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AN EXPERT SYSTEM FOR USE IN DISPATCHING SUPPRESSION RESOURCES TO WILDFIRES*

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1. INTRODUCTION

This paper reports on the development of a prototype expert advisory system for use in dispatching suppression forces to wildfires on the Okanogan National Forest. The system was developed to implement the Okanogan National Forest Appropriate Suppression Response Plan (Anon. 1987). Decision trees used in the plan formed the initial knowledge base for the expert system.

The Okanogan Expert Suppression Support system (OKESS) uses time of year and a variety of data about burning conditions, characteristics of the area in which the fire is burning, past and projected weather, smoke dispersal, etc., to arrive at a decision as to whether to immediately control (suppress) the fire, to contain the fire within set boundaries, or to confine it within a predetermined drainage or area.

A PROLOG-based expert system programming tool was used to develop the prototype.

2. EXPERT SYSTEMS

Expert systems can generally be defined as computer programs that undertake the solution of difficult tasks by using the knowledge of and mimicking the solution methods of human experts in a narrow knowledge domain (Davis et. al. 1986). The knowledge embodied by an expert system may be that of one or more human experts within a given field. The notion of knowledge, as opposed to data, is an important characteristic of an expert system. Traditional computer applications are "procedural" by nature, processing data (rather than knowledge) in predefined procedures to produce quantitative outputs such as predicted rate-of-spread, fire danger codes and indices, etc. By comparison, expert systems use knowledge in the form of facts, lists, production rules and relationships to make inferences and then recommendations. An expert system may use the numerical outputs from the more traditional procedural computer programs as facts to be consulted to make recommendations. More commonly, however, expert systems use the symbolic information which is embodied in an internal knowledge base. Such symbolic knowledge can be encoded as separate statements or declarative representations. Unlike the procedural representations used by more traditional computer programming, declarative representations are easier to maintain and permit the encoding of accurate yet possibly incomplete knowledge into the system.

The performance level of an expert system is primarily a function of the size and quality of a knowledge base it possesses. Knowledge base quality and performance is therefore of prime importance in expert system development.

3. THE OKESS EXPERT SYSTEM

The Okanogan National Forest has developed a plan to implement a range of fire suppression options. The plan (Anon. 1987) identifies three possible fire suppression strategies outlined as follows:

a. Confinement - To restrict the fire within predetermined boundaries established either prior to the fire, during the fire, or in an escaped fire situation analysis. Suppression action could be minimal and could be limited to surveillance.

b. Containment - To surround the fire within natural containment lines or with control lines as needed, which can reasonably be expected to check the fire's spread under prevailing and predicted conditions.

c. Control - To complete a control line around the fire followed by burn out and cold trailing

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techniques until the line can reasonably be expected to hold under foreseeable conditions.

The primary goal of OKESS is to determine which one, or combination of these three suppression responses is most appropriate under given sets of conditions.

3.1 The Programming Environment

The system is written for the IBM PC/XT/AT family of micro-computers using the Arity/Expert development package. Arity/Expert is an expert system development tool which is integrated into the PROLOG programming language. PROLOG is a language of artificial intelligence that is commonly used in the development of expert systems, natural language interfaces and relational databases (Clocksin and Mellish 1984).

3.2 The OKESS Knowledge Base

The OKESS knowledge base was developed from five decision trees found in the Okanogan National Forest Appropriate Suppression Response Plan. A production system approach was taken, since problems that use decision trees are often considered good candidates for this type of knowledge representation. Production systems use a knowledge base composed of if-then production rules and some form of control mechanism or mechanisms to reach a desired goal state.

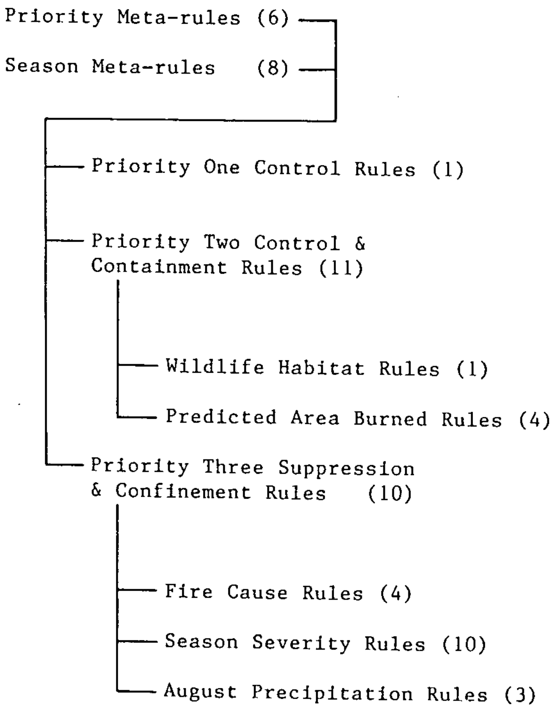

Fig. 1. OKESS production rule hierarchy. Brackets indicate the number of rules in each rule problem class.

3.2.1 Control Mechanisms

One of the control mechanism chosen was to develop a hierarchy of production rules. In any problem beyond the most trivial, it is necessary to determine ways to prune the solution space. In the case of OKESS, 28 goals or va identified. By taking products of all poss values for each variable, over 5 X 10^{15} combinations are possible. This phenomenon of "combinatorial explosion" was reduced by dividing knowledge base into a three level hierarchy of rule problem classes (see Figure 1).

At the highest level of abstraction, meta-rules were developed to determine the fire protection priority and the season of the year. Appropriate suppression response rules were then developed for each protection priority class. Where needed, sub-rules were developed to account for wildlife habitat conditions, area burn predictions, fire cause class, seasonal severity, and August precipitation.

A control measure was included to ensure the pre-calculation of the date (month and day), protection priority and public safety concerns used in the meta-rules.

A final control was to determine the order of goal calculation methods for selected rule classes. Calculation methods included the checking rules, asking questions of the user or by inheritance of a default value.

3.2.2 Production Rules

Production rules consist of two prima components, a premise and a conclusion. Both t premise and the conclusion are made up of go (see Table 1). A goal is a condition that car proved to be either true or false. The premis a rule can have one or more goals, while only goal is permitted per conclusion. The concl of a goal is determined to be true if each c goals or conditions in the premise are pro be true. If one or more of the goals premise are proved to be false, then the said to fail or not succeed (see Figure 2).

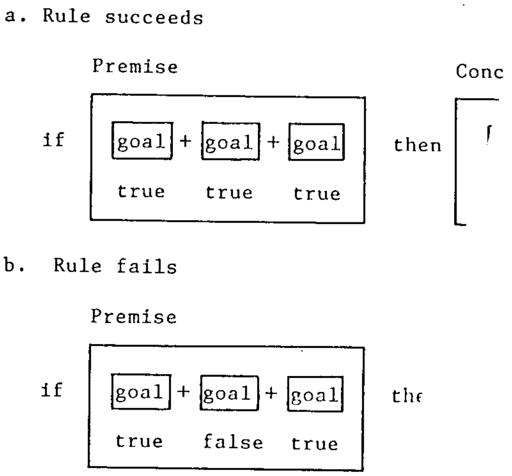

Fig. 2. Satisfying rules; (a) this example all the goals true, hence, the conclusion fails: in this example one g false causing the conclusion

In total, 58 rul replicate the informatio decision trees of the appropriate suppression response plan. An example of a rule written in the Arity/Expert rule language and its English equivalent is shown in Figure 3.

Table 1

OKESS production rule goals by problem class.

		Production rule problem class[1]									
Goal	n[2]	M1	M2	1	2	2W	2P	3	3C	3S	3A
recommended response	4			*[3]	*			*			
month of year	12		+[4]							+	+
day of month	31		+								+
protection priority	3	*		+	+	+	+	+		+	+
public safety	3	+									
season of year	4		*	+		+	+				
land management area	10	+			+	+	+		+	+	+
natural research area	3	+							+		
wildlife habitat	3				+	*					
area burned class	3				+		*				
fire intensity level	5				+						
stand fire type	2				+						
potential area burned	3[5]						+				
fire weather forecast	5				+						
potential escape threat	4				+			+			
suppression preparedness	3				+			+			
suppression capability	2				+			+			
least total cost	2				+			+			
duty officer availability	2				+						
prescribed fire class	2							+	*		
fire cause class	2								+		
season severity	2							+		*	
on/off site smoke effects	2							+			
monitor team availability	2							+			
threaten and endangered species	2							+			
precipitation since march	8[5]									+	
August precipitation period	3									+	*
August precipitation amount	8[5]										+
Maximum number of goals/rule[6]	28	4	3	3	12	4	4	11	5	6	6
Number of production rules		6	8	1	11	1	4	10	4	10	3

[1] Production rule problem class codes:
- M1: Protection priority meta-rules;
- M2: Season meta-rules;
- 1: Priority one control rules;
- 2: Priority two control and containment rules;
- 2W: Wildlife habitat rules;
- 2P: Predicted area burned rules;
- 3: Priority three suppression and confinement rules;
- 3C: Fire cause rules;
- 3S: Season severity rules;
- 3A: August precipitation rules.

[2] Number of valid values for each goal.

[3] The "*" symbol indicates that the goal is the conclusion for the rule class.

[4] The "+" symbol indicates that the goal is in the premise of one or more rules in the class.

[5] Valid values are numeric. The number of values indicate the number of valid value classes.

[6] This total represents the maximum number of goals possible in the premise and the conclusion for any rule in the problem class.

a. Arity/Expert rule language notation

```
the season_severity of dispatch is low
      if
the lma of dispatch is lma1 and
the month of dispatch is M and
M > 4 and
the month of dispatch is N and
N < 7 and
the precip of dispatch is P and
P   0.805
```

b. English rule notation equivalent

```
If the land management area is wilderness and
   the month is May or June and
   the precipitation  is greater than 0.805 inches
Then the season severity index is low
```

Fig. 3. Example of a rule written in Arity/Expert rule language notation and its English equivalent.

3.3 Dealing with Uncertainty

In real life, experts must deal with the uncertainty of their decisions. Therefore if a computer based system is to be truly "expert" it must have some way of dealing with this uncertainty in a human-like fashion. OKESS deals with this problem through the use of confidence factors.

Confidence factors give an index of the relative strength of the conclusion or conclusions. The range of the index is from -1.0, indicating definite evidence that a rule is false, to +1.0, indicating that a rule is definitely true. It is important to note that certainty factors are not probabilities but rather informal measures of confidence or certainty that a recommended action, rule, or fact is true.

The method of confidence factor calculation used in OKESS is based on fuzzy logic. Simply stated, the minimum confidence factor occurring in the premise is assigned to the conclusion of the rule.

3.4 User Interface

The OKESS user interface mimics a consultation that a dispatcher would have with field, district and forest headquarters personnel in order to recommend an appropriate suppression response. Through the use of menu options, the system asks the user questions until it has enough information to make a recommendation. It is important to note that since the system uses knowledge rather than data, inferences can be made from an incomplete information base. For example, if the user does not know the answer to a specific question posed by the system, he/she may respond with "unknown". Most traditional computer programs would crash at this point, however, an expert system can respond to this problem in a number of ways. For example, the system can use default values for questions, ask new questions for which the user may be able to answer, or it may make inferences on its own based on answers supplied previously. The latter case is an example where values could possibly be inherited from previous instances of knowledge.

When queried, the user also has the option to ask why the system is requesting the information. The system will then respond with either a custom response if one exists, or will list the rule or the control option that is being evaluated at the present time. The system also has the ability to explain its recommendation and the reasoning used to reach the conclusion. Fig. 4 shows the type of response that is possible when the system is asked to explain its reasoning.

4. SUMMARY AND DISCUSSION

The decision trees commonly used in forest fire management decision making are well suited for production rule-based expert systems. This programming approach allows the inclusion of agency policy and dispatcher rules of thumb to be incorporated into automated decision support systems.

Due to the demonstration nature of this prototype expert system, no linkages were made to external procedural programs or data bases. Future enhancements might · include procedural attachments to link OKESS to a fire weather data base, geographic data bases and/or programs to calculate fire danger and fire behavior.

```
[ How was the appropriate suppression response
judged to be confine (1.0)?]

[Since [1] the priority is three (1.0)
   and [2] the fire is wanted (1.0)
   and [3] the season severity is low (1.0)
   and [4] the potential for escape is none (1.0)
   and [5] the smoke problems are none (0.8)
   and [6] the monitor team is available (1.0)
   and [7] the regional preparedness level is
           level II (1.0
   and [8] the suppression capability is yes (0.9)
   and [9] the least cost is yes (0.8)
   and [10] the threatened and endangered species
            are none (0.8)
 then the appropriate suppression response is
 confine (0.8).]
```

Fig. 4. Sample output from the OKESS explanation facility. The value and confidence factor for each goal are shown. The confidence factor of the conclusion takes the value of the lowest confidence factor in the premise.

The OKESS prototype is useful as a demonstration and training tool. To be fully useful as an expert advisor, many of the subtle, implicit decision rules which dispatchers use in real situations must be identified and included in the system.

5. CONCLUSIONS

The fields of artificial intelligence and expert systems have the potential to greatly improve real time decision making in forest fire management. Expert systems provide a vehicle to incorporate heuristics, knowledge and inference to computer assisted decision support. The future may see expert systems as "front end" controllers which gather facts from external programs and data bases to combine with their internal knowledge bases. The application of artificial intelligence and expert systems to fire management should not be seen as a panacea for the day-to-day problems of fire managers. Like simulation, modelling and other management science sub-disciplines, it is one of the many tools available to be used when and where appropriate.

6. ACKNOWLEDGEMENTS

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