Erasme: A Multiexpert System for Pavement Assessment and Rehabilitation

F. Allez, J. Palfart, M. P. Joubert, J. P. Labat, A. Meller, O. Corby, and B. Neveu

To facilitate decision making in the area of road maintenance, the Directorate of Roads in France decided five years ago to use AI techniques and to make an expert system called Erasme available to various government agencies. Erasme was developed with SMECI, a high-level expert system shell, and integrates innovative AI concepts. During June to November 1989, Erasme was submitted to 25 sites for field testing. This experience enabled us to assess the benefits, costs, and objectives of Erasme.

Problem Statement

The diagnosis and selection of a maintenance solution for defective pavement are the main characteristics that make the use of an expert system interesting (Allez et al. 1988): First, hundreds of road maintenance decision makers can be found at the national, regional, or local

service levels. Second, only a few pavement specialists are able to define the right pavement rehabilitation technique. Third, these specialists use various types of data: technical and accurate data such as laboratory tests, qualitative data such as surface conditions, incomplete and uncertain data such as traffic volumes and loads, and redundant and contradictory data such as field data. Fourth, some aspects of the pavement maintenance problem are poorly known or stated. In these cases, experts use empirical methods or rules of thumb derived from their own experience or collective practice. Fifth, confronted by an incompletely defined problem and a partially formalized theory, experts trust their own experience to assess the real condition of the pavement and select appropriate pavement rehabilitation techniques. Thus, this decision making is subjective. Sixth, the financial stakes are important. The annual expenses in France for road maintenance approach US$800 million.

Project Objectives

Erasme aims to set up operational expert systems that can perform the following tasks for a given pavement (Hall et al. 1987): (1) evaluation of current condition, (2) construction of different diagnoses, (3) prediction of future condition without rehabilitation, (4) selection of successful rehabilitation approaches, (5) prediction of each rehabilitation approach, (6) cost analysis of each rehabilitation approach, and (7) advice on needed physical tests.

User Assessment

In the development of an expert system, it is important to pay attention to the expected user. Erasme should be available to pavement rehabilitation decision makers at the regional service level. Our typical user manages 3000 kilometers of minor roads, of which he/she analyzes 300 kilometers each year. That leads to about 30 work sites. He/She has a budget of 50 million francs budget (approximately US$7.5 million). Using Erasme, he/she should save at least 2.5 percent of his(her) budget. In France, Erasme should have about 100 such users, leading to a global savings of approximately US$20 million.

Erasme Results

Erasme produced an operational expert system for unbound base pavements by mid-1989. It evaluates current road conditions, constructs various diagnoses, selects successful rehabilitation approaches, and performs a cost analysis for each approach. Validation showed that

Erasme correctly performs on 90 percent of cases and declares itself incompetent on 10 percent of the cases, suggesting that a human expert be consulted.

This expert system was successfully tested on 25 sites from June to November 1989. The word successfully is assessed in 5.

AI Concepts Used in Erasme

The following subsection presents an overview of Erasme's architecture.

Structural Knowledge

Concepts involved in pavement diagnosis and rehabilitation are represented by SMECI (INRIA-ILOG 1989) frames, including classes and instances. The global database is a collection of such instances, called *objects*.

A *class* defines the structure of a family of objects in terms of slots. Classes are refined by standard subclass trees, which specify default values, range constraints, and specific methods. A class inherits methods, values, and constraints from its superclass unless it redefines them.

Structural knowledge includes such classes as Pavement, Distress, and Traffic. Inferences are carried out by production rules whose premises and actions operate on objects. The system records its inferences within slot values and new objects.

Multiple Lines of Reasoning

The SMECI shell provides multiple states that are similar to ART™ viewpoints and KEE multiple worlds (Filman 1988). An expert system using SMECI starts its reasoning from an initial state. Rules of the current rule base generate states that are sons of the current state. If a rule has several instantiations, it produces one state for each instantiation. If several rules fire, each one produces its own states. To prevent combinatorial explosion, it is possible to specify the maximum number of applicable rules for each rule base. It is also possible to prune the tree by means of contradiction rules.

Erasme takes advantage of SMECI 's multiple states to pursue several reasonings in parallel: It proposes several diagnoses when data are lacking or are contradictory. It also sets up all rehabilitation strategies that meet current constraints. These constraints come from attained diagnosis or are set up by the user (specifications). Figure 1 shows a state tree produced by Erasme.

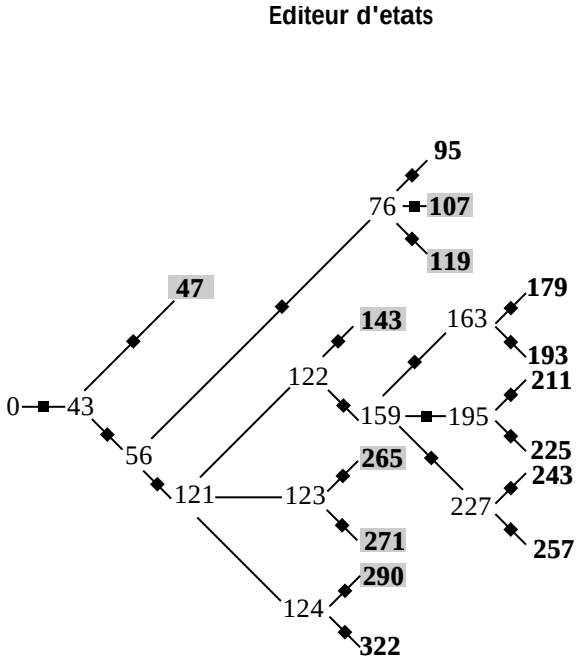

Figure 1. A State Tree with Several Lines of Reasoning.

Innovative Aspects of Erasme

The following subsection outline various aspects of Erasme.

Knowledge Integration

Erasme integrates various skills. Its stored expertise derives from a knowledge elicitation process conducted with 20 pavement laboratory experts and pavement management–oriented engineers.

Working with this large and heterogeneous team of experts was a fruitful challenge for the Erasme knowledge engineers. To encode the various pieces of knowledge, we used a blackboard-like architecture that is described in the following subsection.

The Multispecialist Kernel

The human experts involved in the project numbered about 20. Because their knowledge couldn't be integrated into a single monolithic system, a multispecialist architecture was built by INRIA at Sophia-Antipolis (Corby, Allez, and Neveu 1990) to produce a more modular system. Erasme is built on a blackboard model (Nii 1986). It is a collec-

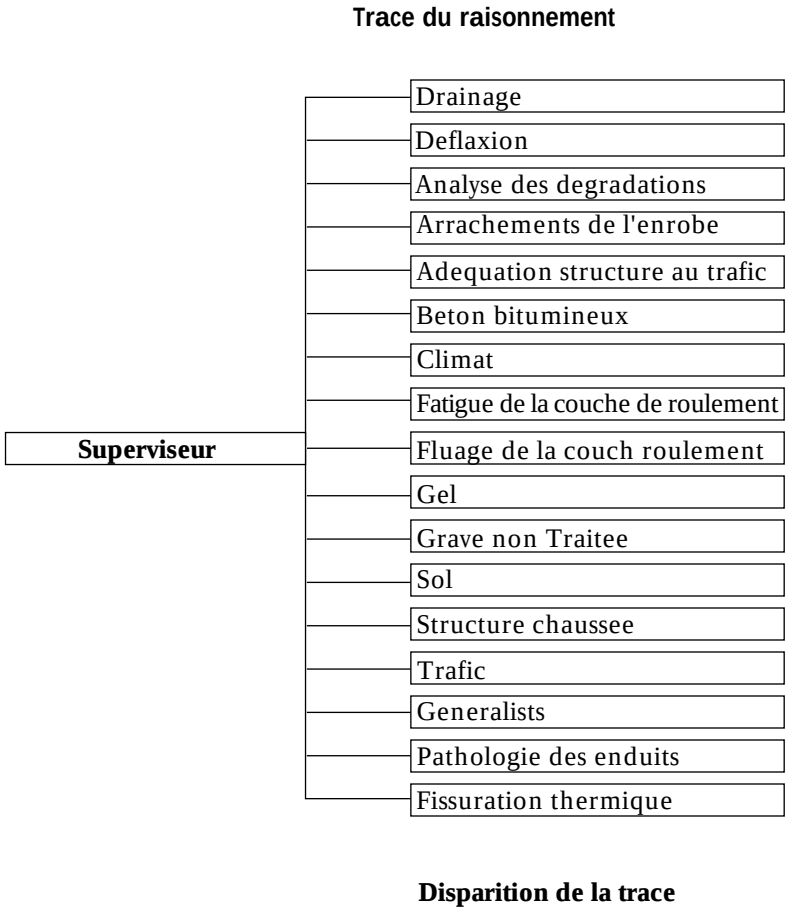

Figure 2. The Supervisor and Its Specialists.

tion of simple cooperating knowledge bases, called *specialists*, each of which embodies specialized knowledge such as frost resistance, asphalt concrete, and adequate structure for traffic load (figure 2). It enables modular knowledge formalization and modular encoding.

Because the system was developed by several persons (currently four), the software engineering modularity concept is highly important. It enables easy internal modification and greatly facilitates debugging. Furthermore, an incomplete system can be tested.

Reasoning on Reasoning

It is possible to have several expert systems in the same SMECI environ-

ment and make them work together. In SMECI, an expert system is an object, an instance of a system class called ExpertSystem. Each expert system has its own knowledge base (classes, rules, methods) and database and derives its own reasoning tree. To build its own reasoning tree, an expert system can look over the results previously generated by its colleagues. This feature is called *reasoning on reasoning*.

Erasme is currently a collection of two expert systems. The first one is in charge of pavement assessment or diagnosis. The second one is able to design rehabilitation techniques associated with previously attained diagnoses. In the future, we plan to build a third expert system for predicting pavement conditions in case of a rehabilitation delay.

Criteria for Efficient Use

The following subsections outline the criteria necessary for the efficient use of Erasme.

Pavement Managers in Search of Performance

Erasme's best users are task motivated, open to new technologies, and eager to become more skilled and efficient. Erasme users need to invest time and money to correctly use the system (a workstation; an Erasme license; and a one-week training session for each user, including the setup of an appropriate organization). In addition, because Erasme encodes high-level pavement engineering techniques, its users can access the knowledge of experts and derive solutions of their own. A significant subset of pavement engineering techniques becomes available to them. Finally, Erasme users enjoy a greater freedom. They might enter into a new relationship with experts, and introducing Erasme might lead to a new decision-making organization in the area of pavement maintenance.

Synergy between Managers and Experts

Five years ago at the beginning of the project, Erasme was seen as a means of establishing a synergy between pavement managers and experts: Using Erasme, pavement managers would be able to express their needs to enhance pavement management. The formalization of these needs would help the French Directorate of Roads to direct research in the field of pavement engineering.

Erasme users have already expressed new needs that constitute important challenges for the experts. Taking them into account will facilitate Erasme's diffusion and development: Erasme must be a market-driven project.

Remark / Site Number	1	2	3	4	5	6	7	8	9	Total
Lead to Safe Decisions			•				•			2
Stimulate Imagination			•	•		•				3
Lead to Scientific Decisions				•	•	•				3
Give Credibility				•	•		•			3
Help Training			•					•	•	3
Motivate Field Datacollection								•		1
Motivate Pavement Manager						•		•	•	3
Save Money			•			•				2
Number of Remarks	0	0	4	3	2	4	2	3	2	20

Table 1. Erasme Qualitative Benefits.

A Continual and Serious Validation

Erasme has worked on more than 300 real cases. It is extremely important to spend time and money on Erasme validation to warrant its reliability. An expert's committee is planned that will be in charge of the validation and evolution of the Erasme knowledge base.

Benefit Evaluation

The benefit assessment that is presented in this section is derived from extensive field testing conducted from June to November 1989 with nine French districts: Aube, Bas-Rhin, Côte d'Or, Eure-et-Loir, Haute-Garonne, Pas-de-Calais, Pyrénées Orientales, Seine-Maritime, and Yonne. The testing was supervised by an independent consulting office.

Qualitative Analysis

In this subsection, we present some qualitative remarks that were made by users at the field test sites after working with Erasme for six months (table 1). Two districts did not have any positive comments on Erasme. They seemed less interested in Erasme because they are less in charge of district road network pavement maintenance.

The following statements were made about Erasme:

- "Erasme leads to safe decision making because its results are reproducible and validated."
- "Erasme stimulates imagination because it proposes several solutions for one problem, whereas experts generally give only one, two, or three solutions."
- "Erasme [performs] scientific decision making since it is knowledge

	Studies Author	Error Rate	Error Cost	Maintenance Budget	Savings
National Road Network	Governmental & Technical Agencies	5%	15%	$130 million	$1 million
District Road Network	Local Agencies	20%	15%	$650 million	$20 million

Table 2. Expected Savings.

Software and Knowledge Engineers	43%
Experts for Elicitation	21%
Research	12%
Experts for Validation	7%
Industrialization	12%
Project Management	4%

Table 3. Project Costs.

based and interfaced with calculation codes that are, up to now, scarcely distributed outside laboratories."

- "Erasme gives credibility to its user because it is an expert system."
- "Erasme appears [to be] a good tool for training: It presents an easy-to-use and friendly interface and is problem oriented."
- "Erasme underlines the need for field data and will stimulate field data collection (data on traffic, pavement structure)."
- "Erasme helps to avoid errors. Its use enables pavement managers to save money."

Macroquantitative Analysis

A synthetic view of expected savings is shown in table 2. There are 25 technical governmental agencies in France and 100 districts. The agencies are working on the maintenance of the national road network but not the district road network. Generally, district road network maintenance is not submitted to any technical agency because of expertise cost (see Studies Author column).

Because of time constraints, we think technical agency studies are subject to a 5-percent error rate. Because of a lack of expertise, local agency studies are subject to a 20-percent error rate (see Error Rate column). Errors can be linked to bad assessment, rehabilitation design, or work planning (either too early or late). The error cost is estimated to 15 percent of the work cost (see Error Cost column).

Microquantitative Analysis

To use Erasme, a district has to buy a workstation and an Erasme license and provide one week of training for each user. For a district, an investment in Erasme amounts to US$60,000. Two districts estimated that this investment has a four-month return time, which is linked to an average annual expense of US$7.5 million for pavement maintenance.

Cost Evaluation

By the end of 1989, US$1,500,000 was spent on the Erasme project, not including the shell run-time cost. A breakdown of the expense is presented in table 3.

Conclusions

Erasme is an appreciated tool because it is knowledge based and validated. It should be considered as an assistance tool for decision making. However, it still has to be developed to account for the new needs of pavement managers.

By the end of 1989, Erasme was aiding pavement maintenance in nine French districts. By the end of 1990, Erasme should benefit pavement maintenance in 40 percent of the French districts.

Finally, Erasme will transform the relationship between managers and experts in the field of pavement engineering. Project management should associate pavement managers with experts to work on future development.

References

Allez, F.; Dauzats, M.; Joubert, P.; Labat, J. P.; and Puggelli, M. 1988. Erasme: An Expert System for Pavement Maintenance, Transportation Research Record 1205, Pavement Maintenance 1988.

Corby, O.; Allez, F.; and Neveu, B. 1990. Erasme, A Multi Expert System for Pavement Diagnosis and Rehabilitation. *Transportation Research Journal* 14A(l).

Filman, R. 1988. Reasoning with Worlds and Truth Maintenance in a Knowledge-Based Programming Environment. *Communications of the ACM* 31(4): 382–401.

Hall, T.; Connor, J.; Darter, M.; and Carpentel, S. 1987. An Expert System for Concrete Pavement Evaluation and Rehabilitation. Presented at the Second North American Conference on Managing Pavements,

Toronto, Canada.

Inference Corporation. Art Programming Manual, Inference Corp., Los Angeles.

INRIA-ILOG. SMECI Version 1.4 Reference Manual. INRIA-ILOG, Paris, France.

Nii, P. 1986. Blackboard Systems: The Blackboard Model of Problem Solving and the Evolution of Blackboard Architectures. *AI Magazine*, 38–53.