GEOMAT EXPERT SYSTEM KNOWLEDGE CAPTURE MODEL

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SUMMARY - The development of materials performance expert systems requires the efficient capturing and organising of diverse engineering knowledge in a form suitable for encoding in an expert system shell. A knowledge capture model has been developed and applied for expertise in the selection and use of materials for geothermal energy applications. The model is described and illustrated for the GeoMat (Geothermal Materials) expert system.

1. INTRODUCTION

Expert systems provide scientists and engineers with a means of capturing technology in an easily retrievable computer format. The technology is ideally suited to "mature" technologies such as the development of geothermal energy applications. Although minimal geothermal development activity is currently being experienced in New Zealand the preservation of expertise in materials selection and use is considered essential; the captured expertise will be available for future applications.

Expert systems developments have been successfully applied to narrow knowledge domains where the knowledge and expertise required to give reliable advice can be critically defined and successfully evaluated (NACE, 1992).

Techniques and practices for these developments have not been standardised, however, models which aid in understanding of knowledge and development of expert systems are being promulgated (Hickman et al, 1989).

A knowledge capture model has ben developed for materials performance applications (Lichti et al, 1992) and has been applied to the preparation of an "in house" expert system for selection and use of materials for geothermal energy applications, GeoMat (Lichti and Wilson, 1990). The model is proposed for use in all stages of expert systems developments to provide a durable record of progress which allows developers to maintain quality assurance throughout the development period.

The developed knowledge capture model is reviewed and the application of the model to the GeoMat system is described. The knowledge capture model and expert system development techniques presented here can be applied to other areas of geothermal technology and other materials applications, so long as the expertise is of significant complexity and is of sufficient value to justify the development costs.

2. MODELS FOR DEVELOPMENT OF EXPERT SYSTEMS

Applications-oriented computer products for abstracts searching, data logging, database developments, corrosion process modelling and more recently, expert systems have become standard tools for many corrosion control technologists (Lichti and Wilson, 1990). The process of developing expert systems which are an application of Artificial Intelligence research typically involves (Lichti and Cradwick, 1991):

- the use of expert system software shells which contain all of the tools required for the development (Mattery, 1991)
- collecting and organising domain expertise in a form which is suitable for encoding in an expert system shell
- evaluating, interpreting and justifying knowledge submitted for inclusion in the expert system
- specifying and programming of user interface facilities designed to meet the needs of the target audience
- management and financial control required to "champion" a particular development through to completion.

A project team approach is most often used for the development of expert systems. Time commitment and expertise required includes:

- domain expertise in the technical area including a knowledge of current industry practice
- expert systems development experience or "knowledge engineering" skills required to obtain, organise and implement the knowledge in an expert system shell
- data evaluation expertise to provide both technical and reliability assessments of advice
- user and reviewer expertise to ensure the development provides useful and correct advice
- programmer expertise to provide custom user interface facilities.

The development process involving such a large team must be structured in order to maintain a focused approach. Structuring of the development process can be achieved using models.

Spiral models of software development provide a means of controlling the activities of the team members, setting target milestones for development and maintaining financial control (Boehm, 1988; Hickman et al, 1989).

Models of knowledge analysis assist system developers in the task of capturing knowledge and designing user interfaces (Hickman et al, 1989).

Knowledge capture models provide developers with a formal method of collecting and organising data in a form suitable for direct encoding in an expert system shell (Lichti et al, 1992).

3. MODELS OF KNOWLEDGE

Knowledge analysis models (models of expertise and conceptual models of knowledge) and knowledge capture models provide a formal means of processing knowledge into a form suitable for use in knowledge based expert systems.

The knowledge capture model described here evolved through experience with development of large materials performance expert systems (Lichti et al, 1989; Lichti and Cradwick, 1991). Formalising of the model was achieved using the results of Artificial Intelligence research from the ESPRIT Project (The European Strategic Programme for Research in Information Technology), in particular the KADS methodology (Hickman et al, 1989).

3.1 KADS Model of Expertise

KADS is the name of a methodology for the development of knowledge based expert systems. The methodology has been developed to speed development of expert systems through an understanding of the structure of knowledge. It includes a *model of expertise* consisting of four layers of knowledge which are considered separately. These are a *domain layer,* an *inference layer,* a *task layer* and a *strategic layer* as illustrated in Figure 1. Capture of knowledge begins within the domain layer and as the collected knowledge is analyzed and prepared for the next layer, available knowledge representation models are tested and revised or a model of the knowledge is developed. Aspects of the development which are to be considered at the separate layers are summarised in Figure 1.

KADS developers argue that access to a series of defined knowledge analysis models speeds development of expert systems as model development or creation is replaced by model selection or refinement.

3.2 Conceptual Models of knowledge

A conceptual model of knowledge provides a representation of the thought processes of an expert as a problem is described, evaluated, diagnosed and solved. Figure 2 illustrates such a model for materials selection. Conceptual models are used to establish the structure or operational requirements of the expert system.

A human expert when asked to provide materials selection advice (see Figure 2) begins by defining *concepts* such as plant details and environment parameters. The next stage is the *classification and comparison* of the collected information with a knowledge of previous cases and previous solutions and fkom this activity a *materials* solution is provided. Human experts then enter a complex reasoning process where potential problem with the materials recommendation are considered and a set of caveats or *warnings* are produced. Even after this stage the expert may reconsider the advice and warnings given for alternative scenarios which are resident in his store of knowledge. This activity is represented by a *What if?* stage in Figure 2.

The availability of suitable conceptual models for materials engineering applications is currently limited and new applications typically require considerable effort in the development of a conceptual model.

3.3 Knowledge Capture Model

The process of capturing knowledge is defined as the collection, organisation, evaluation, and incorporation of knowledge within a working expert system. Models for capture of knowledge and expertise must be designed to provide an efficient means of achieving this process, while providing the development team with a record of progress suitable for achieving quality control through simple review processes. Knowledge capture models must be (Lichti et al, 1992):

- simple and easily understood (permit rapid review and reasoned criticism)
- versatile (meet needs of diverse audience and project team)
- readily modifiable (permit staged contributions from experts)
- easily implemented (without the need for further modelling)
- easily maintained (documented hierarchy structure).

The knowledge capture model described in Figure 3 represents a combining of the KADS model of expertise (Figure 1) with a suitable conceptual model of the domain of interest (Figure 2). The knowledge capture model represents the process of building an expert. system and is an application of the KADS model of expertise.

A. Listing of Defined Concepts - The first stage of the model involves a listing of concepts and relations and a grouping of related concepts. Wherever possible plant and equipment concepts such as items of equipment and component parts or environmental parameters such as physical or chemical conditions are grouped together. Lumping of these parameters using formal models can greatly simplify implementation in an expert system, ie Pourbaix diagram concepts, models for stress cracking resistance, pitting resistance, solution pH and scaling potential. This stage should involve the system developer and one or more domain experts.

KADS Model of Expertise

1. Domain Layer - Static Knowledge
- Concepts (listing of all objects, attributes and their values)
- Relations (relations between concepts)
- Structures (hierarchy and problem solving strategy)
- Models (representations of complex relations)

2. Inference Layer - Types of Inferences
- Meta-classes (groups of concepts)
- Knowledge sources - inference structure (domain concepts - searching, matching, forward or backward chaining)

3. Task Layer - Structured Hierarchies
- Procedures for provision of knowledge (data-driven or solution-driven)

4. Strategy Layer - Combining Tasks
- Task structure, (implementation issues, reasoning processes and conceptual models)
- Level of refinement (advice properties; approximate or exact solution)

Figure 1: Illustration of Stages Within the KADS Model of Expertise (Hickman et al, 1989).

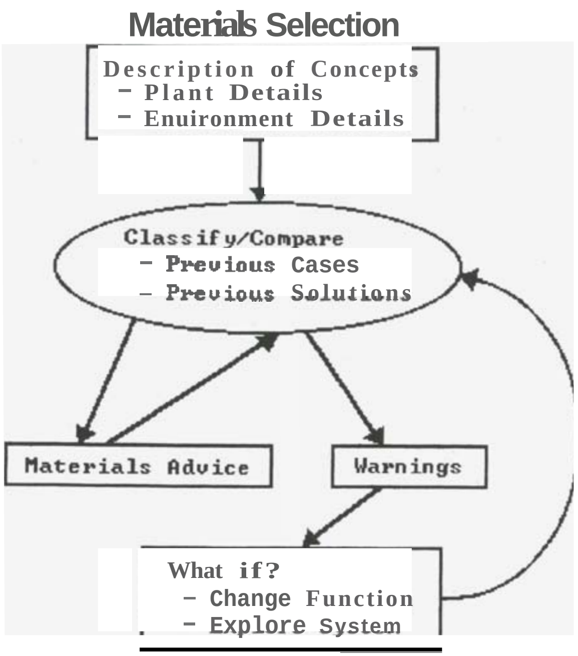

Figure 2 Conceptual Model of Knowledge for Materials Selection.

B. Generation of Hierarchical Tree Structures - This step requires preparation of hierarchical tree structures for each group of related concepts. These trees are generated without consideration for the advice to be given although system developers must at this stage begin considering the design or selection of a suitable conceptual model. The options for the conceptual model need to be considered in the tree design but the model should reflect rather than dominate the developing tree structure. The tree structures *can* be generated by the system developer but should include only sensible combinations of the listed concepts and hence must involve the domain experts.

Knowledge Capture Model

A. Listings of Defined Concepts
- Identify essential concepts
- Group related concepts
- Use lumped parameters (general descriptors for environment and plant parameters)
- Use formal models (relations between materials, chemistry and corrosion processes)

B. Generation of Hierarchical Tree Structures
- Groups of related concepts
- Independent of advice to be given
- All sensible combinations of concepts
- Identify branch nodes or branch endings for provision of advice

C. Generation of Advice Spreadsheets
- Establish spreadsheet format/nomenclature
- Collect and organise domain knowledge
- One spreadsheet per advice node/branch

D. Implementation And Conceptual Model
- Shell selection and interface specifications
- Obtain rule antecedents from the tree structure
- Obtain antecedent relations from the tree
- Obtain rule advice consequents from the spreadsheets
- Develop user interface facilities

Figure 3: Model For Capturing Materials Performance Knowledge (Lichti et al, 1992).

C. Generation of Advice Spreadsheets - The advice knowledge is collected separately in spreadsheets derived for unique combinations of attribute values where advice must be given. These can be tree branch termination points or nodes within the tree. Advice provided by domain experts may apply to several branch end points and must therefore be listed in each of the relevant spreadsheets.

The generated tree and spreadsheet documents provide the required system documentation for quality assurance purposes, formal reviews, and future system maintenance. The entire project team must normally become familiar with these.

D. Implementation And Conceptual Model - Development of prototype systems for evalution of conceptual models, expert system software shells, tree structures, and user interface facilities is a normal practice. The conceptual model must be fully defined before the final implementation process begins. The structure of the model and the form of the advice to be provided will influence expert system shell and user interface specifications which should be made in consultation with the user interface programmer. Specification of the user interface facilities may involve the whole development team although initial prototypes are typically produced by the system developer and programmer (Cradwick, 1991).

Spreadsheet for Branch Number: 1

Plant_parts	Materials	Warnings
pipelines	alloy_1	w_1 and w_2
valves		
stem	alloy_2	w_3 and w_4
body	alloy_4	w_3 and w_5
gate	alloy_4	w_5
external–structures	alloy_1_coated	w_6 and w_7

C. Generation of Advice Spreadsheets For Branches

Implemehted Rule

```
if
   advice–menu = _materials_advice and
   system_type = high-pressure and
   high-pressure-area = steam–field and
   environment–steam–field = separated–steam and
   status (calculated_condensate_pH) = known and
   stable_corrosion_products = yes–carbon–steel and
   pH_minus_pH_of_Fe++ = greater-than-1 and
   velocity = normal
then
   plant_parts:pipelines>material = alloy–1.
   plant_parts:pipelines>warnings = w_1 & w_2.
   plant_parts:stem>material = alloy–2.
   plant_parts:stem>warnings = w_3 & w_4.
   plant_parts:body>material = alloy_4.
   plant_parts:body>warnings = w_3 & w_5.
   plant_parts:gate>material = alloy_4.
   plant_parts:gate>warnings = w_5.
   plant_parts:external_structures>material = alloy–1–coated.
   plant_parts:external_structures>warnings = w_6 & w_7.
endif.
```

D. Implement the Spreadsheets in Rules

Figure 4 - Application of Knowledge Capture Model to the GeoMat Expert System (Lichti et al, 1992).

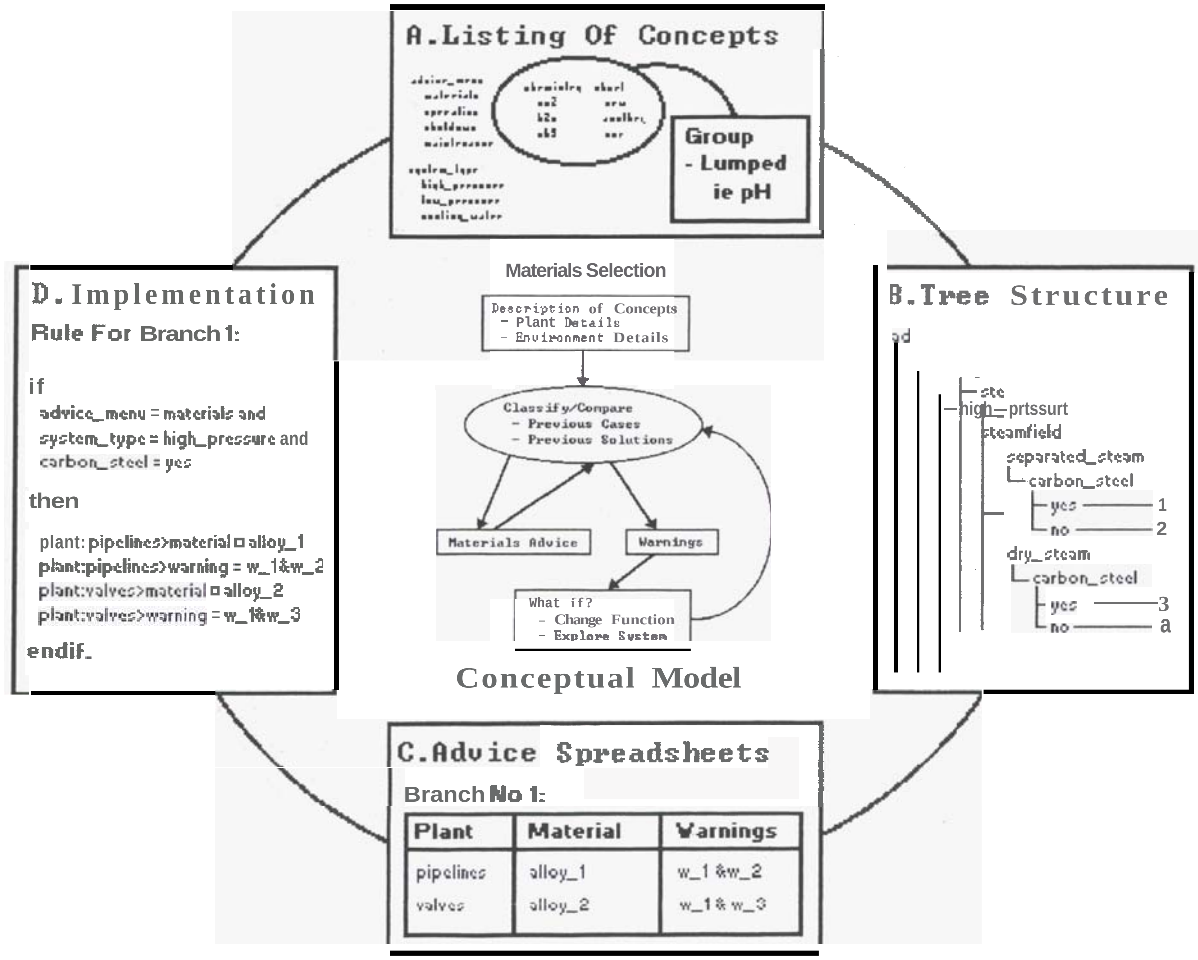

Figure 5: Graphical Illustration of Knowledge Capture Model for Expert Systems Developments