procedures accomplish this); (3) feeding the revised network to the simulation model; and (4) combining the results of the model, the features of the network, and the features of the disaster, so that the expert system can make the final recommendation of what to do. The If-Needed procedure within the "appropriate action to be taken" slot trig-

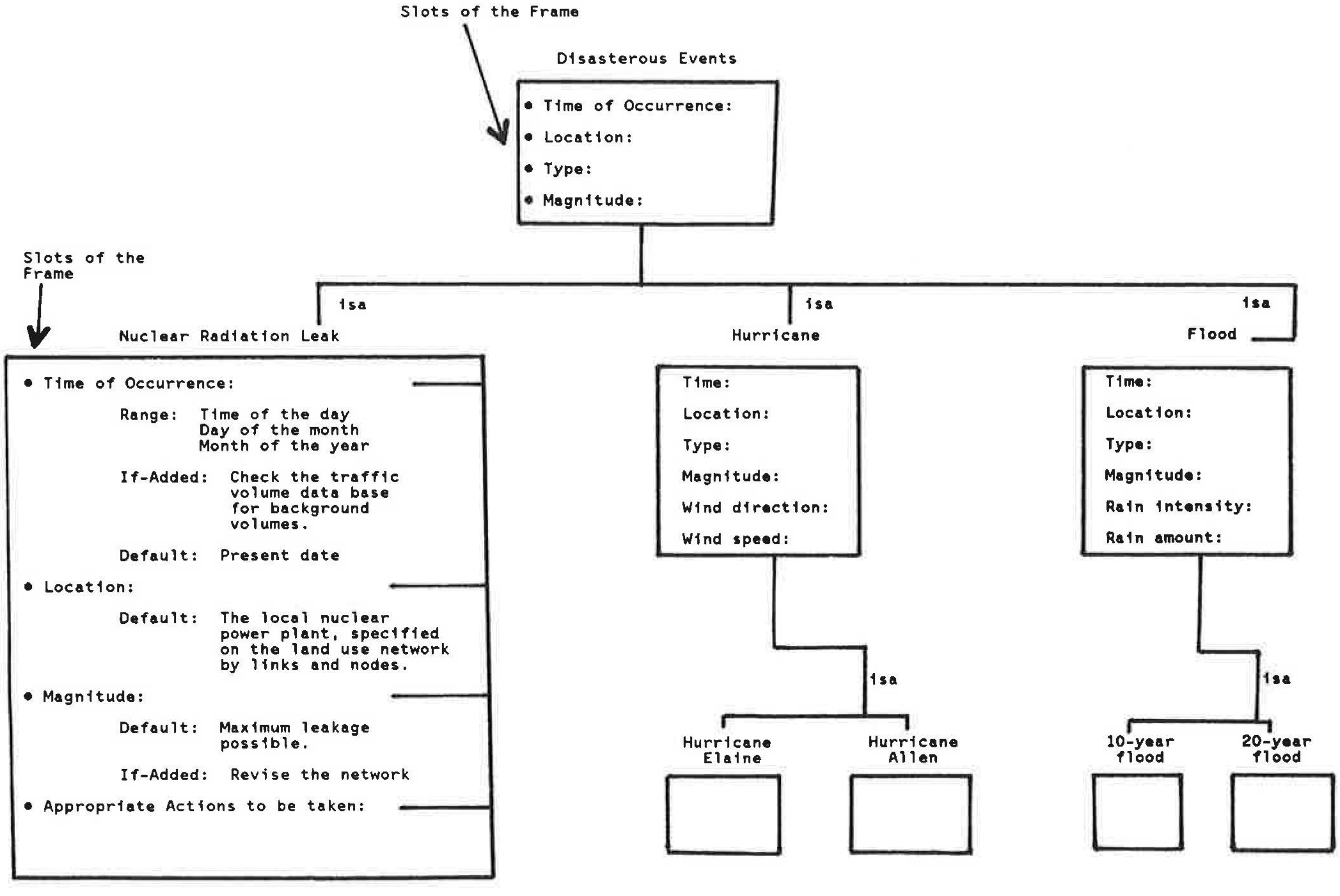

FIGURE 3 Frame-based representation of disastrous events for expert systems.

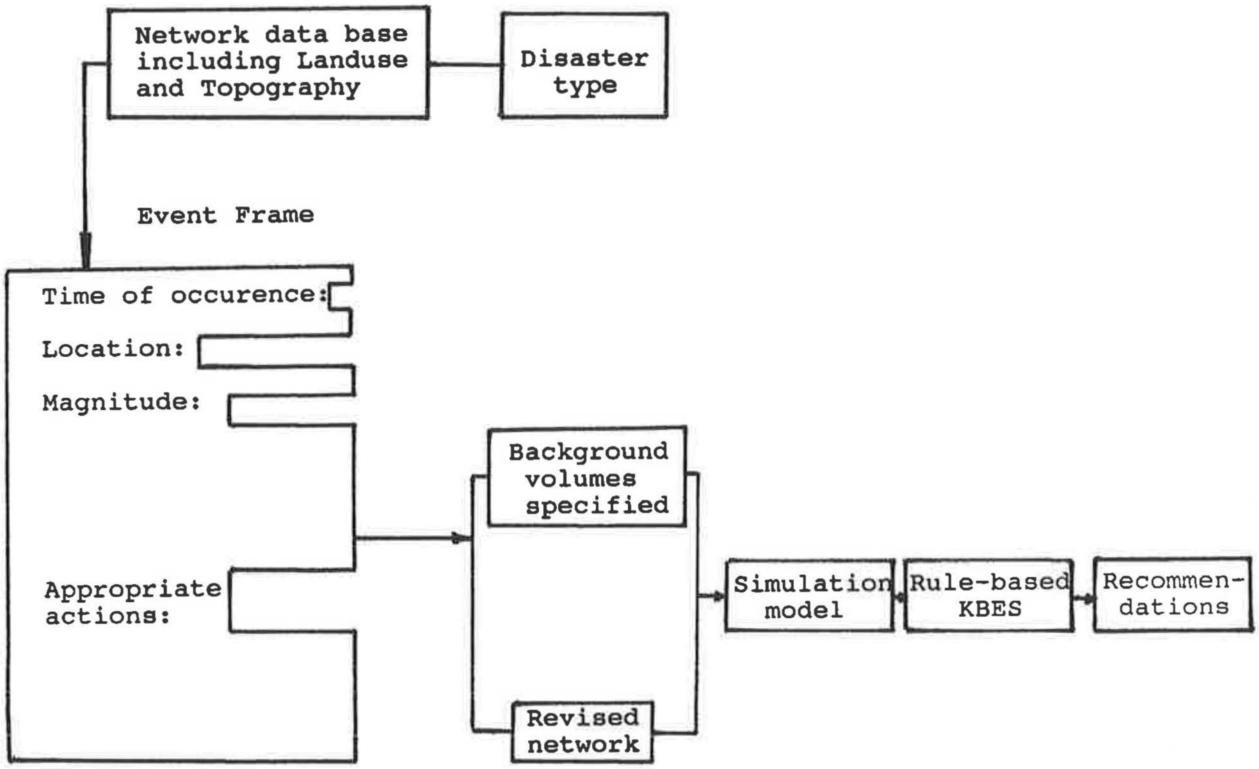

FIGURE 4 Knowledge-based expert system for disaster response planning.

gers this chain of events. Figure 4 shows the diagram for this process.

SUMMARY AND CONCLUSION

Because of the availability of many powerful traffic and transportation engineering evaluation, optimization, and simulation models, the applications of expert systems should be investigated in terms of how best they can be integrated with the available models. Different configurations for combining ES and other computerized models were presented, and the advantages and disadvantages of each configuration were discussed in this paper. The existing computer models consist of mostly algorithmic, sequential procedures with little or no symbolic or heuristic knowledge. Expert systems, on the other hand, are capable of handling symbolic knowledge excellently. Integration of available computer models and expert systems leads to the development of intelligent computer models for solving the problem.

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Publication of this paper sponsored by Task Force on Expert Systems.