Corps-Safe: Using Expert Systems for Safety Hazard Analysis

Bruce Andrew Fink

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Stanford University
Dedicated to

My Family

especially Laura, Andrew, and Lizzie

and to my grandmother

Helene A. Roberts
Acknowledgements

This thesis is dedicated to and acknowledges the contributions of my family. This family includes: my parents, the United States Army Corps of Engineers, the faculty and students of the Stanford Construction Engineering and Management Program, and especially my wife and children.

To my parents and brothers, who taught me that I can accomplish what I set out to do, no matter what the odds. To my mother, Carol, without your support (and babysitting at strategic times) this thesis would not have been completed. To my father, George, who set the proud tradition with 28 years of service in the Corps of Engineers, and my brothers George Jr. and Keith who also upheld that tradition; thank you for your support as I continue the tradition.

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Chapter 1 Introduction

1.1 Purpose

Planning for safety in construction is increasingly being emphasized on United States Army Corps of Engineers projects. Contractors are required to submit an Activity Hazard Analysis, which identifies specific hazards expected during each phase of construction. However, in many cases this analysis is a pro-forma exercise and is not adapted to the specific construction project. An interactive expert system, based on the rules contained in the Corps Safety Manual, that interfaces with the CAD project model and the project schedule should make planning for safety on a specific project a more meaningful activity.

1.2 Scope

The U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) has been working with the University of Illinois Construction Engineering Expert System Laboratory (CEESL) under a multi-year contract to develop a PC-based expert system for analysis of construction schedules. The overall objective of their research is a project control expert system that uses object-oriented programming to interface cost, schedule, and quality control [Adeli 1988]. This research is valuable; however, the safety planning considerations are not integrated into the project control system due to limitations in resources and scope. This thesis will begin the process of integrating safety planning into the project control expert system.

This work, CORPS-SAFE, focuses on "proof of concept" expert systems for two sections of the Corps Safety Manual: Section 22, Scaffolds, and Section 23, Excavations. The primary source of rules for the expert systems is EM 385-1-1, U.S. Army Corps of Engineers Safety and Health Requirements Manual [U.S.A. COE 1987]. The Scaffold Safety Expert System will be used by contractors to develop the Activity Hazard Analysis and by Corps employees to check its compliance with the rules in EM 385-1-1. The Excavation Safety Expert System will be used by a contractor to select an initial bracing scheme for an excavation and then to develop an Activity Hazard Analysis for the scheme selected. The excavation system can also be used by the Corps representative to verify a contractor's Activity Hazard Analysis.

The products of this research are:

• Proof of concept for two Safety Expert Systems
  - Scaffold Safety
  - Excavation Safety

• A user interface for an automated Activity Hazard Analysis output
• A user interface for monitoring an Activity Hazard Analysis
• Specifications for a CAD database interface

1.3 Expert Systems

Expert Systems (ES) are a development from the computer science field referred to as Artificial Intelligence (AI). They are interactive computer programs incorporating the judgement and experience of experts to provide knowledgeable advice about a specific problem. Two excellent references for more information on expert systems are Expert Systems for Civil Engineers: Technology and Applications [Maher 1987] and Expert Systems in Construction and Structural Engineering [Adeli 1988].

Expert systems are especially appropriate to decision making in construction for the following reasons: (1) construction is an experience-based industry, (2) construction decisions must be made fast, and (3) construction decisions involve managerial issues [Levitt 1987b]. These reasons are also applicable to the sub-area of construction safety management. Furthermore, a rule-based expert system is an ideal means for representing the rules available in the Corps of Engineers Safety Manual. These rules incorporate the experience of how to work safely in a dangerous environment.

1.4 Methodology

The prototype expert systems were developed in NEXPERT OBJECT™ provided by Neuron Data Inc. NEXPERT OBJECT is a hybrid rule- and object-based expert system building tool. NEXPERT is written in "C," and can be used on IBM PC and compatible machines, Apple Macintosh computers, DEC VAX stations, and UNIX-based workstations.

The prototypes were developed on the Apple Macintosh II with two megabytes of internal memory. This is the minimum configuration required to develop the prototypes on the Macintosh II. For the runtime version of NEXPERT OBJECT a Macintosh SE with one megabyte of internal memory is sufficient. See Appendix A for more information on running the prototype systems.

An important consideration for delivery of these prototype expert systems is that they should run on a personal computer so that they could be used by construction personnel in the field. The usefulness of these safety expert systems is enhanced if the technology is available to the lowest level manager on the construction site.

1.5 Readers' Guide

The major divisions of this thesis are: the background, the prototypes, and the applications and extensions of the prototypes. This thesis is written for two different audiences. The first audience consists of industry practitioners who would like to know how Safety Expert Systems
can be used to provide a safer work environment on the job site. The second audience consists of researchers or software developers who are interested in how the systems were developed.

For the first audience, the background information in Chapters 2 and 3 and the applications and extensions in Chapters 6 and 7 describe the uses of these systems. For the second audience, the description of the prototypes in Chapters 4 and 5 is of major interest. A short description of each chapter follows.

I. Background

Chapter 2 Current Approach to Activity Hazard Analysis

The current method of identification and elimination of hazards during each major phase of construction is discussed in this chapter. The method is called Activity Hazard Analysis (AHA) on U.S. Army Corps of Engineers projects. The approach of Bechtel, a large construction company, is also examined and compared to the Corps of Engineers approach.

Chapter 3 Literature Review

The background literature for this research comes from three main areas: Construction Safety Management, Construction Methods, and Construction Expert Systems. This chapter discusses how these three areas have been integrated in the chapters that follow. Legislation pending in the United States Senate that relates to this research is also described.

II. Prototypes

Chapter 4 Scaffold Safety Expert System

SAFESCAF, a Scaffold Safety Expert System prototype is described in this chapter. This system prompts the user to focus on the specific hazards for the type of scaffold chosen during an interactive session and provides the output of an Activity Hazard Analysis. Those construction personnel involved with the design, erection, moving, dismantling, or altering of scaffolding will benefit from SAFESCAF. It should be especially useful for training workers on the safe use of an unfamiliar type of scaffold. The reasons for choosing the area of scaffold safety, a summary of the system, and the details about the operation of each part of the system are included in the description.

Chapter 5 Excavation Safety Expert System

This chapter explains and describes EXCASAFe, a prototype Excavation Safety Expert System. This system assists in the initial selection of an excavation bracing scheme, taking into account pertinent site conditions and construction methodology, and provides an output of an Activity Hazard Analysis for the selected bracing scheme. Construction managers, contractors, and anyone else involved in preliminary construction planning can benefit from this program. It is
designed to be used by an engineering professional familiar with general construction and excavation techniques, not by a geotechnical expert. The rationale for choosing the area of excavation safety, an overview of the system, and details about how each part of the program operates are provided.

III. Implementation of the Prototypes

Chapter 6 Application of the Prototype Expert Systems

It is proposed that the first phase of implementation of the prototypes would be to apply the currently available technology of expert systems to the remainder of the Corps of Engineers Safety Manual to produce an automated Activity Hazard Analysis generator. A future developer must decide if the model presented by the Scaffold Safety ES, the Excavation Safety ES, or a completely new approach is appropriate when the prototypes are applied to the remainder of the Corps Safety Manual.

Chapter 7 Future Extensions and Conclusions

The second phase of implementation discusses the development of an interface with databases and project schedules that can make the safety expert systems even more useful. These future extensions focus on making time- and location-specific information on construction hazards available to the user in a more automated and organized fashion. The chapter points out that future extensions of expert systems technology with interfaces to databases and project schedules will still not allow management to provide a totally risk-free work environment. However, an extended system of the kind proposed will allow the identification of time- and location-specific hazards so that workers can intelligently identify and address the risks in their immediate environment.
Chapter 2  Current Approach to the Activity Hazard Analysis

2.1 Introduction

This chapter discusses a method for identification and elimination of hazards during each major phase of construction. The method is called Activity Hazard Analysis in the case of U.S. Army Corps of Engineers projects. Other organizations may have a different name for it, but the process involves identifying and controlling specific hazards in addition to developing a general safety plan and an accident prevention plan. Section 2.2 discusses the Corps of Engineers approach to Activity Hazard Analysis and Section 2.3 examines the approach taken by Bechtel, a large construction company. Section 2.4 provides a comparison and discussion of the two approaches and Section 2.5 presents some conclusions.

2.2 The Corps of Engineers Approach to Activity Hazard Analysis

The U.S. Army Corps of Engineers requires all contractors to submit an accident prevention plan for every construction project. This requirement, listed on the first page of the Corps Safety Manual, states: "prior to commencement of work at a job site, an acceptable accident prevention plan written by the prime contractor for the specific work ... will be reviewed by designated Government personnel." [U.S.A. COE 1987].

As a part of the accident prevention plan, an Activity Hazard Analysis must be submitted to the Corps Resident Office for review and acceptance. The Corps Safety Manual requires that

before beginning each major phase of work, an Activity Hazard Analysis (phase plan) shall be prepared by the contractor for that phase. The analysis will address the hazards for each activity performed in that phase and will present the procedures and safeguards necessary to eliminate the hazards or reduce the risk to an acceptable level.

The responsibility for providing guidance for the preparation of an Activity Hazard Analysis is delegated to the Divisions and Districts of the Corps of Engineers. An example of this guidance is contained in the South Pacific Division Pamphlet SPD P 385-1-7 [U.S.A. COE 1986]. This pamphlet provides a step-by-step procedure giving a sample Activity Hazard Analysis with explanations. It gives an excellent overview of the procedures to review job methods and identify hazards.

The recommended method to complete an Activity Hazard Analysis consists of four steps:

Step 1 - Select an Activity to Analyze
Step 2 - Break the Activity Down into Successive Steps
Step 3 - Identify Hazards and Potential Mishaps
Step 4 - Develop a Control for Each Hazard Identified
Each of these steps is described and analyzed below to fully explain the current approach to Activity Hazard Analysis.

**Step 1 - Select an Activity to Analyze.** The activity should be defined as a sequence of jobs that accomplish a work goal. It should not be defined too broadly or too narrowly. A typical activity relates to a particular phase of work and is assigned to a line supervisor. Example activities are: erecting a block wall, forming a concrete placement, or painting a building. The activities may be defined by the project Work Breakdown Structure (WBS), which defines and organizes the work to be performed [Moder 1983].

**Step 2 - Break the Activity Down into Successive Steps.** The line supervisor or foreman should describe the sub-activities required to complete the overall activity. He should then record the natural sequence using a short descriptive phrase for each step. Each of these sub-activities should be numbered consecutively. An example of two sub-activities is shown in Figure 2.1.

**Step 3 - Identify Hazards and Potential Mishaps.** Experience is the key to identification of hazards. The supervisor or foreman should talk with his workers about past accidents or near accidents. He should also check the first aid log and accident investigations to determine if this activity has caused accidents in the past on similar jobs. Example questions that will help identify hazards are:

- Is there a danger of a worker striking against, being struck by, or otherwise making injurious contact with an object?
- Can the worker be caught in, on, or between objects?
- Can the worker slip, fall or trip?
- Can the worker strain himself by pushing, pulling or lifting?
- Is there an electrical, health, or fire hazard?

The answers to these questions should identify 90% of the potential hazards. The foreman or supervisor must identify the other 10% of the hazards by looking at the unique nature of the activity. Distinctive factors such as the terrain, weather, and elevation of the work place must be identified to have a complete Activity Hazard Analysis.

**Step 4 - Develop a Control for Each Hazard Identified.** There are three ways to eliminate most hazards:

- Change the physical conditions that create the hazard.
- Change the procedures of the step.
- Reduce the frequency with which the task must be performed.

If none of these methods eliminate the hazard, then the employees must be trained to work safely to avoid the hazard. Special training in the avoidance of identified hazards should be given to new workers.

The Activity Hazard Analysis is a living document; it is not set in stone at the beginning of the job. The analysis must be used and updated regularly, since changes in work methods or
environment can create new hazards. The supervisor should continue to identify possible hazards and train his workers to eliminate or avoid the new hazards as the job progresses.

An example Activity Hazard Analysis is shown in Figure 2.1. This example is provided merely to demonstrate one method of completing an Activity Hazard Analysis. By no means should a contractor simply copy an example Activity Hazard Analysis rather than going through the steps described above. The key to safe work is the involvement in the hazard analysis process of the direct supervisor who will be doing the work. If he understands the methodology and purpose of the Activity Hazard Analysis, then the probability of an activity being safe is increased dramatically. Levitt found that pre-planning in this way substantially reduces accident frequency in construction [Levitt 1975].

<table>
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<th>ACTIVITY</th>
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<th>Reviewed by</th>
<th>Date</th>
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<tr>
<td>Interior Demolition of Barracks Building</td>
<td>John Smith Foreman</td>
<td>Jim Dandy Project Mgr</td>
<td>Aug. 17, 1988</td>
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<th>Recommended Controls</th>
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<tr>
<td>1. Remove furniture from work area</td>
<td>1. Back strain</td>
<td>1. Train workmen on proper lifting methods 2. Supply workers with moving equipment</td>
</tr>
<tr>
<td></td>
<td>2. Foot injury</td>
<td>1. Supply workers with workboots</td>
</tr>
<tr>
<td>2. Disconnect plumbing, electrical, and HVAC duct work</td>
<td>1. Electrocution</td>
<td>1. Electricity will be locked off by a mechanical device by a qualified electrician</td>
</tr>
<tr>
<td></td>
<td>2. Falls from elevated work areas</td>
<td>1. Provide scaffolding with standard railings</td>
</tr>
<tr>
<td></td>
<td>3. Asbestos from hot water pipe insulation</td>
<td>1. Test insulation for asbestos 2. Submit removal plan with separate AHA</td>
</tr>
<tr>
<td></td>
<td>4. Trips and falls</td>
<td>1. Remove debris from work area 2. Central tool storage for tools not in use</td>
</tr>
<tr>
<td></td>
<td>5. Noise</td>
<td>1. Supply workers with hearing protection</td>
</tr>
<tr>
<td></td>
<td>6. Dust</td>
<td>1. Provide workers with dust respirators and safety glasses</td>
</tr>
<tr>
<td></td>
<td>7. Materials falling on workers</td>
<td>1. Workers should exercise caution when removing pipe or ductwork from ceilings</td>
</tr>
<tr>
<td></td>
<td>8. Fire and explosion</td>
<td>1. Clean up combustible debris prior to cutting pipe or welding 2. Provide fire barrier below welding activities in the ceiling or high elevation 3. Provide proper fire extinguishers</td>
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Figure 2.1: Example Activity Hazard Analysis
The Corps of Engineers Resident Offices are charged with the responsibility of ensuring that contractors comply with the requirements of the Safety Manual. The Resident Engineer or Project Engineer assigned as the Contracting Officer's Representative (COR) for the project, must review and accept the contractor's Activity Hazard Analysis for each phase of construction. The COR should take the following steps to ensure an acceptable analysis:

Step 1 - During the Pre-construction Meeting before the project starts, discuss the Activity Hazard Analysis with the Corps Project Inspector and the contractor's Safety Manager for the project.

Step 2 - During the Preparatory Inspection for each phase of construction, ensure that the contractor has performed a complete analysis of the possible hazards for the specific phase of construction.

Step 3 - Return an incomplete or unacceptable Activity Hazard Analysis to the contractor for correction.

Step 4 - Upon acceptance of the Activity Hazard Analysis, check to see that the contractor is using the analysis during routine job site inspections. The Corps Safety Manual requires that "identified safety . . . deficiencies and corrective measures shall be recorded in the contractors' Quality Control report." The Project Engineer and Project Inspector should use the contractor's Activity Hazard Analysis to check on the safety of the activity in progress whenever they inspect the job site.

Step 5 - When the work methods or environment for the activity in progress change, the COR should require the contractor to submit an updated Activity Hazard Analysis. These steps are graphically represented in Figure 2.2.

For contractors working on Corps projects no formal training in the area of safety planning is available. Normally contractors learn how to prepare safety plans by "on-the-job training." A new contractor prepares the initial accident prevention plan and Activity Hazard Analysis are prepared based on examples provided by the Corps. An experienced contractor will usually have a number of documents from previous projects that he can use as the basis for the accident prevention plan and the Activity Hazard Analysis. For Corps employees, training in the preparation and review of an Activity Hazard Analysis is available from the Chief of Engineers Safety Office.
2.3 Bechtel's Approach to Activity Hazard Analysis

Bechtel is a large engineering and construction company headquartered in San Francisco with worldwide operations in many sectors of construction. When Bechtel performs contract construction for the Corps of Engineers, the company is required to perform an Activity Hazard Analysis for each phase of construction. However, unless required by contract, Bechtel does not use the AHA on projects for other owners, but, integrates the specific planning for safety into what they term the "Work Planning Process". This involves identifying high hazard activities and
planning for specific actions to be taken to avoid the hazard. Examples of high hazard activities are underground work or work in confined spaces.

In the case of the example shown in Figure 2.1, Bechtel would perform detailed safety planning for step 2, hazard 3 "Asbestos removal from hot water pipe insulation." The other nine hazards shown in the figure typically would not receive the same detailed planning unless such planning were required by contract. When this method of integrating high hazard activities into the planning process is used, approximately 10 percent of the activities will have specific safety plans similar to the Corps of Engineers Activity Hazard Analysis.

Ideally, on Bechtel projects that do not require an AHA for each phase of construction, safety is integrated into the work planning process at bi-weekly meetings. During these meetings the detailed safety requirements for high hazard activities are integrated into the plan for the next two weeks, more general safety plans are examined for the 2-4 weeks that follow, and very general requirements are discussed for the period 4-6 weeks away. In this way, safety planning is integrated on a time basis rather than a task basis.

2.4 Comparison and Discussion

The key differences between the Corps of Engineers requirements and Bechtel's normal approach to safety planning are: Bechtel integrates safety into the planning process on a time basis instead of a task basis, and specific safety planning involves relatively few construction tasks. The advantages of Bechtel's approach are: (1) the impacts of concurrent tasks are considered routinely, and (2) the very dangerous tasks are given high priority for specific safety planning. The disadvantage is that the majority of tasks do not receive any specific safety planning and these "low hazard" tasks can also kill or injure workers.

However, Bechtel's method of integrating the specific planning for safety into the Work Planning Process is much better than no detailed safety planning and may be better than a uniform level of hazard analysis for both routine and hazardous work. Most contractors do not prepare an Activity Hazard Analysis at all; nor do they integrate detailed safety planning into the planning process. At a meeting of contractor safety personnel and insurance representatives in August 1988, only 25 percent claimed that detailed safety planning independent of external requirements was conducted on their job sites [ASSE 1988].

2.5 Conclusion

Even though the Corps of Engineers requires detailed safety planning for each phase of a construction project, the preparation of an Activity Hazard Analysis has become a pro-forma process for many contractors. Although the intent is to have the foreman analyze an activity, identify specific hazards and develop a control for each hazard, the AHA is in many case
performed by an office engineer who does not consult personnel on the job site. There are cases where the AHA is written at the home office and sent to a remote job site. This kind of "analysis" is not very useful. The current alternative to this kind of pro-forma paperwork practice is that when contractors are not required to perform an analysis, most of them do not. For those who perform any type of detailed safety planning, it is only for high hazard activities and considerations of safety are not explicitly addressed in planning for the majority of construction activities.

The requirements for safety planning are clearly stated in the Corps Safety Manual. The intent of the rules in the manual is to make the construction site a safer place to work. However, most contractors avoid the intent of the Activity Hazard Analysis by simply meeting the paperwork requirement and not actually trying to make the Activity Hazard Analysis a tool to provide a safer job site.

There should be a process that is reasonable and useful to the worker, who deserves the best safety planning possible. This process would result in an Activity Hazard Analysis that is applicable to a specific activity on a specific construction project. It would also be convenient to have the analysis focused on the time and location of the activity. The hypothesis of this research was that this type of time- and location-focused analysis is now possible in the form required by the Corps of Engineers with the aid of the currently available technology of expert systems.
Chapter 3  Literature Review

3.1 Introduction

The background literature for this research comes from three main areas: Construction Safety Management, Construction Methods, and Construction Expert Systems. The goal of this chapter is to discuss how these three areas have been integrated in the chapters that follow. The matrix in Figure 3.1 shows how the areas relate to the products of this research.

![Literature Review Matrix]

**CORPS-SAFE: Products of this Research**
- Proof of Concept for two Safety Expert Systems
  - Scaffold Safety
  - Excavation Safety
- A user interface for an automated Activity Hazard Analysis output
- A user interface for monitoring an Activity Hazard Analysis
- Specifications for a CAD Database Interface

![Figure 3.1: Literature Review Matrix]
The organization of this chapter is as follows: Section 3.2 discusses the Construction Safety Management literature, Section 3.3 reviews the material for the Construction Methods, Section 3.4 covers Construction Expert Systems work, and Section 3.5 concludes with information on pending legislation in the area of this research.

3.2 Construction Safety Management

The Construction Safety Management literature reviewed consists of writings by authors in the Construction Engineering and Management Program of Stanford University's Civil Engineering Department and two other authors.

The Stanford Construction Engineering and Management Program had an active program of safety research for 15 years. Several reports and a book provide insight into the importance of the Activity Hazard Analysis for controlling hazards on the construction site. Specific reports on the involvement of top management, middle management, and foremen safety in construction were among the first studies to be completed.

In The Effect of Top Management on Safety in Construction [Levitt 1975] strong evidence is provided that top managers can reduce the number of accidents significantly by following seven guidelines. Two of these guidelines are especially applicable to this research. Guideline #4 requires "detailed work planning to ensure that equipment or materials needed to perform work safely are on hand when required." The Activity Hazard Analysis assists in this aim by completing detailed work planning with special emphasis on safety planning. Guideline #5 requires that "newly hired employees receive training in safe work methods". The AHA is a useful tool for identifying hazards during initial training for newly hired employees.

The Effect of Middle Management on Safety in Construction [Hinze 1976] shows that middle managers can reduce injuries by following four guidelines. The guidelines that apply to this research are "include safety as a part of job planning" and "accept the responsibility of eliminating unsafe conditions and unsafe activities from the job." The Activity Hazard Analysis is a good method to meet both of these guidelines.

The Effect of Foremen on Safety in Construction [Samelson 1977] states that "foremen must integrate safety into the job through specific work rules." An Activity Hazard Analysis identifies specific hazards and the rules to avoid the hazard. In the development of the AHA it is important to involve the foreman actually supervising construction in the identification of the specific hazards that workers will encounter.

The next phase of safety research at Stanford focused on the costs of accidents in construction with Accident Cost Accounting as a Means of Improving Construction Safety [Robinson 1979]. The method of providing an immediate measure of the total cost of an accident gives incentive to management to implement systems that prevent accidents. An Activity Hazard
Analysis is a cost-effective process of identifying and controlling hazards before they impact on the cost of construction.

The last of the reports examined is *Improving Construction Safety Performance: The User's Role* [Levitt 1981]. The report states that for owners to improve safety on their project they must "monitor, evaluate and reward contractors, once selected, to motivate them to perform as safely as possible." The AHA can be used by an owner for each of these purposes. As a monitoring tool it allows the owner's inspector and the contractor to read off the same sheet of music for each movement of construction. The AHA can be used to evaluate the contractor's conformance to a detailed safety plan. Finally, the contractor who uses the AHA to prevent accidents will be rewarded by developing a good working relationship with the owner in addition to all the other benefits mentioned in previous research.

The book that summarizes the Stanford research is *Construction Safety Management* [Levitt 1987a]. Among its recommendations on how an owner can monitor contractor safety, three are implemented by the Activity Hazard Analysis. They are:

- Stress safety as part of the contract during pre-job walk-around. This is the first step of the Activity Hazard Analysis diagram shown in Chapter 2, Figure 2.1.
- Conduct safety audits of the contractor during construction and conduct periodic safety inspections. The AHA is the perfect tool to ensure that a contractor is following his own detailed safety plan.
- Require safety training of contractors' employees. Again the AHA is also ideal for identifying hazards that a new employee will face on a specific task.


### 3.3 Construction Methods

The reviewed literature on Construction Methods covers scaffolds and excavations: the two phases of construction implemented in the prototype Safety Expert Systems. The references provide reasons for choosing the phases of construction and insight into the methods of construction.

For scaffolds, three references provided excellent background information. Chapter 16 in *Handbook of Temporary Structures in Construction* [Ratay 1984] covers the metal scaffold type implemented in the Scaffold Safety ES prototype and includes the sub-types of tube and coupler scaffolds, and rolling scaffolds. Other types of scaffolds and general design considerations are
discussed in this chapter. In *Temporary Structures in Construction Operations* [Ratay 1987] the erection, use, and dismantling of scaffolds are discussed. Chapter 6 of *Temporary Works: their role in construction* provides additional information on checks for the proper use of scaffolds.


### 3.4 Construction Expert Systems

The Construction Expert Systems literature review covers work in the area of construction expert systems, a planning expert system, a general safety expert system, two prototype excavation expert systems, and the interface with a CAD database.

Two books that cover the application of expert system technology in the area of construction are *Expert Systems for Civil Engineers: Technology and Application* [Maher 1987] and *Expert Systems in Construction and Structural Engineering* [Adeli 1988]. These books provide background information on the expert systems that have been implemented in the construction management field.

The latest work on the Planning Expert System for the Construction Engineering and Research Laboratory (CERL) is contained in *A Knowledge Engineering Approach to the Analysis and Evaluation of Schedules for Mid-Rise Construction* [De La Garza 1988]. The prototype safety expert systems discussed here should interface with the end-product of this planning expert system.

A general safety expert system is *HOWSAFE: A Microcomputer-Based Expert System to Evaluate the Safety of a Construction Firm* [Levitt 1986]. The program analyzes how a construction company's organization and procedures impact on safety performance. It was developed and runs on an IBM Personal Computer using *The Deciding Factor* expert system shell. This work is also important because it discusses the implications of the developer as the expert. The developers or "knowledge engineers" for both of these prototype expert systems served as the domain experts, with the additional support of external experts.
Two prototype expert systems have been developed that are important to the excavation portion of this research. These systems focus on the design of safe trenches, which is a part of the prototype EXCASA FE in this research. The first prototype is *A Shallow Trench Design Expert System* [Konkoly 1986], which develops a computer-based tool to assist the foreman in applying the National Bureau of Standards safety standard discussed in Section 3.3 [Yokel 1983]. The system performs three tasks: soil classification, the inference of design parameter values based on soil type, and the design of the trench and its safety measures. The program was developed and runs on an IBM Personal Computer using the Personal Consultant expert system shell. The second prototype is *SFTYCHEF: A Consultative, Diagnostic Expert System for Trench Safety Analysis on Light Commercial Construction Projects* [Nicholas 1987], which develops a knowledge-based expert system to assist the safety analysis of short-term trench excavations on light commercial construction projects. It was developed using the EXSYS expert system shell and runs on an IBM Personal Computer. These two prototypes are extended in this research with EXCASA FE, a prototype excavation safety expert system that not only suggests an excavation bracing scheme but also produces an Activity Hazard Analysis that identifies specific hazards for workers and supervisors on the construction site.

A related research effort that impacts on Construction Expert Systems involves the interface of expert systems with CAD databases. *KADBASE: A Prototype Expert System-Database Interface for Engineering Systems* [Howard 1989] provides the architecture for this interface. The architecture allows multiple expert systems to communicate with multiple databases within an integrated, distributed engineering computing system.

### 3.5 Conclusion

The areas of Construction Safety Management, Construction Methods, and Construction Expert Systems are integrated by two prototype Safety Expert Systems in the chapters that follow. The background literature provides the basis for this integration and the foundation for these prototypes.

A final note on legislation pending in the United States Senate is relevant to this work. Senate Bill 2518 *Construction Safety and Health Improvement Act of 1988* [U.S. Senate 1988] would require a construction process plan and hazard analysis for certain construction operations on construction projects subject to the Occupational Safety and Health Act (OSHA) of 1970. The term "hazard analysis" is defined as:

- a report detailing the potential safety hazards that could occur on a construction site throughout the construction process and containing instructions and provisions for the prevention or handling of potential safety hazards.
This is the same as the Activity Hazard Analysis discussed in Chapter 2 and implemented in the prototype expert systems. The wording of the bill requires a hazard analysis for certain phases of construction. These include: "maintaining structural stability" and "preventing cave-ins." The scaffold and excavation prototype expert systems match these required phases of construction.

Although Senate Bill 2518 was not acted upon in the 100th Congress, Senator Dodd plans to reintroduce a revised version of this bill in the 101st Congress. The requirement for all contractors to prepare a hazard analysis for certain phases of construction similar to the Corps of Engineers Activity Hazard Analysis is not yet law. However, if the revised bill is passed, a hazard analysis will be required on all construction sites subject to OSHA.
4.1 Introduction

Scaffold safety is an area that is particularly suited to an expert system application. One can avoid the main hazards for this phase of construction by paying attention to detail and following instructions. SAFESCAF helps the user to focus on the specific hazards for the type of scaffold chosen by the contractor. Those construction personnel involved with the design, erection, moving, dismantling, or altering of scaffolding will benefit from SAFESCAF. It should be especially useful for training workers on the safe use of an unfamiliar type of scaffold.

This chapter describes the Scaffold Safety ES. Section 4.2 gives the reasons for choosing the area of scaffold safety and Section 4.3 provides a summary of the program. Sections 4.4 through 4.9 furnish details about the operation of each part of the application. The particulars of Sections 4.4 though 4.9 are important to a reader who desires to understand how the application was implemented in NEXPERT OBJECT™. For those not interested in this, Sections 4.2, 4.3, 4.10 (Development), and 4.11 (Limitations and Conclusions) provide a general explanation of the program.

4.2 Why Scaffold Safety was chosen as a Prototype

Scaffold accidents in the United States cost over $1 Billion, and injure or kill approximately 300 people, a year. Most of these accidents can be avoided by following the directions provided by the manufacturers and designers of scaffold systems. Surprisingly, scaffolds less than 10 feet high cause the majority of accidents. Other accidents are attributable to the perceived difficulty of using scaffolds (and are not included in the safety statistics for them). These are injuries and deaths caused by failure to use scaffolding because construction personnel used another makeshift solution. The worst danger of scaffolds is that when they collapse they normally cause great injury and damage. Investigations show that with moderate care most of these tragic accidents could be avoided. The other main dangers of scaffolds are:

1. Improper expedient methods are used to construct and dismantle
2. Proper access to them is not provided
3. Planks or handrails are missing
4. Work platforms are overloaded
5. Materials and equipment are dropped on workers from them

The use of the Scaffold Safety ES will cause those responsible for scaffold safety to focus on the details that make the specific type of scaffold in use as free from hazards as possible. With
the numerous types of scaffolding available, it is critical to train construction personnel on the actual type in use. This is particularly true for workmen who are new to the job and may be familiar with a different type of scaffolding. What works as an expedient method on one type may be dangerous on another. This prototype expert system is intended to help supervisors and workers focus on the importance of attention to detail and of following instructions for the type of system they are using.

4.3 Overview of the Expert System

The Activity Hazard Analysis output requires input from a person familiar with the specific scaffold system used on the construction project. The input is used to drive the General Scaffold Safety Knowledge Base through the initial safety checks that apply to all scaffolds. Next the user is asked to select from 16 scaffold types the one that is in use on the project. This selection will load the type-specific knowledge base and continue to question the user to pinpoint the kinds of hazards that are expected. For many of the scaffold types there are further details for sub-systems. When this is the case, a sub-type specific knowledge base is loaded and continues to check for hazards. The final output provides the hazards grouped in the three categories: general, specific, and more specific, as appropriate to the situation. A flow chart of the application is shown in Figure 4.1.

![Figure 4.1: Overview of Scaffold Safety Expert System](image-url)

**Figure 4.1: Overview of Scaffold Safety Expert System**
4.4 Input - Scaffold Data

The automated hazard analysis generator functions with any input that is available from a user. The user must then know enough about the scaffold system to get the information requested by the expert system. During the interface session the application prompts the user to consider the hazards that will be encountered on the scaffold system. As in all computer applications, the output will only be as good as the input provided by the user. The more concise the input, the more useful the activity hazard analysis will be.

4.5 General Scaffold Safety Knowledge Base

The first question after the initial start-up screen will load the General Scaffold Safety Knowledge Base (SCAFGEN.KB) if scaffolding is being used. This question is intended to screen users that may have been working on an AHA for another phase of construction and allow escape from the program if no scaffolds are used on the project. Figure 4.2 shows the function of SCAFGEN.KB.

![Diagram of scaffold safety knowledge base](image)

Figure 4.2: General Scaffold Safety Knowledge Base (SCAFGEN.KB)

The user is asked several general questions before the specific knowledge base is loaded. The queries are based on the rules from Section 22.A (General Requirements for Ramps, Runways, Platforms, Scaffolds and Towers) of the Corps Safety Manual. These rules identify hazards that are common to raised working platforms and have been modified in this application to focus on scaffold hazards. Some rules refer the user to other sections of the manual when necessary. One of the first questions in the knowledge base refers the user to Section 07.D if safety nets or belts may be required. This question screen is shown in Figure 4.3.
If the question is answered with a "True" response, as shown above, an "apropos" or explanation screen refers the user to the appropriate section of the Safety Manual as shown in Figure 4.4.

If the question in Figure 4.3 is answered "False" the apropos screen in Figure 4.4 is not shown and the next rule in the knowledge base fires to ask another question.

4.6 Scaffold Selection Knowledge Base
The SCAFKIND Knowledge Base prompts the user for the type of scaffold system used. The types of scaffolding covered in the Corps Safety Manual are shown in the flow chart in Figure
4.5. The black boxes show the parts of the manual that have been implemented in this application. Since, metal pole scaffolds are a common type, and have several sub-types; METAL.KB was chosen to demonstrate the Type Specific Scaffold Safety Knowledge Base. The lightly shaded squares remain to be implemented.

**Figure 4.5: Scaffold Selection Knowledge Base (SCAFKIND.KB)**

The screen that appears for the user to select the type of scaffold is shown in Figure 4.6. The scroll bar at the right center of the screen allows the user to view the types available. The selection is made by "double clicking" on the type of scaffold in use for the project. In the example shown, a metal pole scaffold is chosen and the METAL.KB is loaded.
Select one of the following 16 scaffold types for this project

<table>
<thead>
<tr>
<th>metal_pole</th>
<th>OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>horse</td>
<td></td>
</tr>
<tr>
<td>Interior_hung</td>
<td></td>
</tr>
<tr>
<td>large_area</td>
<td></td>
</tr>
<tr>
<td>metal_pole</td>
<td></td>
</tr>
<tr>
<td>needle_beam</td>
<td></td>
</tr>
</tbody>
</table>

NOTKNOWN

Figure 4.6: Screen for Types of Scaffolding from Which user can Select

Each of the 16 types of scaffolds have explicit rules that identify unique hazards. Some of the rules may duplicate the rules of the General Scaffold Safety Knowledge Base since they are listed in both parts of the Corps Safety Manual. However, because the user is not queried for the type until the SCAFKind Knowledge Base is loaded, these duplications are necessary to ensure completeness. When the user is asked for similar information in the specific knowledge base, it is because the focus is more narrow and the hazard more precise.

4.7 Type-Specific Scaffold Safety Knowledge Base

Once the scaffold type has been selected, the corresponding knowledge base is loaded. (In this prototype, if the user chooses any knowledge base other than the one that has been implemented, a message appears stating that the knowledge base has not been completed and the program loads the metal pole scaffold knowledge base). METAL.KB is described in this section as a representative type of scaffold. The flow chart in Figure 4.7 shows the initial metal pole safety checks (INITIAL.KB), and the five Sub-Type Specific Scaffold Safety Knowledge Bases.
Figure 4.7: Type Specific Scaffold Safety Knowledge Base (METAL.KB)

The screen shown in Figure 4.8 asks if the scaffold is a sub-type of metal scaffold known as "tube and coupler scaffold". Specific checks are made if the question is answered as "True". Otherwise, TUBE.KB is not loaded and the user does not check for specific hazards associated with tube and coupler scaffolds.

This is a tube and coupler scaffold

Figure 4.8: Screen Showing "Tube and Coupler" Choice
If the scaffold is a rolling metal scaffold, the user answers "True" when confronted with a similar screen, which loads the ROLLING.KB. If the answer is "False", other initial metal scaffold checks are completed.

4.8 Sub-Type Specific Scaffold Safety Knowledge Base

4.8.1 Introduction

When a user is working with a sub-type of the 16 types of scaffolds provided in the safety manual, a Sub-type Specific Scaffold Safety Knowledge Base is loaded. Any one or all of the Sub-types in this application (ROLLING.KB, TUBE.KB, LIGHT.KB, MEDIUM.KB or HEAVY.KB) will be loaded based on the responses of the user. The loaded knowledge bases check the specific provisions of Section 22J for the sub-type of scaffolding used. Further details on these knowledge bases are given below.

4.8.2 ROLLING.KB

The rolling knowledge base examines the safety aspects of rolling metal scaffolds. The main hazards deal with the scaffold tipping over while it is moving. As shown in Figure 4.9, for all rolling scaffolds the following checks are performed:

- accidental movement must be prevented by a positive locking device on the wheels (Rolling Hazard)
- the force necessary to move the scaffold must be applied as close to the bottom as possible (Movement Hazard)
- the surface must be firm, level, and clean (Surface Hazard)
- the working height must not exceed three times the smallest base dimension (Height Hazard)
- guard rails with mid rail, toe board, and wire mesh must be installed (Guard Hazard)

The rules are especially restrictive if a person rides on the scaffold while it is moving. In this case, four additional checks are performed. They are

- the surface must be within three degrees of level, and free from pits, holes or obstructions (Floor Hazard)
- the minimum dimension of the scaffold base is at least one half of the height (Base Hazard)
- the wheels are equipped with rubber or similar resilient tires (Tire Hazard)
- all tools and materials are secured or removed from the platform before the scaffold is moved (Tool Hazard)
Figure 4.9: Structure of Rolling Scaffold Knowledge Base (ROLLING.KB)

An example of the rule for Rolling Hazard in the ROLLING.KB is:

- *If* there is no evidence of all wheels and casters have a positive locking device

  Then Rolling Hazard is confirmed.

A complete list of rules is available to the user in the development version of NEXPERT OBJECT™.

4.8.3 TUBE.KB

The rules for tube and coupler scaffolding focus on the connections and materials used for construction of the scaffold as shown in Figure 4.10. The specific hazards are

- the size of posts, runners and bracing (Construct Hazard)
- the location of bottom runners (Bottom Hazard)
- the length and spacing of bearers (Bearer Hazard)
4.8.4 LIGHT.KB, MEDIUM.KB or HEAVY.KB

Tube and coupler scaffolds are further defined as light duty, medium duty, or heavy duty. Each of these knowledge bases contains rules about size and spacing of members, height limitations, and maximum allowable loads. For each type, the maximum allowable values are different, but the rule format is the same. Since these knowledge bases are very similar, only the flow chart for Light.KB is shown in Figure 4.11. The rules for light duty scaffolds are

- the size of bearers (Tube Hazard)
- the spacing of posts (Post Hazard)
- the maximum allowable height (Height Hazard)
- the maximum allowable load (Load Hazard)

For Height Hazard, the user is referred to Appendix O EM 385-1-1, page 355. The number of working levels and additional planked levels determine the maximum allowable height. If the height is greater than 125 feet for any of the types of tube and coupler scaffolds, the scaffold must be designed by a professional engineer.
4.9 Output - Activity Hazard Analysis

The output of the Scaffold ES is a simplified Activity Hazard Analysis for the specific scaffold type used on the construction project based on the hazards identified by the user during the expert system interface. This Activity Hazard Analysis is intended to assist the foreman on the job site to identify and avoid hazards in connection with the specific scaffold type and location.

An example of the output for the initial checks of metal scaffolds (INITIAL.KB) is shown in Figure 4.12. The hazards identified correspond to the sections of the Corps Safety Manual. If the hazard is identified as true, it means that the section listed should be complied with to eliminate the hazard. If the hazard is identified as false, it means that there is no hazard for the section listed based on the perception of the user.

An external routine updates a file for each session of the expert system. As shown at the bottom of the figure, the user has the option to save or print the report before continuing the session.
Figure 4.12: Example Output for Metal Scaffold (INITIAL.KB)

4.10 Development

4.10.1 Sources of Knowledge

Rules for the Specific Safety Knowledge Base and the General Safety Knowledge Base were developed from EM 385-1-1, U.S. Army Corps of Engineers Safety and Health Requirements Manual. Mr. Tom Keesling from the San Francisco District, Corps of Engineers assisted with the heuristics for the Scaffold Safety knowledge bases.

4.10.2 Validation

The Scaffold Safety ES was validated both internally and externally to ensure that it properly modeled the expert decision process. Internal validation involves having a novice run the program to check that it matches the expert solution. The techniques to internally validate the application were:

- Ten test cases developed by the expert were run by novices to verify that the solutions matched the expected solutions.
- The developer checked all possible branches of the system to verify that the solutions matched the expected solutions.
External validation confirmed that the Scaffold Safety ES obtained the same results as an expert solving the problem through an independent method. The external validation techniques were the following:

- An external expert examined the rules and made recommendations on how to improve the way in which the questions were presented. He also suggested simple "True or False" questions that could be asked to prompt expert answers.

- An external expert ran the system and suggested improvements for the user interface.

4.11 Limitations

Only an abbreviated general safety check and one type of scaffold safety check are implemented in this application. The knowledge base for the general safety check should be completed to include the other areas in Section 22 of the Corps Safety Manual besides scaffolds. To cover the other 15 possible scaffold types, the additional knowledge bases must be finished. The rules are in EM 385-1-1; some organization and formatting of these rules is required to make the expert system query the user in a logical manner.

As mentioned in Section 4.6 questions from the General Scaffold Safety Knowledge Base are repeated in the Type-Specific Scaffold Safety Knowledge Base (METAL.KB) demonstrated in this prototype. The inclusion of duplicate rules must be carefully considered when this prototype is extended into a working system. The rules from the General part of Section 22, EM 385-1-1, are repeated in several scaffold type sub-sections in the safety manual. Where the repetition serves a useful purpose, duplicate rules are included in the metal pole knowledge base. The repetition emphasizes the importance of the rule, or the rule was more restrictive in the scaffold type paragraph than it was in the General part of Section 22. When this prototype is extended and other knowledge bases are implemented, careful consideration should be given to whether or not to duplicate the rules.

For the output, a screen similar to Figure 4.12 should be implemented to appear at the end of each knowledge base which can be compiled into a final report. The external routines available to produce an output from NEXPERT OBJECT™ do not allow for adaptation to the format currently used for the Activity Hazard Analysis. A future interface with Hypercard being developed by Apple Computers and Neuron Data will allow the output to be printed in the same format as shown in Figure 2.1.
4.12 Conclusions

The prototype discussed in this chapter has the potential for application on all construction projects involving scaffolds. The above limitations must be overcome to make the Scaffold Safety ES usable in the field. Future extensions concerning the interface with a CAD database and project schedule are discussed in Chapter 7.

Figure 4.13 shows the current interaction of the Scaffold Safety ES with the user. When the prototype is extended into an automated system, it will assist the user by providing an Activity Hazard Analysis that focuses on the location-specific hazards of scaffolds on the construction project.

**Scaffold Safety Expert System**

![Diagram of Scaffold Safety Expert System]

**Figure 4.13: Interface of the Scaffold Safety ES**
5.1 Introduction

The application of expert system technology in this Excavation Safety prototype is intended to assist the construction planner with the difficult judgement decisions involved in excavations. The most common decisions are whether or not to brace an excavation, and the type of bracing method to be used if one is required. This system assists in the initial selection of an excavation bracing scheme, taking into account pertinent site conditions and construction methodology. The output of the application is a bracing selection and an Activity Hazard Analysis for the selection.

Construction managers, contractors, and anyone else involved in preliminary construction planning can benefit from this program. It is designed to be used by an engineering professional familiar with general construction and excavation techniques, not by a geotechnical expert.

This chapter explains and describes the Excavation Safety ES. Section 5.2 discusses the rationale for choosing the area of excavation safety and Section 5.3 gives an overview of the system. Sections 5.4 through 5.9 furnish details about how each part of the program operates. The details in these sections are of significance to a reader who wants to understand how the application was implemented in NEXPERT™. For readers interested in an overview of the chapter; Sections 5.2, 5.3, 5.10 (Development), and 5.11 (Limitations and Conclusions) are most important.

5.2 Why Excavation Safety was chosen as a Prototype

Excavation work is one of the most dangerous phases of construction. Each year in the United States over 100 workers are killed, and many more are injured because of excavation failures. Of the fatalities, over 87 percent are in trenches less than 20 feet deep. The majority of excavation failures occur in utility trenches less than 12 feet deep [Yokel 1980a]. Because of these statistics the focus of previous excavation safety efforts in construction has been on shallow, temporary excavations such as the type used for the installation of underground utilities. This prototype focuses on trenches but includes the entire classification of excavations.

Excavations are hazardous for three main reasons: (1) the decision whether or not to brace an excavation is many times delegated to a level where cost and schedule considerations may weigh more heavily than safety considerations, the cost in time and money to properly shore an excavation may cause a foreman under schedule pressure to make an unsafe decision not to brace an excavation; (2) if a bracing system is used it is, in most cases, not designed by a professional engineer, which leaves the planning to someone who may not understand the parameters that affect
the system; and (3) soil conditions may change along the length of the excavation causing differing design conditions for the bracing method [Yokel 1980a, Yokel 1980b, Fullman 1984].

Other safety hazards involved in excavation arise from (1) disturbed soils normally caused by previous excavations; (2) intersecting trenches; (3) narrow rights of way; (4) vibrations usually caused by construction equipment; (5) increased seepage of subsurface water; (6) rainfall; (7) drying of exposed trench walls; and (8) inclined layers of soil dipping into the trench. Many accidents occur during the installation or removal of shoring. Some cohesive soils stand up long enough for workers to enter the trench, and then the trench collapses [Yokel 1980a].

Excavation safety was chosen as a prototype because of the extreme hazards and the differing conditions discussed above. A minor mistaken assumption about the nature of the excavation may cause a major increase in the danger to the worker. Mistakes in judgement by field personnel kill or injure hundreds of construction workers each year. Because of the danger of excavations and the differing conditions at each site, an expert system that focuses the user on the specific hazards of a construction site should help make working in excavations safer.

5.3 Overview of the Expert System

The selection tool and automated hazard analysis generator require input from a person familiar with the specific excavation. The selection tool requires information supplied by the user or a project-specific database on the nature of the excavation, general soil conditions, and site-specific environmental constraints. The automated hazard analysis generator prompts the user to determine that the required safety conditions have been met during the design. It also provides a safety hazard analysis for a particular bracing method and for excavations in general.

A flow chart of this application is shown in Figure 5.1. First, the user is prompted for the particular attributes of the proposed excavation, which are depth, width, soil classification, adjacent structures, and groundwater table. In this prototype the user can request any information that is available from the project database. The user will be prompted for the information that is not available from the database.

Based on the values provided, the selection knowledge base (SELECTION.KB) presents the user with an initial bracing scheme. The proposed bracing plan for the excavation then causes a second knowledge base to be loaded. This specific safety knowledge base (Specific Safety KB) ensures that all safety requirements are met for the plan selected. Then, a third knowledge base (GENEX.KB) checks general safety requirements that apply to all excavations. The final output consists of a proposed bracing plan and a modified Activity Hazard Analysis based on the Corps of Engineers Safety Manual EM 385-1-1.
5.4 Input - Excavation Data

The input to the expert system is provided by a small project-specific database and/or the user. In this prototype the user is asked if the excavation depth and width should be loaded from the database. This data can be examined and changed by the user if the database has provided incorrect input. If the database does not supply the input, the user is asked for the input in the screens shown in Figures 5.2, 5.3 and 5.4.

Since the user responds to questions for the specific excavation system used on the project, the database does not automate the entire process; this is intentional. The database will assist in providing location-specific data that is time consuming, but routine, to supply. The user must then know enough about the bracing system to get the information requested by the expert system. During the interface session the application prompts the user to consider the hazards that will be encountered for the excavation. As in all computer applications, the output will only be as good as the input provided by the user. The more concise the input, the more useful the activity hazard analysis will be.
What is the depth of the excavation, in feet, from the ground surface

20

Figure 5.2: Depth of Excavation Input Screen

What is the width or minimum dimension of the excavation, in feet

20

Figure 5.3: Width of Excavation Input Screen

What is the depth below the ground surface to the water table, in feet

25

Figure 5.4: Groundwater Table Input Screen
The user must normally input the soil classification, and information about the adjacent structure. The soil classification is the most critical input and the most difficult to determine. Entire pamphlets have been written to classify soil for excavation safety [Yokel 1980a]. An expert system to determine bracing of excavations based on certain inputs has also been developed [Konkoly, 1985]. For the purposes of this prototype, the soil classification has been simplified and is shown in Table 5.1. This table is also included as a help screen in the application.

<table>
<thead>
<tr>
<th>Basic Soil Types</th>
<th>Identifying Characteristics</th>
<th>Density</th>
<th>Standard Penetration Test Blows/foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>visible grains; little or no cohesion when dry</td>
<td>Soft</td>
<td>0-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>10-30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td>Over 30</td>
</tr>
<tr>
<td>Gravels and Sands</td>
<td>visible grains some greater than 0.75 inches; little or no cohesion when dry</td>
<td>Soft</td>
<td>0-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>10-30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td>Over 30</td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>grains not usually visible; can be molded with fingers; cohesive</td>
<td>Soft</td>
<td>0-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>4-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td>Over 8</td>
</tr>
</tbody>
</table>

[Adapted from Peck 1974]

Table 5.1: Soil Classification

The input screens for soil information are shown in Figures 5.5 and 5.6.

Figure 5.5: Primary Soil Type Input Screen
What is the consistency of the primary soil type

- soft
- hard
- medium
- soft

**Figure 5.6: Soil Consistency Input Screen**

The final input involves adjacent structures. The Selection KB evaluates the bracing method for the excavation keeping track of attributes of one adjacent structure. A highly sensitive adjacent structure precludes certain methods which cause excessive vibrations. Anything that must not be damaged during bracing is considered to be an adjacent structure. For example, if there is a roadway that must not be disturbed by the construction, the roadway is considered to be the adjacent structure. If there is a building next to the site, it is the adjacent structure. The prototype knowledge base can reason about only one adjacent structure.

The user is prompted for the distance from the excavation to the adjacent structure (B) and the depth from the ground surface to the foundation bearing elevation for the adjacent structure (d₂) as shown in Figure 5.7. If there is no adjacent structure, the user enters that the adjacent structure is a very long distance away from the excavation (e.g., 500 feet).

**Figure 5.7: Diagram of Required Input for Excavation Data**
The screens for entering information about the adjacent structure are shown in Figures 5.8 and 5.9.

What is the distance, in feet, from the closest adjacent structure to the edge of the excavation (must be greater than zero)

Figure 5.8: Distance to Adjacent Structure Input Screen

What is the depth, in feet, from the ground surface to the foundation bearing grade of the adjacent structure (must be greater than zero)

Figure 5.9: Distance to Foundation Bearing Grade Input Screen

Structures are classified as either high or low sensitivity. High sensitivity structures are generally older structures, such as non-reinforced masonry structures, brick-lined sewers, etc. They are highly sensitive to disturbance. Some manufacturing facilities which can tolerate little vibration, such as computer-chip plants, should be categorized as having high sensitivity. In addition, public facilities, such as bridges, subways, and dams, the failure of which would be catastrophic, should be considered highly sensitive. Most modern structures are low sensitivity structures, i.e. have low sensitivity to vibrations. Well-constructed steel-frame, reinforced concrete and wood structures can be considered to have low sensitivity unless their use precludes vibration. Modern utility lines and pavements can also normally tolerate significant disturbance.
and should thus be classified as having low sensitivity. The input screen for structure sensitivity is shown in Figure 5.10.

Note that explanation screens are available during the expert system run for adjacent structure sensitivity, and distance to foundation bearing grade of adjacent structure. These explanation screens appear as "show screens" and the user can save them for future use or close the screens if the explanation is not needed during the session.

![SESSION CONTROL](image)

**What is the sensitivity of the adjacent structure**

![Screen](image)

**Figure 5.10: Sensitivity of the Adjacent Structure Input Screen**

### 5.5 Selection Knowledge Base

The Selection Knowledge Base (SELECT.KB) uses the input data to select one of 13 standard bracing methods. There are three trench bracing systems and ten general excavation systems. The heuristics are shown in the flow charts in Figures 5.11, 5.15 and 5.16. The procedure always leads to a solution.

As shown in Figure 5.11, if the excavation is less than 15 feet in width, then a trench solution will be found. The possible trench solutions are: trench bracing, cut to slope, and trench box. If the excavation is greater than or equal to 15 feet in width, then a general excavation solution will be found. The possible general excavation systems are the following: cut to slope, cantilevered sheet piles, tiebacks, cross lot struts, and rakers. Each of the last three types can be used with H-beam and Lagging, Sheet Piles, or Slurry Walls.

An example of Rule 5 in the SELECT.KB is:

- **If** there is evidence of excavation info retrieved and width of excavation in feet is less than 15.0
  - **Then** examine trench solutions is confirmed.
A complete list of rules is available to the user in the development version of NEXPERT OBJECT™.

![Flow Chart for Trench and General Excavations](image)

**Figure 5.11: Flow Chart for Trench and General Excavations**

The slope of the line to the adjacent structure, if any, is required to determine the optimum bracing scheme for both trench excavations and general excavations. The slope of the line is shown in Figure 5.12 as:

\[
\text{depth of excavation (d1)} - \text{depth to foundation bearing of adjacent structure (d2)}
\]

\[
\text{distance from excavation to adjacent structure (B)}
\]
Figure 5.12: Slope of Adjacent Structure Line

To deduce the best option for trench excavations, the slope of the line from the base of the excavation to the base of the adjacent structure is determined by Rules 18, 19, 20, 21, and 42. A graphical solution to these rules is shown in Figure 5.13. If the slope is between 0.5 and 1, the sensitivity of the adjacent structure and the depth of excavation determine whether trench bracing or trench box is used.

Figure 5.13: Graphical Solution for Trench Excavations
For general excavations, the slope of the line shown in Figure 5.12 is used in Rule 1 to determine if the excavation can be cut to slope or if a bracing system must be used. A graphical solution to this rule is shown in Figure 5.14.

![General Excavation Bracing](image)

**Figure 5.14: Graphical Solution for General Excavations**

If a General Excavation bracing scheme must be used, the knowledge base retrieves information on soil data using Rules 9-17. There are nine possible soil classifications based on Table 5.1. The primary soil types are sand and gravel, silt and clay, or sand. The soil density is classified as soft, medium or hard. The nine permutations of this data are used to select one of the 10 remaining bracing schemes. Figure 5.15 shows the continuation of the flow chart for general excavations.

According to Rule 22, five conditions must be met to use Cantilevered Sheet Piles. These conditions are:

1. the sensitivity of the adjacent structure must be low since these piles allow significant movement and cause disturbance when driven
2. the soil must not be too hard for pile driving
3. the soil must not be too soft since lateral restraint of the toe of the pile is required.
4. the excavation must not be greater than 20 feet in depth or the deflection of the soil behind the piles may cause damage to adjacent structures
5. the groundwater table must be below the bottom of the excavation since these piles do not restrain the flow of water and soil.

If these conditions are met, then the choice is Cantilevered Sheet Piles. If any one of the conditions is violated, then a solution with internal or external bracing is required.
In the flow of the logic in Figure 5.15, Rule 41 determines if tiebacks are suitable given the type of soil and the proximity of the adjacent structure. Conditions similar to the ones for Rule 22 described above apply to rule 41 and subsequent rules.

![Flow Chart for General Excavations](image)

**Figure 5.15: Flow Chart for General Excavations**

If none of the tieback configurations will work, then internal lateral bracing is considered (see Figure 5.16).
Figure 5.16: Flow Chart for Internal Lateral Bracing

For internal lateral bracing, if the excavation is less than 65 feet then cross lot struts will be used. The parameters of soil conditions, groundwater, and adjacent structure sensitivity determine whether the cross lot struts will be used with H-beam and lagging, sheet piles, or slurry walls.

The final type of general excavation to be considered if the excavation is greater than 65 feet in width is rakers. Again, rakers can be used with H-beam and lagging, sheet piles, or slurry walls. Soil conditions, groundwater conditions, and adjacent structure sensitivity determine the specific type of scheme to be used with rakers.

The Selection KB will always chose one of the 13 bracing selections. So, if none of the previous selections are valid, a raker system is the result. Because rakers are merely the last alternative considered by the Selection KB, and are automatically selected in the absence of other solutions, they may not be the optimal choice. Therefore, if the bracing selection result is a raker scheme the user should double check to ensure that it is indeed the best option.

5.6 Bracing Selection

As a result of the Selection Knowledge Base, a preliminary shoring preference will be displayed for the user. This preference is one of the following 13 types:
1. Cut to Slope
2. Trench Bracing
3. Trench Box
4. Cantilevered Sheet Piles
5. Tiebacks with Sheet Piles
6. Tiebacks with H-beam and Lagging
7. Tiebacks with Slurry Wall
8. Cross-Lot Struts with H-beam and Lagging
9. Cross-Lot Struts with Sheet Piles
10. Cross-Lot Struts with Slurry Wall
11. Rakers with H-beam and Lagging
12. Rakers with Sheet Piles
13. Rakers with Slurry Wall

These options are listed in the order of consideration by the Selection KB. The order is based on the relative cost of installing each bracing type. Normally, cutting to slope is the least expensive alternative, and rakers are the most expensive. If the constraints for cutting to slope are satisfied, then that solution will be selected and the other options will not be considered. Clearly, if the contractor has a preference for a certain type of bracing, for reasons of availability or special expertise, the Selection KB may not chose his preference. If the user desires to chose a scheme without the assistance of the Selection KB, he can enter the Excavation Safety ES with the Specific Safety KB for the scheme that he has chosen.

For the data shown in the input screens of the previous sections, the bracing selection is Cross-Lot Struts with Sheet Piles. The screen that shows the user the preliminary shoring selection is in Figure 5.17.

**Preliminary Shoring Selection:**

**Sheet Piles and Cross-Lot Struts**  
(click to continue)

Figure 5.17: Selection Screen for Input Data
5.7 Specific Safety Knowledge Base

5.7.1 Introduction

The final rule fired in the Selection Knowledge Base shows the bracing preference and loads the Specific Safety KB for the scheme selected. Because of the organization of the Corps Safety Manual, there is no specific knowledge for any of the schemes classified as general excavations. So, if a general excavation selection is chosen, then the General Safety Knowledge Base described in Section 5.8 will be loaded.

For trench excavations, a specific knowledge base for each type will be loaded. The specific knowledge bases discussed below are SLOPE.KB, BOX.KB, and TRENCH.KB. SLOPE.KB will also be loaded if the slope of the adjacent structure line is less than 0.5 for general excavations (see Figure 5.11 - Rule 1). Each of the specific safety knowledge bases contains rules from the Corps Safety Manual. A flow chart of the rules is shown in Figure 5.18.

5.7.2 SLOPE.KB

The SLOPE.KB examines the safety aspects of excavations cut to slope. The main hazards identified are adjacent loading, vibration, and location adjacent to a previously excavated area.

5.7.3 BOX.KB

The rules for trench boxes focus on providing protection equal to sheathing or shoring. The rules for this knowledge base concentrate on the additional loads caused by surcharge next to the trench, since surcharge is likely to be piled next to the excavation when a trench box is used.

5.7.4 TRENCH.KB

The TRENCH.KB examines the safety aspects of timber and aluminum hydraulic shoring. The main hazards are inadequate compressive strength of the timber or aluminum, failure to follow manufacturer's specifications during installation and removal, and surcharge loading.

5.8 General Safety Knowledge Base

When the specific knowledge base is finished, the General Safety Knowledge Base (GENEX.KB) is loaded. It checks the general provisions of Section 23 for the bracing scheme selected. The flow charts for GENEX.KB are given in Figures 5.19 and 5.20.
Figure 5.18: Flow Chart for Trench Rules
Figure 5.19: Flow Chart for GENEX.KB
Figure 5.20: Flow Chart for GENEX.KB (continued)
5.9 Output - Activity Hazard Analysis

The output of the Excavation ES is a modified Activity Hazard Analysis for the specific bracing plan chosen by the user assisted by the selection knowledge base. The Activity Hazard Analysis for this prototype system is implemented using "show screens" that explain a hazard to a user when it is identified during the session. The user has the option of printing this screen for future reference. The output is intended to assist the foreman on the job site to identify and avoid hazards in connection with the specific excavation and bracing plan.

5.10 Development

5.10.1 Sources of Knowledge

The rules for the Selection Knowledge Base were derived from the textbook *Foundation Engineering* [Peck 1974]. The heuristics were provided by Jared Nedzel, a graduate student in soils engineering.

Rules for the Specific Safety Knowledge Base and the General Safety Knowledge Base were developed from *EM 385-1-1, US Army Corps of Engineers Safety and Health Requirements Manual*. Two members of the San Francisco District, Corps of Engineers provided heuristics for the safety knowledge bases.

5.10.2 Validation

The Excavation Safety ES was validated both internally and externally to ensure that it properly modeled the expert decision process. Internal validation involves having a novice run the program to check that it matches the expert solution. The techniques to internally validate the application were:

- Three "novices" performed four test cases derived from the expert's experience. Their solutions matched the expert's solutions.
- Fifteen test cases developed by the expert were run by the developer to verify that the solutions matched the expected solutions.

External validation confirmed that the Excavation Safety ES obtained the same results as an expert solving the problem through an independent method. The external validation techniques were the following:

- Two external experts explained their reasoning process for the problem solved by the expert system to ensure that the expert methodology was properly modeled. This explanation occurred prior to the discussion of the expert system approach to ensure that the external experts were not biased by the approach of the developer.
- Two external experts examined the rules and made recommendations on how to improve the way in which the questions were presented. They also suggested simple "True or False" questions that could be asked to prompt expert answers.
5.11 Limitations

Several assumptions have been made that limit the applicability of the prototype Excavation Safety ES. These assumptions were necessary to simplify the problem to a manageable level for the purposes of this prototype. As mentioned in the introduction to this chapter, the system is not meant to be used by, nor to replace the services of, a qualified geotechnical engineer. This prototype demonstrates the concept for future applications in the area of excavation safety.

Specific limitations of this program are (1) the simplification of the soil classification system, and (2) the limitations of the type of bracing scheme selected. To overcome these limitations a future developer should

- Use the National Bureau of Standards soil classification system and prototype by Konkoly, as the basis for a working Excavation Safety ES.
- Modify the heuristics for a specific construction company. The heuristics that select one bracing scheme should be modified based on the experience of an individual contractor. Each contractor has a preferred method of excavation and shoring. This prototype system is a generic one that will always choose a solution. There are cases in which a "no solution found" answer should be given. There are also cases when rank ordering the acceptable solutions would be helpful. The modification of the heuristics to make these solutions available is not a difficult task. However, it is outside the scope of this prototype.

Finally a few notes about the limitations of the structure of this prototype:

- If the user desires to use a different bracing plan, then it is necessary to restart the expert system and begin with the appropriate specific safety knowledge base.
- If a safety problem with the selection cannot be adequately mitigated, the program requires the user to re-initiate the selection process rather than modify the program locally.
- As discussed in Chapter 4, the output for the prototype systems are not in the format required by the Corps of Engineers. Future interfaces with the expert system shell will make the output resemble the current version of the Activity Hazard Analysis.

5.12 Conclusions

The prototype discussed in this chapter has the potential for application on all construction projects involving excavation. The applications mentioned above are necessary to finish the Excavation Safety ES. Further applications are discussed in Chapter 6 and extensions interfacing the system with databases and a project schedule are discussed in Chapter 7.
Figure 5.21 shows the interaction of the Excavation Safety ES with the user and the prototype database. When fully automated, this program will simplify the generation of an Activity Hazard Analysis, so that more time can be spent on the implementation of an effective safety program. The goal is not to replace decision makers, but to assist them with an automated tool that replaces a repetitive process. The process, although similar for most construction projects, has subtle differences that impact on safety. The Excavation Safety ES will make these subtle differences obvious even for an inexperienced user.

The output of a Location Specific Activity Hazard Analysis is only useful if the workers exposed to the hazards of excavations are well informed of the actions necessary to work safely in a dangerous environment. The technology is available to provide a good analysis that identifies specific hazards. All that is needed is to apply the technology. This application is a step in that direction.

**Excavation Safety Expert System**

![Diagram of Excavation Safety Expert System]

**Figure 5.21: Interface of the Excavation Safety ES**
Chapter 6 - Application of the Prototype Safety Expert Systems

6.1 Introduction

This chapter discusses how the currently available technology of expert systems can be applied to the remainder of the Corps of Engineers Safety Manual (EM 385-1-1) to produce an automated Activity Hazard Analysis generator. The organization of the Corps of Engineers Safety Manual is shown in Table 6.1 for reference.

<table>
<thead>
<tr>
<th>SECTION</th>
<th>SUBJECT</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Instruction and Training</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Accident Reporting and Recording</td>
<td>7</td>
</tr>
<tr>
<td>3.</td>
<td>Sanitation</td>
<td>9</td>
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<tr>
<td>4.</td>
<td>Medical and First Aid Requirements</td>
<td>13</td>
</tr>
<tr>
<td>5.</td>
<td>Physical Qualifications of Employees</td>
<td>17</td>
</tr>
<tr>
<td>6.</td>
<td>Emergency Plans</td>
<td>19</td>
</tr>
<tr>
<td>7.</td>
<td>Personal Protective Apparel and Safety Equipment</td>
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</tr>
<tr>
<td>8.</td>
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<td>41</td>
</tr>
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<td>9.</td>
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<tr>
<td>10.</td>
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<td>Material Handling, Storage and Disposal</td>
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<tr>
<td>13.</td>
<td>Fire Protection</td>
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<td>14.</td>
<td>Welding and Cutting</td>
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<tr>
<td>15.</td>
<td>Electrical Wiring and Apparatus</td>
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</tr>
<tr>
<td>16.</td>
<td>Hand and Power Tools</td>
<td>115</td>
</tr>
<tr>
<td>17.</td>
<td>Ropes, Slings, Chains, and Hooks</td>
<td>125</td>
</tr>
<tr>
<td>18.</td>
<td>Machinery and Mechanical Equipment</td>
<td>133</td>
</tr>
<tr>
<td>19.</td>
<td>Motor Vehicles</td>
<td>167</td>
</tr>
<tr>
<td>20.</td>
<td>Aircraft</td>
<td>175</td>
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<td>21.</td>
<td>Pressurized Equipment and Systems</td>
<td>177</td>
</tr>
<tr>
<td>22.</td>
<td>Ramps, Runways, Platforms, Scaffolds and Towers</td>
<td>187</td>
</tr>
<tr>
<td>23.</td>
<td>Excavation</td>
<td>217</td>
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<tr>
<td>24.</td>
<td>Tunnels</td>
<td>227</td>
</tr>
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<td>25.</td>
<td>Blasting</td>
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<td>26.</td>
<td>Floating Plant and Marine Locations</td>
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<td>27.</td>
<td>Work in Confined Spaces</td>
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<td>28.</td>
<td>Safe Clearance Procedures</td>
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<td>29.</td>
<td>Formwork and Falsework</td>
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<td>30.</td>
<td>Access Facilities</td>
<td>281</td>
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<td>31.</td>
<td>Floor and Wall Openings</td>
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</tr>
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<td>32.</td>
<td>Noise Control</td>
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<tr>
<td>33.</td>
<td>Demolition</td>
<td>291</td>
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<td>34.</td>
<td>Steel Erection</td>
<td>299</td>
</tr>
<tr>
<td>35.</td>
<td>Tree Work, Maintenance or Removal</td>
<td>303</td>
</tr>
</tbody>
</table>

Table 6.1: Sections of Corps of Engineers Safety Manual
The future extensions necessary to produce a truly useful system, using technology still being developed, are discussed in Chapter 7. This chapter compares the Scaffold Safety Expert System and the Excavation Safety Expert System to help a future developer decide how to implement the rest of the Corps Safety Manual by using the appropriate model for each section. Although both prototype systems perform similar functions, their approach is different. The prototypes implemented in this research are shown in bold type in Table 6.1. The other sections of the Safety Manual should be applied with the appropriate concepts from each prototype. This chapter gives recommendations for the model and priority of development for the other sections of the manual. The main criteria for implementation should be suitability to the user in the field.

This chapter is organized as follows: Section 6.2 focuses on the key difference between the two prototype systems, Section 6.3 discusses the overall similarities and distinctions in the structures of the systems that are derived from this key difference, Section 6.4 covers the input of data for both systems, Section 6.5 compares the two General Safety Knowledge Bases, Section 6.6 contrasts the Selection Knowledge Bases, Section 6.7 discusses the Specific Safety Knowledge Bases, Section 6.8 compares the output, and Section 6.9 provides the conclusion.

### 6.2 Comparison of the Method Selection

The key difference between the two systems is the selection of method (referred to as *method selection* in what follows) for the phase of construction. The organization of each expert system revolves around this selection. Figure 6.1 shows a matrix comparing the method selection.

<table>
<thead>
<tr>
<th>Name of System</th>
<th>SCAFSAFE</th>
<th>EXCASAFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Scaffold Safety</td>
<td>Excavation Safety</td>
</tr>
<tr>
<td>Section of EM 385-1-1</td>
<td>Section 22</td>
<td>Section 23</td>
</tr>
<tr>
<td>Method Selection</td>
<td>Standard Solution (Off the Shelf)</td>
<td>Non-Standard Solution (Engineered)</td>
</tr>
<tr>
<td>Responsibility for Method Selection</td>
<td>Contractor</td>
<td>Designer</td>
</tr>
<tr>
<td>Examples of Similar Applications</td>
<td>Machinery and Mechanical Equipment Section 18</td>
<td>Tunnels Section 24</td>
</tr>
<tr>
<td></td>
<td>Standard Formwork Section 29</td>
<td>Custom Formwork (Arches, Circular) Section 29</td>
</tr>
</tbody>
</table>

*Figure 6.1: Comparison of Method Selection*
The choice of the type of scaffold is normally a standard decision made by the contractor before the job is started. Most contractors use a standard ("off the shelf") solution on every construction site. In a very few cases, standard solutions do not provide safe results, but as a general rule they do. An example of an application of the scaffold prototype is Section 18, Machinery and Mechanical Equipment. The contractor chooses equipment off the shelf and the appropriate part of Section 18 is applied to ensure the safety of the chosen equipment.

For excavations, the choice of method is non-standard, the nature of the site and the characteristics of the excavation dictate the best bracing system. Therefore an engineered solution by a design professional is normally required for excavation safety. An example of a similar application is Tunnels (Section 24). The design of the excavation and temporary supports for a tunnel requires an engineered solution and the design of the construction method impacts on the contractor's ability to work safely.

One section that can be applied using both approaches is Formwork (Section 29). Standard formwork systems tend to use off the shelf methods. A contractor can often use standard plans or prefabricated systems to meet requirements. Custom formwork, such as the type required to form arches or circular surfaces, must generally be designed by an engineering professional. In fact, several states have laws which require that falsework exceeding a certain height must be designed by a professional engineer. When the formwork section of the Safety Manual is developed, a rule in the front of the knowledge base could ask whether the system is standard or custom. The standard formwork knowledge base should use the same approach the Scaffold ES uses, and the custom formwork knowledge base should use the same approach the Excavation ES uses.

There are exceptions to the general classifications discussed in this section that will be pointed out later in the chapter. An advantage of the expert system technology is that these exceptions will be identified, whereas exceptions are routinely ignored under the current method of Activity Hazard Analysis.

6.3 Overview Comparison

Both expert systems begin in a similar way with input from the the user. The final output in both cases is an Activity Hazard Analysis for the specific activity in progress. The two systems vary in how they get from the input to the output. As shown in Figure 6.2, both applications go through roughly the same steps but in a different order. The organization of each expert system is based on the key difference of the method selection. For the Scaffold Safety Expert System the user is simply asked to choose one of the 16 standard types of scaffolds in SCAFKIND.KB. For the Excavation Expert System the user is asked for the various attributes of the site in the Selection KB and then a bracing plan is proposed based on these unique characteristics. The comparison of
the two prototypes that follows expands on the similarities and differences for each part of the programs.

Scafgen KB

General Scaffold Safety Knowledge → Contractor Proposed Scaffold Type

Scafkind KB

Scaffold Selection

Selection KB

Bracing Knowledge → Proposed Bracing Plan

Specific Safety KB

Sub-Type Specific Scaffold Safety Knowledge → Type Specific Scaffold Safety Knowledge

Genex KB

General Excavation Safety Knowledge → Specific Safety Knowledge

Scaffold Safety Expert System

Excavation Safety Expert System

Figure 6.2: Overview Comparison

6.4 Comparison of Input

The input for each expert system is similar, as shown in Figure 6.3. The scaffold data and the excavation data are provided by the user. In the excavation system the database can supply some factual data, whereas in the scaffold system the user must answer all questions.

<table>
<thead>
<tr>
<th>SCAFFOLD DATA</th>
<th>EXCAVATION DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Depth</td>
</tr>
<tr>
<td>Height</td>
<td>Width</td>
</tr>
<tr>
<td>Width</td>
<td>Soil Classification</td>
</tr>
<tr>
<td>Load</td>
<td>Adjacent Structures</td>
</tr>
<tr>
<td></td>
<td>Groundwater Table</td>
</tr>
</tbody>
</table>

Figure 6.3: Comparison of Input

Although the information is similar in format, the order of the input is reversed because of the difference in overall structure. In the Scaffold Safety ES the user is asked for general safety information, then queried for the type of scaffold in use, which determines the specific safety questions, and lastly the very specific safety questions. In the Excavation ES, the user first must answer questions to determine the proposed bracing plan, which determines the specific safety
questions, and the general safety questions are asked at the end. There is nothing sacred about the order of the input. The sections of the Corps Safety Manual begin with the General portion and then go to the specific. The Excavation ES seemed to flow better in the reverse order, since a specific selection is the result of the Selection KB. The developer should consider what order of input seems most logical and practical to the user.

6.5 Comparison of General Safety Knowledge Bases

The general safety knowledge for the two systems is derived from the General paragraphs of Section 22 and 23 of the Corps Safety Manual. The broad questions are asked at the beginning of the Scaffold ES and at the end of the Excavation ES. This difference in design relates to the selection of the type of system used. For the Scaffold ES the general questions are asked prior to the question about the type of system in use. The scaffold system starts with general hazards and narrows down to specific hazards. For the Excavation ES the general questions are asked after the specific checks of the type selected. The excavation system starts with the selection of a bracing type and checks the specific hazards before moving on to the general checks.

6.6 Comparison of Selection Knowledge Bases

The organization of the selection knowledge bases is directly related to the method selection discussed in Section 6.2. The difference in the selection procedure is shown in Figure 6.4. There is an extensive knowledge base to assist the user in the excavation bracing selection, but there are no heuristics to guide the user in the scaffold selection.

![Figure 6.4: Comparison of Selection Knowledge Bases](image)

Subject to height and load restrictions, any scaffold system that the contractor chooses can be safe as long as detailed checks are made during the design, erection, moving, dismantling, or altering of the system. The Scaffold Safety ES alerts supervisors and workers to the importance of paying attention to detail and of following instructions for the type of system chosen for use on the project.
For excavations, much of the safety of the bracing scheme depends on choosing the right system for the conditions of the site. The Excavation Safety ES shows how the knowledge of an expert can be incorporated to assist the user in choosing a safe bracing scheme. This expert is the designer of the bracing system, but he may have been working with a lack of information when the system was designed. Or the method of construction on the site may have changed the dimensions of the excavation from what was calculated in the original design. The contractor can use the Excavation Safety ES along with the latest information available on the site to ensure that the right system has been chosen. If the wrong bracing system is chosen, all of the safety checks that follow are useless.

### 6.7 Comparison of Specific Safety Knowledge Bases

The detailed knowledge in the Specific Safety KB of both applications serves to alert the user to the actual hazards for the type of system in use. The difference is in the level of knowledge contained in the corresponding sections of the Corps Safety Manual. Figure 6.5 shows that there are subtypes for scaffolds and no sub-types for excavations.

![Figure 6.5: Comparison of Specific Safety Knowledge Bases](chart)

For the Scaffold Safety ES the safety checks first focus on the type specific knowledge and then on any more detailed sub-type knowledge. For the Scaffold prototype, metal pole scaffolds are made up of tube and coupler and rolling scaffold sub-types. The user is questioned only about the specific sub-type in use; no questions about rolling metal scaffolds are asked if this sub-type is not used. This prototype is a useful model for any of the sections of the Corps Safety Manual where there are more detailed sub-types of a specific category. An example of a section that could be implemented based on this prototype is Section 16, Hand and Power Tools. The user should be queried only about the specific sub-types of tools that are on the job site.

For the Excavation Safety ES there are specific rules for each type of bracing scheme, but no further definition of the sub-type. This model is useful for the other sections of the Corps
Safety Manual where there are no further breakdowns of types. An example of a section that could be implemented based on this prototype is Section 33, Demolition.

6.8 Comparison of Output

The output of each prototype expert system is a modified Activity Hazard Analysis for the specific hazards identified by the user during the interface. For the Scaffold Safety ES, the output is at the end of the session in the form of a file that lists the hazards identified. For the Excavation Safety ES the user is presented with a graphical "show screen" whenever a hazard is identified.

The best approach for the use of a show screen is to have a user option at the beginning of the session. The novice will appreciate the show screen at the time of identification of the hazard. The experienced user would find it an unnecessary irritant. The option for displaying the show screen is helpful for a better user interface. This option can be implemented by a general rule to ask the user whether a show screen is desired and modifying the right hand side of each rule where a show screen is currently displayed.

A further refinement of the output is available but not implemented with a specific function in either application. With the development version of the expert system shell, the user can examine the rule tree for the knowledge base by pulling down the "Inspector" menu to "Browse Rule Network". If an explain function were implemented, the user could automatically see why a question is asked and where each answer leads. An example of this refinement is shown in Figure 6.6.

In the bottom left of the figure is the session control that prompts the user for information. The user is asked if the scaffold is designed by a professional engineer. The rest of the figure shows the rule network for the Medium KB of metal pole scaffolds. The light check mark on a dark box ✓ shows that three hazards (tube, load, and post) have been examined, but do not exist on this project. The dark check mark ✓ at the top of the screen next to "higher_than" indicates that the user has answered that the scaffold is more than 125 feet high. The current question in the session control, whether the scaffold is designed by a professional engineer, is represented by "prof-engr" on the rule tree. If the user answers "True" as shown in the figure, then no hazard exists and the "?" next to "ht_hazard" will change to a light check mark in a dark box ✓. However, if the user answers "False", then there is a height hazard and the "?" next to "ht_hazard" will change to a dark check mark ✓, indicating a hazard.

The example shown in Figure 6.6 also demonstrates an exception to the general classifications described in Section 6.2. Although most scaffold solutions are off the shelf, tube
and coupler scaffolds higher than 125 feet must be designed by a professional engineer. This non-standard solution is a rare situation, but demonstrates the usefulness of the expert system to catch exceptions that might otherwise be overlooked. A user might naturally assume that a standard solution will work until the exception to the norm is brought to his attention.

Figure 6.6: Rule Tree as an Explain Function for Output

6.9 Conclusions

This chapter has discussed the advantages and disadvantages of the features of each knowledge base. A future developer will have to decide if the model presented by the Scaffold Safety ES, the Excavation Safety ES, or a completely new approach is appropriate when extending these prototypes to the remainder of the Corps Safety Manual.

The following recommendations on the priority of development for the automation of the Corps Safety Manual are provided for the future developer:

- Complete the Scaffold Safety ES with the extensions described in Section 4.11. This is the simpler of the two prototypes and can be extended following the example for METAL.KB.

- Complete the Excavation Safety ES with the extensions described in Section 5.11. The recommendations from Section 5.11 for the selection knowledge base should be implemented prior to beta testing of the system.

- Field test the extended Excavation Safety ES and Scaffold Safety ES at various Corps of Engineers offices
* Develop the remainder of the sections using the feedback from the field tests in the priority, and using the model suggested in Table 6.2. The models are listed as SAFESCAF for the Scaffold Safety ES prototype, EXCASAFE for the Excavation Safety ES prototype, and NEW for a completely new approach. The development of the NEW model is challenging since, in most cases the section of the Corps Manual does not correspond to a specific phase of work.

<table>
<thead>
<tr>
<th>Priority</th>
<th>Subject (Section #)</th>
<th>Prototype Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ramps, Runways, Platforms, Scaffolds and Towers (Section 22)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>2.</td>
<td>Excavation (Section 23)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>3.</td>
<td>Hand and Power Tools (Section 16)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>4.</td>
<td>Tunnels (Section 24)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>5.</td>
<td>Machinery and Mechanical Equipment (Section 18)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>6.</td>
<td>Custom Formwork and Falsework (Section 29)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>7.</td>
<td>Standard Formwork and Falsework (Section 29)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>8.</td>
<td>Poisonous and Harmful Substances (Section 8)</td>
<td>NEW</td>
</tr>
<tr>
<td>9.</td>
<td>Personal Protective Apparel and Safety Equipment (Section 7)</td>
<td>NEW</td>
</tr>
<tr>
<td>10.</td>
<td>Aircraft (Section 20)</td>
<td>NEW</td>
</tr>
<tr>
<td>11.</td>
<td>Blasting (Section 25)</td>
<td>EXCASAFE</td>
</tr>
<tr>
<td>12.</td>
<td>Demolition (Section 33)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>13.</td>
<td>Steel Erection (Section 34)</td>
<td>EXCASAFE</td>
</tr>
<tr>
<td>14.</td>
<td>Ropes, Slings, Chains, and Hooks (Section 17)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>15.</td>
<td>Work in Confined Spaces (Section 27)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>16.</td>
<td>Electrical Wiring and Apparatus (Section 15)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>17.</td>
<td>Lighting (Section 9)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>18.</td>
<td>Safe Clearance Procedures (Section 28)</td>
<td>NEW</td>
</tr>
<tr>
<td>19.</td>
<td>Material Handling, Storage and Disposal (Section 11)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>20.</td>
<td>Fire Prevention (Section 12)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>21.</td>
<td>Fire Protection (Section 13)</td>
<td>NEW</td>
</tr>
<tr>
<td>22.</td>
<td>Welding and Cutting (Section 14)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>23.</td>
<td>Pressurized Equipment and Systems (Section 21)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>24.</td>
<td>Access Facilities (Section 30)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>25.</td>
<td>Floor and Wall Openings (Section 31)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>26.</td>
<td>Floating Plant and Marine Locations (Section 26)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>27.</td>
<td>Noise Control (Section 32)</td>
<td>NEW</td>
</tr>
<tr>
<td>28.</td>
<td>Tree Work, Maintenance or Removal (Section 35)</td>
<td>SAFESCAF</td>
</tr>
<tr>
<td>29.</td>
<td>Instruction and Training (Section 1)</td>
<td>NEW</td>
</tr>
<tr>
<td>30.</td>
<td>Accident Reporting and Recording (Section 2)</td>
<td>NEW</td>
</tr>
<tr>
<td>31.</td>
<td>Sanitation (Section 3)</td>
<td>NEW</td>
</tr>
<tr>
<td>32.</td>
<td>Medical and First Aid Requirements (Section 4)</td>
<td>NEW</td>
</tr>
<tr>
<td>33.</td>
<td>Physical Qualifications of Employees (Section 5)</td>
<td>NEW</td>
</tr>
<tr>
<td>34.</td>
<td>Emergency Plans (Section 6)</td>
<td>NEW</td>
</tr>
<tr>
<td>35.</td>
<td>Signals, Warning Signs, and Signaling (Section 10)</td>
<td>NEW</td>
</tr>
<tr>
<td>36.</td>
<td>Motor Vehicles (Section 19)</td>
<td>NEW</td>
</tr>
</tbody>
</table>

Table 6.2: Priority of Development for Corps of Engineers Safety Manual

A final consideration for the application of these expert systems is the difference in point of view of the user of the system. The designer does not necessarily consider the constructability of the design when engineering a solution, his responsibility is to present a structurally sound design.
The contractor cares about the method selection because it has a direct impact on his performance. The Corps of Engineers employee is not concerned about the method selection as long as that selection is safe. The integrated system will allow the contractor to review the designer's rationale for the choice of method, if one is made, and to understand the safety implications of the method selection. The Corps employee can look at the choice of method if safety is questionable, but normally will concentrate on the safety of the chosen method. Thus this integrated safety expert system will allow everyone involved in the project to understand the safety impacts of design decisions and the design impacts of safety decisions.
Chapter 7 - Future Extensions and Conclusions

7.1 Introduction

Chapter 6 discussed the first phase of the application of the prototype safety expert systems which automates the present manual process for generating the Activity Hazard Analysis. The second phase of implementation, proposed in this chapter, describes the design of an interface with databases and project schedules that can make the safety expert systems even more useful. These future extensions focus on making time- and location-specific information on construction hazards available to the user in a more automated and organized fashion.

In this chapter Section 7.2 discusses the interface between one of the safety expert systems and three CAD databases, Section 7.3 extends the interface for multiple expert systems and multiple databases, Section 7.4 comments on an automated accident reporting system, Section 7.5 covers the concept of the link to a project schedule, and Section 7.6 discusses how the results of these future extensions can be used in the field.

7.2 CAD Database Interface

The database interface of the excavation prototype is simplistic. The database is a file inside NEXPERT that is accessed if the user asks for information from the database on the depth and width of the excavation. To realize their full potential, the safety expert systems must be fully integrated with project-specific databases. The ongoing research of Craig Howard on KADBSE (Knowledge Aided Database Management System) will allow integration of multiple CAD databases with the safety expert systems. KADBSE is a knowledge-based interface in which multiple knowledge-based systems and multiple databases can communicate [Howard 1989].

The architecture of KADBSE adapted for the Excavation ES is shown in Figure 7.1. The knowledge-based system on the left (Excavation ES) will access one or more specific CAD databases through the Network Data Access Manager (NDAM). For the example shown in Figure 7.1, if Project 1 is a building that has utility services provided through underground trenches, the depth below ground of the utilities is stored in the database. The Excavation ES requires information on the depth of the excavation, so a query for information on the location of the utilities is sent to the NDAM. This query will be passed through the NDAM to the project-specific database and back through the NDAM to the Excavation ES.
Figure 7.1: KADBASE Architecture for Excavation Expert System

An example of this single query frame is shown in Figure 7.2.

```
utility-query-frame
REQUEST-TYPE: query
OBJECT: utility-project1
TARGET: bottom-elevation
```

Figure 7.2: KADBASE Utility Depth Query Frame

A conversion of the raw data on the depth of utilities provided by the project database to the information required by the Excavation ES will be performed by the Knowledge-Based System Interface (KBSI). If the user needs two feet of over-excavation for bedding material below the utilities, the KBSI makes the conversion by adding two feet to the depth of utilities provided the database. So the depth of the excavation required by the Excavation ES for input is the utilities depth from the CAD database, plus two feet as converted by the KBSI.

In the example shown in Figure 7.1 the Excavation ES also requires information on adjacent structures as part of the initial input. This information is stored in the Adjacent Structures Database and is accessed in the same way as described for the utility query. Finally, information about the existing utilities around the site must be furnished for the safety checks in the Excavation ES. The expert system could send a query to check on the presence of existing utilities that the NDAM would route to the Existing Utilities Database for an answer.
7.3 Extension of CAD Database Interface

The architecture of KADBASE adapted for the two implemented prototypes and a future safety expert system is shown in Figure 7.3. Multiple safety expert systems will interface with multiple project-specific databases through the KADBASE architecture. The knowledge-based systems on the left (Scaffold ES, Excavation ES, Future ES) will access project-specific databases through the Network Data Access Manager.

![Diagram](image)

Figure 7.3: KADBASE Architecture for Multiple Safety Expert Systems

Figure 7.3 provides the framework for an expanded example. This example uses the Excavation ES, Scaffold ES, Project 1 database and Project 2 database. Again Project 1 is a building that has utility services provided through underground trenches. The information stored in the Project 1 database includes the following: (1) depth of utilities, (2) width of utilities, and (3) depth to groundwater table. The Excavation ES queries the NDAM for the information on the location of the utilities from the project-specific database. An example of this query frame is shown in Figure 7.4.
At the same time the Scaffold ES requires information on the scaffold required for Project 2. The following information is needed: (1) height, (2) width, and (3) design load. This query frame is shown in Figure 7.5.

The requested information may not be stored in the project database. If this is the case, the user will be asked to input the information since it was not supplied by the database. Also any data supplied by the project database can be examined by the user to ensure correctness.

The KADBAS architecture will allow multiple expert systems to query multiple databases for the information required to run the expert systems. Since a communications module isolates the communication between the components, the KADBAS architecture is hidden from the user. The user will know that the information is being supplied from databases, but will not have to be concerned with the mechanics of this process.

7.4 Accident Reporting Database

A second type of database that will add to the usefulness of this system is an accident reporting database. This idea is an automated extension of the accident reporting system that the Corps of Engineers already uses. Whenever there is an accident on a Corps project, information on the mishap is distributed to other Corps offices around the world. This method of learning from other people's accidents sensitizes contractors to timely hazards in construction. The current system would continue, but the accident information would also be entered into an accident reporting database. Figure 7.6 shows how the accident reporting database would be integrated in the KADBAS Architecture.
The information could be filed by type of accident, and refer to the applicable section of the Corps Safety Manual. When a user is running an Activity Hazard Analysis session, a special alert would draw his attention to the most recent accidents and their causes. If there is no applicable rule in the Safety Manual, an additional rule could be incorporated to ensure that field personnel are aware of a new danger. Since construction methods change with new technology, this system is especially useful.

While the database begins to accumulate information, the user could access the historical record of accidents for a specific phase of construction. Whenever there is an excavation accident, the information would be compiled in the database together with the cause and recommended steps for prevention. When a user is running the Excavation Safety ES, routine alerts would appear at the rule corresponding to recorded accidents and the user would be asked if more information on the accident is desired. If more information is needed by the user, the database could supply the details.

The accident reporting database is not a new idea; it is a way of organizing and implementing an existing system in a more useful way. The institutional memory of contractors and Corps of Engineers employees in the field is limited by their experience and access to information. This automated reporting system would make the information available in a more timely and organized manner.
7.5 Interface with Project Schedule

Even with the CAD database interface mentioned in the previous sections, the output is still a location-specific Activity Hazard Analysis. A further extension would allow the safety expert systems to interface with the project schedule and hence to allow an output of a time- and location-specific Activity Hazard Analysis. Figure 7.7 shows this extension for the Scaffold Safety ES.

![Scaffold Safety Expert System Diagram]

**Figure 7.7: Scaffold Safety ES Linked to Project Schedule**

Under the current system of Activity Hazard Analysis, workers are told general hazards to avoid during the entire phase of construction, which may cover a period of weeks. A future system that could access project-specific scheduling data would give workers on the job site real-time information on the hazards expected on a specific day. This detailed information is available today, but the time to analyze the hazards and inform the workers is not available. The automated interface with a project schedule makes specific hazard information available to supervisors and workers on a construction site. Figure 7.8 shows the final interface between the Excavation Safety ES and the Project Specific Scheduling Data.
Excavation Safety Expert System

Excavation Specific Data (User Input)

Design Selection Knowledge Base

Selection of Bracing Scheme

Bracing Scheme Safety Check Knowledge Base

General Excavation Safety Check Knowledge Base

Prunes Output with Location Specific Data

Prunes Output with Time Specific Data

Project Specific Data (CAD Database Input)

- Bracing Selection
- Time and Location Specific Activity Hazard Analysis

Figure 7.8: Excavation Safety ES Linked to Project Schedule

The link to the project schedule would also focus on the safety hazards caused by the interaction between the two phases of construction. For the two prototypes shown here, if workers are in an excavation beneath a scaffold system, a special warning would be given to each crew to be alert to falling hazards. The workers in the trench would be reminded to wear their hard hats and install overhead protection if necessary. The workers on the scaffold would be alerted to ensure their tools and equipment were secured and to use safety nets if appropriate.

This is a simple example of how the project schedule could assist in the coordination of crews on a job site, but this coordination is not a trivial task. There are so many concurrent activities on a construction site that crews tend to work around other crews without paying attention to each other. The link to the project schedule, in conjunction with focusing the concerns on location-specific hazards from the CAD interfaces would make the safety interaction between crews an explicit area of concern for the appropriate levels of management on a construction site.

7.6 Conclusions

A question the reader may well ask is, "How is all of this state-of-the-art technology going to make the construction site a safer place to work?" Figure 7.9 shows a hierarchy of Activity Hazard Analysis that would be available to managers of the construction project to assist them in making it a safer place.
Senior Management would receive an AHA that covers the whole phase of construction. The most dangerous activities for the phase would be identified so that the top management could put special emphasis on making them safe. More details, down to the most location-specific and time-specific hazards, would always be available to the Senior Management. The Project Manager would likely be interested in monitoring the most dangerous activities in a given week. The Superintendent could focus on the daily project hazards that demand his attention. The Area Foreman would get a daily AHA from which he could brief his foreman each day. He could concentrate on the safety hazards that arise from parallel activities of the crews under his supervision. The foreman for each crew would then have a location- and time-specific AHA with which to hold his daily toolbox safety meeting.

![Diagram of Hierarchy of Activity Hazard Analysis](image)

**Figure 7.9: Hierarchy of Activity Hazard Analysis**
Similar information would be available to the Corps of Engineers employees responsible for inspection on the project. Note that the hierarchy of Activity Hazard Analysis is not meant to take responsibility and initiative away from the leaders and workers on a construction site. It is meant to help focus their attention on current hazards in their immediate environment to help them work safely in an increasingly complex environment.

The findings of the safety research conducted by the Stanford Construction Engineering and Management Program show that managers can control safety performance just as they can control cost and schedule performance. The extensions of the prototype safety expert systems are intended to provide a better mechanism to assist managers in controlling safety performance.

A second question the reader might have is: "the automated Activity Hazard Analysis seems like a good idea, but why does it need to be tied into databases and project schedules?" As suggested by *James March*, there are three major reasons for going beyond the first phase of automating the manual process and providing detailed safety information to workers on a construction site.[March 1989]:

1. **Insight** It provides the workers with a better mental map of potential hazards to work safely in a dangerous environment.

2. **Attention** It focuses attention on the most likely dangers that are going to be faced in a specific time and location.

3. **Credibility** It provides credibility for the managers in construction. By providing detailed safety guidance with reasons for this guidance to workers, management shows that it is not only truly concerned about the welfare of the workers but also knowledgeable about construction methods and their associated risks.

The future extensions of Activity Hazard Analysis using expert systems technology with interfaces to databases and project schedules will still not provide a risk-free work environment. They will, however, allow the identification of time- and location-specific hazards, so that workers can intelligently face the risks in the environment. Towards that end, when these prototypes are extended into working expert systems, they should be integrated with the schedule, cost, and quality object-oriented expert system being developed by the U.S. Army Corps of Engineers, and other enlightened buyers and providers of construction services.
Bibliography


Appendix A - Running the Expert Systems

To run the prototype expert systems the following hardware and software are required:

1. Hardware - any of the following:
   a. Apple Macintosh SE or Macintosh II computer
   b. IBM PC-AT or PS/2 computer
   c. DEC VAX station
   d. UNIX-based workstations

2. Software - the development or runtime version of NEXPERT OBJECT™, plus:
   a. For Apple - if running under Multifinder a minimum of 2 Mbytes is suggested
   b. For IBM - Microsoft Windows with 640K of memory
   c. For DEC VAX stations - VMS or Ultrix
   d. UNIX-based workstations - X Windows Version 11

Note: Since the applications were developed, and are available in the Macintosh environment, options b-d also require the ability to port the developed application to the specified hardware version of NEXPERT OBJECT™.

To obtain a copy of the Macintosh version of these systems write to:

Center for Integrated Facility Engineering
Department of Civil Engineering
Stanford University
Stanford, CA 94305-4020

To obtain more information on the development of the prototype systems, write to the author:

Bruce A. Fink
PSC Box 6155
APO SF 96519

To obtain the development or runtime version of NEXPERT OBJECT™ contact:

NEURON DATA
444 High Street
Palo Alto, CA 94301
(415) 321-4488

The following pages provide information on how to use the runtime version of NEXPERT OBJECT™.
Information on the NEXPERT OBJECT™ Runtime System for the Macintosh includes a general description and short descriptions of the files on the runtime disk. This information is included by permission of Neuron Data. To begin a session go to the "Window" menu and pull down to "Set up Environment". Ensure that the "Suggest Selection" and "Restart Session" boxes are checked. Then hit "Command K" to begin the session.

NEXPERT OBJECT Runtime System for the Macintosh
Version 1.1 Release Notes

General description

NEXPERT OBJECT Runtime is a reduced version of the Development System version intended to be used for the delivery of NEXPERT applications. It has no edition or browser capabilities, which means the end-user can neither modify nor look at knowledge bases.

The differences between the Runtime and the Development System 1.1 are:

- No Editors available. (The "Edit" menu is reduced to the Undo, Cut, Copy, and Paste commands)

- No Rule notebook. (Other notebooks are still available in order to modify values or suggest hypotheses before or during a session).

- No networks. (And thus the "Inspector" menu has been removed)

- No "Save KB" or "Set KB" commands in the Expert menu.

- No Debug Text windows (Transcript, Current Hypo, Current Rule, Conclusions)

- Requires less RAM (750K is enough to run the application with about 400 rules)

- Faster inference sessions (see Changes Notes at the end).

No special documentation comes with this runtime version; refer to your NEXPERT OBJECT 1.1 manual for a complete description of the environment, to the NEXPERT Callable Interface manual for building external routines, and to other separate manuals for graphic interface programs such as AlVision 3.0.
NEXPERT OBJECT Runtime

This application is software-protected, like the Development System version. See the Installation Guide enclosed with this disk for more information on hard disk installation. The procedure for installing/deinstalling the protected copy and other advice are the same as for the Development System.

nexpertrun.dat

The file "nexpertrun.dat" is loaded by NEXPERT OBJECT Runtime at launch time. It is a reduced version of "nexpert.dat" used with the Development System. It holds all the non-Macintosh resources used by NEXPERT and IT MUST ALWAYS STAY IN THE SAME FOLDER. Because some parts of the NEXPERT interface are not available in the Runtime System, "nexpertrun.dat" has been made much smaller than "nexpert.dat" and thus saves a lot of memory while the application is running.

nexpertrun.dat.small

Use this file instead of "nexpertrun.dat" if you are running on a Mac Plus or Mac SE with the standard 9" screen. It is a reduced version of "nexpert.dat.small" coming on the Examples disk of the Development System. It is similar to "nexpertrun.dat" above except that the color resources have been removed (that's why it is a little bit smaller) and most of the windows have been resized to fit in a small Mac screen.

In order to make NEXPERT Runtime load this file instead of the default "nexpertrun.dat" you must simply:
1) make a backup copy of "nexpertrun.dat" to keep the original version.
2) rename "nexpertrun.dat.small" as "nexpertrun.dat".

TeachText is an Apple utility for making simple text files with pictures, such as these Release Notes. It should already been included with your Apple System disk.