One of the objectives of SHRP research conducted in the concrete and structures technical area was to improve concrete technology, primarily for pavements. Contract C-206, Optimization of Highway Concrete Technology, included the development of an expert system for highway concrete activities. The effort resulted in HWYCON (SHRP product 2039) which is an operational and computerized knowledge-based system. This brief is intended to help interested practitioners evaluate the system, and it includes some comments on the software with excerpts from the HWYCON documentation, Users Guide to the Highway Concrete (HWYCON) Expert System (SHRP-C-406).

To install the software, provided on diskettes with SHRP report C-406, a 386 or 486 computer with a minimum of 4 megabytes of memory and 20 megabytes of free disk space are required. A mouse and Windows 3.1 are needed to run HWYCON.

**SUMMARY**

HWYCON is designed to assist highway department staff in three main areas and these are:

1) diagnostics: distress identification and causes of distress(es) in highway pavements and structures,

2) materials selection: the selection of materials for construction and reconstruction, and

3) repair and rehabilitation: recommendations on materials and procedures for concrete pavement repair and rehabilitation.

![Figure 1 - HWYCON Subsystems and Users](image-url)
To accomplish this, the expert system is organized in five modules or subsystems, and these are depicted in Figure 1, along with the target audience for each. More discussion of the individual subsystems is provided in a subsequent section.

All five modules follow a question-and-answer format in which the system prompts the user for answers to a series of questions about materials, construction type, or distress characteristics. In many cases, the user can choose to view photographs or drawings to assist in answering the questions. Explanations are offered in some cases as to why the requested information is important. Finally, the system provides a final recommendation or diagnosis based on the responses to the questions. It should be noted that the questions and answers are purely descriptive and no numerical analysis is conducted by the system. In the absence of sufficient information the system may recommend further tests be conducted before a conclusion can be reached.

HWYCON's menu-driven format is easy to follow and use, however, the documentation provided with the software is not very well written. Although the manual is titled a Users' Guide, no tutorials or instructions for use beyond installation are included. Nonetheless, the system is self-explanatory and largely self-teaching.

The expert system is easy to use but the subject matter may have been over-simplified. The authors of the work acknowledge that HWYCON will be most useful to beginning engineers and inspectors which suggests that the scope of the software is limited. It is questionable whether the computerized system provides any great benefits beyond that which could be provided by a series of flow charts or tree diagrams. However, the use of digitized photographs and drawings in HWYCON is attractive and informative.

Finally, it should be noted that HWYCON is still in the prototype stage and it is not without minor programming flaws. For example, within CONSTRUC-D (Bridge Decks) it is possible to enter an endless loop between two screens from which there is no legitimate exit. Nonetheless, the system is sufficiently easy and quick to use that aborting from such procedures does not represent a tremendous loss of time or effort.

The following paragraphs are excerpts of relevant information from the HWYCON documentation about the system modules and knowledge domain.

**KNOWLEDGE DOMAIN**

A fundamental component of an expert system is the knowledge domain, or what is known about the subject area. The knowledge base for HWYCON was developed using what was considered to be the best sources available during the development period. Every effort was made to incorporate SHRP-developed technology in the HWYCON system. In some cases this was difficult because the development of the other SHRP products and the expert system were taking place at the same time. In the absence of SHRP-developed knowledge, knowledge from leading industry organizations and state departments of transportation (DOTs) was used. In each case the knowledge was tested by the development team and other experts to ensure that it represented the most reliable and applicable information available. The process of knowledge acquisition consisted of the following activities:

1) literature searches,
2) interviews with concrete experts,
3) interviews with state departments of transportation,
4) SHRP Expert Task Group (ETG) meetings,
5) review of published guidelines, standards, and practices, and
6) interviews with SHRP project investigators.

An important factor in developing any expert system is the need to limit its scope. Expert systems often fail because the scope of the system is too broad. A more successful approach is to develop a system that accomplishes well-defined goals initially and allows for the addition of new knowledge as it becomes available or as the system matures. HWYCON was developed with these basic principles in mind. The system tends to have more breadth than depth in some areas. The subsystem on materials selection is considered to be comprehensive in its scope. However, other areas may lack depth because more detailed knowledge on a topic was not readily available.

HWYCON is not intended to replace the high-level expert. It is considered a decision-making tool, and there will be solution sets that it cannot handle. It will be useful for staff with knowledge levels for beginner to mid level.
consensus developed during the review of the HWYCON prototypes that the system would be particularly useful for new inspectors and engineers.

**SUBSYSTEMS**

The primary focus of HWYCON is on concrete pavements, and knowledge on that subject is represented in three subsystems, CONPAV-D, CONMAT, and CONPAV-R. Knowledge related to highway concrete structures is represented in CONSTRUC-D (one module for bridge decks and one for substructural elements including bridge columns, piers, and parapet walls).

Each of HWYCON's five subsystems is designed to be used separately, but it is suggested that information obtained from one subsystem can be used in another. For example, information from the diagnostics modules can assist in the design of durable replacement material or the proper rehabilitation method.

**DIAGNOSTICS**

The CONPAV-D and CONSTRUC-D subsystems represent the diagnostic component of HWYCON. They are designed to identify distresses and make conclusions about the cause(s) of the distresses. Figures 2 through 4 show the types of structures and pavements covered by each of the subsystems as well as the information required to diagnose the distresses.

The approach taken by the expert system mimics that of an expert in diagnosing a distress. HWYCON queries the user for information on the type of structure and distress (i.e., cracking in a pavement, spalling of a bridge deck), the location of the distress and exposure conditions. A session may involve questions related to the constituents and composition of the concrete, the type of aggregate involved or the aggregate's history in relation to known cases of reactivity. Examples of the questions and field inspection sheets are included in Appendix A of the Users' Guide. At this time HWYCON evaluates distresses individually and there is no provision to make conclusions in situations that involve multiple
causes or distresses that occur simultaneously at one location.

SELECTION OF MATERIALS FOR CONSTRUCTION AND RECONSTRUCTION

Designing concrete to perform satisfactorily in adverse environments requires knowledge about the anticipated exposure condition, accepted and proven methods for specifying the amount and performance of constituents, and specifications for the production and placement of the concrete, such as desired opening times. CONMAT gives recommendations on the design of concrete for four areas of durability and includes knowledge on three methods. The durability areas include:

1) corrosion of reinforcing steel,
2) sulfate attack,
3) freezing and thawing actions, and
4) alkali-aggregate reactions.

The methods represented in the knowledge base include recycling concrete, permeable bases, and fast track concrete. These are shown in Figure 5.

Materials durability knowledge included in CONMAT closely parallels the Guide to Durable...
Concrete published by the American Concrete Institute. This document served as the basis for developing the knowledge. New knowledge from other SHRP projects on freezing and thawing actions and alkali-aggregate reactivity was also included in the subsystem, along with knowledge from high-level experts in the field of concrete durability.

### REPAIR AND REHABILITATION OF CONCRETE PAVEMENTS

The HWYCON subsystem CONPAV-R gives recommendations on the selection of materials and procedures for the repair and rehabilitation of concrete pavements. The program assumes that the procedure has already been chosen. The procedures covered in CONPAV-R include bonded and unbonded overlays, full and partial depth repairs, and diamond grinding and milling, as shown in Figure 6. CONPAV-R gives recommendations on materials and steps for performing the procedure. The operation of CONPAV-R involves the user specifying whether information is needed on procedures or materials.

### CONCLUDING REMARKS

It should be noted that HWYCON’s conclusions and recommendations are meant to be used as a decision-making tool. The recommendations are based on the responses from the user and the final responsibility for the decision still lies with the user. Although the system contains high-level information, it is important to understand that variations can occur in the perception of the structures’ performance and condition. The misstatement of the observer or absence of informa-
tion may make a recommendation invalid.

The object oriented architecture of the system and the development tools allow new knowledge to be added. Modifications can be made to the system’s operation more easily than with most expert systems that have been developed. This is important to prevent expert systems from becoming obsolete. Specific items for future enhancements were identified that would make HWYCON more comprehensive and useful to highway department staff.

For example, causes of distress often involve non-materials related factors. Other distress types could be added to include those dealing with interactions between concrete and the soil, and structurally induced cracks in concrete pavement. New knowledge developed in other SHRP projects which addressed the corrosion of reinforcing steel in bridge decks may be important additions to HWYCON.

Other knowledge developed in the SHRP project on high performance concrete could be included in the CONMAT selection of materials module. Also, intrinsic materials-related problems, including plastic shrinkage and thermal cracking, could be added to CONMAT. The CONPAV-R subsystem assumes that the user has already selected the procedure to be used. This subsystem could be enhanced to give recommendations on the selection of the repair method based on the cause and the density of the distress, and this would be a very powerful feature.