Integrating the art and science of papermaking in an expert system

Donal R. Windon Jr., Deborah F. Cook, and Joseph G. Massey

An expert system called AESOP is helping inexperienced personnel identify and solve problems related to paper defects.

The expertise applied by a person to find solutions to manufacturing problems combines knowledge and experience. There is both an art and a science to problem solving in a manufacturing environment. The science aspect is the knowledge that can be documented in manuals and the literature. The art of problem solving is a form of creativity that allows a person to solve a problem based on knowledge of similar experiences.

The manufacture of paper requires knowledge about the raw material, all intermediate products, and the mechanics of the process. In this paper, an expert system installed in a large Texas paper mill is used to demonstrate that such systems provide an environment suitable for a problem-solving approach to manufacturing problems.

The environment of a paper machine is carefully designed and maintained for producing paper products that meet very rigid quality specifications. Each quality attribute, such as strength or appearance, can be measured in some form. All the equipment and processes necessary to control these parameters can be adjusted. If a quality-related defect occurs, the papermaker determines which factor or combination of factors is affecting the quality of the paper and then adjusts the process accordingly. If the direct cause of a quality defect is not apparent, the papermaker then must use diagnostic skills to find likely solutions to the problem.

Diagnostic skills combine the art and science of papermaking. The science of papermaking is built on qualitative and quantitative knowledge about the manufacture of paper. For example, increasing the speed at which the sheet of paper is processed from 905 ft/min to 915 ft/min will decrease the rush/drag ratio of the sheet from -0.1% to -1.0% and improve the formation of the paper. However, for each instance of a well-defined factor, there is another factor that must be analyzed based on experience or common sense. This component of the person's skill, expertise, and intuition demonstrates the art of papermaking. For example, an experienced papermaker observes the surface appearance of the wet press felt to determine whether to clean or replace that felt. A wrong decision can result in a defect, unnecessary cost, or downtime. The ability to choose which factor or what combination of factors to adjust in a changing, complex process is an illustration of the art of papermaking.

The total skill of the papermaker is a combination of documented knowledge, experience with the process, creativity, and common sense. Documented knowledge is learned through professional training. Knowledge learned from experience is gained on the production floor by controlling the process and correcting problems that develop. Experience is gained when solving problems using a basic trial-and-error approach. The art of papermaking is the knowledge that allows a papermaker to suggest a solution to a problem when only incomplete information is available, using past experience with similar situations.

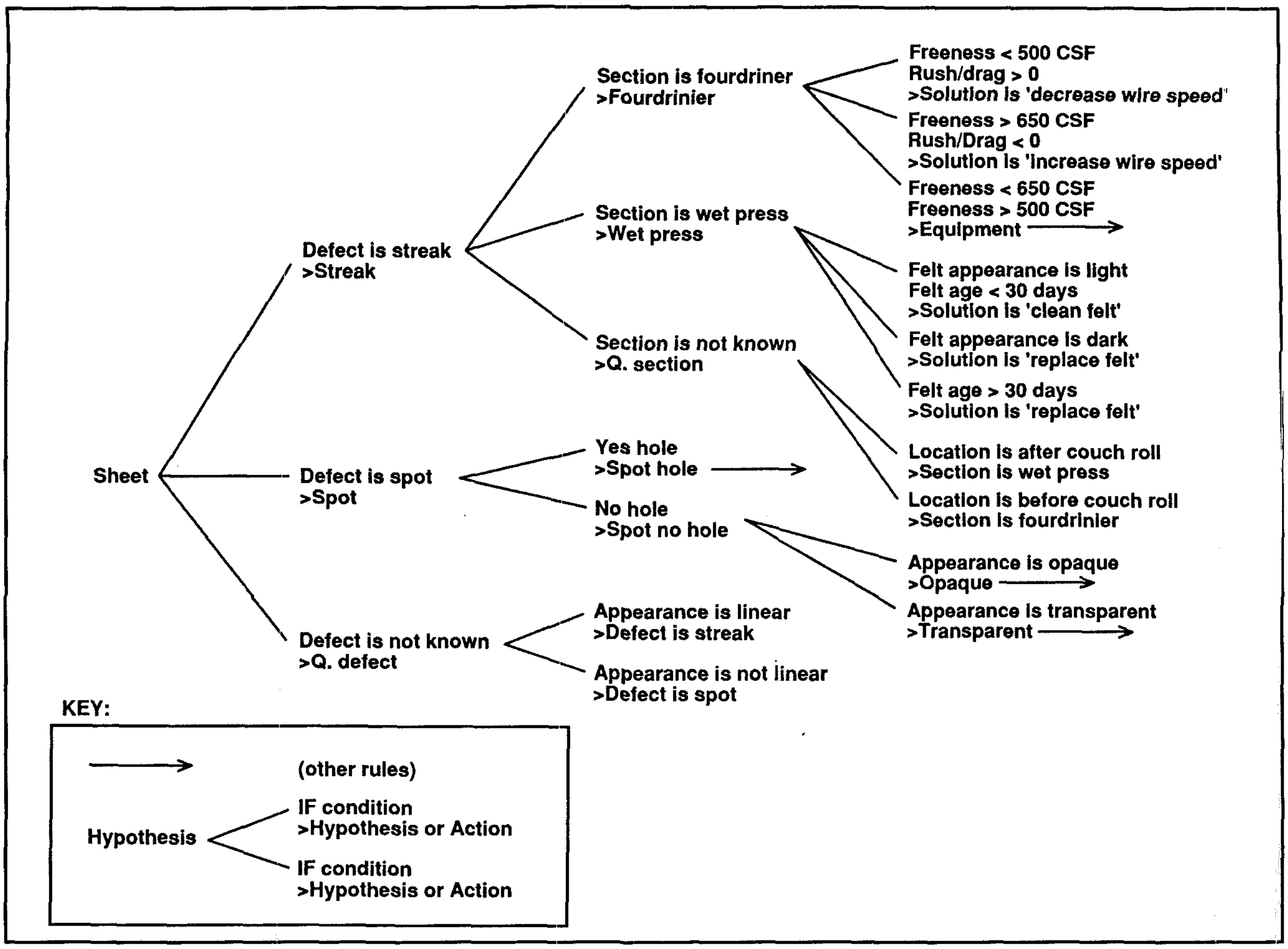
Expert systems provide a framework for representing such decision-making processes. Expert systems have the ability to store, manipulate, and search symbolic and heuristic information. These abilities distinguish expert systems from conventional computer programs (*1*) and provide the ability to house the type of knowledge that exists in both the art and science of papermaking. Mills (*2*) points out that the greatest utility for future systems in the forest products industry will occur where the problem domain is well defined and where qualitative judgment and experience are important factors. Papermaking is an excellent example of such a problem domain. Expert systems are rapidly becoming valuable tools for improving industrial operations (*3*).

Art, science, and expert systems

The dictionary defines science as a branch of study concerned with observation and classification of facts and with the establishment of verifiable general laws. The determining factors used to segregate knowledge based on science from knowledge based on art are experience and intuition. Science is knowledge that is based on and can be proven by experimental hypotheses. Physically based equations and laws are examples of scientific

Windon is operations research analyst, Temple-Inland Forest Products Corp., P.O. Box 816, Silsbee, Tex. 77656. Cook is assistant research scientist, Industrial Engineering Department, Texas Engineering Experiment Station, and Massey is associate professor in the Department of Forest Science, Texas Agricultural Experiment Station, at Texas A&M University, College Station, Tex. 77843-2135.

1. A sample of AESOP rules to evaluate formation defects



knowledge. Art can be defined as a systematic use of experience or intuition in accomplishing a goal. Art is the information gained from experience in a specific knowledge domain.

Fischler and Firschein (*4*) found that two very different reasoning techniques are used by expert and nonexpert problem solvers. Nonexperts used only the quantitative and qualitative knowledge of science to create a logical chain of steps to follow to solve a problem. Experts used heuristic knowledge, developed from experience, to skip several or all intermediate steps to go directly to a solution. An expert may have seen similar problems in the past and may have tried many alternative solutions. The expert can now use intuition gained from experience to infer a feasible solution to a given problem. A person evolves from a nonexpert to an expert through experience and the development of problem-solving intuition. An expert learns to develop shortcut solutions to production problems.

An expert in a manufacturing environment has developed a model of that environment. The derivation of the model is described as an intuitive art (*5*). The expert uses that model of the system to diagnose problems and determine solutions. An expert system is a computer environment suitable for merging both the art and science of a process into a model of the process to be used for problem solving, similar to a human expert.

The objective of the AESOP (An Expert System on Papermaking) project was to build a rule-based expert system that contains diagnostic knowledge about the papermaking manufacturing process. The purpose of AESOP is to assist inexperienced personnel in identifying visual paper defects, diagnosing the cause of a given defect, and recommending a solution for the problem causing the defect.

AESOP

AESOP was installed in a study paper mill in February 1990. The expert system is a conventional interactive, diagnostic expert system that identifies corrective action based on information supplied by the user. It was written using the NEXPERT Object expert system shell and installed on a MS-DOS microcomputer.

The paper company was interested in the development of AESOP in order to capture the problem-solving expertise of one of its most experienced papermakers on a specific paper machine. The engineer has over 20 years' experience in production problem solving. This engineer's problem-solving approach incorporates training, intuition, and experience to allow him to converge on solutions to a problem quickly. The paper machine is a 216-in. trim, 1500-ft/min fourdrinier machine producing coated paper products. Several grades of food-grade board and printing quality papers are manufactured from southern yellow pine and hardwood fibers.

Previously developed problem-solving systems at the paper mill attempted to establish troubleshooting procedures for quality-related defects. These procedures were in the form of written manuals. AESOP sought to combine and expand these problem-solving procedures with the problem-solving approach of the engineer. Whereas the troubleshooting manuals were limited to lists of defects and their solutions, AESOP attempted to converge on a feasible solution quickly, using all available knowledge and information. To accomplish this goal, the system incorporated scientific knowledge about papermaking along with the intuitive knowledge based on the art of papermaking.

How the expert system works

AESOP identifies visual paper defects, diagnoses the cause of the defect, and suggests a solution for the defect. Each consultation of the expert system leads the user through a series of questions. Answers to these questions include true or false, multiple choice, or numeric inputs from process or quality control equipment. Figure 1 shows the possible solution paths used by the AESOP system to determine the various types of formation defects.

If at any time during a consultation, a user does not understand a question or know an answer, the response "I don't know" can be entered into AESOP. When this option is selected, AESOP analyzes all the information and knowledge currently available to try to identify the problem cause and suggest a solution. If all the queries can be answered, AESOP will arrive directly at a solution.

To identify the characteristics of a visual defect, the user answers a series of questions to determine the location and appearance of the defect. The answers to the questions are used as the conditional statements (IFs) in the rules. The issue of the question is used as the hypothesis (THEN) of the rule. The IFs of a rule represent the required information to test the hypothesis. All hypotheses have a value of true or false. Any conclusion (ACTION) attached to the hypothesis of a rule is performed if the hypothesis is found to be true.

Science and AESOP

The science of papermaking is based on knowledge about the chemical and physical processes and equipment of the papermaking process. The mechanical and chemical processes, along with the quantitative measures of equipment performance, represent the scientific knowledge of papermaking.

The papermaking process is performed in two major equipment sections of the paper machine: the wet end and the dry end. The wet-end equipment prepares the raw materials, creates a continuous sheet of paper, and removes much of the water. The dry-end equipment removes any additional water and improves the surface qualities of the sheet.

Much of the success of papermaking depends on controlling the formation of the sheet. Good formation is defined as a uniform distribution of fibers with no streaks or spots. The fourdrinier machine at the wet end of the process has a major influence on sheet formation.

While formation is qualitative in nature, factors affecting formation can be monitored and adjusted. These factors are the operational conditions of key equipment on the fourdrinier machine. The key components of the fourdrinier machine as it relates to formation are the headbox, wire, table, and dandy roll. The headbox is a closed rectangular container with a long, thin horizontal opening called a slice. Within the headbox, the stock is stirred and fed through the slice. Stock is poured from the slice onto a continuous plastic mesh called a wire. The wire is supported by the table. On the wire, the low consistency fibers—the stock is approximately 1% fibers and 99% water—are allowed to mesh or form to make the base sheet of paper. Excess water is drained through the wire and away from the base sheet. The table is made of rolls to support the wire and to assist the vacuum boxes and aerodynamic foils in removing water from the base sheet. As the water drains from the sheet, fibers are pulled toward the wire, and fines and other small particles are removed from the web. This causes the side of the sheet toward the wire (wire side) to be smoother than the side away from the wire (felt side). To correct for this difference in smoothness, the dandy roll is pressed against the felt side of the sheet.

During the operation of the fourdrinier machine, several variables are measured and controlled. These include the size of the slice opening, the speed of the wire and dandy roll, the height of stock in the headbox, and the vacuum pressure applied by the vacuum boxes. For each grade of paper made, predetermined values for these variables are used to operate the machine.

The solution to formation defects caused by changes in measurable and well understood variables can be determined without heuristic knowledge. For example, if the freeness of the stock has decreased due to changes in pulp conditions, several changes can be made to maintain the same rush/drag ratio and consequently the formation. Therefore, to keep the same moisture content at the couch roll, the wire speed must be decreased (*6*). This decrease, of course, will change the rush/drag ratio, and it must be changed by decreasing the height of the stock in the headbox. If the wire speed or the height of the stock in the headbox cannot be decreased, then the pressure in the vacuum boxes can be increased to adjust for the change in freeness.

Changes made to adjust these operating conditions have been documented and well understood. Sources such as *Papermaking and Paperboard Making* (*6*) offer detailed information on controlling paper machine variables, e.g., rush/drag ratio. Information or knowledge from these sources provides a foundation for developing a knowledge base for an expert system.

Art and AESOP

The art of papermaking is the expertise and intuition acquired through the experience of solving problems on the paper machine over time. An inexperienced papermaker, depending only on quantitative methods described in the literature, may reach invalid conclusions in a specific situation. The use of experience and intuition allows the expert to consider the heuristic information available and converge quickly on solutions to quality problems. In papermaking, formation is one of the most complex of the various processes to understand and control. The papermaker must have a great deal of expertise to interpret the various situations that can affect these qualities.

Formation defects are identified by characteristics that can be seen with the naked eye. Within AESOP, all formation defects are classified as either spots or streaks, as illustrated in **Fig. 2.** A spot is any localized, nonlinear defect. It may or may not repeat at regular intervals, and it can be less than a quarter of an inch to several feet in diameter. A streak is any linear defect with a width of a quarter of an inch to several feet. A defect may be further classified based on the orientation of the defect to the directional flow of the machine.

Most formation defects have several causes and locations of occurrence, or both. To determine the source of the defect, additional visual observation is required, either of the defect itself or of the paper machine. By using the definition of good formation listed above, an expert can use the visual characteristics of the defect to evaluate potential causes. For example, a machine direction streak in the sheet could be caused by external forces or incorrect deposition onto the wire. By observing the base sheet as it leaves the fourdrinier machine at the couch roll, it may be determined if the streak is occurring on the fourdrinier machine or in the wet press. If the streak does not appear at the couch roll, it is occurring in the wet press and is a defect caused by external forces.

The operating conditions of the paper machine will help determine the correct solution to the problem. From the previous example, if a streak is caused in the wet press, the condition of the wet press felts will establish the proper corrective actions. Wet press felts are responsible for carrying moisture away from the sheet as the sheet passes between two heavy press rolls. These felts have a specific water carrying capacity. Over time, the performance of a felt deteriorates, but the change in capacity cannot be measured directly. The usefulness of a felt can be determined heuristically by learning the felt age and by observing the surface of the felt. If it has been in use for more than 30 days or is discolored, wrinkled, or compressed, then it should be replaced. If not, then the felt may require additional cleaning to improve its capacity to carry away moisture and remove the streak.

The example used above to describe the problem-solving processes of papermaking demonstrates the use of heuristics in the art of papermaking. It is important to realize that the use of heuristics does not necessarily result in the correct answer to every situation. The problem identification comes from the rules of thumb developed through experience and intuition. These rules may not lead to the correct solution on the first try, but they can offer insight that will lead the user to the problem source.

Conclusions

The AESOP expert system combines the art and science of papermaking to diagnose visual defects in paper. The user of AESOP is unaware whether knowledge gained from the art or the science of papermaking has been applied to arrive at a conclusion. The development of AESOP has created a useful expert system to assist paper machine personnel in the diagnosis of visual defects. It combines the quantitative and qualitative knowledge of the science of papermaking with the expertise and intuition involved in the art of papermaking. The expert system models the problem-solving and decision-making processes used by the expert. AESOP helps less experienced personnel learn the complex manufacturing process of papermaking and provides manufacturing problem solutions to operators of all experience levels to help maintain quality production.

In the future, additional expertise can be added to AESOP to continue to develop a more effective production environment. The expert system knowledge base could be instrumental in the development of millwide information systems. The identification of heuristic factors for diagnosing problems and defects can also be used to specify important areas for future scientific research. Analysis of an expert system knowledge base may highlight areas where the art of papermaking is currently used in place of more desirable scientific information. By attempting to discover what the expert does heuristically when diagnosing a problem, researchers can work to uncover a qualitative or quantitative method for solving problems.□

2. Photographic examples of visual defects characteristics: streak (top) and spot (bottom)

Literature cited

1. Hayes-Roth, F., Waterman, D. A. and Lenat, D. B., Building Expert Systems, Addison-Wesley, Reading, Mass., 1983, p. 1.
2. Mills, W. L. Jr., Forest Products Journal 37(9): 40(1987).
3. Massey, J. G., Thompson, R. P., and de Hoop, C. N., Forest Products Journal 39(11/12): 37(1989).
4. Fischler, M. A., and Firschein, O., Intelligence: The Eye, the Brain and the Computer, Addison-Wesley, Reading, Mass., 1987, p. 190.
5. Shannon, R. E., Systems Simulation: The Art and Science, Prentice-Hall, Englewood Cliffs, N.J., 1977, p. 19.
6. MacDonald, R. G., Papermaking and Paperboard Making, McGraw-Hill, N.Y., 1970.

The project on which this paper is based was funded by the Texas Agricultural Experiment Station and the Temple-Inland Forest Products Corporation at Evandale, Tex. The authors wish to thank Ralph Fournier, technical director, and Al Guillory, technical superintendent, for their time, assistance, and insight in the creation of AESOP.

The use of a trade name does not imply endorsement of a product by the authors or the Texas A&M University System.

Received for review Oct. 1, 1990.

Accepted March 28, 1991.