

# EQUIP: Earthwork Equipment Selector Expert System

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A prototype knowledge-based expert system to select equipment for earthwork operations, EQUIP, is presented. The earthwork operations considered are (a) land clearing, (b) stripping and stockpiling topsoil, (c) rough grading, (d) fine grading, (e) re-spreading topsoil, (f) loading excess on-site materials, and (g) soil compaction. EQUIP was developed in conjunction with a leading local earthwork contractor. EQUIP was developed using Personal Consultant Easy and a backward chaining problem-solving strategy. The expert system is based on Caterpillar equipment, but EQUIP can be easily modified to include other manufacturers' equipment.

Construction management is defined as the application of management techniques and systems in construction to complete projects on budget and on schedule safely and according to the plans and specifications. Another classical definition of construction management is the effective and efficient use of the five M's (money, machines, manpower, materials, and management) to accomplish those same goals.

One of the several categories of management systems available to construction engineers and managers to achieve the aforementioned goals is the knowledge-based expert system (KBES). Knowledge-based expert systems are becoming widely used in the industry (1-3).

The proper selection of construction equipment significantly affects the completion time and cost of construction operations. The selection of equipment is typically done by the foreman, superintendent, and project manager, either individually or in a group depending on the conditions and complexity of the job. Sometimes experienced personnel must be consulted for such decisions. The decision to select a piece of construction equipment can be very difficult because it involves a large dollar investment based on expected use, operating and maintenance costs, and productivity.

A prototype KBES, EQUIP, was developed by the construction engineering and management program of the department of civil engineering at Case Western Reserve University in Cleveland, Ohio. EQUIP is designed to aid in the selection of construction equipment for earthwork operations. EQUIP was developed in conjunction with a leading local earthwork contractor, who provided both practical input and verification of results. EQUIP was created using Personal Consultant Easy (PC Easy, an expert system building tool) and a backward chaining problem-solving strategy. EQUIP is based on Caterpillar equipment, but can be easily modified to include other manufacturers' equipment.

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## KNOWLEDGE-BASED EXPERT SYSTEMS

Artificial Intelligence (AI) is a computer science field concerned with developing intelligent software including KBES, game-playing, general problem-solving, perception (vision, speech), and natural language processing. An expert system is "a computer program using expert knowledge to attain high levels of performance in a narrow problem area" (3,p.11).

The process of building an expert system (knowledge engineering) typically involves interaction between the expert system builder (knowledge engineer) and domain experts. The domain experts' rules of thumb, procedures, and strategies are extracted and built into the expert system by the knowledge engineer. The main elements in the development of a KBES are the domain expert, the knowledge engineer, the expert system building tool, the user, and the expert system (Figure 1).

The general features of an expert system are: (a) expertise; (b) predictive modeling power; (c) institutional memory, a permanent record of domain experts' rules of thumb, procedures, and strategies; (d) training facility for key personnel; (e) symbolic reasoning, representing knowledge symbolically; (f) depth to handle difficult problem domains and use complex rules; and (g) self-knowledge, examining its own reasoning and explaining its operation (3,pp.7,25).

Expert systems consist of two basic parts: (a) knowledge base (domain knowledge) and (b) inference engine (general problem-solving knowledge). The knowledge base contains facts (data) and rules. The inference engine consists of interpreter (decides how to apply the domain knowledge) and scheduler (decides when and in what order to apply the domain knowledge); it uses the domain knowledge to reason and draw conclusions.

EQUIP was created using PC Easy, one of the top-rated microcomputer-based expert system building tools. PC Easy is a highly functional tool for the development of a small- to medium-sized KBES. PC Easy runs on IBM and IBM-compatible microcomputers and requires 512K bytes of random access memory (RAM).

PC Easy includes the following powerful and helpful features (4,pp.1-3):

- Interactive environment for development and testing,
- Debugging and value-checking aids,
- Graphics capability,
- Handling uncertainty,
- Explanation options as to why the KBES is asking for information and how it reached a conclusion,
- English-like rule-entry language,

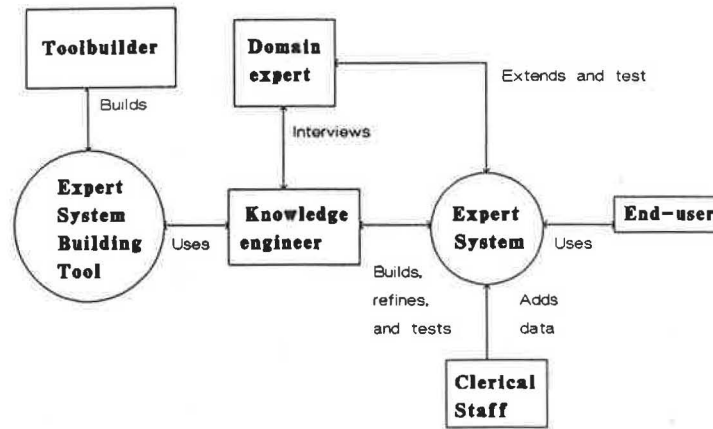


FIGURE 1 Elements in expert system development (3,p.8).

- Window-oriented interface and on-line help,
- Full-screen editor, and
- Access to external DOS files, 1-2-3 worksheets, and dBASE data bases.

A catalog of 95 selected expert system tools is provided by Waterman (3,pp.339-365).

**EARTHWORK OPERATIONS CONSIDERED IN EQUIP**

Earthwork consists of many separate operations. Equipment and methods are different for each operation. For many con-

struction projects, earthwork starts with clearing the land, followed by stripping and stockpiling the topsoil, rough grading, fine grading, loading excess on-site materials, respreading topsoil, soil stabilization, soil compaction, and trenching for foundations and site utilities. These steps are performed in sequence or, in some cases, simultaneously. On some jobs the operations are separated by a period of time.

The earthwork operations included in EQUIP are (a) land clearing; (b) stripping and stockpiling topsoil; (c) rough grading; (d) fine grading; (e) respreading topsoil; (f) loading excess on-site materials; and (g) soil compaction.

Many of these operations are affected by soil conditions and bearing capacity, topography, rainfall and climate, job specifications, and magnitude of area. Figures 2-8 illustrate

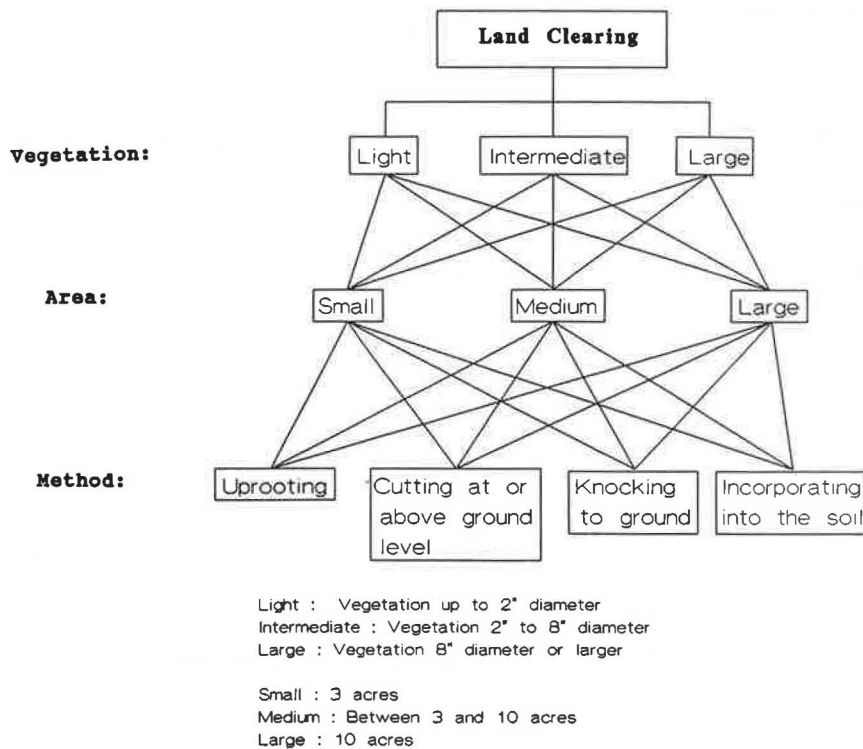
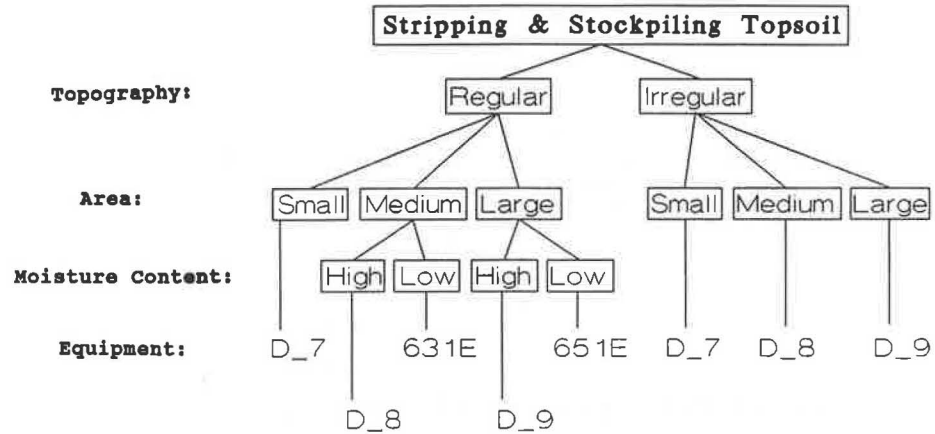


FIGURE 2 Major factors and logic steps affecting selection of land clearing equipment.

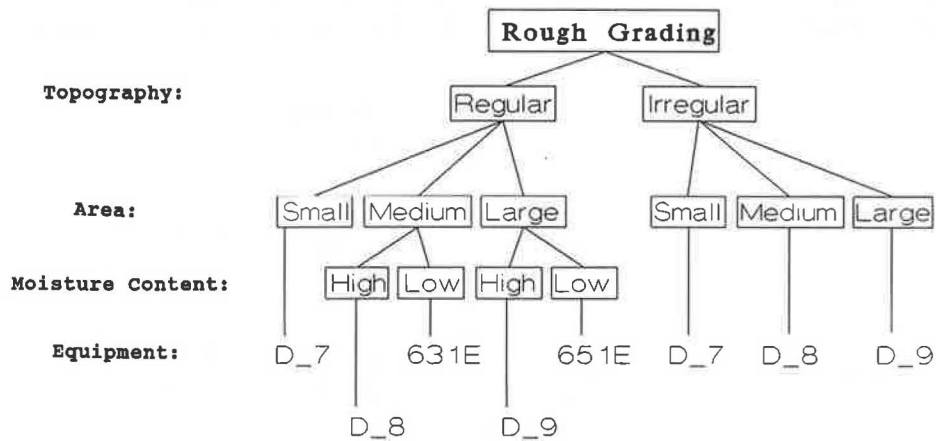


Topography : Regular  
Irregular

Area : Small - less than 2 acres  
Medium - between 2 and 4 acres  
Large - more than 4 acres

Moisture Content - High or Low

**FIGURE 3** Major factors and logic steps affecting selection of topsoil stripping and stockpiling equipment.

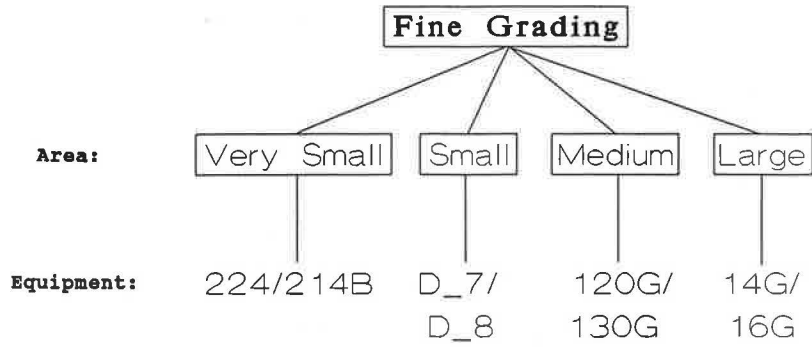


Topography : Regular or Irregular

Area : Small - less than 2 acres  
Medium - between 2 and 4 acres  
Large - more than 4 acres

Moisture Content - High or Low

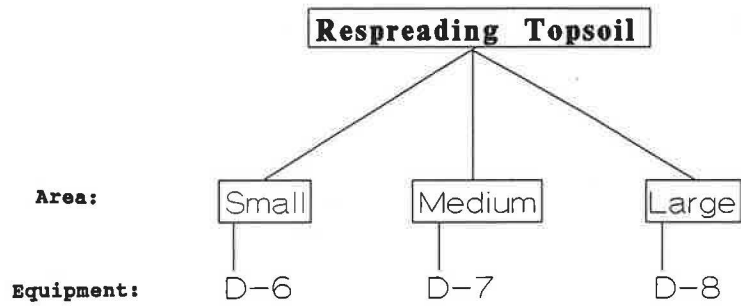
**FIGURE 4** Major factor and logic step affecting selection of rough grading equipment.



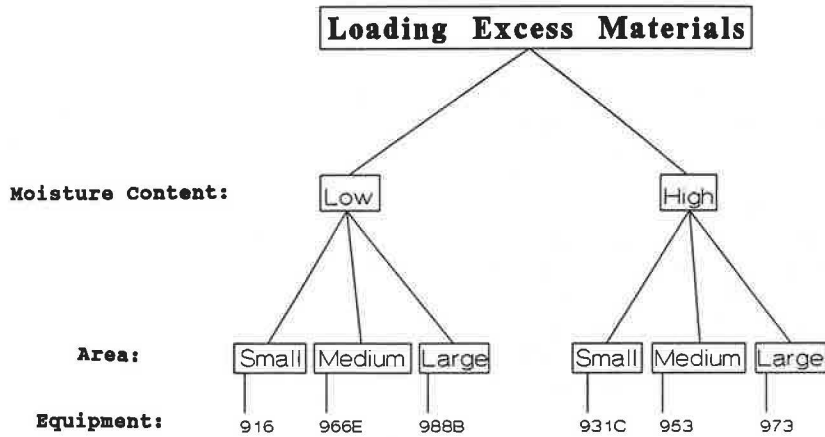
Area :

- Very small - < 500s/f
- Small - < 18,000 s/f
- Medium - > 18,000s/f < 45,000s/f
- Large - > 45,000s/f

**FIGURE 5** Major factor and logic step affecting selection of fine grading equipment.



**FIGURE 6** Major factor and logic step affecting selection of topsoil respreading equipment.



**FIGURE 7** Major factors and logic steps affecting selection of loading excess on-site material equipment.

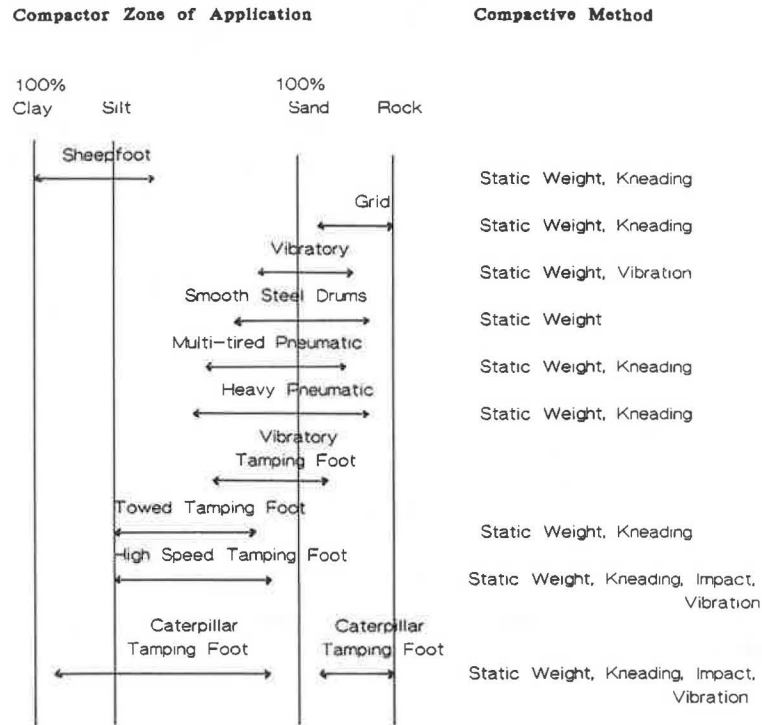


FIGURE 8 Zones of application chart (5,p.518).

the major factors and logic steps affecting selection of equipment for each of the earthwork operations.

**EQUIP AND PC EASY**

EQUIP, created by using PC Easy, is composed of three basic parts: (a) knowledge-base properties, (b) parameters, and (c) rules.

**Knowledge Base Properties**

A knowledge base property is defined as “a structure that contains a piece of information about the knowledge base as a whole or controls a knowledge base characteristic” (6,pp.1-3). Figure 9 shows the knowledge base properties; only DOMAIN and GOALS are required. DISPLAYRESULTS is assigned by PC Easy, and the others are optional. DOMAIN of EQUIP is “Earthwork Equipment Selector,” and GOAL parameters are LC\_EQUIPMENT, ST\_EQUIPMENT, RG\_EQUIPMENT, FG\_EQUIPMENT, RT\_EQUIPMENT, HEM\_EQUIPMENT, and CO\_EQUIPMENT (the first two characters represent the earthwork operation).

**Parameters**

A parameter is defined as “a structure that identifies or contains a piece of information that PC Easy uses to arrive at a

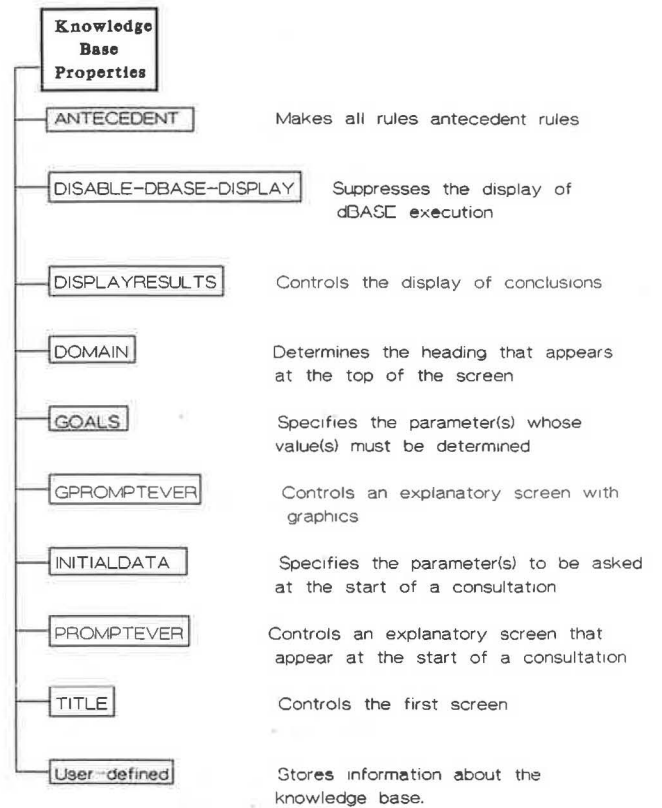


FIGURE 9 Knowledge base properties of PC Easy (6,pp.1-2,1-9).

conclusion" (6,pp.2-4). Parameters have values and many properties that determine their characteristics or describe them (Figure 10). When a parameter is created, PC Easy requests values for a parameter's TRANSLATION, its TYPE, and its PROMPT. TYPE is the only required property; other properties are optional. EQUIP consists of 23 parameters, including 7 GOAL parameters. The first two characters of each parameter name represent the type of earthwork operation. Some of the EQUIP parameters are LC\_AREA, LC\_TYPE, LC\_VEG, and LC\_EQUIPMENT.

### Rules

Rules are IF-THEN statements that "express relationships among the parameters and conclusions about them" (4,pp.4-

8). PC Easy rules are written in a language called Abbreviated Rule Language (ARL). PC Easy rules have associated properties including two required properties: IF and THEN. THEN property expresses the actions carried out if the conditions in the IF statement are met. The IF and THEN properties of a rule contain parameters, parameter values, and ARL functions. PC Easy rules are consequent rules (backward chaining) unless ANTECEDENT property (forward chaining) is added to it. EQUIP has 38 rules; however, these rules could have been broken down into more than 100 simpler rules. Figures 11 and 12 illustrate the rules used for selecting land clearing equipment.

A PC Easy KBES can have multiple rule groups. Rules related to each earthwork operation are stored in different rule groups in EQUIP.

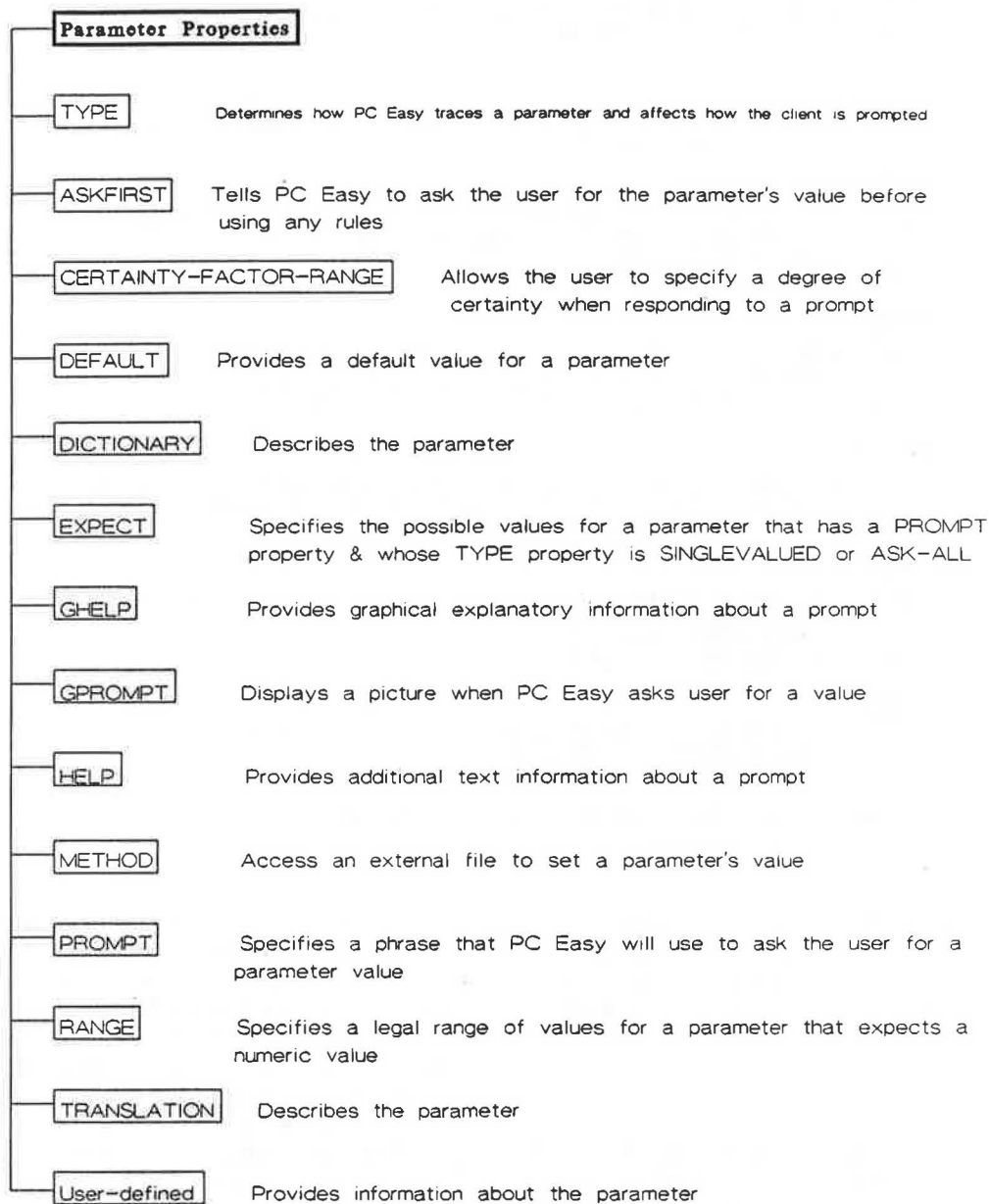


FIGURE 10 Parameter properties of PC Easy (6,pp.2-6,2-7).

```

RULE001
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LIGHT AND LC_AREA = SMALL
      AND LC_TYPE = UPROOTING OR LC_TYPE = KNOCKING_TO_GROUND
THEN :: LC_EQUIPMENT = CAT_D-6
DESCRIPTION :: light vegetation - small area - uprooting & knocking to the
              ground

RULE002
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LIGHT AND (LC_AREA = SMALL
      AND LC_TYPE = INCORPORATING_INTO_THE_SOIL) OR (LC_AREA = MEDIUM AND
      LC_TYPE != CUTTING_ABOVE_GROUND_LEVEL) OR (LC_AREA = LARGE AND
      LC_TYPE = INCORPORATING_INTO_THE_SOIL)
THEN :: LC_EQUIPMENT = CAT_D-7
DESCRIPTION :: light clearing - all areas, incorporating into the soil -
              medium area, uprooting

RULE003
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LIGHT AND LC_AREA = LARGE
      AND LC_TYPE = UPROOTING OR LC_TYPE = KNOCKING_TO_GROUND
THEN :: LC_EQUIPMENT = CAT_D-8

RULE004
=====
IF  :: OPERATION = LAND_CLEARING AND LC_TYPE = CUTTING_ABOVE_GROUND_LEVEL
THEN :: LC_EQUIPMENT = HYDRO_AXE

RULE005
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = INTERMEDIATE AND LC_AREA =
      SMALL AND LC_TYPE = UPROOTING OR LC_TYPE = KNOCKING_TO_GROUND
THEN :: LC_EQUIPMENT = CAT_D-6

RULE006
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = INTERMEDIATE AND (LC_AREA =
      MEDIUM AND LC_TYPE = UPROOTING) OR LC_TYPE =
      INCORPORATING_INTO_THE_SOIL
THEN :: LC_EQUIPMENT = CAT_D-7

RULE007
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = INTERMEDIATE AND (LC_AREA =
      MEDIUM AND LC_TYPE = KNOCKING_TO_GROUND) OR (LC_AREA = LARGE AND (
      LC_TYPE = UPROOTING OR LC_TYPE = KNOCKING_TO_GROUND))
THEN :: LC_EQUIPMENT = CAT_D-8

RULE008
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LARGE AND LC_AREA = SMALL
      AND LC_TYPE = UPROOTING OR LC_TYPE = KNOCKING_TO_GROUND
THEN :: LC_EQUIPMENT = CAT_D-7

RULE009
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LARGE AND LC_AREA = MEDIUM
      OR LC_AREA = LARGE AND LC_TYPE = UPROOTING OR LC_TYPE =
      KNOCKING_TO_GROUND
THEN :: LC_EQUIPMENT = CAT_D-8

RULE010
=====
IF  :: OPERATION = LAND_CLEARING AND LC_VEG = LARGE AND LC_TYPE =
      INCORPORATING_INTO_THE_SOIL
THEN :: LC_EQUIPMENT = NOT_AVAILABLE

```

FIGURE 11 Land clearing rules in Abbreviated Rule Language.

EQUIP adopts a backward chaining (top-down, goal-driven, hypothesis-driven, and consequent-driven) strategy. In backward chaining the expert system starts with the goals (what it wants to prove) and tries to establish the facts it needs to prove the goals.

### Consultation

In a consultation session (Figure 13), the title of EQUIP (TITLE knowledge base property) and a brief description of EQUIP (PROMPTEVER knowledge base property) are displayed. The user is then prompted to select the earthwork

operations for which EQUIP is to recommend the most suitable construction equipment. Depending on the user's selection, EQUIP prompts for additional related questions (Figures 2-8). The user can ask WHY a response to the current prompt is needed: PC Easy "identifies the parameter that depends on this value, cites the rule it is trying to use, and explains what the rule is about" (6, pp.4-48). The user can get help by pressing the F1 function key at any prompt throughout the consultation. EQUIP provides many help texts. All the parameters have EXPECT values; hence at each prompt, possible responses are displayed. The user must select the most probable response from the list.

RULE001

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LIGHT, and  
 3) area of land clearing is SMALL, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-6.

DESCRIPTION :: light vegetation - small area - uprooting & knocking to the ground

RULE002

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LIGHT, and  
 3) 1) 1) area of land clearing is SMALL, and  
 2) type of land clearing is INCORPORATING\_INTO\_THE\_SOIL, or  
 2) 1) area of land clearing is MEDIUM, and  
 2) type of land clearing is not CUTTING\_ABOVE\_GROUND\_LEVEL, or  
 3) 1) area of land clearing is LARGE, and  
 2) type of land clearing is INCORPORATING\_INTO\_THE\_SOIL,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-7.

DESCRIPTION :: light clearing - all areas, incorporating into the soil - medium area, uprooting

RULE003

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LIGHT, and  
 3) area of land clearing is LARGE, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is

CAT\_D-8.

RULE004

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) type of land clearing is CUTTING\_ABOVE\_GROUND\_LEVEL,

Then it is definite (100%) that Land clearing equipment recommended is HYDRO\_AXE.

RULE005

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is INTERMEDIATE, and  
 3) area of land clearing is SMALL, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-6.

RULE006

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is INTERMEDIATE, and  
 3) 1) 1) area of land clearing is MEDIUM, and  
 2) type of land clearing is UPROOTING, or  
 2) type of land clearing is INCORPORATING\_INTO\_THE\_SOIL,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-7.

RULE007

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is INTERMEDIATE, and  
 3) 1) 1) area of land clearing is MEDIUM, and  
 2) type of land clearing is KNOCKING\_TO\_GROUND, or  
 2) 1) area of land clearing is LARGE, and  
 2) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-8.

RULE008

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LARGE, and  
 3) area of land clearing is SMALL, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-7.

RULE009

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LARGE, and  
 3) 1) area of land clearing is MEDIUM, or  
 2) area of land clearing is LARGE, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,

Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-8.

RULE010

=====

- If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LARGE, and  
 3) type of land clearing is INCORPORATING\_INTO\_THE\_SOIL,

Then it is definite (100%) that Land clearing equipment recommended is NOT\_AVAILABLE.

FIGURE 12 Land clearing rules in English.



\* EQUIP \*  
An Expert System  
for  
Earthwork Equipment Selection

\*\* End - RETURN/ENTER to continue

Current objective:

Earthwork Equipment Selector

This program helps you to select best earthwork equipment for different operations suitable for your job conditions

Types of operations considered include land clearing, strip topsoil, rough grading, fine grading, respread topsoil, load excess materials, and soil compaction

Mainly equipment manufactured by Caterpillar Inc. are considered

Consult as many times as you want, I am friendly!

\*\* End - RETURN/ENTER to continue

Select earthwork operation/s to be performed from the list shown

- Yes
- \* LAND CLEARING
  - \* STRIP TOPSOIL
  - \* ROUGH GRADING
  - \* FINE GRADING
  - \* RESPREAD TOPSOIL
  - \* HAUL EXCESS MATERIALS
  - \* COMPACTION

1. Use arrow keys or first letter of item to position cursor.
2. Select all applicable responses.
3. After making selections, press RETURN/ENTER to continue.

What is the type of clearing operation to be performed ?

UPROOTING  
CUTTING ABOVE GROUND LEVEL  
KNOCKING TO GROUND  
INCORPORATING INTO THE SOIL

1. Use the arrow keys or first letter of item to position the cursor.
2. Press RETURN/ENTER to continue.

FIGURE 13 Consultation screens for land clearing example.

What is the type of clearing operation to be performed ?

UPROOTING

Why:

Type of land clearing is needed to determine Land clearing equipment recommended

RULE004

If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) type of land clearing is CUTTING\_ABOVE\_GROUND\_LEVEL,  
 Then it is definite (100%) that Land clearing equipment recommended is HYDRO\_AXE.

\*\* End - RETURN/ENTER to continue

2. Press RETURN/ENTER to continue.

What is the vegetative growth of land to be cleared ?

LIGHT  
 INTERMEDIATE  
 LARGE

Help:

Select LIGHT if vegetation is upto 2 inch diameter

Select INTERMEDIATE if vegetation is between 2 to 8 inch diameter

Select LARGE if vegetation is greater than 8 diameter

\*\* End - RETURN/ENTER to continue

1. Use the arrow keys or first letter of item to position the cursor.  
 2. Press RETURN/ENTER to continue.

What is the magnitude of land clearing area ?

SMALL  
 MEDIUM  
 LARGE

1. Use the arrow keys or first letter of item to position the cursor.  
 2. Press RETURN/ENTER to continue.

Conclusions:

Land clearing equipment recommended is as follows: CAT\_D-6

:attr (blue high) Land clearing equipment recommended

Determined to be: CAT\_D-6  
 ... by using RULE001

If 1) earth work operation/s to be performed is LAND\_CLEARING, and  
 2) vegetative growth of land to be cleared is LIGHT, and  
 3) area of land clearing is SMALL, and  
 4) 1) type of land clearing is UPROOTING, or  
 2) type of land clearing is KNOCKING\_TO\_GROUND,  
 Then it is definite (100%) that Land clearing equipment recommended is CAT\_D-6.

\*\* More - RETURN/ENTER to continue

\*\* End - RETURN/ENTER to continue

FIGURE 13 (continued)

EQUIP then recommends the most suitable equipment. The user can ask HOW the conclusion was reached (Why is the equipment recommended?). PC Easy shows the rules corresponding to the user's responses and clearly explains the reasons in English (using TRANSLATION parameter property).

### POTENTIAL BENEFITS

The major advantages of using EQUIP are

- Ability to plan equipment requirements by office personnel without demands on field personnel;
- More comprehensive and accurate bid preparation;
- Better ability to forecast cash flow, especially for equipment rentals;
- More realistic activity duration estimation for bar charts or CPM networks;
- Optimum use of the available construction equipment as reflected in both time and cost expenditures; and
- Ability to train entry-level construction engineers and managers by simulating different job scenarios.

EQUIP can easily be expanded to include productivity data and cost accounting data. These data allow a construction manager to perform cost-effectiveness analyses to evaluate cost-time tradeoffs among equipment alternatives.

EQUIP contains data on several pieces of Caterpillar equipment; other manufacturers' equipment and Caterpillar equipment can be easily added to the knowledge base. Sources of information on construction equipment applicability, productivity, and cost include manufacturers, field personnel, construction industry associations, and construction industry information references (e.g., R.S. Means or DataQuest).

The garbage in, garbage out (GIGO) term referring to incorrect input resulting in incorrect output applies to EQUIP as well as other knowledge-based expert systems.

### CONCLUSIONS

The KBES presented in this paper, EQUIP, provides an interactive base system to select construction equipment for earthwork operations. Proper selection of equipment not only makes the construction time shorter but also reduces the overall project cost. The base system is effective in itself, but also has potential to be expanded or tailored to meet user requirements. EQUIP can be easily expanded to cover other construction operations and other manufacturers' equipment. The system developed is practice-oriented and designed to demonstrate the desirability and accessibility of knowledge-based expert systems in construction engineering and management. Even though EQUIP is developed in PC Easy, other expert system building tools could be adapted.

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