ERASME: An Expert System for Pavement Maintenance

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To facilitate decision making in the area of road maintenance, the Directorate of Roads in France decided to use artificial intelligence techniques and to rapidly make available to various government agencies an expert system serving as an aid to decision making on maintenance (*1*). ERASME (a French acronym for road maintenance assisted by a multiexpert system) aims to produce an operational expert system by mid-1988 for flexible pavements, by mid-1989 for bituminous pavements, and by the end of 1989 for hydraulic binder-treated pavements. This article reviews its present status of development.

Very swift development of artificial intelligence techniques and, more precisely, of expert systems has led to their progressive integration, during the past years, within all human activities.

The field of civil engineering very seldom calls for these incredible performing tools called expert systems. As shown in a recent American report (*2*), a large number of teams around the world are working on the elaboration of products meant for the road sector, which represents a market that must not be neglected.

The diagnosis and selection of the maintenance solution for a defective pavement present the main characteristics that make the use of an expert system interesting. Hundreds of decision makers in the field of road maintenance can be found at the national, regional, or local service levels. Only a few pavement specialists are able to define the right pavement rehabilitation technique. Those experts are working essentially in government technical services. They use the following kinds of data:

- technical and accurate data such as produced by laboratory tests,
- qualitative data, such as surface condition,
- incomplete and uncertain data, such as traffic volumes and loads, and
- redundant and contradictory data, as frequently occur in the real world.

Some aspects of the pavement maintenance problem are poorly understood or stated. In these cases, experts use empirical methods or "rules of thumb" derived from experience or collective practice.

Confronted by an incompletely defined problem and a partially formalized theory, experts trust their own experience to assess the real state of pavement and select appropriate rehabilitation techniques. This decision making is partly reflexive and irrational.

The economic stakes are important. In France, annual road maintenance expenditures range around 5 billion francs.

This field thus has a well-identified need that the Road Directorate has decided to fill by supplying services with a "maintenance" expert system. This product will be developed under the supervision of an Owners Committee associating several dedicated representatives of system users and the central administration. The system must be considered an *assistance* tool for decision making. Within this scope, its functions include guiding the user in the collection of the data needed for an accurate diagnosis and proposing technically equivalent alternatives to users, providing the elements needed to enable them to reach sensible selections.

ERASME will, of course, benefit from the qualities inherent to expert systems:

- a great possibility for updating, ensuring the permanence of the product,
- teaching potential: explanation of the thinking path and justification of the thinking upon request. These features will make it a teaching tool with no match in classical data processing.

ERASME PROJECT OBJECTIVES

Subject Definition

Homogeneous Section

ERASME assists the user in selecting among pavement diagnosis and rehabilitation techniques for homogeneous sections that are declared such when all their significant parameters are homogeneous:

- deflection signal (deflection analysis involves no destructive measurement of the surface deflection under a standard load),
- pavement structure,
- nature and date of pavement repairs-traffic, and
- surface condition.

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Homogeneous section lengths vary from a few hundred meters to a few kilometers. ERASME deals strictly with section problems, not network problems. It is in fact complementary with tools developed in the field of pavement management systems.

Diagnosis and Design

In the first stage, ERASME assists pavement engineers in assessing the pavement condition. The information necessary to establish the diagnosis are gathered from data files or input interactively by the user. ERASME tries to reproduce the expert thinking process; it collects only the relevant data and can provide explanations about the questions it asks the user.

In the second stage, after problem assessment, ERASME seeks successful rehabilitation techniques; the selection is linked to the initial diagnosis. Several alternatives are generally proposed to the user. Each solution is evaluated in terms of service life, costs, and short-term serviceability. (Serviceability can be predicted in the long term at the network level but not at the section level, because the dispersion is too large.)

Calculations

Like pavement engineering specialists, ERASME makes some calculations:

- whether to validate or invalidate current hypotheses during problem assessment, and
- whether to define design parameters such as overlay thickness during the conception stage.

ERASME will be interfaced with several algorithmic subroutines:

- ALIZE3, which computes stresses and strains in pavement structure (*3*),
- a model predicting rut depth resulting from asphalt concrete flow,
- a model predicting cracking due to the aging of asphalt concrete,
- a model for evaluating pavement resistance to frost thaw cycles, and
- an economic model (cost estimation and volume and surface calculations).

Incomplete Data

Information is sometimes scarce, especially for low-traffic roads. Pavement structure and traffic should be known. ERASME will manage cases where laboratory tests and measurements are missing, however. The expert system will show the user how the absence of a certain type of information can lead to the selection of an unsuccessful rehabilitation technique. The user will be able to require some laboratory tests or choose a relatively unreliable rehabilitation technique knowledgeably.

ERASME's Users

ERASME users should be primarily engineers in charge of pavement management at local, district, or regional levels and members of the national technical services working in the field of pavement engineering, such as LCPC, SETRA, and CETE. To a lesser extent, they will be at engineering schools (expert systems are valuable tools for lifelike teaching).

ERASME's Operational Version

The native version will be available on Unix workstations such as SUN 3/140. The portability of ERASME depends on that of LE-LISP (INRIA-ILOG) and X-WINDOWS. These choices should warrant very good portability.

Studies are being made to assess the possibilities of transferring the system for use on equipment of the IBM PC type. According to their outcome, distribution of the product will be ensured either by teleprocessing from service centers fitted with a workstation or by supplying the software to PC users. In any case, users will have access to a runtime version that will not allow them to modify the software or the knowledge bases.

PROJECT EXPERTS

Representative Expertise

The expert system integrates various competencies. Its stored, encoded expertise derives from a knowledge elicitation process conducted with pavement laboratory specialists and pavement-management-oriented engineers. This collaboration between pavement engineers with two different kinds of experience should enhance the encoded knowledge's quality (*4*).

Concentric Expertise

About ten experts will be associated with system development. From the beginning, two experts have been involved in knowledge elicitation. Two expert teams with specialized backgrounds (drainage and pavement resistance to frost effects) are assisting them. Other experts will use ERASME's successive prototypes to validate, criticize, and develop the expert system's encoded knowledge.

Validation Procedure

Validation is costly and time-consuming (30 to 40 percent total cost). A few dedicated future users will validate the expert system. Their remarks will be gathered into related fields and sent to the development team.

DIAGNOSIS

Subproblems

The knowledge in the diagnosis system is structured with prototypes inspired by Aikins (*5*) and by those in a French expert system project called DIVA (*6*). Each prototype is associated with a subproblem involved in the decision-making process. One prototype defines the part of knowledge required to solve a subset of the problem; it consists of procedures, collections of rules, and problem domain attributes. Examples of prototypes are "subgrade assessment," "representativeness of deflection," and "deflection measurement conditions."

Decentralized Decision

The structure of the selected knowledge leads to development of a decentralized system: each one of the subproblems is taken care of by a specialized expert subsystem (Figure 1). A control modulus—a supervisor—is in charge of the cooperation of these different subsystems or knowledge moduli. This supervisor is equipped with a high-level expertise that allows it to decide, during the process, either to carry on with the thinking process while assigning an analysis to a subsystem, to conclude, or to invalidate a hypothesis (*7*).

Finally, the supervisor is fitted with a local data structure that is fed with the expert subsystems proceedings. These proceedings are high-level abstractions of the state of the problem. For example, if one does not take the action of water into account, the pavement shows no fatigue.

Reentry and Nonmonotonous Subsystems

In the course of thinking, each one of the specialized expert subsystems may be called upon by the supervisor several times. Each one of these calls is the subject of a special analysis. The first analysis, performed during the first call, consists of a "quick general view" of the problem. It is generally completed with a series of hypotheses produced by the subsystem and eventually questioned on the occasion of later stages (nonmonotonous thinking process).

For example, as it was called for the first time, the "deflection analysis" modulus supposes that it refers to the "representative deflection." It will question this hypothesis if the supervisor makes such a suggestion and will then evaluate the "conditions of the deflection measurement."

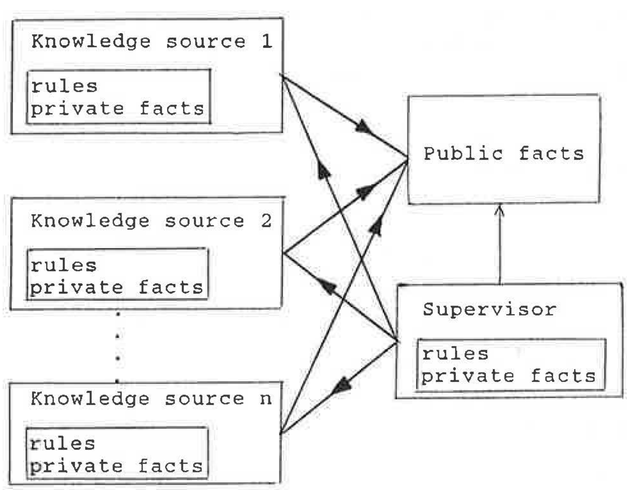

FIGURE 1 A decentralized structure.

Analysis

During the thinking process, pavement specialists use expertise of various types. For a given subproblem, they usually develop several relatively independent analyses that are subsequently synthesized. For example, structure fatigue can be evaluated by two separate analyses: elastic analysis (traffic, structure) and surface condition analysis (surface condition, date, and nature of repairs).

Models

A pavement specialist also reasons with models that are abstracted from the real pavement. Hence, when he or she focuses on surface cracking, the stages of the reasoning process are as follows:

- forgets traffic action,
- evaluates surface course cracking that results from aging,
- integrates the dynamic action of traffic on these cracks, and
- compares the obtained cracks with the real ones, and so on.

DESIGN

Having assessed the pavement problem, the expert system tries, as a second stage, to select successful rehabilitation techniques.

Generate-and-Test Expertise

Part of the encoded expertise is of the generate-and-test type. Some production rules state the concurrent alternatives in a given situation. For example, if pavement rehabilitation is to be realized, then the following techniques can be used:

asphalt concrete + bituminous base

asphalt concrete + granular base

surface dressing + granular base

Some other production rules state the constraints that constructed solutions must meet. For example, if a pavement surface course is subjected to snow removal, then surface dressing cannot be used as a long-term solution.

Procedural Expertise

Procedural knowledge is implemented as procedural attachments to objects. These procedural attachments are expressed along inheritance trees. Intensive use is made of object programming style, in particular, for interfacing ERASME with FORTRAN subroutines.

Problem Breakdown

Complex problems are broken down into simpler subproblems. Final solutions are the synthesis of more elementary solutions. For example, defining a rehabilitation technique consists of pavement structure improvement and complementary constructions (e.g., drainage).

Multicriteria Decision

Constructed solutions must satisfy several requirements (durability, serviceability, cost, and construction duration). ERASME makes no choice among solutions; rather, it evaluates them in terms of the foregoing criteria, enabling users to select their own solution.

LABORATORY TEST MANAGEMENT

For a low-traffic pavement network, generally limited data are available (laboratory tests such as deflection tests or in situ materials tests).

ERASME will generate a hypothesis and thus use hypothetical reasoning. The main stages of the solution process should be

- definition of concurrent diagnosis,
- indication of laboratory tests that would reduce the number of these concurrent diagnoses, and
- selection of rehabilitation techniques for each diagnosis.

Then the user would either make some laboratory tests or knowingly select a hypothetical rehabilitation technique.

This difficult aspect is now under development with SMECI by authors of INRIA at Sophia-Antipolis.

PROJECT CURRENT STATE

Expert System Shell

ERASME's first prototype was developed (April 1986, December 1986) with CRIQUET (*8*), an expert system shell developed by INRIA at Sophia-Antipolis. For product development, SMECI (*9, 10*) (a high-level expert system shell developed at Sophia-Antipolis by INRIA) has been chosen for the following reasons:

- It has knowledge encoding techniques (objects, methods, state graph, and production rules) facilitating knowledge maintenance.
- It includes tools for construction of user-friendly interfaces (icons, mouse, windows, various editors).
- SMECI is a commercial tool (marketed by ILOG Inc., a subsidiary of INRIA).

First Prototype

The first prototype assists local engineers in analyzing and designing flexible pavement sections. Knowledge encoded in the system is limited to the principal distresses of flexible pavements.

Interaction with this first prototype allows users, with their own defined data (e.g., surface condition, deflection test, laboratory test), to assess the problem and to select one or several rehabilitation techniques. This first prototype includes 210 rules and 50 decision and computation tables; it is interfaced with ALIZE3 (10,000 FORTRAN lines) (*3*).

A powerful feature of this prototype is that it enables users to record sessions. Sessions can be modified and rerun, automatically or not. If user changes necessitate that the expert system obtain further information not defined in the session, these are requested by the program. This feature enables the user to make sensitivity studies.

Present Prototype

This prototype (April 1987, June 1987) developed with SMECI diagnoses pavement structure fatigue and builds rehabilitation design according to four different techniques. Each solution is assessed in terms of costs. Particular efforts were made to construct a user-friendly interface.

CONCLUSION

The first prototype of ERASME (210 rules), similar to projects now developed in North America (*2,11–13*), shows that knowledge-based expert system technology should benefit pavement maintenance.

The presence within the Owner's Committee of user representatives warrants that their needs and wishes will be taken into account from the elaboration stage onward.

The interfacing of the expert system with the calculation codes will make it possible to supply all users with a complete line of software that, up to now, was scarcely distributed outside the laboratories.

A compromise remains to be found between the system products (e.g., calculation speed, graphic output), the equipment likely to receive them and the group of potential users.

The development and maintenance of such a tool are powerful encouragement to validate the national and regional research in the road field.

The setup of the expert systems makes them a very valuable complement to pavement management systems.

Five billion francs are now spent each year for French highway network maintenance. ERASME should generate savings of about 100 million francs each year. Economies are high, although still only anticipated at the moment.

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