Application of Expert System Technology to the Hydrology of the Coal Fields of Eastern and Western Kentucky

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ABSTRACT

The Office of Surface Mining Reclamation and Enforcement is planning to fund the development of an expert system that will define the predominant conceptual models capable of describing ground-water flow in the Illinois Basin and Appalachian coal field regions of Kentucky. This expert system will also assist with baseline data collection and analysis, in that the system will be cognizant of reasonable ranges (credible values, plausible combinations) of data, and the data required (location, frequency and duration) to confirm the applicability of a particular conceptual model to a given area.

BACKGROUND

The Office of Surface Mining Reclamation and Enforcement (OSMRE) was formed after the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Mining activities are regulated by state regulatory agencies operating under the oversight of OSMRE. OSMRE is mandated to provide technical support to the states, including assistance in carrying out permitting and AML reclamation programs. In 1986, the National Wildlife Federation, et al. brought suit against the Kentucky Natural Resources and Environmental Protection Cabinet, in the United States District Court for the Eastern District of Kentucky, Frankfort Division. The plaintiffs argued that, among other things, the Commonwealth of Kentucky was derelict in enforcing the hydrologic protection mandates of SMCRA. Part V. of the ensuing Settlement Agreement (Civil Action No. 86-99) dictates that a study of the hydrology of the coal fields of Eastern and Western Kentucky be undertaken under the management of OSMRE.

The purpose of the study is to assist both the regulated industry and regulatory authority in

meeting the hydrologic protection mandates of SMCRA. In response to the responsibility conferred on OSMRE by the Settlement Agreement, OSMRE plans to develop an expert system that identifies the relevant conceptual flow models in the Illinois Basin and Appalachian coal field regions of Eastern and Western Kentucky and specifies the data that are necessary to distinguish the operative flow regime(s). The expert system will also evaluate and verify the integrity of submitted data by comparing it with the typical ranges of data and plausible combinations of pre-mining conditions for these areas that are contained in its knowledge base.

Expert system programs are the most practical application of artificial intelligence research efforts. Expert systems are computer programs which use expert knowledge to attain high levels of performance in narrowly defined problem areas. These programs enable human reasoning to be augmented by artificial expertise when algorithmic approaches to automated problem solving are not appropriate. Expert system programs have demonstrated proficient capabilities in the review and evaluation of assembled facts. This technological advance allows the problems formerly relegated to human experts to be solved by less knowledgeable individuals using expert system computer programs. A sound expert system program lends virtually expert skills to its user which are consistent, easily transferable, and not prejudiced to only one discipline. These programs assimilate expert knowledge from one or more disciplines and can potentially solve problems in complex fields as effectively as the most highly regarded people in those fields.

EXPERT SYSTEM PROGRAMS

In order to write an expert system program, exhaustive interviews are first conducted with human experts in order to extract the expertise, tactics, and rules of thumb which are used in problem solving. The interviewer must get the expert to explain clearly, concisely, and systematically, how he forms strategies and evaluates possible moves. Knowledge from diverse specialties can be integrated into one system capable of providing a more thorough analysis than would be possible through an individual's single perspective. The interviewer must elicit the heuristic methods, or rules of thumb, used in problem analyses, from the expert. The use of heuristic rules is a central concept for expert systems. Unlike an algorithmic method which is guaranteed to produce the single correct or optimal solution to a problem every time; a heuristic method produces an acceptable answer most of the time.

In expert system programs, procedures are expressed in English and used to process both numerical and non-numerical data; this is a fundamental departure from conventional computer programming where fixed algorithms are used to process numerical data. Rules and symbolic logic are used because certain problems such as the description of conceptual flow models and analysis of baseline data tend to defy rigorous mathematical analysis or algorithmic solutions. These programs are not a simple reiteration of the knowledge contained in textbooks; experts seldom follow a linear approach to problem solving and these programs mimic an expert's chain of logic. The ability to make decisions quickly, based upon holistic comparisons with analogies from past experience, rather than upon a detailed analysis of all the elements of a given situation, is the hallmark of a successful expert or expert system program. An expert system program can capture an experienced person's knowledge about the key attributes of potential situations in order to select valid analogies from prior experience and to recommend suitable action plans in a short period of time. The

expert system will be capable of performing analyses and making logical recommendations concerning surface mine conditions and conditions in ground-water aquifers within Kentucky coal fields based on the appropriately formatted information stored in its knowledge base.

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A heuristic hasn't been rigorously proven, it usually can I t be, but experience has shown it to be a reliable guideline. The heuristic procedures concerning the subtle intangibles of a situation are articulated and formalized for use in the program.

An expert system program has two major components: a knowledge base and an inference engine. The knowledge base is a collection of all the facts and rules about the problem domain. The inference engine contains the procedures used to manipulate the facts in order to solve the problem.

As stated previously, the knowledge base is founded on human Expertise. Interviews are conducted with experts in order to Acquire the facts and rules governing the subject of the program. The rule based systems are the simplest, in them the knowledge base is often developed in discrete sections, with each expert's domain represented in separate modules. Specialists, called knowledge engineers, reconcile differing opinions, accumulate and codify this information, then work backwards to derive axioms that embody the key knowledge.

The inference engine directs the way the expert system applies its knowledge rules, this is sometimes called the heuristic search strategy. It is not necessary to have all the facts to initialize a search, any amount of information can be used to eliminate some possible outcomes and to indicate places where further information is needed to proceed. No one standard heuristic search strategy is suitable for every expert system program. Unlike tactical thinking, which uses basic rules to proceed along specified lines, strategic thinking uses shortcuts, psychology, and rules of thumb, to decide between possible moves. An efficient search strategy must be selected since successful execution relies on the elimination of unpromising avenues of search as soon as possible.

APPLICATION OF EXPERT SYSTEM TECHNOLOGY TO KENTUCKY COAL FIELDS

Since passage of SMCRA in 1977, proposed surface coal mine activities are required to be permitted prior to mining. In order for an area to be considered for a mine permit, the applicant must submit a determination of Probable Hydrologic Consequences (PHC) as part of the permit application package. The PHC should delineate and predict the likely influences of the environmental perturbations which are expected to result from the proposed mining and reclamation activities. Preparation of a PHC entails accumulation of baseline information,

analysis of these data, development of a hydrologic reclamation plan, and reanalysis of the hydrologic system with the proposed reclamation plan superimposed. The PHC determination should predict the magnitude of impacts to be expected after preventive and remedial measures have been applied. These impacts are those anticipated to be unmitigated; some degree of hydrologic disturbance will result regardless of deterrent or corrective measures. The magnitude of the hydrologic disturbances can be minimized, but never completely eliminated; analysis of the impact of these unmitigated disturbances is considered to be the required PHC determination. The regulatory authority uses the PHC determination and other data to formulate a Cumulative Hydrologic Impact Assessment (CHIA) which is used to determine if the application warrants approval.

The CHIA is a quantitative and qualitative evaluation of the additive hydrological impacts resulting from projected mining and reclamation activities within a cumulative hydrologic impact area. Despite the efforts to minimize the hydrological impacts of individual mining activities, residual impacts from different mining activities in one area may accumulate to significant magnitudes. The CHIA is necessary to assure that such aggregate impacts will not be overlooked. The regulatory agent first examines the PHC to ensure that the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area. If the design is acceptable, the authority must then compile data from references and other PHCs in order to write a CHIA.

The review of PHCs and preparation of CHIAs involves few formal techniques, the process is left to the discretion of experts since experience plays a predominant role. An informed decision can only be made by an individual who possesses both a knowledge of the pertinent physical laws, which can be learned in a relatively short time; and a familiarity with the more subtle aspects of hydrological and environmental protection, which can only be acquired through extensive and diverse personal experience. While physical principles must not be ignored, the evaluation is not predicated entirely on physical laws; instead, the decision is often based on the heuristic rules acquired through experience, used by an expert. In the review of a mine permit application, the regulatory authority must make an assessment of the probable cumulative impacts of all anticipated mining in the area. The review of PHCs requires that regulatory authority personnel qualitatively consider factors which are not amenable to a more rigid systematic approach. The composition of a CHIA requires that the regulatory authority must qualitatively consider factors which are not amenable to a more mechanical quantitative approach. Inasmuch as simple addition of values is not a valid combinative procedure for most hydrologic parameters, the regulatory authority must use professional judgement. The regulatory authority has wide latitude in determining the manner in which individual elements will be evaluated. Interpretation of the data can be accomplished through a variety of divergent methods; selection of an analysis method should be justified and the rationale should be adequately supported in the CHIA. The actual assessment can frequently draw heavily on previously prepared CHIAs. PHC evaluation and CHIA preparation require sophisticated review; there is not one prescribed procedure, and there are numerous uncertainties. The findings are probable, not precise or exact. The preceding description of mine permit application review and CHIA preparation process, is nearly a verbatim reiteration of the type of problem described as well-suited for expert system analysis.

The expert system program will assist Kentucky DSMRE personnel in the review of the PHC by

identifying the applicable flow regime(s) and evaluating the veracity and adequacy of submitted baseline data. The review of PHCs involves few formal techniques, the process is left to the discretion of experts since experience plays a predominant role. Effective mine permitting and reclamation require the concerted efforts of experts from a diverse group of scientific backgrounds; civil and mining engineering, agronomy, hydrology, water quality, biology, and chemistry; each discipline possesses specialized technical knowledge. A mixture of training, and experience and judgement, from each of these fields is necessary in order to determine which areas and procedures are acceptable or which combination of remedial actions is best. A properly developed expert system could supply this expertise. An expert system program designed to assist regulatory authorities in the review of mine permit applications and preparation of CHIAs would significantly fortify present efforts to preserve the integrity of existing water resources. Expert system programs have demonstrated proficient capabilities in the review and evaluation of assembled facts. Currently, not enough experts are available, causing critical decisions to be made with limited technical information. Mine operators are often unnecessarily required to supply more data when the data already provided are adequate, thereby incurring unnecessary expenses. Even more alarming is the fact that some permit applications which do not merit approval, are approved by regulatory agents who lack the knowledge and experience to recognize unforeseen potential hazards or deleterious effects. This can cause unnecessary degradation of water resources and confers the onus of perpetual treatment on mine operators. This expert system program will be designed to assist regulatory authorities in PHC review by identifying the conceptual model capable of describing the ground-water flow system and by helping to verify the submitted data.

The use of this program will also extend the user's personal capabilities; the system will serve as a teaching tool because it will be possible for the user to query the program's internal chain of logic during program execution. This interactive documentation of the reasoning process will allow the user to examine the appropriateness of the system's logic while enhancing his expertise by exposing him to expert knowledge that is not limited to one educational or regional background. There are numerous advantages associated with expert system programs. Unlike human expertise, the expertise which resides in these programs offers permanence, and suffers no diminution of skill level following periods of disuse. The program has institutional memory, it can be encoded with current policy, and can be expanded to accommodate new facts, regulations and standards as they arise. In times of stress, the program will not omit germane questions, no factors are forgotten. As alluded to previously, the program can be armed with expertise from several domains. A system written to be used in conjunction with mining could encompass knowledge from experts in any pertinent field. The users of this system will be guided through an organized series of logical steps, and will be reminded of pitfalls at each juncture, en route to being apprised of the expert system's recommendation. This is a major advantage in that the program will help clarify knowledge and effective problem solving approaches in the field. The rationale will be consistently and concisely explained, thereby facilitating the documentation and defense of decisions.

Unlike conventional computer programs, expert system programs can operate without a full suite of data. Human experts make good decisions before all the facts are known. Doctors making diagnoses do this every day. In a manner similar to human expert analyses, the program can be started with scant information. The program reviews the input for

inconsistencies and then prompts for more information or provides a conclusion. As is the case with human experts, the conclusions are not certain, so certainty factors and confidence levels are rendered along with conclusions. Uncertainty is introduced from different sources; the quality of data is sometimes suspect and even with verified data, it is often less than certain that a consequence accompanies a condition. Expert system programs can calculate using certainty factors to combine several sources of uncertain evidence to reach conclusions with a high level of certainty.

FEASIBILITY

While an expert system program to assist in the review of PHCs and CHIAs has not yet been developed, expert system programs have been demonstrated to be feasible in other technical fields. Expert systems have been developed and successfully applied as "consultants" in medical diagnoses, oil and mineral exploration, and computer configurations. These expert system programs were built up over time by extensive interviews with numerous experts to capture the essence of their problem solving processes. Each program functions like a team of seasoned experts who are able to pore over reams of data.

The expert system is not a panacea, it cannot resolve every complex issue. However, certain types of situations are excellent candidates for expert system analysis. When an analysis requires many site and time specific data, or when knowledge based on breath and depth of experience is more important than mere knowledge of facts, expert system programs are appropriate resources which are just now beginning to be exploited. The programs perform well when information is incomplete, uncertain, subjective, inconsistent, or subject to change. Successes have been demonstrated when expert systems have been applied to problems which are normally solved by a few key individuals who are in short supply. These programs excel at tasks which normally involve a number of people because no one person knows enough, or when performance is typically degraded because a task demands a thorough analysis of a complex set of conditions and the usual performer never seems to remember everything. Because of the accuracy realized in a short execution time, the programs have been effective resources when the cost of a poor or late conclusion is very high.

Other Federal agencies, including the Social Security Administration and the Army Corps of Engineers, have already begun to explore the advantages offered by expert system programs. The Social Security Administration has at least three working expert system prototypes. The efforts of the U.S. Army Corps of Engineers are more mature. The Corps maintains data on U.S. Army facilities in various stages of planning in a data base; the information includes statistics on programming, budgeting, design, and construction. An expert system program is being developed which will couple the facts stored in the data base with expert knowledge about problem solving procedures to answer complex, high-level questions. The program will be able to extract answers to questions such as, "Why is project X so far behind schedule?" The expert system program will incorporate natural language processing, machine learning, and speech understanding in a very user friendly system. The system will be able to learn by example. It is being developed at the U.S. Army Construction Engineering Research Laboratory (CERL) under the direction of Ms. Sandra Kappes and Dr. Simon Kim and is scheduled for completion late in 1988.

Expert system programs will revolutionize computer applications within the next 10 years, the

programs provide quick, pragmatic approaches to problems which have hitherto defied solution. A dedicated effort toward the development of an expert system program to be used in a consultant - advisory capacity in the mine permit review process has a high probability of success. Small expert systems, containing less than 400 rules, can be used on personal computers and would be part of the technical support that is offered to the state and federal regulatory offices in Appalachia.

CONCLUSION

Increased adherence to SMCRA can be realized through an innovative approach, the development of an expert system program to be used in the mine permit application process. An expert system program could help create technically sound and legally defensible CHIAs. A sound expert system program would provide an expert opinion to assist state and federal regulatory agencies in the review of mine permit applications. Program usage would lead to more thorough and cost effective document review, with a more holistic, unbiased approach than might be attained through an individual's single perspective. What was formerly tacit, idiosyncratic, heuristic and not validated will be accessible; expert level knowledge will be disseminated widely. Both industry and regulatory agencies would benefit from the consistency an expert system program would impart to the mine permit review process. CHIA preparation is intrinsically a complex, multifaceted undertaking; an expert system program would make a substantial contribution toward realizing the intent of SMCRA by formalizing the entire permit application review process, thereby removing many ambiguities and allowing industry and regulatory agents to understand the criteria better. The review process would become much more systematic and efficient. Elucidation of the critical aspects considered in permit review would have the impact of increasing adherence to the hydrologic protection mandates of SMCRA. An expert system program, equipped with multidisciplinary knowledge from the foremost authorities in mining, has a high probability of success and a wide range of applicability.

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