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16. Abstract

The development of a prototype knowledge-based expert system (KBES) for selecting appropriate traffic control strategies and management techniques around highway work zones was initiated. This process was encompassed by the steps that formulate the problem as an expert system: identification, conceptualization, implementation, and testing. The resulting EXSYS prototype system, TRANZ, is described in the report and demonstrated on the system disk. An alternative approach using the LISP programming environment was produced using a part of the TRANZ knowledge base for comparative purposes. This EXSYS prototype system is interpreted as the initial stage in the development of an expert system. Additional work that includes testing, validation, and verification is necessary before the system can be recommended to practitioners for professional applications.

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SI CONVERSION FACTORS

To Convert From	To	Multiply By

Length:

in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344

Area:

in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01

Volume:

oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01

NOTE: $1 m^3 = 1,000$ L

Volume per Unit Time:

ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05

Mass:

oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02

Mass per Unit Volume:

lb/yd^2	kg/m^3	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01

Velocity: (Includes Speed)

ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00

Force Per Unit Area:

lbf/in^2 or psi	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01

Viscosity:

cS_t	m^2/s	1.000 000 E-06
P^t	Pa·s	1.000 000 E-01

Temperature: $(°F-32)^5/9 = °C$

FINAL REPORT

A DEMONSTRATION OF EXPERT SYSTEMS APPLICATIONS
IN TRANSPORTATION ENGINEERING

VOLUME II

TRANZ: A PROTOTYPE EXPERT SYSTEM FOR
TRAFFIC CONTROL IN HIGHWAY WORK ZONES

by

Ardeshir Faghri
Research Scientist Assistant

and

Michael J. Demetsky
Faculty Research Scientist

(The opinions, findings, and conclusions expressed in this
report are those of the author and not necessarily those of
the sponsoring agencies.)

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ABSTRACT

The development of a prototype knowledge-based expert system for selecting appropriate traffic control strategies and management techniques around highway work zones was initiated. This process was encompassed by the steps that formulate the problem as an expert system: identification, conceptualization, implementation, and testing. The resulting prototype system, TRANZ programmed with the EXSYS shell, is described in the report and demonstrated on the system disk. An alternative approach using the LISP programming environment was produced using a part of the TRANZ knowledge base for comparative purposes. This prototype system is interpreted as the initial stage in the development of an expert system. Additional work that includes testing, validation, and verification is necessary before the system can be recommended to practitioners for professional applications.

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INTRODUCTION

The first volume of two reports on expert systems applications in transportation engineering was published by the VTRC in June 1987. Entitled "Transportation Engineers and Expert Systems," the report introduced the basic concepts and characteristics of expert systems to transportation engineers. Knowledge engineering, the process of building expert systems, was described, and the general differences between expert systems and conventional computer programs were explained (1).

This report describes the application of an expert system in transportation engineering. A prototype knowledge-based expert system (KBES) is presented that selects appropriate traffic control strategies and management techniques around highway work zones. This problem was selected because of the unstructured way that related decisions are made, which results from the fact that judgment and experience must supplement organizational guidelines in most situations.

The reasons for selecting this problem for an expert system are described. Next, the tasks that set the problem for coding into an expert system are presented with a case study. These steps include problem identification, conceptualization, implementation, and testing. The resulting EXSYS prototype system, TRANZ, is described and its working environment explained. An alternative approach using the LISP programming environment was produced using a part of the TRANZ knowledge base for comparative purposes. This prototype system represents the initial formulation of an expert system;

it must next be carefully tested, validated, and verified before it can be recommended to practitioners for professional applications.

Appendix A provides information for obtaining a copy of the Runtime version of TRANZ and directions for using it. The user can print out files from the program that serve as further appendices to this report. It is intended that this report and the program disk complement each other for a better understanding of both.

Problem Definition

The complexity and diversity of highway reconstruction zones necessitate that a variety of traffic-handling approaches be considered and utilized. The effectiveness of some of these traffic-handling approaches has been evaluated and documented. These results need to be collected, and recommended strategies need to be established for specific prevailing conditions. A coordinated and comprehensive effort to develop greater uniformity is desirable (2).

The characteristics of the problem of routing traffic through work zones that make it appropriate for a KBES model include:

o All procedures and techniques used for controlling traffic around work zones are not straightforward.

o Many tasks require the engineer to make judgments because the guidelines only provide options (available devices), and the final decision for a plan must be made by the engineer.

o Experts are available to develop the system's knowledge base.

o Many tasks require cognitive skills.

o Human expertise in the field is localized.

o A KBES could be used by many persons at many locations.

The knowledge base of this KBES for traffic control in highway work zones (TRANZ) is derived from a survey of the literature on existing techniques and approaches for handling traffic around highway work zones along with interviews with selected experts in charge of the planning and design of traffic control strategies for work zones in Virginia. For this problem, the expert considers (1) the different types of construction associated with roadways, (2) the techniques used to control traffic around different kinds of reconstruction sites, and (3) the classes of roadways involved.

The objectives for traffic control in maintenance work zones are (1) the protection of the freeway user and the work force, (2) the movement of the maximum traffic volume (minimization of delay), and (3) efficiency and economy in work procedures. These objectives are related to combinations of construction control and roadway factors when the appropriate controls are selected.

The intended users of this KBES are personnel in highway agencies, construction companies, and utility agencies and others involved in the planning and design of work zones. The purpose for using the KBES is to establish a uniform, rational practice for the execution of the previously mentioned objectives.

Translation into an Expert System

This report describes how the KBES approach is adapted to a specific problem. It complements the basic and fundamental literature on expert systems. The stages of knowledge acquisition and KBES development can be conceptually described, but they are not necessarily neat and well defined. These steps are referred to as problem identification, conceptualization, formalization, implementation, and testing and apply to the development of any expert system.

PROBLEM IDENTIFICATION STAGE

Prior to acquiring knowledge for a KBES, the important dimensions of the problem are characterized. This involves identifying the participants, problem characteristics, resources, and goals (3).

In the development of TRANZ, the participants were selected and their roles defined. Mr. Faghri served as the knowledge engineer. The selection of the domain expert(s) for this project, however, was a complicated process. First, the possible candidates who work as full-time employees of the Virginia Department of Transportation in different districts and are directly in charge of the task of selecting traffic control devices and management strategies for work zones were contacted. After initial telephone conversations, a two- to three-hour interview was conducted with each candidate, which reduced the list of experts to three. It was then decided to build the prototype system by interacting directly with one of those experts and then to get advice and comments from the other two. Some in-house help was also provided by the professional staff at the VTRC who have been involved in research and the teaching of short courses in the area of traffic control and safety issues regarding highway construction and maintenance work zones.

The principal expert for this task has been directly involved in selecting and implementing appropriate traffic control strategies around highway construction/maintenance zones and employs experience-based heuristics and rules of thumb that normally cannot be found in guidelines or publications. Before the first meeting between the expert and knowledge engineer took place, an extensive survey of the literature on the subject of traffic control around highway work zones was conducted by the knowledge engineer, and a small version of the prototype microcomputer-based KBES was used to illustrate the nature and objectives of this undertaking to the expert.

The knowledge engineer met with the expert to discuss the objectives of the project and to identify the expert's role in the development of a knowledge base. Several iterations of the problem definition were necessary

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since the original problem was excessively large and unwieldy. The several issues addressed in the problem identification process are described in the following sections.

Problem Definition

The traffic engineering problem that the system addresses requires the selection of appropriate traffic control measures and management strategies for protection of the freeway user and the work force as well as the provision for the movement of the maximum traffic volume around work zones on limited access, primary, and secondary highways. In current practice, the supervising engineer is usually responsible for the final selection of control measures and techniques based on his experience and knowledge of the different devices described in the Manual on Uniform Traffic Control Devices (MUTCD) (4). The channelization devices described in Part VI of the MUTCD have evolved from experience rather than as a result of scientific testing as to what best stimulates driver awareness of work zone situations (5). Several recent publications have reported on the effectiveness of different control devices based on scientific research and testing (5,6,7). The KBES developed here encompasses the results of these publications, and in particular the Virginia Work Area Protection Manual (8), in conjunction with the experience and knowledge of the domain expert who selected specific control devices and techniques for different construction and maintenance projects.

Characterization of the Problem

A certain maintenance project, for instance, may involve rehabilitating the deck of a bridge on a busy urban freeway. The nature of the construction project underway, the volume of traffic on the roadway during both off-peak and peak hours, the characteristics of the road, and the anticipated amount of time the project will take are examples of the types of information that the system requests from the user. Another typical maintenance project may require the closure of a lane for 48 hours. Furthermore, the roadway on which the maintenance is being conducted may be located near a drop-off. The system will first try to determine whether or not the drop-off that is located near the roadway constitutes a hazard for the traffic and/or the work crew. Questions regarding considerations such as the distance of the drop-off from the shoulders of the roadway, the slope of the drop-off, the depth of the drop-off, the operating and the posted speeds, and the volume of traffic will be asked by the system regarding these possible hazards. The system will also query the user regarding the type of roadway (limited access, primary, nonlimited access, secondary) and the position of the closed lane (inner lane, center lane, or outer lane). After obtaining sufficient information from the user, the system recommends a set of devices along with other specific information, such as the height and spacing of each device.

The Data

The necessary types of data are from three basic groups. The first deals with the nature of the project itself. Information such as the anticipated length of time for the project, the anticipated size of the work

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force, and the type of project such as pavement marking, ditching, and lane closures are examples of the first category of descriptive data. The second type of data is information on the roadway involved. These data are usually maintained on a computer data base of the state DOT. The third category of data includes environmental factors surrounding the project. In this category items such as the season of the year, temperature, and information regarding potential pedestrian-generating facilities such as schools and shopping centers in the vicinity of the project are included. Table 1 summarizes these three basic categories of data and typical items for each category.

Table 1

The Three Basic Data Categories for TRANZ

Road Parameters	Construction Parameters	Environment
Traffic	Nature	Season
Geometry (alignment)	Mobility	Temperature
Condition	Length (Time)	Vicinity
	Crew Size	
	Length (in feet)	

Base of Knowledge and Human Expertise

The knowledge necessary for selecting appropriate traffic control measures for highway work zones can be grouped into three independent but interrelated categories:

1. A familiarity with the MUTCD (4). Chapter VI of the MUTCD establishes principles to be observed in the design, installation, and maintenance of traffic control devices and prescribes standards where possible. Some states have slightly modified the MUTCD to better suit their own needs. In the state of Virginia, for example, The Virginia Work Area Protection Manual (8) is used for the purpose of controlling traffic around highway construction/maintenance zones. This manual is the primary knowledge base for the prototypic version of TRANZ.

2. An up-to-date knowledge of the currently available scientific publications that deal with testing and evaluating different traffic control devices and techniques for highway work zones.

3. An experienced interpretation of problems through the intuitive use of heuristic judgments and rules of thumb for situations where guidelines and available procedures are of little use. Each construction project is unique, and only an expert experienced in selecting appropriate measures can employ heuristics and rules of thumb to make the most effective and useful decisions.

Situations That May Impede Solutions

TRANZ has been designed in such a way that if the user does not have the piece of data requested by the system, he or she can simply respond with "information not available" to the system's prompt. However, there are five important pieces of data that the user must provide in order for the system to recommend the absolute minimum number of devices and strategies needed for a particular project. These are operating speed, posted speed, volume, type of highway, and at least one potential hazard that exists near the work zone project. Without these five basic variables, TRANZ will not operate.

CONCEPTUAL ANALYSIS

The key concepts and relations identified during the identification stage are made explicit during the conceptualization stage.

Availability of Data

As mentioned in the previous section the three types of data that are required for this system are information on the type and the nature of the construction project, relevant information about the roadway on which the construction is being conducted, and data concerning the project's environment. All of the relevant information about the roadway that was required by TRANZ was extracted from Virginia's road inventory system.

The types of data for operating TRANZ are reduced to numerical and symbolic categories. In the numerical category, items such as speed, volume, and depth of a drop-off are included. The symbolic data include, for example, the nature of an obstruction or the type of activity centered around the project. It is the latter type of data that the expert systems approach can handle more easily than can conventional programming strategies.

Table 2 shows examples of some of the categories and subcategories of construction types, road types, environment, and techniques that are subsequently integrated into the system using KBES tools.

Table 2

Examples of Categories and Subcategories of Data

Road Parameters	Construction Parameters	Environment
Traffic	Nature	Season
-volume	-pavement marking	
-operating speed	-pavement patching	Temperature
-posted speed	-mowing	
-composition of trucks	-ditching	Vicinity
-composition of buses	-painting	-school
		-mall

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Table 2, continued . . .

Geometry	Mobility	-church
-vertical alignment	-mobile	-hospital
-horizontal alignment	-stationary	
-superelevation	-moving	Pedestrians
-number of lanes		

Length (time)

Condition
-poor pavement   Crew Size
-potholes

Length (in feet)

Vicinity
-near a ditch, drop-off
-shoulders

Some of the relationships between objects in the domain are as follows:

o   relationship between high traffic volume and types of traffic
    control required
o   relationship between types of maintenance operations and types of
    traffic control required
o   relationship between road types and types of traffic control
    required.

Processes Involved in the Problem Solution

After the necessary information for a project has been acquired, the
system recommends a set of candidate solutions together with a rating of the
relative potential of utilization and application of each solution. The
problem solution process consists of the following major steps:

1. Acquire all the necessary information for each project. The system
    will obtain this information by asking questions such as: What is
    the percentage of trucks on the road where the work effort is taking
    place? or What is the 85th percentile operating speed on the roadway
    in question?

2. Answer the relevant questions that the user may ask. At any stage
    the user may need to know why a certain question is being asked.
    The system will then explain in detail why that particular question
    was asked.

3. Determine the interrelationships between variables and store them in
    the system's memory. All the relevant quantitative data for each
    project will be integrated and saved in the system's dynamic memory
    before the final conclusion is reached.

4. Develop the final list of devices and/or strategies that are
    appropriate for each construction/maintenance project.

FORMALIZATION

Formalization involves expressing the key concepts and relations associated with the problem domain in a formal way, usually within the framework suggested by the language of a KBES. Thus the knowledge engineer should have some ideas about appropriate tools for the problem by the time formalization begins (9). The important tasks carried out during the formalization process are discussed below.

Selection of Tools

The implementation of a KBES for handling traffic around construction zones requires the selection of a programming language and/or knowledge engineering language. The tools selected had to be microcomputer-based because of the unavailability of or lack of access to mainframe computers in many highway and utility departments. As a result, the following tools were selected:

o EXSYS (10) is used to implement the aforementioned problem in the form of a production system. The rules that the program uses are of the IF-THEN-ELSE type. A rule is made up of a list of IF conditions (normal English sentences or algebraic expressions) and lists of THEN and ELSE conditions (more sentences) or statements about the probability of a particular choice being the appropriate solution to the problem. If the computer determines that all of the IF conditions in a rule are true, it will add the rule's THEN conditions to what it knows to be true. If any of the IF conditions are false, the ELSE conditions will be added to what is known. The computer determines what additional information it needs and how best to get it. If possible, the program will derive information from other rules rather than asking the user for more data. This ability to derive information allows the program to combine many small pieces of knowledge to arrive at logical conclusions about complex problems. The rule editor allows rules to be easily modified, added, or deleted. In addition to the IF-THEN-ELSE part, each rule can have an optional NOTE and REFERENCE associated with it. The NOTE and REFERENCE are displayed whenever the rule is displayed. The NOTE and REFERENCE have no effect on the running of the rule and are only for the user's information. The reference part of the rule is especially useful for the traffic control problem since a great deal of the information, particularly the graphical illustrations, are obtained from references such as the MUTCD and other publications.

o The Salford LISP programming environment on a PRIME mainframe computer was used to develop an abridged version of TRANZ to compare with the EXSYS program. Here both the knowledge base and inference engine were completely programmed. This LISP system used a frame representation of the knowledge base, while EXSYS used a rule-based representation of it.

Formalization Process

After the appropriate tools were selected, the available knowledge was formalized within the framework suggested by the languages.

The factors that must be considered in designing appropriate traffic control configurations are identified and formalized into knowledge by representing the expert's decision process for the problem. The two major sources of information for practicing engineers in Virginia for developing work zone traffic controls are the Virginia Work Area Protection Manual and supporting material on channelization (8). The next two sections summarize the major factors included in this knowledge base for (1) barrier selection, and (2) general layout (signing, delineating, flagging, etc.)

Barrier Selection Criteria

This section illustrates the technical considerations that are used in TRANZ for barrier selection.

1. Determine the variables.

o Speed: The anticipated 85th percentile operating speed must be used in all calculations.

o Volume: Volume is expressed as the average daily traffic (ADT) volume expected to traverse the construction zone, as predicted by preconstruction data.

o Hazard time (t): Hazard time, expressed in years, is the most realistic estimate available of the time that fixed objects or work crews will be near the travel way. Thus, a new bridge pier might be a hazard from the first excavation until it is finally protected by permanent guardrails or a concrete median barrier. However, an excavation for a culvert may be hazardous for only 18 days (0.05 year) even though the total project would continue for 180 days (0.5 year). If this excavation is the only anticipated hazard in this part of the construction zone, the actual time (0.05 year) should be used. Also, stationary work crews (such as a crew at a bridge repair site) are treated as fixed objects. This practice ensures that workers are protected even in the absence of other hazards to vehicles. Even though crews are normally exposed fewer than 24 hours per day, one full day should be used for each work day when computing t. This will add a margin of safety for the crew and provide for the equipment normally stored near the work area overnight, if it cannot be safely stored elsewhere.

2. Determine the locations of all nonremovable fixed objects and work crews hazardously close to the road.

o Clearance guide (C): Examples of fixed objects are listed in Table 3.

-- Measure the distance to the nonremovable fixed object from the edge of the travelway to the near edge of the object, d(fixed) (see Figure 1).

-- Next, enter the clearance (C) guide to fixed objects by using the anticipated speed and find the hazard distance (c) by using Figure 2.
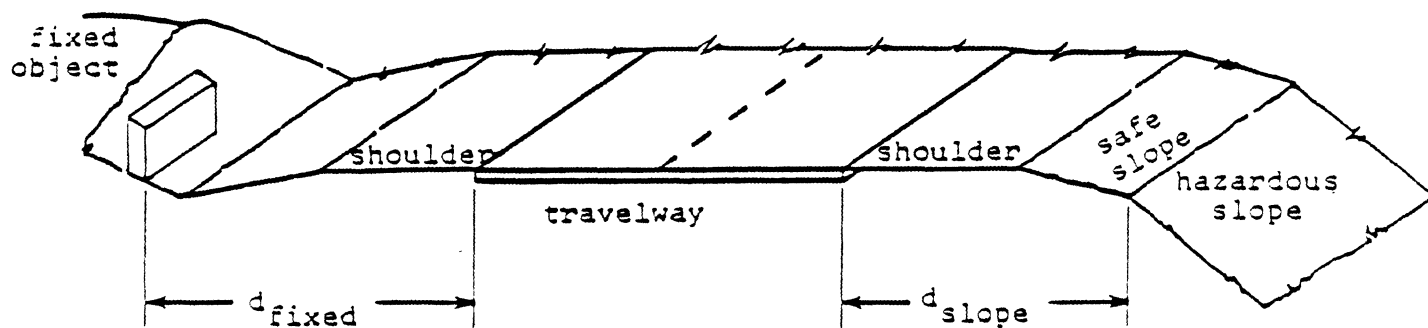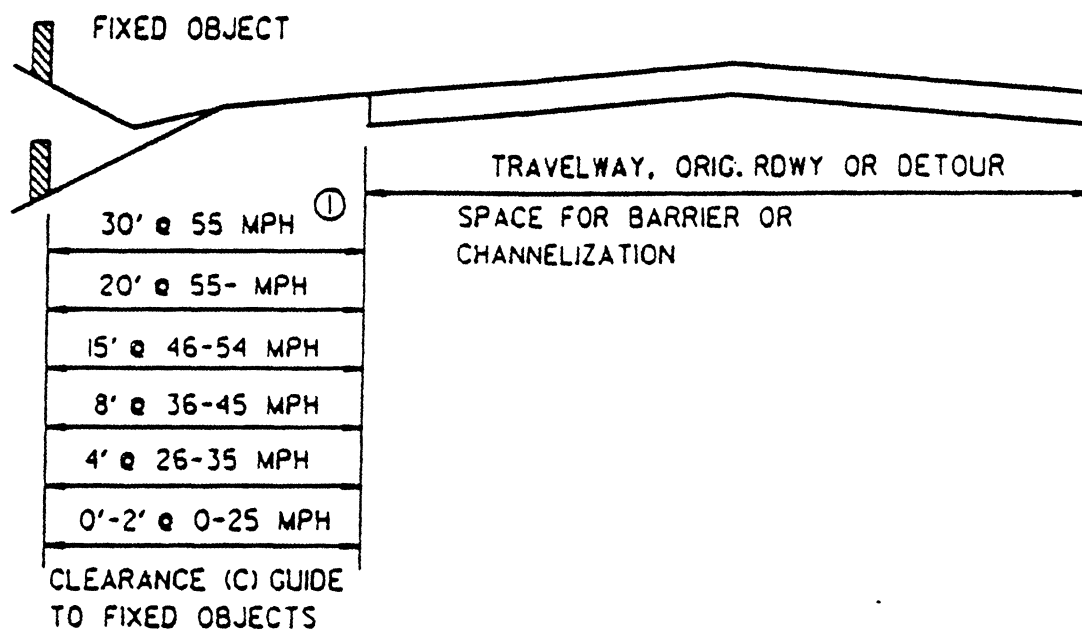
Figure 1. Exhibition of Dfixed and Dslope.
Source: Virginia Work Area Protection Manual: Standards and Guidelines.

Figure 2. Clearance guide.
Source: Virginia Work Area Protection Manual: Standards and Guidelines.

-- If <u>d(fixed)</u> is less than <u>c</u>, then the object should be considered hazardous.

Table 3

Examples of Fixed Objects

1.	Headwall	9.	Slope
2.	Parapet	10.	Equipment
3.	Manhole	11.	Open excavation
4.	Guardrail end	12.	Sign poles and bases
5.	Stored material	13.	Bridge pier
6.	Barrier ends	14.	Box culvert
7.	Drop inlet	15.	Any other object considered
8.	Pipe		damaging to a moving vehicle

o <u>Slope guide (S)</u>: Combination of steep slopes and sizable depths are also treated as fixed objects.

-- Determine the slope of the ground that leads to any ditches, drop-offs, etc. near the road. If the slope is flatter than 3 to 1, it may be disregarded.

-- For slopes greater than 3 to 1, if the depth is greater than shown on the right side of Figure 3, the slope is treated as a fixed object.

-- Measure the distance from the road edge to the top of the slopes, <u>d(slope)</u> (see Figure 1).

-- If <u>d(slope)</u> is less than (<u>c</u>) from the clearance guide, the slope should be treated as a hazardous fixed object.

3. Determine the expected frequency (<u>p</u>) of run-off-the-road accidents near the hazardous objects or work crews.

o <u>Fixed object length (L)</u>: For the purposes of computing the probability that an errant vehicle will encounter a fixed object, the length of the hazardous fixed object, <u>L</u>, must be measured. If the hazardous fixed object is shorter than 0.2 mile, then TRANZ sets <u>L</u> = 0.2 mile when computing <u>p</u>. For example, if a bridge abutment is 36 ft long, TRANZ sets <u>L</u> = 0.2 mile, but an excavation of 0.3 mile has <u>L</u> = 0.3 mile. Anytime work crews are exposed to traffic, TRANZ sets <u>L</u> = 0.2 mile (minimum requirement) whether or not other hazardous objects are near the travelway. If there are multiple short fixed objects near the travelway that violate clearance, <u>C</u>, simply ignore all such objects within 0.2 mile for an included object when computing <u>L</u>. Say, for example, objects a, b, c, d, and e in Figure 4 are fixed and will violate clearance, <u>C</u>, during the same time span, <u>t</u>. Once object a is counted as having <u>L</u> = 0.2, then object b need not be counted. Similarly, once object c is counted, d and e may be ignored when computing <u>L</u>. Add up all the <u>L</u>'s.
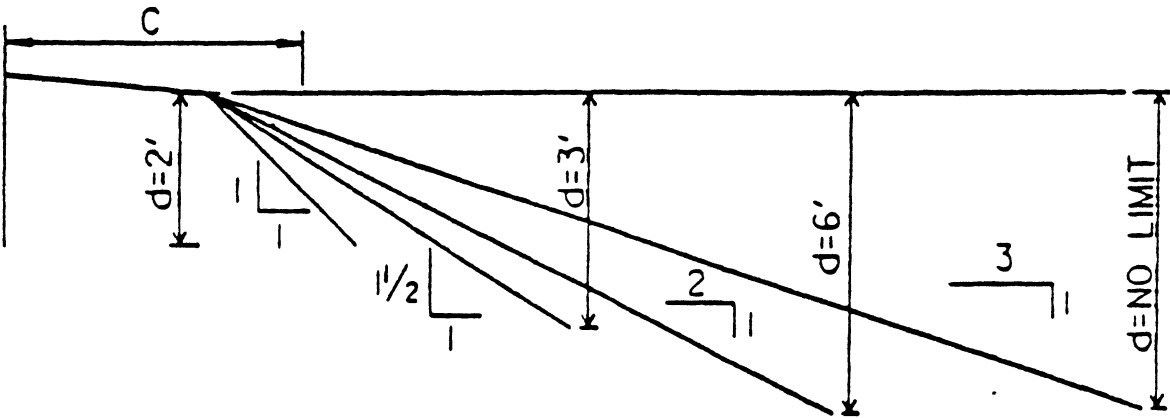
Figure 3. Slope and depth.

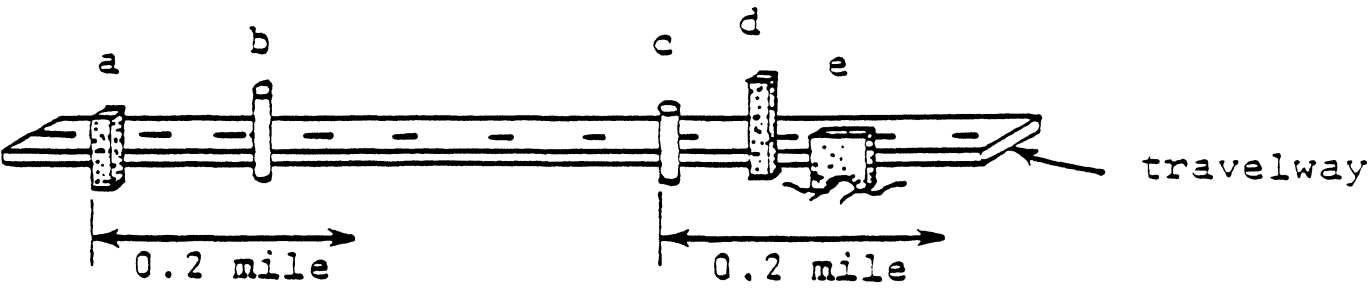Source: Virginia Work Area Protection Manual: Standards and Guidelines.

Figure 4. Distance of fixed objects.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

In this example, the total L equals 0.4. Then, compute the fixed object length L on only one side of the road at a time. A separate decision regarding barriers must be made for each side of the road.

o Accident Frequency Factor (Figure 5): Using the ADT volume for the length of highway under consideration, TRANZ computes the accident frequency factor using the following equations:

ADT ≤ 12,000

$$y = SQRT ((1 + \frac{(x-15)2}{225})324) \quad \text{elliptical}$$

ADT > 12,000

$$y = \frac{6}{5} (x - 47) + 60 \quad\quad \text{Linear}$$

These equations were derived from Figure 5. When 4-lane traffic or divided highways are involved, TRANZ reduces the ADT volume by half before calculating the accident frequency factor since opposing traffic cannot physically cross into other areas, or the traffic is sufficiently clear (C) of the hazard.
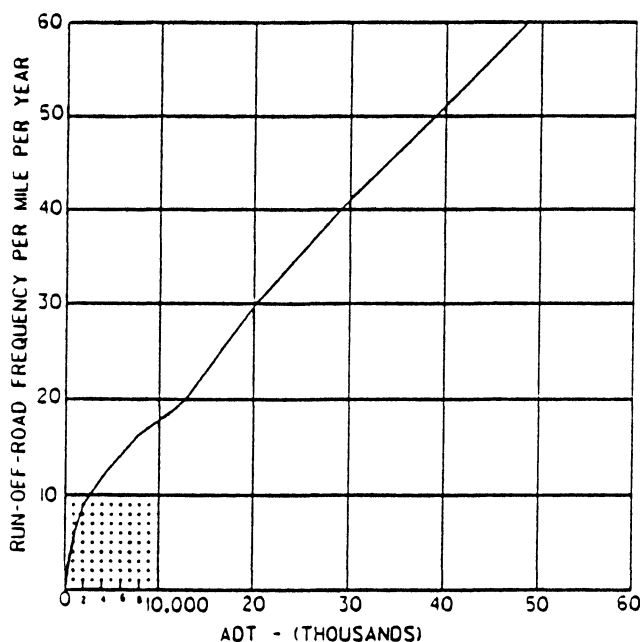

Figure 5. Frequency factor curve for average generalized conditions (statewide) for run-off-the-road accidents in construction zones. Data are for 2-way ADT. When applying chart to 4-lane undivided and to divided roadways, reduce ADT by one-half before entering chart.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

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It is instructive to note that Figure 5 was generated from actual accident experience in the state of Virginia. Since research has indicated that only one in six run-off-the-road incidents results in a recorded accident, the Virginia experience was multiplied by six. Other Virginia researchers indicated that in construction zones, accident rates double so another factor of two was applied to the statistics before the curve was plotted (8).

o Accident factor (p): $p = f \cdot t \cdot L$. The expected number of run-off-the-road accidents, p, that will happen in the particular hazard time, t, is computed by multiplying $p = f \cdot t \cdot L$, where f is the accident frequency factor in accidents per mile per year, and L is the length of the hazardous fixed object in miles. Values of p that are less than 0.5 indicate the chances of an accident in the hazardous part of the construction zone are less than one per zone; therefore, no barriers are warranted.

4. In the event that p is less than 0.5, proper control devices from Group 1 or 2 shown in Figure 6 should be used until the road alignment, signing, and marking are up to final standards.

5. In the event work crews are exposed or (C) or (S) is violated and p is more than 0.5, Figure 7 cites the proper barrier or channelizing device(s) from Figure 6 that should be employed until the violation is cured. When using this figure, the device indicated in the lower right corner of the block must be used unless the hazard is an excavation (within the clearance C) with a depth of 6 in to 2 ft. In this case, the device indicated in the upper left segment of the chart must be used. Figure 7b states that a type A barrier is the most positive type and may replace any other. However, it may not be used when Group 1 or 2 is indicated.

6. Concrete Parapet Service, shown in Figure 8, bolted to the bridge deck should be used to serve as a temporary parapet for vehicular traffic where the permanent parapet is being installed or where the parapet has been removed. Also, concrete traffic barrier service in Figure 8 should serve as a traffic separator or to separate traffic from a work area. The channel bolted to the deck is required only for separating traffic lanes in opposite directions or on surfaces superelevated at a rate greater than 3/4 in per foot. Figure 9 shows the flowchart for the selection of group 1 and group 2 control devices.

Traffic Control Configurations

General guidelines used in TRANZ for selecting different traffic barriers were described in the preceding section. Devices used for the overall traffic control configuration are illustrated in the Virginia Work Area Protection Manual: Standards and Guidelines. These configurations are classified according to the following factors.

1. Type of work effort: This includes maintenance operations such as pavement marking, mowing, ditching, excavating, or any other project that requires the closure of shoulder, inner lane, center lane, or outer lane to traffic.
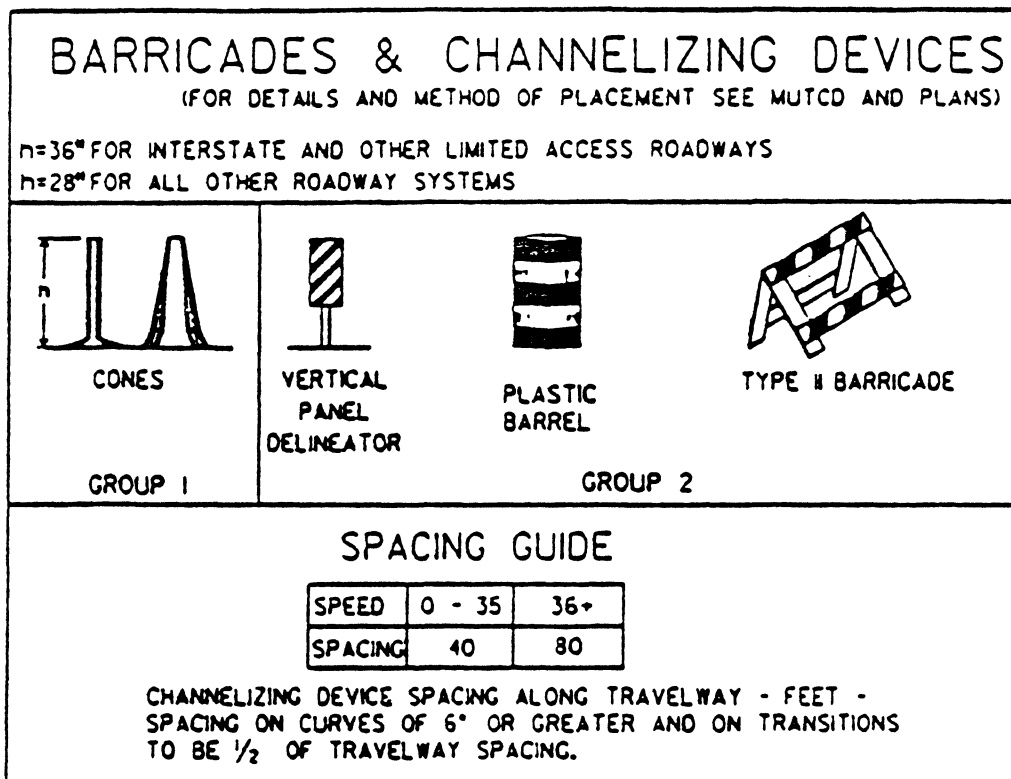
BARRICADES & CHANNELIZING DEVICES
(FOR DETAILS AND METHOD OF PLACEMENT SEE MUTCD AND PLANS)

h=36" FOR INTERSTATE AND OTHER LIMITED ACCESS ROADWAYS
h=28" FOR ALL OTHER ROADWAY SYSTEMS

CONES

VERTICAL
PANEL
DELINEATOR

PLASTIC
BARREL

TYPE II BARRICADE

GROUP I

GROUP 2

SPACING GUIDE

SPEED	0 - 35	36+
SPACING	40	80

CHANNELIZING DEVICE SPACING ALONG TRAVELWAY - FEET -
SPACING ON CURVES OF 6° OR GREATER AND ON TRANSITIONS
TO BE ½ OF TRAVELWAY SPACING.

Figure 6.   Group 1 and Group 2 devices.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

TYPES OF BARRIERS
(Fixed Object Class)

FOR DETAILS - SEE PLANS

ALPHABETICAL LISTING OF BARRIERS IS IN
ORDER OF POSITIVE REDIRECTION CAPABILITY.
INSTALLATION IS TO BE IN ACCORDANCE
WITH THE ROAD DESIGNS AND STANDARDS.

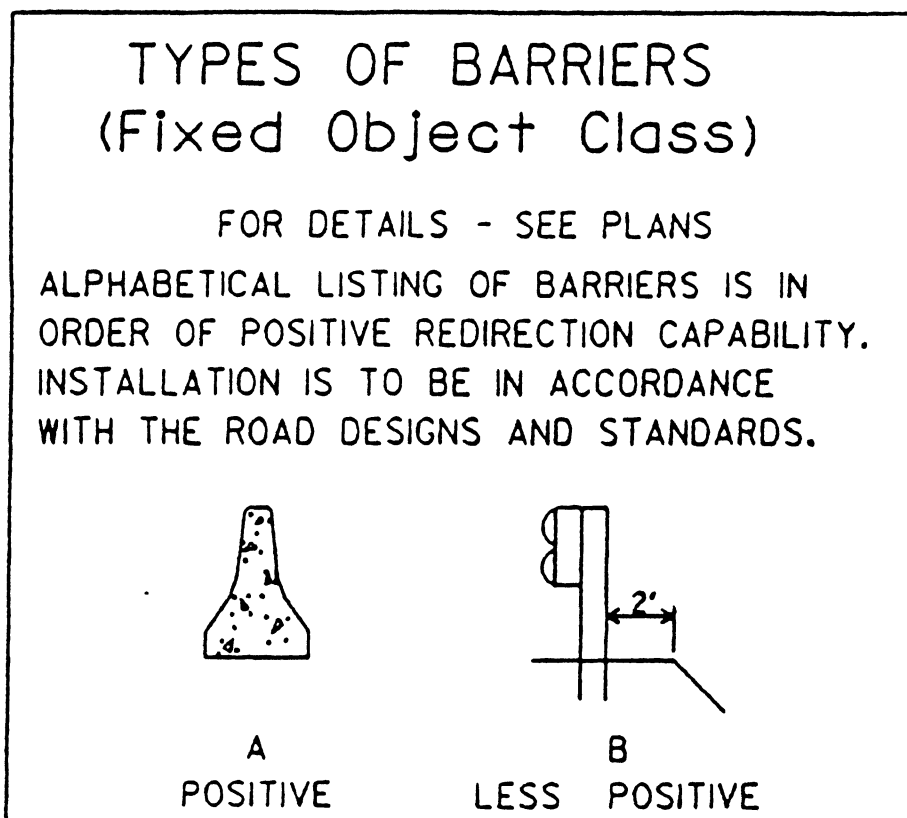A
POSITIVE

B
LESS POSITIVE

Figure 7a: Barrier-channelizing device chart.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

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BARRIER-CHANNELIZING DEVICE CHART

	AVERAGE ANTICIPATED OPERATING SPEED				
EXISTING TRAFFIC VPD	0-25	26-35	36-45	46-54	55+
0-750	1,2 / 1,2	1,2 / 1,2	1,2 / 1,2	1,2 / 1,2	1,2 / 1,2
751-5500	1,2 / 1,2	1,2 / 1,2	1,2 / 1,2	1,2 / B	B / B
5500-15000	1,2 / 1,2	1,2 / 1,2	1,2 / D	B / B	B / A
ABOVE 15000	1,2 / 1,2	1,2 / 1,2	1,2 / B	A / A	A / A

A MORE POSITIVE TYPE OF BARRIER CAN BE SUBSTITUTED FOR VALUES SHOWN.

Figure 7b: Fixed object class.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

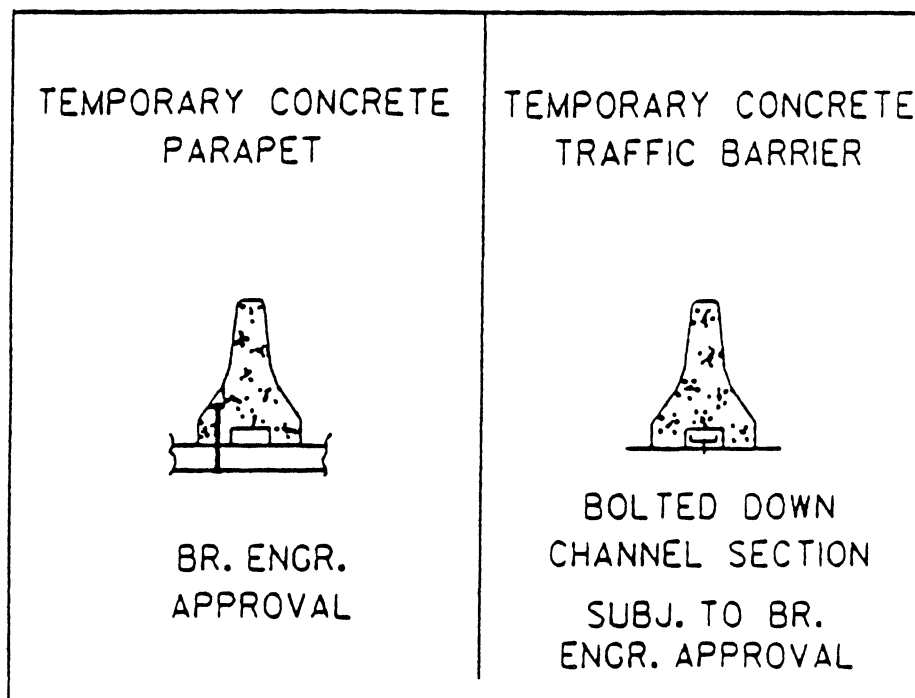| TEMPORARY CONCRETE PARAPET	TEMPORARY CONCRETE TRAFFIC BARRIER
BR. ENGR. APPROVAL	BOLTED DOWN CHANNEL SECTION SUBJ. TO BR. ENGR. APPROVAL

Figure 8.   Temporary parapet/barrier for bridge decks.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

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DETERMINATION OF BARRIER / CHANNELIZATION DEVICES

DETERMINE TRAFFIC VOLUME
DETERMINE OPERATING SPEED
DETERMINE TYPE OF CONSTRUCTION

CHECK CONSTRUCTION ZONE
FOR FIXED OBJECT. USE
CLEARANCE (C) AND SLOPE
(S) GUIDES.

NO FIXED OBJECTS

FIXED OBJECT

REMOVE FIXED OBJECT

FIXED OBJECT NOT REMOVABLE

USE APPROPRIATE
CHANNEL DEVICE

DETERMINE ACCIDENT
EXPOSURE FROM FREQUENCY
FACTOR CURVE.
ACCIDENTS / YEAR / MILE

APPLY LENGTH OF CONSTRUCTION
ZONE (MIN. 0.2 MI.*) AND ESTIMATED
DURATION OF CONSTRUCTION ACTIVITIES
IN TERMS OF YEARS OR PORTION THEREOF.

★ MINIMUM LENGTH IS APPLICABLE
TO SINGULAR TYPE FIXED OBJECTS
SUCH AS HEADWALLS, PIERS, AND
SMALL WORK SITES.

IF ACCIDENT FACTOR IS GREATER THAN
0.5. DETERMINE BARRIER TYPE NEEDED
FROM BARRIER-CHANNELIZING DEVICE
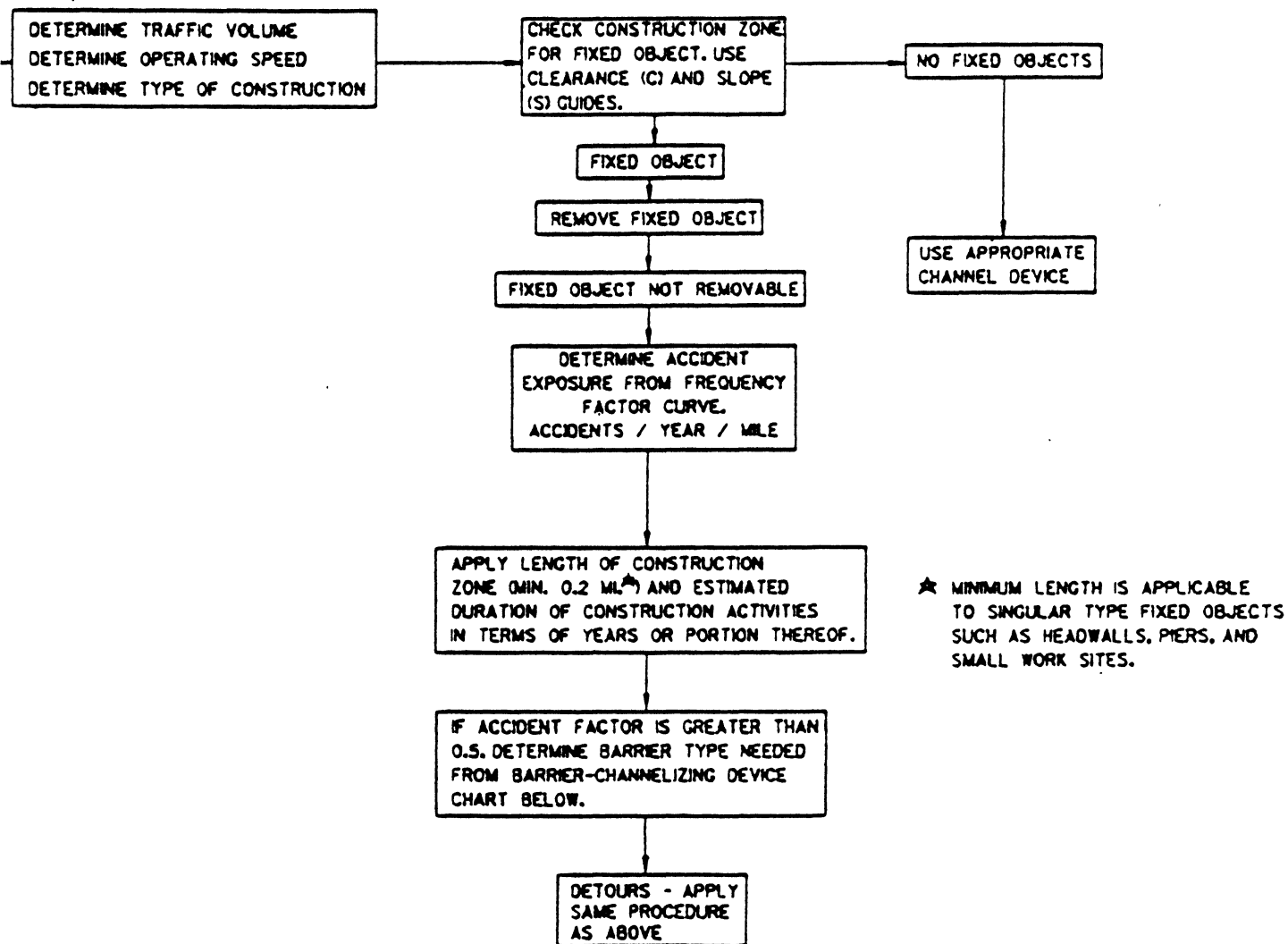CHART BELOW.

DETOURS - APPLY
SAME PROCEDURE
AS ABOVE

Figure 9. Flowchart for Group 1 and Group 2 control devices.
Source: Virginia Work Area Protection Manual: Standards and Guidelines.

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2. <u>Type of roadway involved</u>: This category includes primary, secondary, and limited access highways.

Rules based on these recommended configurations for specific work tasks constitute the basic rules in TRANZ. Figure 10 illustrates the delineation of a typical maintenance operation.

IMPLEMENTATION

The formalized knowledge was developed into two working computer programs using EXSYS and LISP. The domain knowledge acquired in the formalization stage was reduced to two different types of KBES representation schemes. For EXSYS, the knowledge was codified into a production system in the form of IF-THEN-ELSE rules. The LISP programming environment was used to represent the same knowledge in the form of a frames representation scheme with a forward chaining control strategy (<u>3</u>). The LISP version of TRANZ was developed to investigate the utilization of frame representation strategy for this problem and also to compare the efficiency and utility of the two programs. It was not carried to the full prototype stage as was done with EXSYS. The details of the LISP program are described in <u>Computerization of Heuristic Decisionmaking Problems in Transportation Engineering</u> (<u>11</u>).

Development of TRANZ by EXSYS

The EXSYS version of TRANZ consists of some 107 rules in the form of IF-THEN and IF-THEN-ELSE. The backward chaining technique was used for TRANZ's control strategy. Appendix A describes how to obtain a listing of the rules, qualifiers, traffic control devices and variables used in TRANZ for reference. The following strategies were taken during the programming.

1. <u>Data structure</u>: EXSYS provides the option to structure the data in one of three modes of probability. The three modes are: (a) simple yes or no; (b) a range of 0-10, where 0 indicates absolutely not and 10 indicates absolutely certain (1-9 indicates degree of certainty); and (c) a range of -100 to +100 indicating the degree of certainty. Mode a was not suitable, and the problem did not seem to require the complexity of mode c; therefore, mode b, which allows probability values between 0 and 10, was selected.

2. <u>Selection of choices</u>: EXSYS calls the possible solutions the user is going to select among CHOICES. There can be a very large number of choices. The maximum is governed only by the available memory. The choices in TRANZ include 61 different traffic control devices and management strategies for highway work zones. A sample of how these choices are presented in TRANZ is shown in Figure 11. The complete list of the choices is presented in Appendix B which can be obtained from the TRANZ disk.

3. <u>Qualifiers and values</u>: The rules in EXSYS are made of CONDITIONS, which are just sentences. These conditions are often made of QUALIFIERS and VALUES. The qualifier is the first part of the sentence (usually to the verb) and the values are the possible completions of the sentence. There are eleven
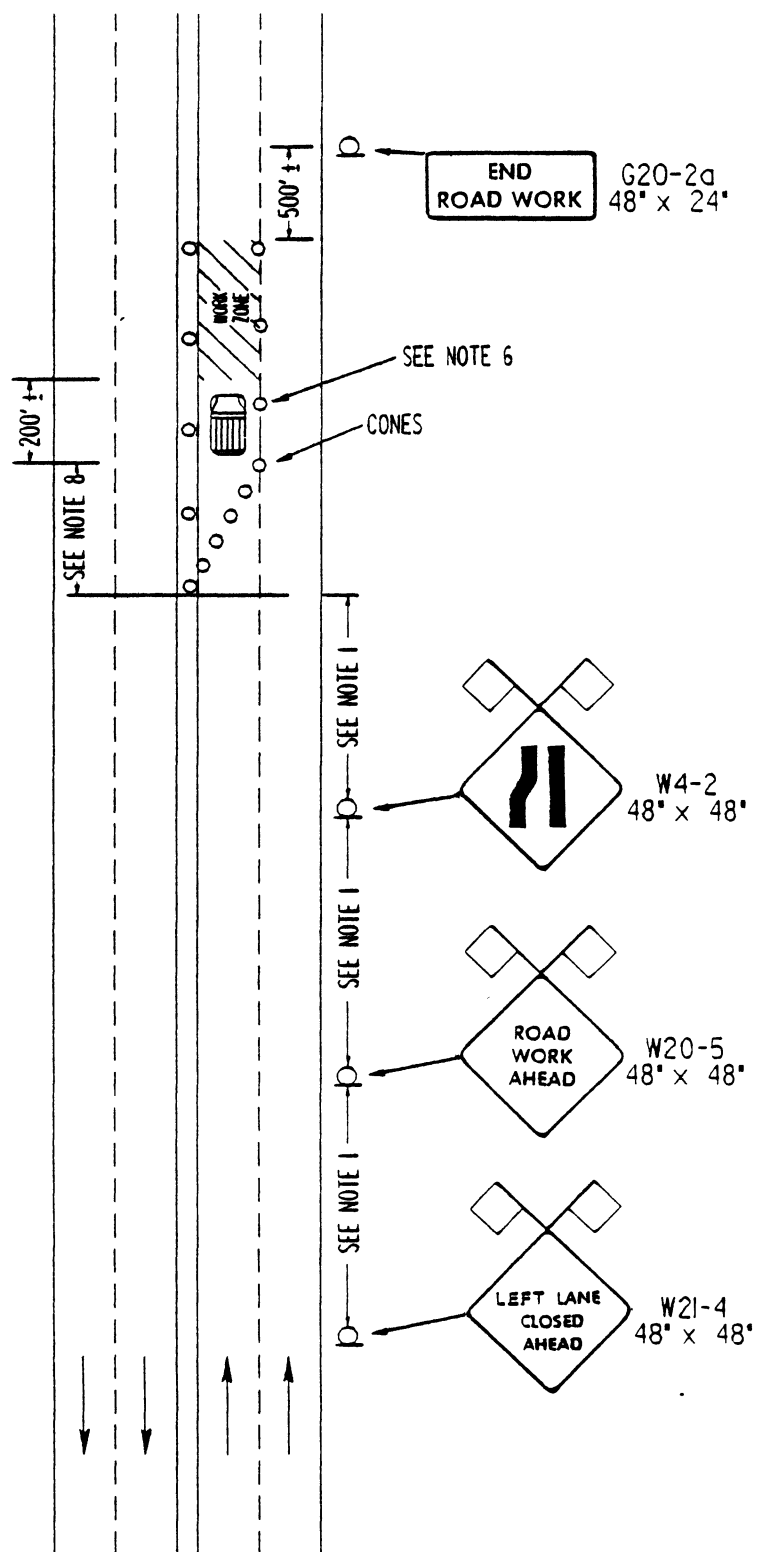
18

Figure 10. Typical maintenance operation on a secondary highway.

Source: Virginia Work Area Protection Manual: Standards and Guidelines.

CHOICES:

1 ROAD WORK AHEAD W21-4, 48"X48")

2 ROAD WORK 1 MILE (W21-4, 48"X48")

3 TRUCKS MUST USE RIGHT LANE (VR-26, 48"X60")

4 NEXT 2 MILES (VR-27, 48"X12") UNDER VR-26

5 RIGHT SHOULDER CLOSED AHEAD VW-28, 48"X48")

6 RIGHT LANE CLOSED 3/4 MILE (W20-5, 48"X48")

7 RIGHT LANE CLOSED AHEAD (W20-5, 48"X48")

8 LEFT LANE CLOSED 3/4 MILE (W20-5, 48"X48")

9 LEFT LANE CLOSED AHEAD (W20-5, 48"X48")

10 LEFT TWO LANES CLOSED 3/4 MILE (W20-5,48"X48")

Figure 11. A sample of choices in TRANZ (EXSYS).

QUALIFIERS:

1 THE NONREMOVABLE FIXED OBJECT(S) EXISTING NEAR THE TRAVELWAY IS(ARE):

EXPOSED WORK CREW
ANY OBJECT CONSIDERED TO BE DAMAGING TO A MOVING VEHICLE SUCH AS:
  HEADWALL   PARAPET   MANHOLE   GUARDRAIL END
  DROP INLET   BARRIER ENDS   PIPE   STORED MATERIAL
  BRIDGE PIER   EQUIPMENT   SLOPE   SIGN POLES/BASES
  BOX CULVERT
AN EXCAVATION WITH A DEPTH OF 6" TO 2' ON OR NEAR THE TRAVELWAY
NONE OF THE ABOVE

2 THE OBJECT IS CONSIDERED:

NONREMOVABLE FIXED OBJECT
REMOVABLE OBJECT
INFORMATION NOT AVAILABLE OR NOT APPLICABLE

3 THE NONREMOVABLE FIXED OBJECT IS CONSIDERED AS:

HAZARDOUS
NOT HAZARDOUS
INFORMATION NOT AVAILABLE OR NOT APPLICABLE

Figure 12. A sample of qualifiers in TRANZ (EXSYS).

qualifiers in TRANZ. A sample of how qualifiers are presented in TRANZ is shown in Figure 12. The complete list of qualifiers can be obtained from TRANZ as described in Appendix A and is referred to as Appendix C.

4. Rules: After specifying the data structure, choices, qualifiers, and values, rules can be built into the newly formed file (in this case TRANZ) in the EXSYS edit mode (called EDITXS).

The 107 rules in TRANZ's knowledge base are created using a series of complex inference chains that take into consideration all of the variables and parameters described in the formalization process. First, the system determines whether an obstruction in the vicinity of the project is considered a "fixed object" or "nonfixed object." This is done by requesting information regarding the nature of obstruction (such as a slope) and all the other information regarding the obstruction (such as depth and distance of the obstruction to the roadway). Second, the system determines whether the fixed object is considered a "removable fixed object" or a "nonremovable fixed object". This is done at several different levels by asking the user questions regarding the quantitative variables of the roadway (such as speed and volume) and other relevant information. At this level the system can determine whether the situations described are considered "hazardous" or "nonhazardous." Depending on the decision, different groups of control devices and techniques are saved in the system's memory. Third, the system requests all the other information regarding the nature of the project, the different variables associated with the roadway, and any other relevant information needed to recommend a set of traffic control devices and/or management strategies. Figures 13 and 14 show two sample inference chains in the knowledge base of TRANZ along with the rules they represent. The rules used by TRANZ can be printed for examination following the procedure described in Appendix A and are referred to as Appendix D.

5. Interface: Interaction with TRANZ is user-friendly so both novice engineers as well as experts can interact with all aspects of the system. Figure 15 shows how the NOTE and REFERENCE parts associated with each rule can help the user gain extra information on the validity of each rule. The user can use the explanation facility at any time during interaction with TRANZ by simply typing WHY at any of the system's prompts. TRANZ will then exhibit all the rules that are being executed at that particular instance.

TESTING AND EVALUATION OF TRANZ

When the prototype system was built, it was tested by running some hypothetical cases. The system handled these hypothetical cases in much the same manner as the knowledge engineers would expect. A final validation of the prototype system could only be given by the expert after carefully comparing the results from this system with some real-life examples. During this testing and evaluation process, Waterman's approach to seek answers to the following types of questions were sought (9).
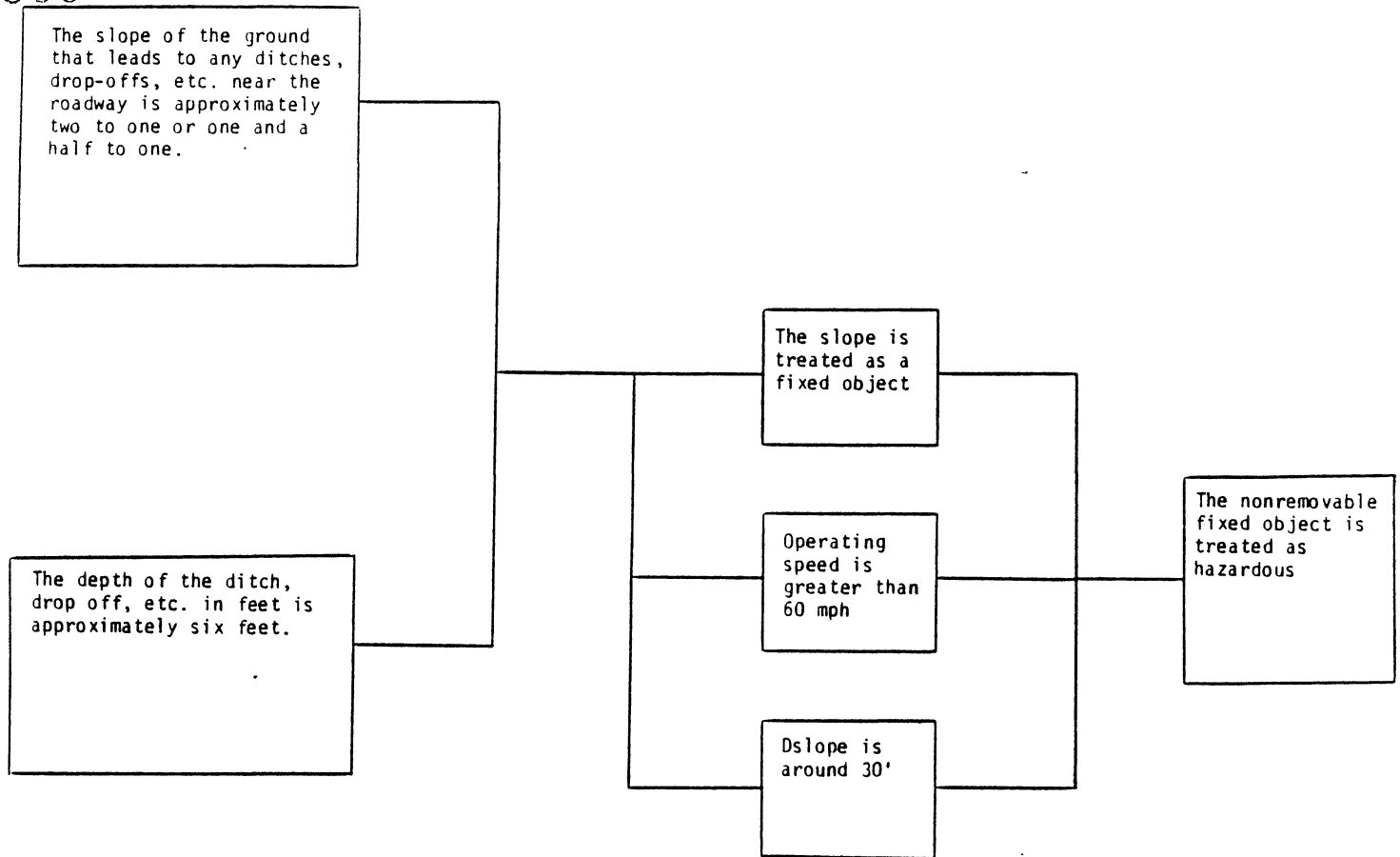
The slope of the ground that leads to any ditches, drop-offs, etc. near the roadway is approximately two to one or one and a half to one.

The depth of the ditch, drop off, etc. in feet is approximately six feet.

The slope is treated as a fixed object

Operating speed is greater than 60 mph

Dslope is around 30'

The nonremovable fixed object is treated as hazardous

Figure 13. Example of an inference rule chain in TRANZ.

The nonremovable fixed object is considered Not Hazardous.

The roadway on which the project is being conducted on is an interstate highway.

The anticipated 85th percentile operating speed is around 36 mph.

Recommend the followings strongly:
Group 1 barricade
H = 36", S = 40'

Recommended, but not required:
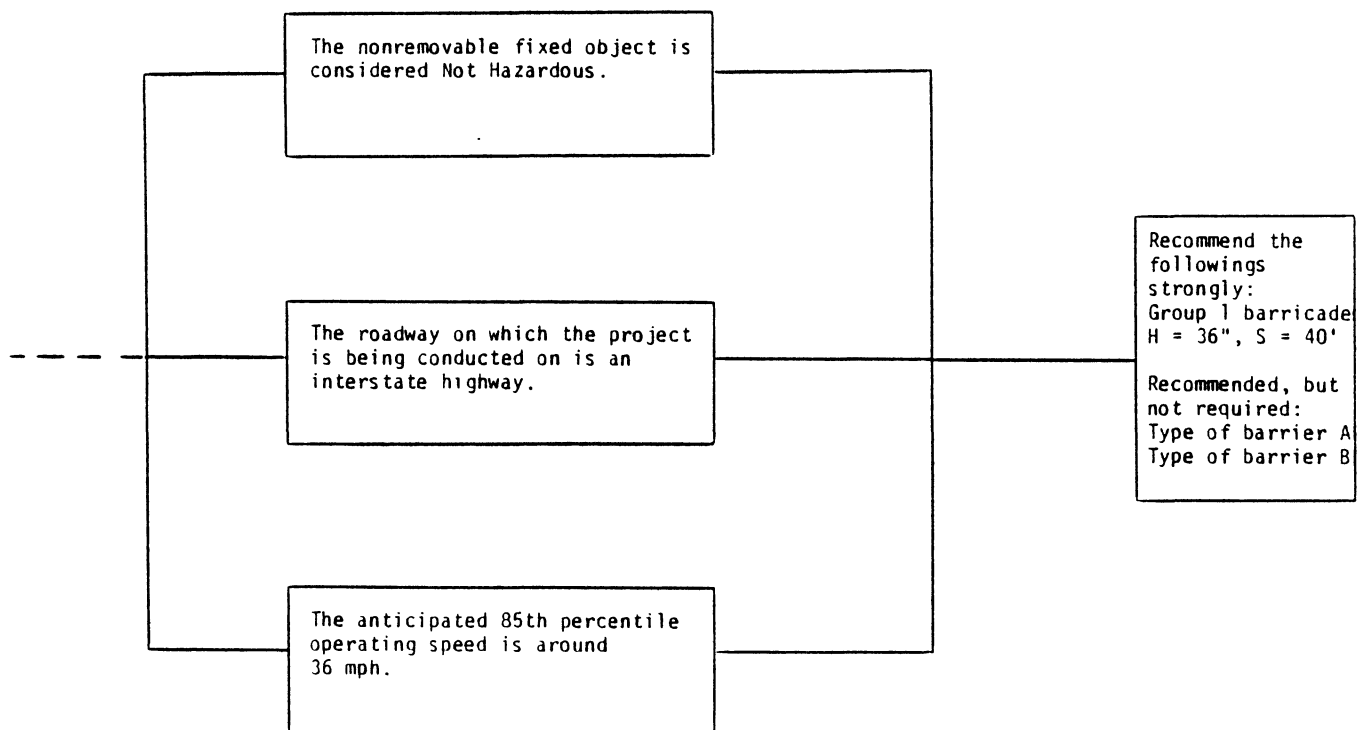Type of barrier A
Type of barrier B

Figure 14. Example of an inference chain in TRANZ.

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RULE NUMBER: 14

IF:

      THE CONSTRUCTION/MAINTENANCE OPERATION IS: STATIONARY
and THE CONSTRUCTION/MAINTENANCE OPERATION IS BEING CONDUCTED: ON TRAVELWAY.
and THE NUMBER OF LANES OF THE HIGHWAY ON WHICH THE
      CONSTRUCTION/MAINTENANCE IS BEING CONDUCTED IS: 2 LANES
and THE ROADWAY ON WHICH THE CONSTRUCTION IS BEING CONDUCTED IS: PRIMARY
      (NONLIMITED ACCESS) or SECONDARY

THEN:

      ROAD WORK AHEAD (W21-4, 48"X48") - Probability=9/10
and ONE LANE ROAD AHEAD (W20-4, 48"X48") - Probability=9/10
and BE PREPARED TO STOP (VW-27, 48"X48") - Probability=9/10
and W20-7A, 48"X48" - Probability=9/10
and FLAGGER STATION - Probability=9/10
and A TRUCK OR TRAILER WITH AT LEAST ONE ROTATING OR TWO ALTERNATING HIGH
      INTENSITY AMBER FLASHERS PARKED AT BEGINNING OF WORK ZONE IN ADVANCE
      OF WORK CREW. - Probability=9/10
and END ROAD WORK (G20-2A, 48"X24") - Probability=9/10
and [SUGGESTED SIGNING] IS GIVEN THE VALUE 1
and [SUGGESTED DEVICE] IS GIVEN THE VALUE 1
      D] / (30 * .32)

Figure 15. Sample rules in TRANZ (EXSYS).

1. **Does the system make decisions that experts generally agree are appropriate?**

Certainly, the expert agreed, but they may need testing with other experts.

2. **Are the inference rules correct, consistent, and complete?**

The correctness, consistency, and completeness of all the rules were validated with a review by the expert.

3. **Does the control strategy allow the system to consider the items in the natural order the expert prefers?**

Yes, this is the main feature of the system.

4. **Are the system's explanations adequate for describing how and why conclusions are being reached?**

Yes, this feature has already been addressed.

5. **Are the system's conclusions appropriately organized, ordered, and presented at the right level of detail?**

Yes, but further improvements may be necessary.

6. **Is the inference friendly enough?**

Yes, after some changes, all questions are descriptive enough for the expected users to understand. A help facility is available at each level which provides further information when the user types '?'.

After consulting with the expert regarding each one of the above questions, modifications were made in the prototype so that the expert was completely comfortable with it.

Members of the Office of Technology at the Turner-Fairbank FHWA facility provided further testing of the system. After this round of evaluation, it was determined that the prototype of TRANZ constituted a framework for the rules for designing traffic control configurations through work areas. In some cases that were more complex, the basic rules covering the system had difficulty in deriving elements for essentially new rules. The relation between the expert's decision process in complex cases and the general guidelines must be investigated in depth. This will be undertaken in the next stage of this research. Accordingly, the next phase of this study will further test and validate TRANZ in different working environments. Specific expansion recommendations and strategies for improvement will then be made.

Programming Considerations

EXSYS provided a microcomputer-based programming environment to represent TRANZ's knowledge base in a rule-based manner. Once the available knowledge was codified into a rule-based format, it was entered into EXSYS with relative ease. Interacting with the experts was done conveniently since the system was portable. The explanation facility, the note, and reference parts of each rule also helped the users to better understand the system.

Programming with EXSYS, however, had certain disadvantages. The available memory on the EDITXS floppy disk was not sufficient to allow building the entire system on one disk. In the case of TRANZ, the knowledge base had to be transferred from the floppy disk to the microcomputer's hard disk after writing about 90 rules in the knowledge base. Also, the representation scheme provided by this version of EXSYS only allowed a rule-based format. This does not permit the programmer much flexibility in programming the system and creates severe limitations.

LISP, on the other hand, offered much more flexibility in terms of how the knowledge may be represented in the knowledge base. The combination of a rule and frame-based representation scheme appeared to represent the problem more efficiently. Also, adding additional knowledge to the knowledge base at a later time is easier.

The LISP programming environment that was used for building TRANZ, however, was on a PRIME mainframe computer and made interaction with the experts more difficult than EXSYS. Also, due to the rather unsophisticated version of LISP available on PRIME (SALFORDLISP), long texts were difficult to enter interactively. New microcomputer LISP packages will ultimately eliminate these problems.

Both approaches to expert systems development have merit and each has been used successfully in different places. The EXSYS shell was chosen for the production tool for TRANZ because of its relative ease of use and transferability to other users in the Department. Also, the system can be distributed by the FHWA for further evaluation by users.

CONCLUSIONS AND RECOMMENDATIONS

This report described the tasks involved in the application of KBES to control and manage traffic around construction/maintenance zones. The method used was presented step by step to show the KBES approach and how it can be used to address transportation and traffic engineering decision problems.

The prototype system was based on information obtained through an extensive literature study and interactions and interviews between the knowledge engineer and the experts. The original purpose for developing TRANZ was to provide an example of an operative expert system as a demonstration of the method for addressing certain transportation problems that require expert judgment along with analytical ability and knowledge of accepted regulations and guidelines.

The potential for practical applications of this system motivates continued effort into the development of a full-scale KBES. The next phase will revise and modify TRANZ as a result of extensive expert reviews and in-house testing and evaluation. The scope of the system will be reviewed for its role in a complete problem domain that consists of project planning and worker safety in addition to traffic management. Interactions and tradeoffs among different basic rules will be addressed.

The Department should begin to assess other areas where expert systems may aid in their work. The ultimate ability of TRANZ to be of assistance to staff and local transportation officials, construction companies, utility agencies, and others involved in the design of construction and maintenance zones will influence other applications.

In addition to being a decision tool, TRANZ has potential to be used as an educational tool. This use will be investigated in phase II. Overall, the system formalizes an otherwise informal set of current practices and creates a means for consistency in interpretation of procedures.

ACKNOWLEDGMENTS

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APPENDIX A

PROCUREMENT, DOCUMENTATION, AND USE OF TRANZ

A limited number of evaluation copies of the prototype TRANZ, described in this report can be obtained by request from.

James A. Wentworth
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101
(703)285-2511

Minimum System Requirements

Operation of TRANZ in the EXSYS program requires an IBM PC, XT, AT or compatible, with 320K RAM, one floppy disk drive, and DOS 2.0 or higher. (A second disk drive is very useful. The programs can be used on a hard disk, but at present the RUNTIME system cannot be copied to the hard disk.)

Obtaining Additional Appendices from TRANZ Disk

To supplement the report TRANZ: A Prototype Expert System for Traffic Control in Highway Work Zones, a set of appendices is available from the TRANZ disk. These appendices and their content are defined as follows:

Appendix B: Listing of all traffic control devices used in TRANZ.

Appendix C: Listing of qualifiers used in TRANZ.

Appendix D: Listing of all rules used in TRANZ.

To obtain the computer printout for the referenced Appendices B, C, and D, follow the instructions given below.

Instructions for Printing Appendices

Appendix B

To obtain a printout of the traffic control devices used in TRANZ:

1. Insert the MS/DOS system disk into Drive A.
2. Insert the EXSYS Runtime disk into Drive B.
3. At the MS/DOS prompt A:, type
      PRINT B:DEVICES
    and press ENTER (or RETURN).
4. Press ENTER (or RETURN) for the default value when
      'Type of printer?' is asked.

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Appendix C

A printout of all qualifiers used in TRANZ can be obtained by following the steps in Appendix B, but substituting

PRINT B:QUALIFS for PRINT B:DEVICES.

Appendix D

Also on the EXSYS Runtime disk is RULES, a file containing a listing of all rules used in TRANZ. To obtain a printout of the rules, follow the same instructions as in Appendix B, but substituting

PRINT B:RULES for PRINT B:DEVICES.

Using TRANZ

To implement TRANZ from MS DOS, place the EXSYS RUNTIME disk into drive A, type 'EXSYS' and then enter. When EXSYS prompts for the expert system file name, type 'B:TRANZ'. TRANZ will then be ready to accept input.

Follow the directions as they appear on the screen, and input the information asked. In order for TRANZ to recommend the absolute minimum devices and strategies needed for a particular project, the operating speed, posted speed, ADT, type of highway, and at least one potential hazard that exists near the project have to be known. TRANZ will continue to ask for this information until it is entered.

Answers to other questions are not required. When there are choices to select, 'Information not available' should be entered to signal unknown data.

If, during execution of TRANZ, the user wants to know why a question is asked, entering 'WHY' or '?' will bring the rule concerning the question to the screen.

Again, just follow the directions that EXSYS supplies at the bottom of the screen, and read the questions carefully. Remember to enter data in the correct units to avoid erroneous output.

The user has the option of saving the data entered into the computer and being able to return to that place later. If one wishes to quit the program, enter 'QUIT' in response to any of the requests for information. The program will then ask for the name of the file in which to store data. DO NOT USE THE

NAME OF THE KNOWLEDGE BASE or <u>part</u> of the knowledge base would be accidentally erased. When the program is run, one of the first things it asks is whether to restore data from a file. If [Y] is indicated, the program will ask for the name of the file from which to read the data and will return to the point that was QUIT previously.

User Communication with TRANZ

EXSYS is a program for running expert system knowledge bases. Expert systems are programs that allow the computer to emulate a human expert in a subject area. The computer will ask you questions and arrive at a conclusion. The program can explain why it needs the information it is requesting and can explain its conclusions.

The program will ask a series of questions by displaying a statement with a numbered list of alternatives that could finish the statement. Enter the number or numbers of the items in the list correct for a given situation. If more than one number is desired, separate the numbers with a comma or space. If it is appropriate to know why the question is being asked, enter 'WHY', and the computer will display the rule it is using.

The computer may also need numeric or text data. The program will state what information it needs and ask for input. Again, if 'WHY' is input, the computer will display the rule it is using.

Rules are expressed in the IF-THEN-ELSE format. If ALL of the statements in the IF part are true, the rule is true and the THEN statements are considered to be true and added to what the program knows. If any of the statements in the IF part are false, the rule is false, and any statements in the ELSE part are then taken to be true and added to what the program knows.

· The statements in the rule are English sentences or algebraic expressions and should be easily read.

The THEN and ELSE parts may also contain the possible solutions among which EXSYS will select. These solutions are indicated by a statement followed by " - Probability - " and are followed by a ratio that indicates the likelihood of the solution. The closer the ratio is to 1 the more likely the solution is.

The computer will attempt to derive information from other rules rather than ask the user. This is called backward chaining. If the user asks 'WHY' the computer needs information, more than one rule may be displayed. This is because the first rule is being used to derive information needed by the second, etc., down to the final rule which is the actual rule being tested.

If more details on the meaning of the questions being asked are desired, press <?> in answer to the question. The author of the knowledge base may have created a file of information on the various questions. If such a file has been created, additional information will be displayed. If there is no such file, the program will say so.

When a rule is displayed, the computer may be asked how it knows the rule's IF conditions are true by entering the line number of the IF statement. The computer will either say the user told the program the statement was true or display the rule that was used to derive the information. If a rule is in the process of being tested, the program may respond that it does not know if the statement under review is true. If a mathematical expression were questioned, the program would show the value of each of the variables. The user may then ask how the program arrived at each of these values. The reference for a rule can be requested by pressing the <R> key.

When the computer has arrived at its conclusion, it will display an ordered list of the possible solutions with their final scores. The program may also display additional notes or calculated values that were determined by the program. The user may ask how it arrived at any of these results by entering the line number in question, and the appropriate rules that were used will be displayed. The list may be printed.

A very useful feature once the list of solutions is obtained, is to change one or more of the answers that were input to see how it changes the results. To do this, press the <C> key and obtain a list of all the input you provided. Enter the number of the item to be changed. When all of the changes are made, press <R> to re-run the data. The program may ask you additional questions if the changes necessitate additional information in reaching conclusions. The program will display the new sorted list of choices with both the previous and new values for comparison. (An option is given to switch off the display of the previous values.)

When finished, press <D> and retain the option of running the program again.