# Integrating Expert Systems in Existing Pavement Management Systems on Microcomputers

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**The expert system technology is having an increasing role in the continuing development of new pavement management applications for the state and local highway agencies. In recent years, several prototype expert systems have been developed in the pavement management area. Expert systems were often developed as stand-alone systems without considering the existing pavement management systems (PMSs). This paper discusses a concept of integrating an expert system in existing pavement management systems. The expert system components should be combined with the existing pavement management system to make it more intelligent and friendly. Merging an expert system technology into the pavement management system will lead to a complete system capable of managing a large base of complex pavement-related data in an integrated way. This paper presents an expert system that can be integrated into the existing pavement management systems on microcomputers. This expert system is developed to enhance the existing PMS, not to replace it.**

Pavement management problems involve empirical knowledge, but many existing pavement management systems (PMSs) use complex procedural algorithmic routines without fully incorporating human expertise. Recently, a number of excellent expert system developments in the pavement management area have been presented at the several workshops and conferences (*1–5*). The expert system technology is having an increasing role in the continuing development of new pavement management applications for state and local highway agencies.

The expert systems developed generally provide interactive input mode through the computer terminal and display conclusions on the screen after completing expert system consultation. The user manually enters all the data items as requested by the expert system, and these inputs and expert system consultation results are not often saved for later analysis or database queries. The expert system's ability to use and propagate the information flow of the existing PMS is critical for the acceptance of the expert system by the user.

Several expert systems were designed for use by state highway engineers with extensive data processing capabilities. For example, the EXpert system for Pavement Evaluation And Rehabilitation (EXPEAR), which was designed for high-type conventional concrete pavements, possesses extensive capabilities for storage and retrieval of input data, as well as output of pavement performance and cost analysis results (*3*).

This paper discusses a pavement management expert system (PMES) that was designed for a local community. The PMES was developed to support the existing PMS. Basic pavement inventory data can automatically be extracted from the pavement databases, and the PMES asks only for the information that is not available from the pavement database. The recommendation by the PMES is then automatically saved in the pavement database to be later utilized by the PMS. The PMES can further provide a detailed description of how to apply the recommended rehabilitation and maintenance strategy for the particular pavement section.

## KNOWLEDGE- AND DATA-BASED SYSTEMS

Expert systems have often been developed as stand-alone systems without considering the use of existing application programs and databases. However, the increasing number of applications of expert systems in engineering require algorithmic routines and data processing capabilities (*6*). Consequently, it becomes necessary to develop an interface to connect an expert system with these existing conventional environments, including database management systems (DBMSs).

The concept of knowledge and database systems has been discussed in numerous workshops and textbooks (*7–10*). A knowledge or database system can be defined as "a system for developing applications requiring knowledge-directed processing of shared information" (*7*). The interaction between knowledge-based systems and data-based systems can be organized from "loose" to "tight" coupling of the expert system with a DBMS (*8*).

The tight coupling approach usually requires a sophisticated mechanism for a completely integrated system, such as an intelligent database system and an internal expert system database. A loosely coupled, expert system–database management system concept is more flexible. This concept allows an expert system to be connected to the existing systems as one of the application programs. The conceptual architecture of the PMES is shown in Figure 1. As shown in that figure, the expert system is just an extension of the existing system to provide the deductive inferencing search and explanation capabilities.

Recently, the necessity of integrating the expert systems and the existing database management technologies has been

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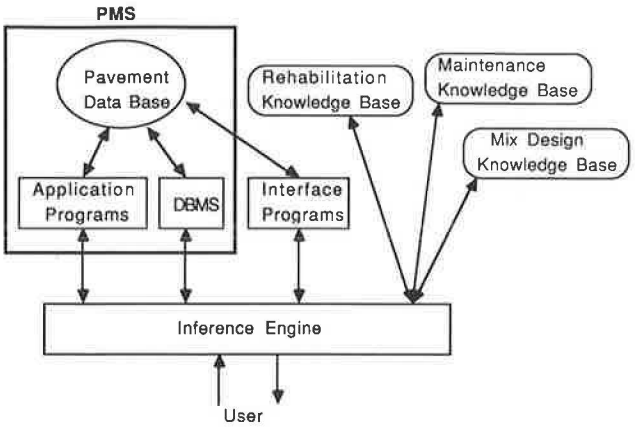


**FIGURE 1 Conceptual architecture of PMES.**

widely recognized, and the concept has been implemented in several expert system building tools. These tools, also referred to as shells, are now commercially available for microcomputers. Out of sixty commercially available expert system shells (*11*), eleven microcomputer-based expert-system shells were evaluated on the basis of their integration capabilities with conventional programming environments (*12*).

Only five shells have been reported to offer database management system interfacing. One of these shells, called INSIGHT 2+, was used to develop the PMES. This shell provides the integration capabilities through the special Pascal language DBPAS and its database extensions. The interface programs were written using DBPAS for accessing and manipulating the dBase III Plus database files.

DBPAS and its database extensions have somewhat limited data-base interface capabilities. For instance, a maximum of ten variables can be passed between the expert system environment and the interface programs, and a maximum of four database files can be open at the same time. INSIGHT 2+ may not be capable of serving as a shell for the large-scale expert system for the state agency that would require a large pavement database. The compilation and execution times for large knowledge bases could be prohibitively long for practical use by any state highway agency.

## EXPERT SYSTEMS FOR A SMALL COMMUNITY

The Town of Huntington, New York, is located on the north shore of Long Island, 50 miles east of New York City. The town highway department is responsible for maintaining approximately 790 miles of two-lane roadways. The majority of this mileage can be classified as low-volume roadways with average daily traffic volume of fewer than 400 vehicles per day.

In 1984, through the efforts of the highway engineer, a PMS was developed by the in-house staff. The PMS developed was a modified version of a system used in Cherry Hill, New Jersey. The system, a manual one, was used by Huntington to produce a road program for the next construction season. The PMS was capable of identifying only two types of treatments, overlay or reconstruction, based upon an aggregate pavement condition rating score.

In 1987, after 3 years of use of the PMS, the town realized that the system needed to be enhanced to include a greater range of treatment options and identification of the appropriate treatment based on factors other than just an aggregate pavement condition rating value. The town highway department hired the firm of Pavement Services, Inc., to develop software for a new PMS. The development of the entire software package has been planned over three phases. A brief description of each phase follows.

### Phase I—Current Network Needs

1. Identify the framework and data requirements for the PMS;
2. Collect and interpret the data;
3. Define broad-based maintenance and rehabilitation options; and
4. Assess overall network needs.

### Phase II—Project Selection and Optimization

1. Identify potential projects;
2. Develop feasible maintenance alternatives;
3. Test each alternative using an economic analysis;
4. Select the optimum treatment; and
5. Establish a logical priority for taking action.

### Phase III—Network Level Programming

1. Develop a long-range program;
2. Input budget and/or condition-level constraints;
3. Evaluate the effectiveness of each program;
4. Suggest a series of potential alternative programs; and
5. Select the final overall program.

Data collection and development of the Phase I module began during the summer of 1988. A new pavement condition survey form was first developed for the town. The new survey form is much more detailed and comprehensive than the one previously used by the town. A condition survey has been completed using the new form during Phase I.

The project is now in the second phase to identify feasible maintenance and rehabilitation alternatives. The improvements in the survey form should allow the town to use the individual distress items instead of an aggregated pavement rating score. During discussions with the town highway department with regard to the general framework of the PMS package, an interest was shown in the possible development of an expert system to aid department personnel in determining the most appropriate strategy for each pavement section.

The highway department was interested in an expert system for the following reasons: (a) lack of pavement management expertise in the town, (b) limited resources available for development, (c) fast prototyping of the system for initial acceptance, and (d) ease of modifying the system because of changing administrative policies.

## DEVELOPMENT OF A PAVEMENT MANAGEMENT EXPERT SYSTEM

The Pavement Management Expert System (PMES) is being developed during the second phase of the project for the town of Huntington. The PMES is to determine the most appropriate rehabilitation and maintenance strategy for each pavement section based on condition survey data and other factors. The PMES is linked to the pavement database through the interface program written in the DBPAS language for which data had been previously collected and saved by the prototype PMS developed in dBASE III Plus.

Given the present condition of a pavement, the most appropriate rehabilitation or maintenance strategy is recommended by the PMES after all other subjective factors are fully considered. The basic pavement inventory data, such as distress condition survey, will automatically be extracted from the existing pavement database through the interface program named GetProgram, written in DBPAS.

The GetProgram can be called from a decision rule written in INSIGHT 2+. The simplified rule to access the pavement database using GetProgram is shown in Figure 2. This rule asks the user to provide the road name, then calls the GetProgram. The GetProgram searches through the pavement database to locate the pavement section requested by the user and returns the condition survey data to the knowledge base. Using distress information obtained from the database, an initial decision on whether to rehabilitate the pavement section will be made. A simple example of a decision rule for rehabilitation is shown in Figure 3.

The user will be asked only about other judgmental factors that are not currently available from the database, such as geometric design requirements, administrative information, pavement history, and so forth, to arrive at the final recommendation. This final recommendation is then automatically saved in the pavement database to be utilized later by the PMS. An example of the decision rule for a pavement recycling strategy is given in Figure 4. This rule utilizes the program called SaveProgram written in DBPAS to save the recommendation

PMES can further provide a detailed description of how best to apply the recommended rehabilitation and maintenance strategy for the particular pavement section. Thus the user does not have to look for additional reference materials regarding the specific application procedure.

For example, it can assist in determining the portions of reclaimed asphalt pavement and aggregate materials that are allowed in order to obtain a combined aggregate gradation that meets the specification requirement for recycling hot-mix design. A decision rule to determine optimum proportions

```
RULE        For Accessing Data Base
IF          Get the Pavement Data
AND ASK     Road Name
AND CALL    GetProgram
SEND        Road Name
RETURN      Distress Data
THEN        Have Distress Data
```

**FIGURE 2 A rule to access pavement database.**

```
RULE        For Rehabilitation
IF          Have Distress Data
AND         Rutting Area = Extensive
AND         Rutting Level = Severe
THEN        Evaluate for Rehabilitation
```

**FIGURE 3 A sample decision rule for rehabilitation.**

interactively is shown in Figure 5. A small GradProgram was written to conduct a gradation test against the specification.

After the gradation test is satisfied, another decision rule can be activated to compute the asphalt content needed for hot-mix recycling based upon the California Kerosene Equivalent formula, as shown in Figure 6.

A final recommendation can be displayed with all the necessary information at the end of consultation with the PMES. A sample recommendation display is shown in Figure 7. This DISPLAY function can be used to provide explanatory information for any technical jargon or ambiguous word for the user in the middle of the expert system consultation.

Any application program can be run from the PMES using the ACTIVATE function. The program should exist as an .EXE or .COM file. The parameter data can be passed via memory or a disk file. The rule shown in Figure 8 activates the program dBASE.EXE, and the COMMAND function is used to specify the program "PMS" that dBASE.EXE program will use. This ACTIVATE function will allow the PMES to access instantly any application program in the middle of an expert system consultation.

## CONCLUSIONS

Pavement management is an appropriate application area of an expert system because pavement management problems require sound engineering knowledge provided by a human expert. An expert system can also provide explanatory information on the technical jargon and decision flow to make the existing PMS more friendly to the user.

The PMES is being developed for the local government, which is not capable of predicting the pavement performance and conducting life-cycle cost analysis. The running speed and the maximum number of rules allowed for the expert system shell are not constraints for developing a system for the small community.

In expert system applications in the pavement management area, it becomes necessary to integrate an expert system into the existing PMS. The inability of an expert system to inter-

```
RULE        For Recycling
IF          Evaluate for Rehabilitation
AND         Sufficient Pavement Thickness
AND NOT     Too Many Manhole Covers
THEN        Pavement Recycling Recommended
AND         Strategy := Recycling
AND         CALL SaveProgram
SEND        Strategy
```

**FIGURE 4 A sample decision rule for pavement recycling.**

```
RULE        For Gradation Test
IF          Have Aggregate Proportion
AND         CALL GradProgram
SEND        Initial Proportions
RETURN      Combined Proportions
THEN        Gradation Test Satisfied
DISPLAY     Gradation Test
```

**FIGURE 5 A rule to determine aggregate proportions.**

```
RULE        For Asphalt Content Required
IF          Gradation Test Satisfied
AND         CALL GetProgram
RETURN      Sieve8
RETURN      Sieve200
THEN        Asphalt Content Recommended
AND         AsphaltNeed:=0.035*Sieve8+0.045*Sieve200
AND         Asphalt:=AsphaltNeed-AsphaltReclaimed
DISPLAY     Final Recommendation
```

**FIGURE 6 A rule to compute asphalt content needed.**

```
DISPLAY          Final Recommendation

[Road Name] Is recommended for Recycling with
preliminary specifications as follow:
Reclaimed Asphalt Pavement Proportion is [RAP]
Reclaimed Aggregate Material Proportion is [RAM]
New Aggregate Material Proportion is [NEW]
Recommended Asphalt Content is [Asphalt]
```

**FIGURE 7 A final recommendation display.**

```
RULE            For Huntington PMS Active
IF              Menu Option IS Run PMS
THEN            PMS Activated
AND ACTIVATE    dBase.exe COMMAND PMS
```

**FIGURE 8 A rule to activate external programs.**

face with the existing PMS could lead to a low rate of acceptance of an expert system by the user.

In regard to the interface between the PMES and the existing PMS, the user sees the PMES as an extension of the PMS. The PMES can access the database whenever the data are needed. If the data are not available from the database, the PMES will automatically turn to the user for the information. The PMES can be considered an intelligent interface to the PMS.

Merging of an expert system technology into the existing PMS will lead to a complete system capable of managing a large base of complex pavement-related data in an integrated way. The PMES is developed to supplement the existing PMS, not to replace it.

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