DEVELOPMENT OF AN EXPERT SYSTEM FOR DIAGNOSING PROBLEMS ON A PAPER MACHINE

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ABSTRACT

This paper discusses the development of an expert system for diagnosing problems leading to sheet breaks on a papermaking machine. Such a system is expected to result in both energy and monetary savings by reducing both the frequency and duration of unscheduled machine outages. The knowledge base for this system, which uses a commercial software shell, is still under construction and currently contains about 1600 rules.

One of the unique features of this system is the fact that four experts are supplying the knowledge. These experts are the superintendents of the four paper machines at the mill participating in the project. The advantages and disadvantages of using this many experts are discussed, as is the method for handling the differences between them in the prototype system.

I INTRODUCTION

Energetics, Incorporated and Champion International Corporation are currently engaged in a joint effort to explore the potential use of expert systems in the papermaking process. Energetics is providing the knowledge engineering for the effort, while Champion provides the papermaking expertise. The work is being funded by the U.S. Department of Energy (DOE) under the Small Business Innovation Research Program, and builds on earlier work, also funded by DOE, conducted by Energetics in association with the St. Regis Paper Company.

II BACKGROUND, OBJECTIVES, AND SCOPE

The objective of the project is to promote commercialization of expert system technology within the pulp and paper industry through the creation of a prototype expert system. One of Champion's major reasons for participating in the project was to determine whether expert systems technology had practical applicability for papermaking. From the standpoint of DOE, use of such technology by the pulp and paper industry would result in energy savings from a reduction in unscheduled machine downtime.

Initial project efforts focused on the selection of an appropriate application for an expert system within the industry. Candidate applications were evaluated based on their potential for savings, and the application chosen was replacement of wet felts in the press section of the paper machine. Wet felts are used both to transport the paper sheet and as a means of removing the water and fines that are squeezed out of the sheet by the press rolls. However, it became increasingly clear that an expert system capable of recommending whether a felt should be replaced would need to possess the capabilities for diagnosing not only press section problems but many other problems on the machine. Because sheet breaks on the machine are responsible for the majority of unscheduled outages, the scope of the project was modified to the diagnosis of problems causing sheet breaks.

The mill selected by Champion to supply the papermaking knowledge needed to develop the system was its Courtland, Alabama mill. There are four paper machines at this mill: two Fourdrinier machines and two twin-wire machines. On a Fourdrinier machine, stock is sprayed onto a horizontal wire; on a twin-wire machine, the stock is sprayed vertically between two converging wires. Products of this mill include register bond, xerographic, offset, and coated paper.

III THE EXPERTS

One of the more unusual features of this expert system is the fact that there are four experts supplying the knowledge. This was not done by choice, but rather by necessity. Champion had determined that the people most knowledgeable about diagnosing paper machine problems were the machine superintendents (one per machine). However, because the paper industry is highly production-oriented, and because the machine superintendents are involved in the day-to-day operations of running the machine, it was realized that no single expert could devote the necessary amount of time to the project. Therefore, all four superintendents were invited to and agreed to participate.

The use of four experts had both advantages and disadvantages over the conventional method of using a single expert. Higher levels of insight into papermaking and machine troubleshooting were gained by viewing them from four different perspectives. Perhaps the biggest benefit of using multiple experts was the cross-checking that it allowed. Machine problems or issues raised by one expert could be brought up with other experts who had not mentioned them before, enabling a more comprehensive coverage of the various types of problems that could occur. Another advantage of using the four superintendents was that it helped to prevent the project from interfering too much with the day-to-day operations of the mill. Although retired or off-line personnel may have had more time to give for answering questions, it was felt that the benefit of using the high quality information acquired from on-line personnel far outweighed the higher availability of the off-line experts.

In terms of the amount of knowledge acquired as a function of time, the use of four experts was at a disadvantage compared to using just one expert. Four hours of interviewing four experts (one at a time) was definitely less productive than four hours of interviewing a single expert. There was no way to avoid covering some of the same material with each expert because of what could be considered the major disadvantage of using multiple experts, at least for this application: the experts didn't always agree on standard operating procedures, much less troubleshooting techniques. For example, each press felt has associated high pressure showers that can be run on it. Of the four experts, one runs the high pressure showers one hour every eight-hour shift, two run the showers when they are having runability problems or abnormal sheet moisture profiles that are caused by the felts, and one has only ever run the showers once in the past five years.

The differences in operating and troubleshooting procedures between experts is complicated by the differences between the four machines themselves, differences not only in specific equipment types but also in historical problem areas. For example, the two Fourdrinier machines at the Courtland mill have different types of press sections; in addition, one of these machines has a much higher degree of computer control than the other. Only one of the four machines makes coated paper, which is much more problem-prone than uncoated paper.

IV HANDLING THE EXPERTS

All of the above differences had to be dealt, with in the system in order to make it worthwhile to the mill. Focusing on one expert would be risky in terms of assuming that he would have enough time to devote to comprehensively test the system. Also, using all of the experts to test a system that focused on only one of them would give unsatisfactory results. The success of the project depends in large part on the attitude of the four experts toward the system prototype. The manner in which the differences between the four experts were incorporated into a single prototype is outlined under Section V.

Though unanticipated, the manner in which the experts were dealt with in order to extract the desired knowledge became an extremely important factor in the development of the paper machine diagnostic expert system. An important aspect of this was to avoid interfering with their normal duties, because without their full cooperation, a successful system could not be realized.

The knowledge acquisition or interviewing sessions were held approximately once every three to four weeks over a period of about two years. The sessions were held at the mill in the superintendents' offices. On one occasion a joint interview session was held with two experts, but the more talkative expert dominated the conversation to such an extent that joint sessions were never again attempted.

Preparation for each session was essential, especially the first session. Before the first trip to the mill, the knowledge engineer became knowledgeable on papermaking technology in order to get off to a good start with experts and begin to develop a good rapport with them. It was soon discovered that the knowledge engineer would not only have to take the lead in setting the course of each session, but in most cases would have to have an entire session's worth of questions laid out in advance. Although the experts often related fairly detailed case histories or discussed topics at length, the ball eventually came back to the knowledge engineer's court to continue the questioning. However, interview sessions never had a rigid format; if a subject arose during a discussion, the engineer would pursue it while the expert's mind was still focused on it. More about the knowledge acquisition strategy is discussed in the next section.

In addition to being conversant in papermaking technology, the knowledge engineer had to learn the specific slang used at the Courtland mill. The engineer also had to avoid using "high-tech" terms that might annoy the experts, men without formal education who have worked their way up through the various positions on the machine crew because of their technical and managerial skills. From the beginning, it was necessary to stress that an expert system is a tool that will help them, not something that will replace them.

V SYSTEM DEVELOPMENT STRATEGY

The information acquired during the first interview session with the experts included equipment descriptions, major paper grades produced, general operating procedures, personnel responsibilities, maintenance schedules, and the degree of computer control. In addition, because wet felt problems were being used as a starting point for the system, questions were asked on types of wet felts used and on felt cleaning and maintenance. The next several sessions dealt with felt and press section problems in greater detail, and an overview of the different types of sheet defects that exist and their possible causes. This overview of sheet defects provided "seeds", in the form of references to past problems and troubleshooting efforts, for developing a questioning strategy for the session. Using these "seeds", the knowledge engineer could encourage the expert to go through a case history in as much detail as the expert could remember. In addition to case histories, any issues that were unclear once the knowledge engineer reviewed a session (all sessions were recorded on tape and later transcribed) were resolved at the next session.

After four or five interviewing sessions at the mill, it became apparent that decisions would have to be made on which machine problems would be covered in depth for inclusion in the expert system, and which topics would be left for later exploration, time and money permitting. The method used for organizing the various problems and topics into some kind of reference chart was the fault-tree method, most commonly used in reliability analyses. Top-level fault trees were developed showing general categories of sheet defects that can lead to unscheduled machine outages. These categories (e.g., holes, crushing) were then further subdivided, and separate fault trees were developed for each sub-category. In this way, all known possible causes of machine failure due to sheet defects were illustrated; any lower-level event within the tree (e.g., slime on the shower pipes) can cause the top-level event in that tree (e.g., hole in the sheet).

In addition to developing the fault trees, the knowledge engineer laid out a description of the troubleshooting procedures for each expert. This included a list of the possible types of clues that they look for both on the end of the sheet where the break occurred and in the various instrumentation readings, and how these items affect where on the machine they go first in trying to solve the problem. These procedures were then reviewed with the experts and corrected as necessary.

The expert system software shell that was chosen for this project was EXPERT, developed by Weiss and Kulikowski at Rutgers University. EXPERT, which is written in FORTRAN, has been used most extensively in medical diagnostic applications. There were several features of this shell that emerged during the course of the project as being particularly helpful in the paper machine application. One of them was a bonus factor option that enabled less costly troubleshooting options to be explored before more likely but much more costly options (e.g., ones that involved shutting down the machine). Another feature was the ability to set up multiple HH rule tables. In EXPERT, an HH rule table is a set of rules relating findings and hypotheses already determined to other hypotheses. The table itself is triggered when an initial "IF" condition is satisfied.

The use of multiple HH rule tables in the prototype system became the primary means for incorporating the differences between the four experts into a single expert system. Rules that were common to all of the experts/machines were grouped in certain HH rule tables. Rules that applied to only one expert/machine or to a particular combination of experts/machines were organized into separate HH rule tables whose "IF" condition was that the case being run was for a given machine or one of two or three given machines. The questioning strategy within the system was set up so that the first query made of the use was for his machine number. So far, this methodology has proven satisfactory in handling the multiple experts; questions that do not apply to a particular machine are never asked for any cases run for that machine, and treatments that a certain expert would never perform are not recommended to him.

VI CONCLUSIONS

Work to date on this project has shown the extreme importance of the interactions between the knowledge engineer and the domain expert or experts in determining the success of expert system development. This importance has been pointed out by other practitioners, but it is especially critical when multiple experts are used. Those who will be supplying the knowledge should ideally be involved in project planning from the very beginning. However, the domain experts often have inadequate time or familiarity with software tools available to be able to serve as knowledge engineers themselves. A project team that includes both industrial and computer-oriented personnel is recommended.

For this particular application, it proved to be feasible to build a prototype expert system using more than one expert. This was possible because the prototype in a sense contained four smaller, customized systems in addition to a section of general rules in the knowledge base. It cannot be concluded from this work, however, whether using multiple experts to create a prototype expert system for a single machine, for example, would have advantages over using a single expert.

It is anticipated that the paper machine diagnostic expert system discussed in this paper will be useful in several different capacities - as a tool to aid operators in diagnosing problems that cannot be solved quickly by normal means, as a training tool for inexperienced personnel, and as a means of storing information related to hard-to-solve cases that occur so infrequently that they are usually forgotten by the time they happen again. Although it is likely that this system would have to be customized for each specific machine on which it is intended to be used, such an extensive groundwork has already been built that customization efforts would not be prohibitive in terms of time or money.

It is very likely that additional opportunities for expert system application in the pulp and paper industry exist. The Industry is investing heavily in various forms of computer process control, and should prove highly receptive to many forms of artificial intelligence.

REFERENCES

1 Weiss, S.M., "A Guide to the EXPERT Consultation System", Rutgers University, January 1986.