

Validation of an Expert System: A Case Study

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The steps taken to verify and validate a prototype expert system (TRANZ) for traffic control through highway work zones are described. The prototype is viewed as an applied statement of the system requirements and a focus for the development of a complete knowledge base. The tasks used in the validation included (a) revisiting the experts who assisted in developing the program, (b) selectively distributing validation copies of TRANZ, (c) identifying problems and decisions that interface with and affect the work zone traffic control problem, and (d) conducting a validation workshop. The workshop was found to be the most effective way to review the system because the results represent a group consensus, whereas the prior tasks encompassed only individual inputs obtained in isolated instances. The informal request for reviews from users was completely ineffective. The workshop results were interpreted as general comments on the overall concept of TRANZ and specific programming modifications that resulted from erroneous recommendations by TRANZ. The general comments indicated that the attendees would not completely rely on TRANZ for finding traffic control solutions for work zones. However, they did indicate a willingness to work with TRANZ in the field and during instructional programs and thus to bring it along slowly while carefully validating it. The conclusions show the relatively long time needed to continue to validate and update an expert system until it correctly addresses a good majority of cases. The specific changes recommended by the panel demonstrated how the basic prototype can be expanded through experience. In the case of TRANZ, the knowledge base was expanded by adding new rules. The strategy used of asking experts to use the system can quickly expand the set of problems that a system addresses via direct expert input. Overall, the validation process must address both the accuracy and the completeness of the system.

A critical stage in developing an expert system is verifying and validating it as an acceptable piece of applied software. It must be proved that the system is an accurate and useful representation of knowledge. At present, "bits and pieces of a verification and validation methodology currently exist, but have not been assembled and standardized due to the many applications, design paradigms, development approaches, and the stage of development and fragmentation of the industry" (1).

Verification has come to deal with the program text development, which is simplified when a shell such as EXSYS is used. Validation "is a determination that the completed program performs the functions in the requirements specification and is usable for the intended purposes" (2).

This paper focuses on the validation of TRANZ, which is an expert system for traffic control in highway work zones

(3,4). It describes the steps in the validation process and the relevant findings.

The function of TRANZ is to specify appropriate traffic handling strategies for a specified highway work zone operation. The objectives of traffic control in maintenance work zones are (a) protecting the freeway users and the work force, (b) moving the maximum volume of traffic (minimization of delay), and (c) providing efficiency and economy in work procedures. TRANZ achieves these objectives by interpreting construction control and roadway factors to recommend appropriate traffic controls.

BACKGROUND

In recent years, researchers have been investigating and developing knowledge-based expert systems for transportation engineering applications. These computer programs, however, are not ready for commercial use. The state of the art is a range of prototypes that typically require extensive testing and refinement before they are acceptable for regular use. These systems typically are used only by the developer or sponsoring agency. These prototypes are an applied statement of the system requirements and provide a focus for the ultimate development of a complete knowledge base (1). The prototypes provide a framework for a continuous process of working with experts in supplying the required knowledge.

Factors that limit the utility of these prototypes are (a) the scope of the problem domain addressed by a prototype in relation to the appropriate scope of issues influencing decisions (this conflicts with the notion that the narrower the scope, the better the expert system), (b) the inability of the system to combine rules or other logic representations suitable for simple situations into more complex relationships suitable for more complex situations, and (c) the accuracy of the representation of the decision process of the expert(s).

This paper describes the steps taken after a prototype expert system was developed to validate the system as a decision aid to engineers.

OVERVIEW OF TRANZ

Figure 1 illustrates a comprehensive formulation of traffic management tasks for highway work zones. This model describes the work zone scenario and indicates how the traffic volume through the work zone is derived after demand management strategies have been implemented. The TRANZ module, in this case, reflects the traffic control plan for the

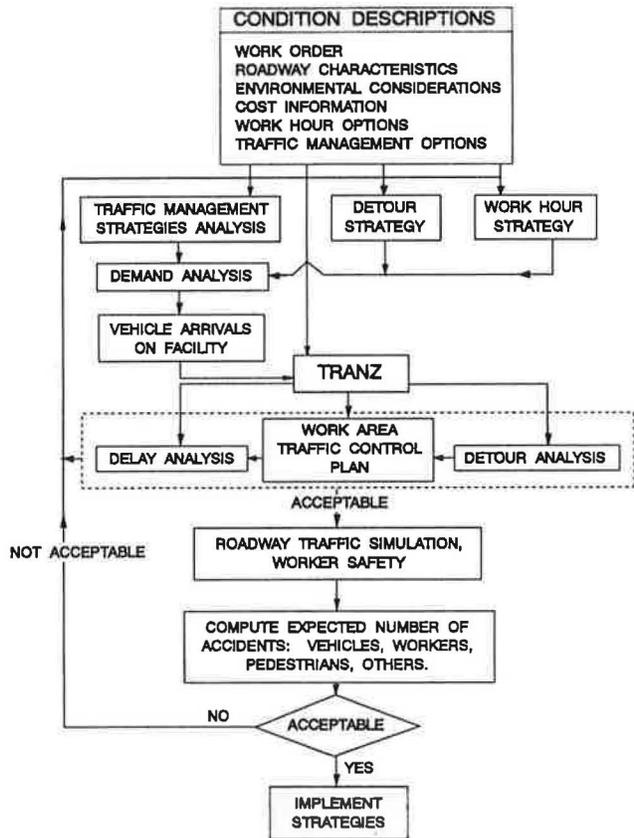


FIGURE 1 Traffic management tasks for highway work zones.

work area plus detour and delay analysis to examine the adequacy of the work zone to handle the generated traffic. Figure 2 illustrates the micro decision framework of TRANZ for which the rule base was developed. This figure shows the range of control options (barrier, cones, drums, signs, vehicles, etc.) and associated conditional variables [roadway type, location of work, average daily traffic (ADT), etc.] that interact to produce control requirements. All of the rectangular boxes in Figure 2 show places at which a second-level decision analysis takes place and a further decision tree can be established.

The *Virginia Work Area Protection Manual* (WAPM) offers a selection of typical traffic control plans for certain work activities (5). These plans provided an initial collection of cases for the prototype system. The decision tree in Figure 2 provides a framework for extending the WAPM knowledge box by working with experts who have field experience.

VALIDATION PROCEDURE

The overall validation plan for TRANZ actually began before the publication and release of the prototype. The prototype that was distributed for limited validation by the public is an improved version of the original prototype. The actual validation began with the assignment of a second software engineer to the project. The knowledge engineer of the first prototype was a transportation engineer who used an expert system shell (EXSYS) to code the knowledge base into rules.

The second knowledge engineer was a computer scientist who took a more mechanical view of the system and improved its efficiency by an informal validation that included correcting logical errors, modifying rule specifications and structure, and enhancing the user interface.

The validation consisted of the following:

1. Revisiting the experts who helped develop the system to receive comments about the current prototype, and revising the prototype as warranted.

2. Selectively distributing copies of TRANZ with documentation and a validation form to Virginia Department of Transportation (VDOT) personnel and others requesting it. Users were asked to apply the system and report their observations on the forms. The intent was to compile an exhaustive list of case applications to enhance the knowledge base. If necessary, respondents were to be contacted by telephone to clarify the data. The information sought included the appropriate input data for TRANZ and a description of the traffic control plan as implemented.

3. Performing research on related problems that interface with and affect the work zone traffic control problem—This would allow expansion of the system so that it encompassed a broader and more complete decision problem than the prototype covered. Issues considered included queuing and delays to traffic, traffic diversion strategies (facility demand management), detour alternatives, time of day for the work effort (including nighttime), delineation of traffic lanes through work zones, and worker safety (including applications of new technology).

4. Conducting a workshop with approximately eight experts on traffic management through highway work zones to finalize the initial validation of TRANZ for field applications.

The version of TRANZ used in Task 4 is a version that reflects the results of the first three tasks. Most of this paper will focus on the workshop (Task 4) because it was there that the status of the system as an aid to transportation practitioners was tested. The results represent a group consensus, whereas the prior tasks encompassed only individual inputs obtained in isolated instances. However, summary statements about the other tasks are provided.

EXPERT REVIEWS

The first step in the formal validation of TRANZ required the participation of the knowledge engineer, an expert, and two users. The first user was a novice safety engineer who was interested in using TRANZ in an office environment for consultation and learning. The second user was interested in seeing TRANZ used in seminars and short courses in freeway work zone safety.

There were two tests. The first applied to TRANZ to 11 problems that were used for a short course sponsored by the Virginia Transportation Research Council. To these 11 textbook problems, TRANZ gave correct solutions in all cases. This could be expected because the manuals were used in the development of the knowledge base, and no judgment was required beyond that given in the WAPM (5). The second test applied TRANZ to six actual problems that were provided

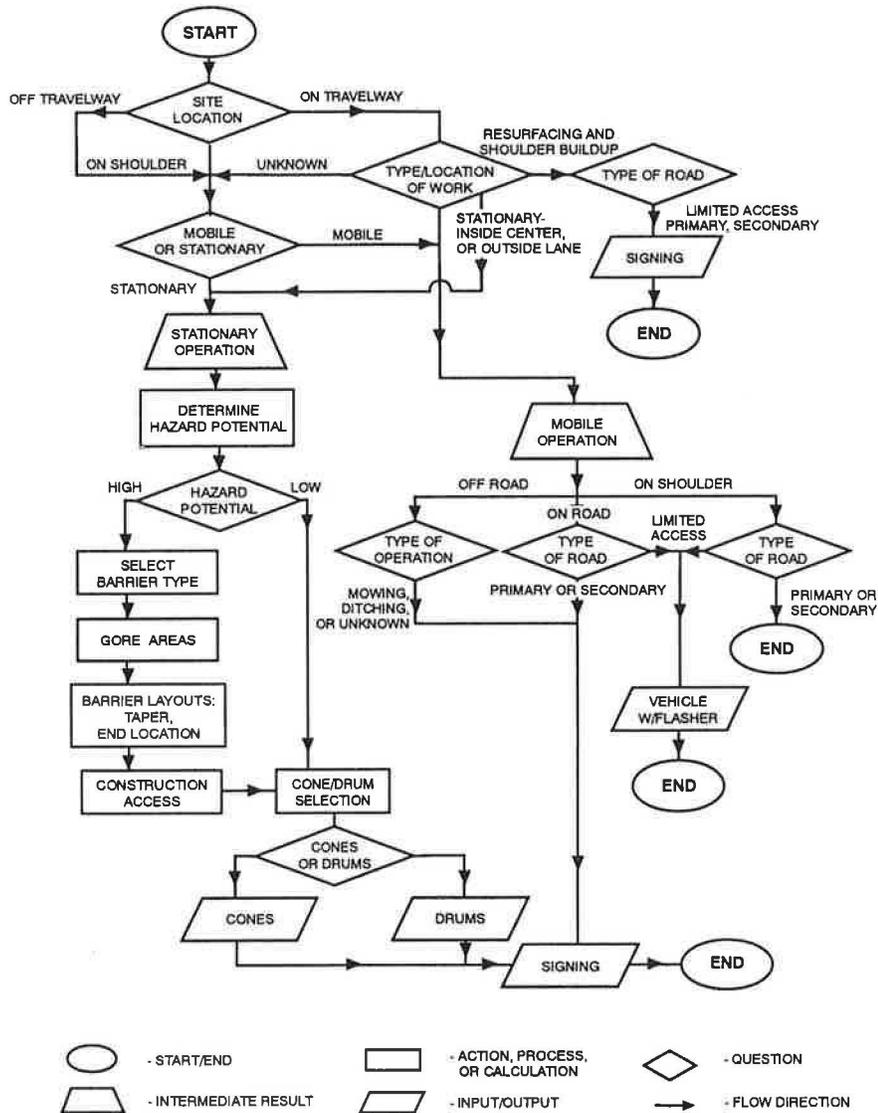


FIGURE 2 TRANZ decision framework.

by the Staunton District of VDOT. In this test, TRANZ and the expert disagreed in four of the six cases.

Bridge Deck Maintenance

Problem

A bridge deck operation is being conducted on a two-lane, two-way secondary road with ADT of 5,000 and an anticipated operating speed of 45 mph. This operation is being conducted off of the travelway with the accident factor *P* greater than 0.5 (*P* is the expected number of run-off-road accidents that will happen in the particular hazard time, *T*).

Results

In this case, the expert used temporary concrete traffic barriers but agreed that other devices recommended by TRANZ

would also be applicable. However, the expert pointed out the fact that TRANZ did not recommend any signs such as Construction Ahead or Reduce Speed Ahead.

Pavement Milling and Plant Mix Operation

Problem

A pavement milling operation on one lane of a four-lane Interstate highway.

Results

In this case, the expert agreed with all TRANZ's recommendations but thought that the recommended values should have been 9 on a scale of 0 (impossible) to 10 (certain), and TRANZ failed to recommend the necessary signs for this project.

Pipe Placement

Problem

This pipe replacement project is being conducted on a two-lane two-way secondary road. About 1,200 vehicles with an average speed of 45 mph traverse the site. The value of the accident factor P is greater than 0.5, and the operation is being conducted off of the shoulder.

Results

The expert completely agreed with TRANZ's recommended devices but mentioned TRANZ's failure to recommend the appropriate signs.

Excavation Project

Problem

Excavation activity with equipment near the roadway is being conducted on I-81 off of the shoulder. The operating speed of vehicles passing through the zone is about 60 mph, and the ADT is more than 15,000. The P value is greater than 0.5.

Results

The expert completely agreed with TRANZ's recommended device but mentioned TRANZ's failure to recommend the appropriate signs.

Mowing Operation

Problem

Mowing operation is being conducted on the inside shoulder of I-81. More than 150,000 vehicles are expected to pass through the work zone at an average speed of 60 mph. The P value is greater than 0.5 for this project.

Results

The expert completely agreed with TRANZ's recommendation.

Pavement Patching

Problem

Pavement patching on the inside lane of I-81. More than 15,000 vehicles are expected to pass through the work zone with an average speed of 60 mph. The P value is greater than 0.5 for this project.

Results

The expert completely agreed with TRANZ's recommendation.

The results of these six problems directed the knowledge engineer to modify TRANZ so that the system's recommendations would agree with the expert. Essentially, the disagreements were associated with the lack of signage in TRANZ's solutions. This is an easy modification to make.

This test was relatively simple in comparison with the evaluations that were accomplished in the workshop phase. However, these tests were beneficial in the early testing of TRANZ because significant improvements resulted from them.

DISTRIBUTION OF PROTOTYPE

One of the reasons EXSYS (6) was selected to develop TRANZ was that FHWA has a license for the run-time version. This made it possible for a limited number of copies of TRANZ to be distributed to potential users including members of state DOTs outside Virginia. Because TRANZ followed procedures used in Virginia and because procedures for directing traffic through or around highway reconstruction zones differ among states, the Virginia prototype was directly useful for practice only in Virginia. It would need to be modified for use in other states, notably California and New York. A form for documenting the problems to which TRANZ was applied was included in the distribution. Very few cases, however, were recorded on the forms and returned. It was concluded that this approach was unrealistic, and the workshop strategy was initiated to meet the objectives of both tasks.

PROBLEM INTERFACES WITH TRANZ

With given data on the job and roadway environment (condition descriptions), various options for traffic management are available. Any option will use information obtained from a series of appropriate analyses. TRANZ focuses on the traffic controls of the affected facility, but additional considerations are usually relevant. For example, the design of transit schemes for diverting traffic is not included in TRANZ. However, TRANZ does interface with detour considerations and construction work-hour choices. These three strategies reduce overall traffic on the facility during reconstruction. Given the final demand estimate and the condition descriptions that have been prepared exogenous to TRANZ, the system then defines the appropriate traffic control plan, aids in the evaluation of the adequacy of any proposed detour, and calls the QUEWZ program (7) to compute delay on the facility. If any components of the traffic management plan are inadequate, the analyst must go back and alter the demand plans to arrive at an acceptable plan. Once an acceptable strategy or traffic management plan is formulated, the safety of the traffic flow through the work zone should be evaluated. The capability to assess safety does not exist in the current TRANZ, but a simulation model similar to the QUEWZ program could be coupled with it to perform this task.

EVALUATION WORKSHOP

Eight transportation engineers from different divisions of VDOT were invited to attend a workshop for validating TRANZ. Five representatives from the traffic engineering, location and design, and construction divisions and three representatives from the district engineers offices participated. The Richmond Division Office of FHWA was also represented.

Before the workshop, copies of a notebook and a TRANZ disk were sent to the attendees. They were to familiarize themselves with TRANZ and the issues to be addressed. The attendees were requested to document applications (as in Task 2) for discussion at the meeting.

The results of the workshop were first stated in terms of both comments received and in terms of specific tasks that rendered a validated version of TRANZ.

General Comments

1. "The TRANZ expert system should be a very beneficial tool for engineers dealing with the development of traffic control plans . . . it should not replace the important aspect of engineering judgment and the knowledge and experience gained from the individuals who are responsible for the traffic control devices in the field. In other words, you should generally know what the answer will be before applying TRANZ." (This indicates a lack of confidence in TRANZ in that it should be used only by experts themselves as a check on plans. This concern should be lessened as experience with TRANZ is gained.)

2. "One . . . use [of TRANZ] could be to allow students in a classroom situation to solve some problems using the manual and some using TRANZ, or a combination of the two. Feedback from the instructor could then be an asset in considering further upgrades of TRANZ." (This is a necessary stage if TRANZ is to become a reliable tool.)

3. "Once the existing logic is refined, field-tested, and the bugs worked out, one desirable feature for consideration . . . would be the inclusion of graphics in both the screen as well as printed output." (This could be accomplished with the integration of a laser disk with TRANZ.)

4. "When the program is revised, it is recommended that the new software be provided to the districts for a further evaluation. This should be a good test for the system."

5. "Traffic engineering and location and design strongly support the program and we will be glad to assist in any way to implement the project."

These comments indicate that the attendees would not completely rely on TRANZ for controlling traffic in work zones. However, they also indicate a willingness and desire to work with TRANZ in the field and during instructional programs and thus to bring it along slowly while carefully validating it. These conclusions show the relatively long time needed to continue to validate and update an expert system until it correctly addresses a good majority of cases.

TRANZ deals with a very complex and open-ended problem. It will require a long period of testing and revision before it becomes a complete knowledge system. This clearly requires a continuing effort toward maintaining the expert sys-

tem, which is not normal for software developed and used only at the state level; but it is the norm for many federally supported software packages such as HCM and NETSIM, which are distributed and supported through McTRANS. Maintenance of an open-ended software package such as TRANZ is much more critical and consumes many more resources than maintenance for a conventional algorithmic program. Accordingly, this issue must be addressed when a state DOT plans for the development of an expert system.

Programming Modifications

Specific recommendations for improvements in the overall program derived from applications of TRANZ to real problems by experts included the following:

1. When the program was run, there was some uncertainty in selecting the option of whether or not the work crew was exposed to traffic. This operation should be given further explanation to ensure consistent application, preferably on the screen where the question is displayed. For example, "Does this mean before traffic control devices are installed?" or "Does this mean the crew will be working in the lane(s) of travel?"

2. Selecting Resurfacing and Shoulder Buildup as the type of operation on an Interstate resurfacing job does not give the desired level of work zone protection, but selecting Stationary Operation gave the desired result. The resurfacing option should be further explained so that the user will know up front when to select this option and precisely what it means.

3. In certain situations, it is not clear if the recommended devices are alternatives or are to be used in conjunction with one another. For example, on an Interstate lane closure, Barrier A, Temporary Concrete Parapet, Temporary Concrete Traffic Barrier Drums, and Temporary Asphalt Median all had a value of 9 on the output screen. Discussions at the workshop revealed that drums would be used in conjunction with the physical lane closure device but that a Type A device would not be used in conjunction with a Temporary Asphalt Median. Devices that are alternatives to one another should be clearly shown on the output.

4. Several recommended signs were indicated only by the code in the manual such as W20-7A or W4-2. It would be desirable to have a short verbal description with each recommendation.

5. The inclusion of QUEWZ is a favorable option. Perhaps the TRANZ manual could include the title page and summary pages ii and iii from QUEWZ as information for the operator who is unfamiliar with its use.

6. TRANZ should include quantities for the recommended traffic control devices.

7. New accident data for different classes of roads are used by the department to replace the single bar graph listed in the Work Zone Safety Short course Notebook for run-off-roadway accidents. Also, new values for different road systems by ADT levels are recommended to be used in the following formula:

$$p = f * t * l$$

where

- p = expected number of run-off-the-road accidents,
 f = accident frequency factor,
 t = particular hazard time, and
 l = length of hazardous fixed object (mi).

These changes should be made in TRANZ.

8. In the question-and-answer process of TRANZ, the following adjustments should be made: (a) define "Barrier A" in the answers as "concrete"; (b) define "Barrier B" in the answers as "guardrail"; (c) define terms "on travelway" and "off travelway," and (d) "travelway" perhaps should read "edge of pavement."

These are the key statements made by the panel concerning changes that should be made to clarify the TRANZ question-and-answer process. Appropriate corrections were made in the revised version of TRANZ.

Errors in Recommendations of TRANZ

TRANZ gave incorrect solutions to the following problems, according to the experts:

1. *Problem:* Interstate facility, ADT = 20,300 vehicles per day (VPD), operating speed = 68 mph; replacing existing concrete pavement, 2-mi segments, four lanes, close one lane while work is under way in the adjacent lane. *Solution:* TRANZ provides different traffic control devices for the inside lane and outside lane. WAPM 6-79 is used for the inside lane and WAPM 6-83 for the outside lane. In this problem, WAPM 6-83 should have been used for both inside and outside lanes. The only difference should be the messages on the signs. The WAPM does not provide a typical drawing for both the inside and outside lanes for the same type of construction. In other words, if the typical drawing indicates the inside lane, then the same drawing would apply to the outside with word changes on the signs.

2. *Problem:* Four-lane divided primary route, ADT = 40,000 VPD, operating speed = 35 mph; excavation of a 10-ft vertical drop trench in the median 3 ft from the edge of pavement, 15 ft wide, and 30 ft long. *Solution:* TRANZ indicates channelizing devices (Group 2 drums) as the solution. It appears that signing should also be included in this solution and in solutions to similar problems.

3. *Problem:* Limited-access roadway; on travelway, resurface and shoulder build-up operation. *Solution:* The sign layout provided is wrong. It should be the same as for a mowing operation.

4. *Problem:* Drop inlet existing in the median of a four-lane limited-access roadway; 30-day work operation is stationary and off the travelway; work crew is not exposed to traffic; operating speed = 55 mph; ADT = 37,500 VPD; hazard length = 0.3 mi. *Solution:* A minimum sign layout should be given that includes Roadwork Ahead and End Roadwork.

5. *Problem:* Stationary work off the travelway is being conducted for 120 days on a four-lane limited-access highway; the work crew is exposed to traffic; operating speed = 65 mph; ADT = 37,500 VPD. *Solution:* A barrier is specified

by TRANZ. A sign layout should also be displayed. Also, the distance from the traveled roadway should be considered. On some Interstates, this work could be within 25 ft of the traveled roadway.

6. *Problem:* Stationary work off the travelway is being conducted for 120 days on a four-lane primary highway; the work crew is exposed to traffic; variable operating speed = 55 mph; ADT = 30,000 VPD. *Solution:* Same as Solution 5 except on a primary highway. This work could be behind the ditch line but within 10 to 15 ft of the traveled roadway.

7. *Problem:* A stationary operation between the travelway and ditch line is being conducted on a four-lane primary highway for 120 days; the work crew is exposed to traffic; operating speed = 55 mph; ADT = 30,000 VPD; median width = 50 ft. *Solution:* Distance from the roadway should be a factor. This work could be anywhere from 1 to 20 ft from the edge of the pavement. If it were 1 ft, lights would be needed.

8. *Problem:* A stationary operation between the travelway and the ditch line is being conducted on a four-lane limited-access highway for 120 days; the work crew is exposed to traffic; operating speed = 65 mph; ADT = 37,500 VPD. *Solution:* When work is on an Interstate or divided primary, the left shoulder also needs to be considered. The program now assumes everything is on the right.

9. *Problem:* A stationary operation is being conducted off of the travelway on a four-lane Interstate highway for 120 days; a nonremovable fixed object near the travelway exists for 2.5 mi; the work crew is not exposed to traffic; operating speed = 65 mph; ADT = 43,130 VPD. *Solution:* If a barrier is specified, there should be a minimum sign layout of Road Work Ahead and End of Roadwork.

10. *Problem:* The work is a deck replacement on the inside lane of a four-lane limited-access highway; the work is to be done between 8:00 a.m. and 4:30 p.m. for 4 months; the length of the work zone is 300 ft; the work crew is exposed to traffic; operating speed = 65 mph; ADT = 35,000 VPD. *Solution:* The solution provides devices that are alternatives to one another, but it does not indicate what they are. The temporary asphalt median recommended is not likely to be used on an Interstate highway.

11. *Problem:* Resurfacing job on the travelway of the outside shoulder on a four-lane limited-access highway; the length of the work zone is 10,000 ft; the stationary work crew is exposed to traffic; the duration is 90 days; work is conducted between 8:00 a.m. and 4:30 p.m.; operating speed = 65 mph; ADT = 29,569 VPD; if barriers are used, access openings to the construction site will be used by work vehicles entering the main traffic flow. *Solution:* TRANZ provided an incorrect solution, according to the experts. The solution should include advanced construction signs, taper lane closure, drums or cones, 72-in. concrete barriers, and a flashing arrow. Selecting "stationary operation in the outside lane" gave the correct solution.

12. *Problem:* A one-way deck operation on Route 60, which is a two-lane undivided primary highway, between 8:00 a.m. and 4:30 p.m. for 120 days; the length is 400 ft for a stationary operation where the work crew is exposed to traffic; no access through the barrier is required; gore areas are not present; operating speed = 55 mph; ADT = 3,255 VPD. *Solution:* TRANZ specified a flagger, but in the actual case reviewed,

a temporary traffic signal was used; the solution gave Barrier B as an option, but these are not used on a bridge deck.

These changes resulting from the experts' use of TRANZ demonstrate how the basic prototype was expanded through testing. Specifically, the knowledge base was expanded by adding rules. Thus, this evaluation expanded and reexamined the knowledge acquisition process. A large rule base presents a complex set of possible outcomes based on the application of relevant rules. Incorrect recommendations are expected from prototype systems. The strategy used here can quickly expand the set of problems that a system addresses by way of direct expert input.

QUALIFICATIONS

At this time, TRANZ can be recommended as either a check on a plan for work zone traffic control in Virginia or as a first formulation of such a plan. If it is used as a first formulation, experienced engineers should continue to verify the recommendations from TRANZ until the user community is comfortable with the accuracy of TRANZ. In either case, TRANZ should replace at least one expert in the process and provide savings in time and costs. TRANZ can be used in short courses or as a pseudotutor for individuals who wish to become familiar with Virginia's WAPM. Because the WAPM's problems and solutions have been validated for TRANZ, it can help novices in learning to use it or substitute for it.

Since the purpose of the project from which TRANZ was developed was to demonstrate expert system applications in transportation engineering, the completion of TRANZ as a validated professional tool was beyond the scope of the effort. The present version of TRANZ meets the study objective by providing a case study that demonstrates

1. The development of an expert system, which incorporates standard engineering procedures with expert judgments and interpretations;
2. The programming complexities of combining rules, calculations, and external programs in a complete decision support system;
3. The need to identify the role of the expert system in a broad system decision framework (i.e., its interaction with other decisions and the assumptions governing the scope of the system);
4. The identification of inappropriate (voluntary) and appropriate (controlled) validation procedures; and
5. The identification of the continuing maintenance and support requirements necessary for an expert system to remain relevant.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study reveal that a complex expert system must be patiently developed until it behaves as an "educated expert." The evaluation of TRANZ revealed that it is difficult

to quickly develop a system that will accurately handle all possible permutations of a problem.

Widespread distribution of a prototype expert system with a request that users validate it resulted in little feedback. This pointed to the need for a structured validation process.

This case indicates that the application of a prototype expert system, rather than completely solving a problem, may actually show a need to expand the scope of the decision problem. Accordingly, the system design can be expanded to interface with complementary decisions. In this case, traffic control strategies are seen to be related to other traffic management strategies including detours, work-hour choices, and transit diversions.

Finally, an evaluation workshop should be seriously considered in the evaluation of any expert system. The workshop led to an expanded knowledge base rather than to corrections of TRANZ's logic. Accordingly, the validation process must focus on both the accuracy and the completeness of the expert system.

Overall, the effort in validation of an expert system that was discussed herein prompted the following summary recommendations for agency policy regarding expert system validations in the future.

1. Personnel and resources need to be budgeted for 3 to 4 years beyond the development of a prototype to continue to evaluate, support, and update the system.
2. Once a focused prototype is developed, it must be slowly modified; it cannot be accelerated.
3. The validation process should use the workshop as a focus to establish a core group of supporters to continue to work with the developer to apply the system and include it in appropriate training programs.

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