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Expert Systems as Applied to Bridges -- Knowledge Acquisition Phase

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Abstract

Presented in this report is a detailed description of the procedure to be followed to develop a knowledge-based computerized expert system for determining whether to rehabilitate, improve, replace, abandon, or just to routinely maintain an old highway bridge in the VDOT road system. Based on extensive interviews with bridge engineering experts, the type of data needed, the rules to be used and interference procedures are described, along with an example for the expert system called DOB (for Disposition of Old Bridges). Future studies are expected to program this information into a format suitable for use in a personal computer.

FINAL REPORT

EXPERT SYSTEMS AS APPLIED TO BRIDGES
-- KNOWLEDGE ACQUISITION PHASE --

by

William Zuk
Faculty Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
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The research reported here, because of the scope, does not fall within the purview of any currently established advisory committee. However, the research was supported by the Council administration in connection with the conceptual research mission.

ABSTRACT

Presented in this report is a detailed description of the procedure to be followed to develop a knowledge-based computerized expert system for determining whether to rehabilitate, improve, replace, abandon, or just to routinely maintain an old highway bridge in the VDOT road system. Based on extensive interviews with bridge engineering experts, the type of data needed, the rules to be used and interference procedures are described, along with an example for the expert system called DOB (for Disposition of Old Bridges). Future studies are expected to program this information into a format suitable for use in a personal computer.

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INTRODUCTION

A 1986 report of mine entitled "Expert Systems as Applied to Bridges and Pavements" presented an overview of what expert systems are and how they may be applied to highway-related problems. In this report, a specific problem is singled out: namely, how to decide whether to rehabilitate, improve, replace, abandon, or maintain an old highway bridge in the VDOT road system. To rehabilitate a bridge is to restore it to its original condition; to improve a bridge is to strengthen or widen it over and above its original condition; to replace a bridge is to replace it with a completely new structure; to abandon a bridge is to take it out of service from the VDOT highway system; and to maintain a bridge is to keep it functioning essentially in the condition that it is in.

This study will have three phases. The current phase is devoted to the acquisition of the necessary data and other information needed to understand how decisions regarding the subject are made by bridge engineering experts. The next phase will involve taking this information and programming it into a computerized expert system. The last phase will be devoted to testing, debugging, and refining the system, and then making it operational.

PROCEDURE

After discussion with key bridge engineers of the VDOT concerning various problems potentially suitable for adaption into expert system formats, it was decided to focus initially on the problems relating to the disposition of old bridges as described in the Introduction. Since approximately eight thousand such bridges have to be evaluated annually in Virginia, an operational expert system would be a significant aid to the Department.

Armed with a list of questions and a tape recorder, the writer held lengthly interviews with the following people in the VDOT concerning how decisions are made relative to the problem under study.

F. G. Sutherland, State Structure & Bridge Engineer, Richmond

J. E. Andrews, Assistant Structure & Bridge Engineer, Richmond
F. L. Prewoznik, District Bridge Engineer, Culpeper
L. L. Misenheimer, District Bridge Engineer, Staunton
J. K. McEwen, Assistant Maintenance Engineer, Richmond
C. E. Young, Bridge Safety Inspector, Charlottesville

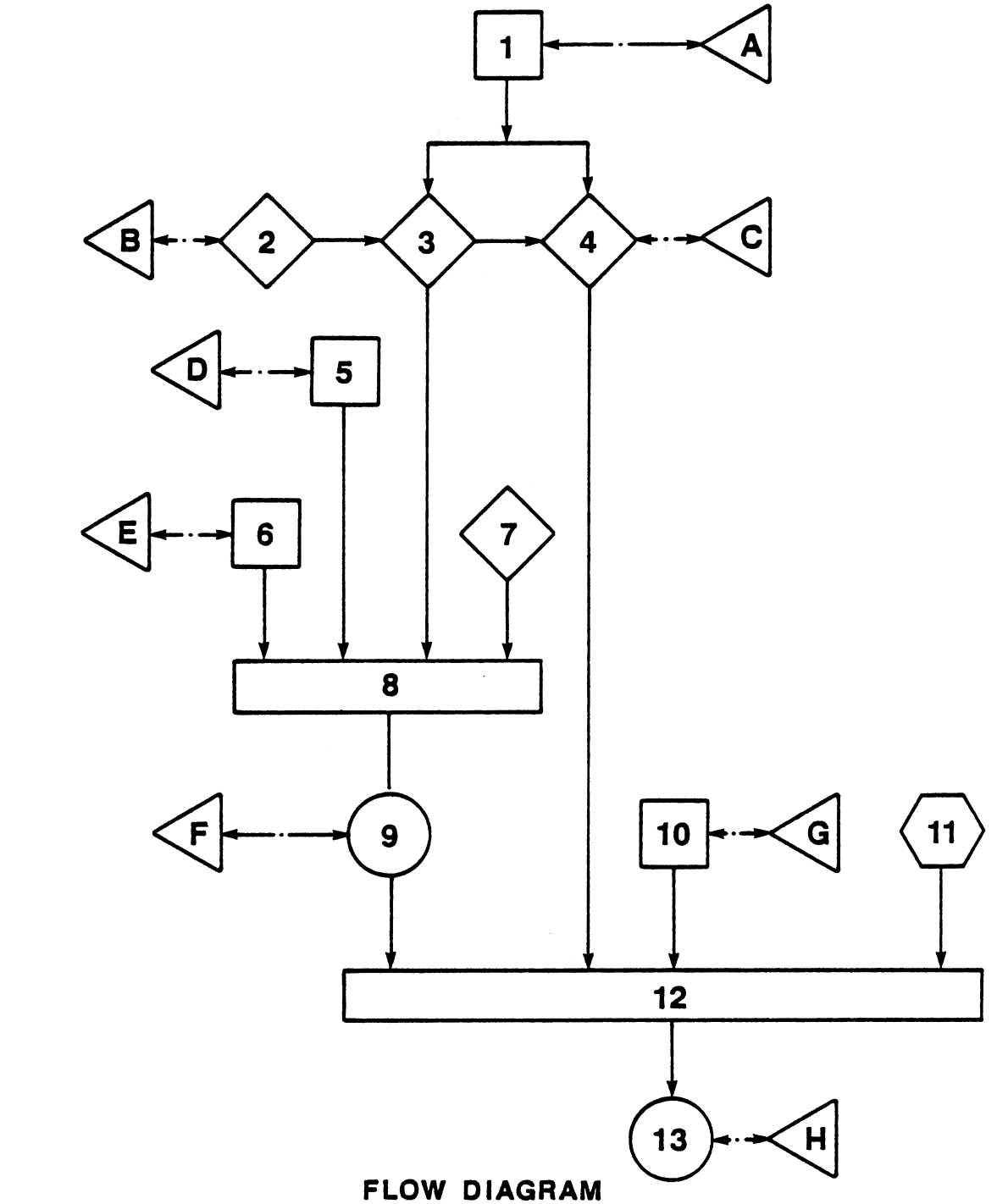
Information supplied by W. T. McKeel, Jr., Senior Research Scientist of the Virginia Transportation Research Council, on specific points of concern also proved helpful.

The interviews covered a wide range of issues, from the evaluation of cracks in concrete beams to the status of federal funding of bridges. Among the various experts, there were some areas of agreement and other areas of differences. Moreover, the decision-making processes differed from expert to expert. Sorting out and organizing the knowledge gleaned from these experts for application in a computerized expert system format was a major challenge. The human mind organizes knowledge and makes decisions in its own complex and mysterious ways. These processes are sometimes consciously rational and sometimes subconsciously inituitive; whereas, the computer requires its "knowledge" and decision-making processes to be much more formalized. Yet, for an expert system to be successful, it must yield conclusions identical to those of the expert, despite the occasional incompleteness and fuzziness of the information.

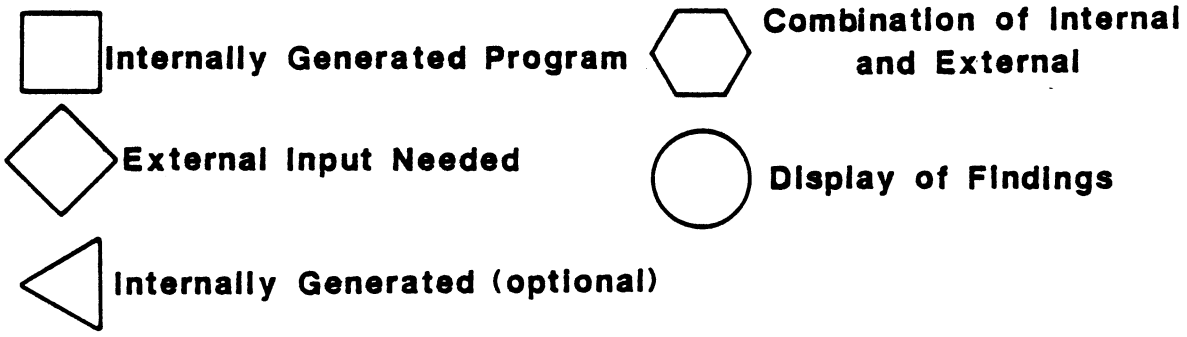
The basic flow diagram developed for the expert system under study is named DOB for "disposition of old bridges" (see Figure 1). In principle, operations flow sequentially from block 1 to block 13, with optional information and operations contained in blocks A through H.

1. Description of DOB expert system program
2. List of bridges
3. Data regarding a specific bridge
4. Data on funds
5. Rules
6. Inference procedure
7. Data from other bridges on list
8. Initial screening process
9. Trial recommendation
10. Final screening procedure
11. Trial recommendation concerning other bridges
12. Final evaluation process
13. Final recommendation

A. Query regarding 1
B. Query regarding 2
C. Query regarding 3 & 4
D. Query and changes regarding 5
E. Query and changes regarding 6
F. Query regarding 9
G. Query and changes regarding 10
H. Query regarding 13



FLOW DIAGRAM



SYMBOLS

Figure 1. DOB Expert Systems

Development

Prior to line-by-line programming for a computer, it is necessary to know in some detail what operations are involved in blocks as 1, 2, 3, A, B, and C. In this section, each of the blocks will be explained.

Block 1

This block generally describes the Expert System Program:

1. Disposition of Old Bridges, DOB

2. An Expert System recommending whether to rehabilitate, improve, replace, abandon, or only maintain an old bridge in the Virginia Department of Transportation highway system.

3. To rehabilitate is to restore the bridge to its original condition.

4. To improve is to strengthen or widen the bridge over and above its original condition.

5. To replace is to replace with a totally new bridge.

6. To abandon is to take the bridge out of service in the VDOT highway system.

7. To maintain is to keep the bridge operational in its present condition.

All data concerning the bridge must be supplied by the user. Decision-making rules are preprogrammed and are those currently used by bridge engineering experts in the VDOT.

1. DOB was developed in 1987 by the Virginia Transportation Research Council in Charlottesville, Virginia.

2. For further information, query block A.

3. To proceed with program, go to block 2.

Block A

In this block, answers (using a menu format) to various user inquiries relating to Table 1 will be found. Some sample questions with answers provided by the program are as follows:

1. (Q) What is an Expert System?

(A) An interactive computerized program that generates recommendations for the solution of complex problems; it simulates the decision-making process of human experts.

2. (Q) What kind of data is needed?

   (A) Data in the form of such needed information as sufficiency rating, condition rating, deficiency points, bridge type span length and the like will be supplied by the user in response to questions. Requested data is categorized as being of primary or secondary importance.

3. (Q) Who are the bridge engineering experts who formulated the rules?

   (A) F. G. Sutherland, State Structure & Bridge Engineer
   J. E. Andrews, Assistant Structure & Bridge Engineer
   F. L. Prewoznik, District Bridge Engineer
   L. L. Misenheimer, District Bridge Engineer
   W. T. McKeel, Jr., Senior Research Scientist

   All are associated with the VDOT.

4. (Q) How reliable are the recommendations generated?

   (A) Since even the best of experts may disagree in some cases, these recommendations may not be subscribed to by all experts. However, since they do represent the consensus of a number of experts, the user can employ them with the expectation that they will be generally reliable. In some instances, where insufficient data is provided by the user, the recommendations are qualified.

Block 2

In this block, the list of bridges (each with its deficiency point rating) competing for funds in the construction district in which the bridge in question is located is tabulated. The 10% of all the bridges in the district with the highest deficiency point ratings should be listed.

Since this 10%, or short list, is used just for screening, only the bridge route number, inventory description, and deficiency point rating need be noted.

For further information, query block B.

If the bridge in question is not on this short list, it must be assumed that for the given year, the bridge will not be rehabilitated, improved, replaced or abandoned, but only routinely maintained. In this case, the program is terminated.

If the bridge in question is on this short list, proceed to block 3.

Block B

In this block, answers to various user inquiries relating to Block 2 will be found, using a menu format. Some sample queries with their answers are as follows:

1. (Q) Why use only the top 10% of all bridges?

   (A) From past experience, there are only enough annual funds to rehabilitate, improve, or replace approximately 5% of all bridges in a district. A figure of 10% is used to be more inclusive.

2. (Q) Why use the deficiency point rating?

   (A) The deficiency point rating system was specifically developed to prioritize bridges needing work. It takes into account such things as load capacity, geometry, and traffic. For details, refer to the report entitled "Establishing the Priority of Funding for Deficient Bridges" by W. T. McKeel, Jr., Transportation Research Council, February 1985.

3. (Q) Where can this list of bridges and deficiency point ratings be obtained?

   (A) It is available as a computer printout entitled "Bridge Replacement and Rehabilitation Selection List" from the Structure and Bridge Division of the VDOT in Richmond, Virginia.

4. (Q) What happens to bridges not on this short list?

   (A) They will be subject only to routine maintenance for the given year.

Block 3

In this block, questions pertinent to the specific bridge in question are asked, and data is received and stored. A question-and-answer format is used; the questions are asked by the computer and answered by the user. Each question has been assigned an importance rating (IR) of "primary" (P) or "secondary" (S).

Much of the data that does not change from year to year can be precompiled and fed into the program in batch form from the central computerized bridge inventory system.

The following are questions to be asked.

1. Construction district in which the bridge is located?

   IR/P

2. County?

   IR/P

3. Route Number on which it is located?

   IR/P

4. Location description on route? (Use inventory description as in block 2.)

   IR/P

5. Functional classification?

   Interstate (IN)
   Primary (PR)
   Secondary (SE)

6. General condition rating of bridge?

   IR/P

7. Deck condition rating?

   IR/P

8. Substructure condition rating?

   IR/P

9. Superstructure condition rating?

   IR/P

10. Deficiency points?

    IR/P

11. Sufficiency rating?

    IR/P

12. Clear roadway width in feet?

IR/P

13. If the bridge is classified as Interstate or Primary, is its capacity less than for an H22 loading? (YS) (NO)
See question #5.

IR/P

14. If the bridges is classified as Secondary, is its capacity less than for H15 loading? (YS) (NO)

IR/P

15. Basic bridge type?

Deck Girder (DG),
Through Girder (TG)
Deck Truss (DT)
Through Truss (TT)

IR/P

16. Basic material of superstructure? List all materials if more than one.

Timber (T)
Metal (M)
Concrete (C)

IR/P

17. Span length or lengths in feet? List in sequence if multi-span.

IR/P

18. Number of traffic lanes?

IR/P

19. Average Daily Traffic (ADT) on bridge?

IR/P

20. Cost in dollars to rehabilitate the bridge?

IR/P

21. Cost in dollars to replace the bridge?

IR/P

22. If the bridges is classified as Interstate and its roadway width in feet is less than the goal width of 12 times the number of lanes plus 4, what is the cost in dollars to widen the bridge to its goal width? See questions #5 and #18.

IR/P

23. If the bridge is classified as Primary and its roadway width in feet is less than the desirable widith of 12 times the number of lanes, what is the cost in dollars to widen the bridge to the desirable width? See questions #5 and #18.

IR/P

24. If the bridge is classified as Secondary and its roadway width is less than 24 feet, what is the cost in dollars to widen the bridge to 24 feet? See question #5.

IR/P

25. If a metal girder bridge is classified as Interstate or Primary and has a load capacity of less than H22, what is the cost in dollars to strengthen the bridge to H22 standards? See questions #5, #13, #15, and #16.

IR/P

26. If a metal girder bridge is classified as Secondary and has a load capacity of less than H15, what is the cost in dollars to strength the bridge to H15 standards? See questions #5, #14, #15, and #16.

IR/P

27. Is the bridge scheduled for replacement within the next six years?

(YS) (NO)

IR/P

28. Is the bridge deemed of historic importance by the Environmental Quality Division of VDOT?

(YS) (NO) (UN)

IR/S

29. Has the bridge had a major repair more than once within the last six years?

(YS) (NO) (UN)

IR/S

30. Has the average daily traffic (ADT) on the bridge increased by at least 20% in the last year?

(YS) (NO) (UN)

IR/S

31. Is the bridge located in an urban or rural area?

(UR) (RU)

IR/S

32. If the bridge is in an urban area, is there another bridge on this same route on the short list of bridges located within a distance of 10 miles?

(YS) (NO) (UN)

IR/S

33. If the bridge is in an rural area, is there another bridge on this same route on the short list of bridges located within a distance of 20 miles?

(YS) (NO) (UN)

IR/S

34. Would the detour length be less than two miles if the bridge were abandoned?

(YS) (NO) (UN)

IR/S

35. Would there be any objection from local political authorities if the bridge were abandoned?

(YS) (NO) (UN)

IR/S

Block 4

In this block, information regarding available funds for bridge rehabilitation, improvement, or replacement is requested, received, and stored. A question and answer format is used; the questions are asked by the computer and answered by the user. Each question has been assigned an importance rating (IR) of "primary" (P) or "secondary" (S).

The questions are as follows:

1. Total federal and state funds in dollars for the given year for the construction district in which the bridge is located for replacement of bridges classified as Interstate?

2. Total federal and state funds in dollars for the given year for the construction district in which the bridge is located for rehabilitation and/or improvement of bridges classified as Interstate?

3. Total federal and state funds in dollars for the given year for the construction district in which the bridge is located for replacement of bridges classified as Primary?

4. Total federal and state funds in dollars for the given year for the construction district in which the bridge is located for rehabilitation and/or improvement of bridges classified as Primary?

5. Total federal and state funds in dollars for the given year for the county in which the bridge is located for replacement of bridges classified as Secondary?

6. Total federal and state funds in dollars for the given year for the county in which the bridge is located for the rehabilitation and/or improvement of bridges classified as Secondary?

Block C

In this block, answers to various user inquiries relating to Blocks 3 and 4 will be found, using a menu format. Some sample queries with their answers are as follows:

1. (Q) What are the construction districts?

   (A) Virginia is divided into districts centered around the areas of Bristol, Culpeper, Fredericksburg, Lynchburg, Northern Virginia, Richmond, Salem, Staunton, and Suffolk. Each area has its own district engineer. A map of the districts is available from the Construction Division of the VDOT in Richmond.

2. (Q) What are condition ratings?

   (A) These are evaluations of the structural conditions of a bridge as judged by trained bridge inspectors and filed on the "Bridge Inspection Report." Values range from 9 (for new condition) to 0 (for critical condition). Separate ratings are assigned for general condition (bridge as a whole), the deck, the substructure, and the superstructure.

3. (Q) Where can the condition ratings be found?

   (A) From the "Structures Inventory Listing" available in the Structure and Bridge Division of the VDOT in Richmond.

4. (Q) What are deficiency points?

   (A) They represent a rating of bridges based on load capacity, deck width, vertical clearance, sufficiency rating of a bridge. The higher the number, the worse the bridge. For reference, see "Establishing the Priority of Funding for Deficient Bridges" by W. T. McKeel, Jr., VTRC, February 1985.

5. (Q) Where can deficiency points be found?

   (A) From the "Structures Inventory Listing" available in the Structure and Bridge Division of the VDOT in Richmond.

6. (Q) What is the sufficiency rating?

   (A) It is a numerical rating of a bridge using a system developed by the Federal Highway Administration to evaluate the overall condition of a bridge. Values range from 100 (for extremely good) to a 0 (for extremely bad). For reference, see "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges," FHWA, January 1979.

7. (Q) Where can sufficiency ratings be found?

   (A) From the "Structures Inventory Listing" in the Structure and Bridge Division of the VDOT in Richmond.

8. (Q) How can the loading capacity of a bridge be found?

   (A) From the "Structures Inventory Listing" in the Structure and Bridge Division of the VDOT in Richmond. Standards are set by the Association of American State Highway & Transportation Officials (AASHTO) Manual for Maintenance Inspection of Bridges.

9. (Q) Where can the average daily traffic on a bridge be found?

   (A) From the "Structures Inventory Listing" in the Structure and Bridge Division of the VDOT in Richmond.

10. (Q) Where can the cost to rehabilitate a bridge be found?

    (A) Unit costs can be obtained from the Construction Division of the VDOT in Richmond.

11. (Q) Where can the cost to replace a bridge be found?

    (A) Estimates found in the "Structures Inventory Listing" in the Structure and Bridge Division of the VDOT in Richmond.

12. (Q) Where can the cost to widen a bridge be found?

    (A) Unit costs can be obtained from the Construction Division of the VDOT in Richmond.

13. (Q) Where can the cost to strengthen a metal girder bridge be found?

    (A) Unit costs can be obtained from the Construction Division of the VDOT in Richmond.

14. (Q) Where can the scheduled replacement date for a bridge be found?

    (A) From the "Six Year Improvement Program" in the Programming and Scheduling Division of the VDOT in Richmond.

15. (Q) Where can available funds for bridge rehabilitation, improvement, or replacement be found?

    (A) From the "Six Year Improvement Program" in the Programming and Scheduling Division of the VDOT in Richmond.

Block 5

In this block, rules are set forth relating to information in Blocks 3 and 4. Each rule has been assigned an importance rating (IR) of "primary" (P) or "secondary" (S). Each rule also has been given a variation number (VN). If no variation is necessary, it is shown as "none" (N). Although the rules (IR) and (VN) are set in the program, they can be displayed if requested.

The rules are as follows:

R.1 If a bridge has a sufficiency rating greater than 80, then it is to be subject only to routine maintenance until the rating at some future time falls to 80 or below.

IR/P VN/N

R.2 If a bridge has a sufficiency rating of 50 through 80, then it should be rehabilitated or improved.

IR/P VN/N

R.3 If a bridge has a sufficiency rating of less than 50, then it should be replaced, rehabilitated, improved, or abandoned.

IR/P VN/N

R.4 If any one component of a bridge (name the substructure, superstructure or deck) has a condition rating of 6 or greater, then only routine maintenance is required on that component.

IR/P VN/N

R.5 If any one component of a bridge (namely the substructure, superstructure, or deck) has a condition rating of 5 or less, then the deficient portion or portions should be rehabilitated (unless the bridge is to be replaced or abandoned).

IR/P VN/N

R.6 If two or more components of a bridge (namely the substructure, superstructure or deck) have condition ratings of 4 or less, then the bridge should be replaced or abandoned.

IR/P VN/N

R.7 If all the following conditions concerning a bridge are met, it should be abandoned. (a) It has a sufficiency rating less than 50. (b) It has a general condition rating of 4 or less. (c) The average daily traffic (ADT) on the bridge is fewer than 10 vehicles. (d) A detour route of less than two miles is available. (e) It is not of significant historical importance (as judged by the VDOT Environmental Quality Division). (f) Local political authorities have no objection to taking the bridge out of the VDOT highway system.

IR/P VN/N sufficiency rating
N condition rating point
+5 ADT
+1 detour mile

R.8 If a bridge is classified as Interstate, has a roadway width in feet less than 12 times the number of lanes plus 4, does not have any above structure (as deck girder or deck truss bridge) on each side of roadway, has a general condition rating 5 or greater, and has average daily traffic (ADT) greater than 100 vehicles, then it should be improved by widening.

IR/P VN/N

R.9 If a bridge is classified as Primary, has a roadway width in feet less than 12 times the number of lanes, does not have any above structure (as deck girder or deck truss bridge) on each side of roadway, has a general condition rating 5 or greater, and has average daily traffic (ADT) greater than 100 vehicles, then it should be improved by widening.

IR/P VN/N

R.10 If a bridge is classified as Secondary, has a roadway width less than 24 feet, does not have any above structure (as deck girder or deck truss bridge) on each side of roadway, has a general condition rating 5 or greater, and has average daily traffic (ADT) greater than 100 vehicles, then it should be improved by widening.

IR/P VN/N

R.11 If a bridge is classified as Interstate, has a roadway width in feet less than 12 times the number of lanes plus 4, has an above deck structure on each side of roadway (as in a through girder or through truss bridge), has average daily traffic (ADT) greater than 100, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.12 If a bridge is classified as Primary, has a roadway width in feet less than 12 times the number of lanes, has an above deck structure on each side of roadway (as in a through girder truss or through truss bridge), has average daily traffic (ADT) greater than 100, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.13 If a bridge is classified as Secondary, has a roadway width less than 24 feet, has an above deck structure on each side of roadway (as in a through girder (TG) or through truss (TT) bridge), has average daily traffic (ADT) greater than 100, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.14 If a bridge is classified as Interstate, has a roadway width in feet less than 12 times the number of lanes plus 4, has a condition rating of 5 or less for any one or more of its components (namely the substructure, superstructure, and deck), and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.15 If a bridge is classified as Primary, has a roadway width in feet less than 12 times the number of lanes, has a condition rating of 5 or less for any one or more of its components (namely the substructure, superstructure, and deck), and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.16 If a bridge is classified as Secondary, has a roadway width in 24 feet less than, has a condition rating of 5 or less for any one or more of its components (namely the substructure, superstructure, and deck), and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/P VN/N

R.17 If a reinforced concrete bridge classified as Interstate or Primary has a load capacity less than for H22 loading, has average daily traffic (ADT) greater than 100 vehicles, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/S VN/N

R.18 If a reinforced concrete bridge is classified Secondary and has a load capacity less than for H15 loading, has average daily traffic (ADT) greater than 100 vehicles, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then it should be replaced.

IR/S VN/N

R.19 If a metal girder bridge classified as Interstate or Primary has a load capacity less than for H22 loading, has a general condition rating of 5 or greater, and has average daily traffic (ADT) greater than 100 vehicles, then it should be improved by strengthening.

IR/S VN/N

R.20 If a metal girder bridge classified as Secondary has a load capacity less than for H15 loading, has a general condition rating of 5 or greater, and has average daily traffic (ADT) greater than 100 vehicles, then it should be improved by strengthening.

IR/S VN/N

R.21 If in a cast-in-place reinforced concrete bridge, the deck component condition rating is 4 or less, then the entire bridge should be replaced.

IR/S VN/N

R.22 If a bridge is scheduled to be replaced within 6 years, then only routine maintenance is necessary until it is replaced.

IR/P VN/N

R.23 If a detour of less than 2 miles cannot be made during the rehabilitation or improvement of a bridge that has an average daily traffic (ADT) of 100 or more vehicles, then the bridge should be replaced on a new alignment.

IR/S VN/N ADT
+1 detour mile

R.24 If a bridge has had a major repair more than once in the last 6 preceding years, then the bridge should be replaced.

IR/S VN/N

R.25 If the rehabilitation and/or improvement costs exceed 65% of the cost of a replacement bridge (exclusive of realignment costs), then the bridge should be replaced.

IR/P VN/-5% on cost percentage

R.26 If the average daily traffic (ADT) on a bridge that is scheduled for replacement in 5 or 6 years increased by 20% or more in the preceding year, then it should be rescheduled for replacement in 4 years or less.

IR/S VN/N

R.27 If a through metal truss bridge classified as Interstate or Primary has a load capacity less than for H22 loading, has average daily traffic (ADT) greater than 100 vehicles, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then the bridge should be replaced.

IR/S VN/N

R.28 If a through metal truss bridge classified as Secondary has a load capacity less than for H15 loading, has average daily traffic (ADT) greater than 100 vehicles, and is not considered of historic importance (as judged by the VDOT Environmental Quality Division), then the bridge should be replaced.

IR/S VN/N

R.29 If among bridges with high deficiency points (such as those on the short list) two or more short-span bridges (under 100 feet in span lengths) appear along with long-span bridges (over 500 feet in span length) and all have general condition ratings of 5 or more and average daily traffic (ADT) of less than 500 vehicles, then work priority is given to the short bridges.

IR/S VN/+20% on short-span lengths
-20% on long-span lengths

R.30 If among bridges in an urban area with high deficiency points (those on the short list), two or more bridges appear along the same route in a distance of 10 miles, then these bridges together have a work priority over bridges further apart.

IR/S VN/+20% on miles

R.31 If among bridges in a rural area with high deficiency points (those on the short list), two or more bridges appear along the same route in a distance of 20 miles, then these bridges together have a work priority over bridges further apart.

IR/S VN/+20% on miles

R.32 If among bridges with high deficiency points (those on the short list) some have over twice the average daily traffic (ADT) of others, then those with the higher traffic volume have work priority.

IR/S VN/-20% on ADT

Block D

In this block answers to various user inquiries related to the rules in Block 5 will be found, using a question-and-answer menu format. This block will also allow for changes or additions to the rules in Block 5.

1. (Q) What are the rules used?

   (A) (Listing of the 32 rules in Block 5)

2. (Q) Explanation of Rule 1 (R1)?

   (A) At these high sufficiency rating levels, a bridge is in excellent condition.

3. (Q) Explanation of R2?

   (A) At these sufficiency rating levels, there are serious problems concerning the bridge that should be taken care of.

4. (Q) Explanation of R3?

   (A) At these sufficiency rating levels, problems are so serious that the bridge should be replaced with a new structure, unless it is a historic bridge or the cost to fully upgrade it is much less than the cost of a replacement bridge.

5. (Q) Explanation of R4?

   (A) At these condition rating levels, there are no serious problems.

6. (Q) Explanation of R5?

   (A) At these condition rating levels, there are serious problems that should be taken care of.

7. (Q) Explanation of R6?

   (A) Such a bridge has so many serious problems that it probably would not be economically feasible to rehabilitate it.

8. (Q) Explanation of R7?

   (A) Such a bridge is economically unfeasible to rehabilitate, improve, or replace, and its maintenance would drain funds from other more worthy structures.

9. (Q) Explanation of R8, 9, 10?

   (A) A narrow bridge impedes traffic and constitutes a safety hazard. Such a bridge carries enough traffic and is in good enough condition to warrant the expense of widening.

10. (Q) Explanation of R11, 12, 13?

   (A) Although such a narrow bridge impedes traffic and constitutes a safety hazard, it is impractical to widen it due to the obstruction of the above deck structure; therefore, it should be replaced with a new wider bridge.

11. (Q) Explanation of R14, 15, 16?

   (A) The combination of the bridge's narrowness and poor condition makes it economically unfeasible to both widen and rehabilitate the bridge. Replacement is thus warranted, unless conditions for abandonment exist.

12. (Q) Explanation of R17, 18?

   (A) A reinforced concrete bridge is difficult to strengthen. Although weight limit posting is an option, it is considered only a temporary measure for a bridge carrying moderate to heavy traffic. Replacement is the preferred solution.

13. (Q) Explanation of R19, 20?

   (A) It is relatively easy to strengthen a metal girder bridge that is in generally good condition. Although weight limit posting is an option, it is considered only a temporary measure. Strengthening is the preferred solution.

14. (Q) Explanation of R21?

   (A) It is difficult to replace only the deck in such a bridge because the deck is monolithic with the superstructure; thus, full replacement is preferred.

15. (Q) Explanation of R22?

   (A) Routine maintenance will usually keep the bridge in usable condition for several years until it is replaced.

16. (Q) Explanation of R23?

   (A) The inconvenience of a long detour to the public is unwarranted, particularly on a bridge with considerable traffic. A detour is eliminated when a replacement bridge is constructed near the old bridge, keeping the old bridge in use until the new bridge is completed.

17. (Q) Explanation of R24?

    (A) The bridge is likely to need more than average repair work on it in the future and it would be economically prudent to replace the structure.

18. (Q) Explanation of R25?

    (A) Although rehabilitation will extend the life of a bridge for 15 to 20 years, a new bridge at a relatively small extra cost will generally last over 30 years before it requires repairs, thus making replacement more cost effective.

19. (Q) Explanation of R26?

    (A) A rapid rise in traffic indicates that the bridge is becoming of greater importance and that action needs to be taken sooner than previously planned.

20. (Q) Explanation of R27, 28?

    (A) A metal truss bridge is difficult to strengthen and weight limit posting is considered only a temporary measure. In addition, such bridges are generally old and narrow and not suitable for current traffic conditions.

21. (Q) Explanation of R29?

    (A) To make the maximum use of available funds, several short bridges could be rehabilitated, improved, or replaced for the cost of one long bridge.

22. (Q) Explanation of R30, 31?

    (A) It is less expensive to work on bridges close together than far apart.

23. (Q) Explanation of R32?

    (A) Bridges carrying more vehicles are more critical to traffic than those carrying fewer vehicles.

Block 6

This block embodies the inference procedure that outlines how the rules in Block 5 operate on the data in Blocks 4 and 5 to infer a trial recommendation. The procedure is basically a forward-chaining process, which is a sequential application of each of the rules to the data. The procedure results in a filtering down or screening of the possible recommendation to the one best fitting the situation. Account is taken of the relative importance of the various rules and data as well as possible fuzzy areas, such as unknown or uncertain data.

Procedure 1:

Apply Rule 1 to each datum listed in Block 3 (datum 1 through 35 in this case) in sequence and indicate the findings (e.g., to rehabilitate, replace, or improve). If the rule is not applicable to a particular datum, indicate by "NA". Indicate the relative importance of the rule and each datum by assigning "P" (primary) or "S" (secondary) to each of them.

Procedure 2:

Continue applying all the other rules (rules 2 through 32 in this case) in sequence to the data (datum 1 through 34) as in Procedure 1.

Procedure 3:

List the summarized findings in three categories by relative importance of the rules and data. The three categories would be "P.P", "P.S/S.P," and "S.S."

Procedure 4:

Using an appropriate weighting factor for each category, tally the weighted findings derived from Procedure 3 for each option, namely, rehabilitation, improvement, replacement, abandonment or maintenance. Note any special comments, conditions, or qualifications. The result of the tally becomes the trial recommendation.

Block E

This block is devoted to answering some anticipated questions relating to the inference procedure in Block 6, along with provision for making possible future changes in the inference procedure. The question portion of the block will be in a question-and-answer format:

1. (Q) What basic procedure is used to arrive at a recommendation?

   (A) Forward chaining in which each of the rules are applied sequentially to each datum. Additional screening is done based on the relative importance of the particular rules and data. The result is a numerical ranking of findings, leading to a trial recommendation.

2. (Q) How is the relative importance of each rule or datum handled?

   (A) By first ranking it as "primary" or "secondary". When a primary rule is applied to a primary data, the finding is assigned a weighting factor of 3. When a primary rule is applied to a secondary data or when a secondary rule is applied to a primary data, the weighting factor is 2. When a secondary rule is applied to a secondary data, the weighting factor is 1.

3. (Q) How is missing data handled?

(A) Missing primary data is serious and will negate the usefulness of this program. Missing secondary data is less serious, and will still allow recommendations to be reached, although qualified in nature.

(4) (Q) How are the recommendations affected by available State and Federal funding?

(A) The recommendations at this stage are trial ones; they are tested in a later procedure with regard to cost and available funds.

Block 7

This block contains the data from Block 3 of all the other bridges on the short list as cited in Block 2.

Block 8

In this block, the data from Block 3, the rules from Block 5, and the inference procedure from Block 6 interact to arrive at a single trial recommendation. A fictional example, described as follows, is given to explain this interactive process.

Assumed data for Block 3:

1.	Staunton	18.	18.2
2.	Augusta	19.	920
3.	1001	20.	100,000
4.	Jumbo River	21.	290,000
5.	PR	22.	NA
6.	5	23.	40,000
7.	5	24.	NA
8.	6	25.	60,000
9.	5	26.	NA
10.	8.1	27.	NO
11.	49	28.	UN
12.	23	29.	NO
13.	YS	30.	NO
14.	NA	31.	RU
15.	DG	32.	NA
16.	M	33.	YS
17.	50, 85, 62	34.	NO
		35.	UN

Assumed data for Block 4:

1.	NA	4.	2,679,000
2.	NA	5.	NA
3.	3,550,000	6.	NA

The next step involves the application of Rule 1 to each datum in Block 3 in sequence. The following are examples.

Application of Rule 1, IR (P), to each Datum

Datum	1	2	3	-	-	-	-	-	-	-	34	35
IR	P	P	P	-	-	-	-	-	-	-	S	S
Finding	NA	NA	NA	-	-	-	-	-	-	-	NA	NA

Application of Rule 3, IR (P), to each Datum

Datum	1	2	3	-	-	-	11	-	-	-	34	35
IR	P	P	P	-	-	-	P	-	-	-	S	S
Finding	NA	NA	NA	-	-	Rehabilitate, Improve, Replace or Abandon			-	-	NA	NA

This process is continued until all 32 rules have been applied in sequence. After all the rules have been applied, the findings can be summarized as follows. The findings shown in parenthesis are considered marginal or secondary in nature.

Summary of Rules to Data

Rule	Applicable Data	Findings
1(P)		
2(P)		
3(P)	11(P)	Rehabilitate, improve, replace or abandon
4(P)	8(P)	Only maintenance required on substructure
5(P)	7(P),8(P),9(P)	Rehabilitate deck and superstructure (or replace or abandon bridge)
6(P)		
7(P)		
8(P)		
9(P)	5(P),6(P),12(P) 15(P),18(P),19(P)	Improve by widening
10(P)		
11(P)		
12(P)		

13(P)		
14(P)		
15(P)	5(P),7(P),9(P), 28(S)	Replace (Historic importance unknown)
16(P)		
17(S)		
18(S)		
19(S)	5(P),6(P),13(P), 15(P),16(P),19(P)	Improve by strengthening
20(S)		
21(S)		
22(P)		
23(S)	19(P), 34(S)	Replace a new alignment
24(S)		
25(P)	20(P),21(P),23(P) 25(P)	Replace
26(S)		
27(S)		
28(S)		
29(S)		
30(S)		
31(S)	33(S)	Work priority
32(S)		

The findings of this summary are further reduced by grouping them into three categories: namely "P.P," "P.S/S.P," and "S.S." Assign a weighting factor (WF) 3 on the "P.P." category, 2 on "P.S/S.P," and 1 on "S.S."

"P.P." Category (WF=3)

Replace
Replace (Historic importance unknown)
Rehabilitate, improve, replace, or abandon
Rehabilitate deck and superstructure
Improve by widening
Only maintenance required on substructure

"P.S/S.P." Categroy (WF=2) (This category is used whenever a rule, datum, or finding is designated as secondary along with a rule, datum, or finding designated as primary.)

Replace on new alignment
Improve by strengtheing
Abandon

"S.S." Category (WF=1)

Work priority

Tally the findings regarding the options of rehabilitation, improvement, replacement, abandonment, and maintenance using the weighting factors. The results of this step are as follows:

		Total Points
Rehabilitate	3	3
Rehabilitate deck	3	3
Rehabilitate superstructure	3	3
Improve	3	3
Improve by widening	3	3
Improve by strengthening	2	2
Replace	3+3+2	8
Replace or new alignment	2	2
Abandon	3+2	5
Maintain, substructure	3	3

Special comments:

Work priority Historic importance unknown	1	1

In tallying the total points, the five options should be reviewed as follows:

A scan of the total points shows "replace" leading with 8 points. If "replace or new alignment" is added, the total is 10 points.

"Rehabilitate" carries only 3 points. However, in interpreting the rules involving rehabilitation, rehabilitation may be considered the rehabilitation of the whole bridge or the rehabilitation of a major component such as the deck, substructure, or superstructure. Thus, for comparative purposes, all of these conditions may be lumped together, making a total of 9 points for "rehabilitate," with the recommendation that only the deck and superstructure be rehabilitated.

Similarly, the total for "improve" is 8 points, with the recommendation that both widening and strengthening be done.

The "abandon" option carries 5 points; but unless Rule 7 is fully met, and it is does not in this case, then abandonment is not a viable option. Use zero as a rating in this case.

"Maintain" carries only 3 points, and that pertains to only the substructure (the implication being that the deck and superstructure are beyond routine maintenance and need work).

The conclusion of this tally then is that the replacement option with preference on a new alingment becomes the trial recommendation at

this stage of the evaluation procedure because it carries the most points. It may also be noted that if the bridge is replaced, the recommendations for rehabilitation, improvement, and maintenance will also be met. However, the recommendation is not final until an overall cost analysis is undertaken at a later stage. Special comments should also be attached for the consideration of the user; namely, that a work priority of 1 point is noted and that there is no knowledge of its historic importance. If in the judgment of the user, any insufficiencies with regard to data (which in this example are of secondary importance) have an especially high significance, then the missing data must be obtained before proceeding. If primary data are missing, the user is strongly advised to obtain that data before proceeding since the resulting recommendation would be unreliable in the absence of this data.

Several other special rules may be necessary.

1. If the abandon option has the highest point score and Rule 7 applies, then the bridge should be abandoned.

2. If the abandon option has the highest point score and Rule 7 does not apply, then the option with the next highest point score should be selected.

3. If the rehabilitation or improvement option has the highest point core and its cost equals or exceeds the replacement cost, then the bridge should be replaced.

4. If two options equally have the highest point ratings, then the option costing the lesser amount of money should be selected.

Block 9

This block represents the display of the trial recommendation, along with appropriate comments or qualifications. In some cases a trial recommendation may be associated with missing data, thereby requiring the user to either accept the conditions as they are shown and proceed, or go back and obtain the missing data for a less qualified trial recommendation.

In the example cited in Block 8, the trial recommendation would be to replace the bridge, preferably on a new alignment. It should further be noted that the recommendation carries a work priority of 1 point. Also noted would be the fact that the historic importance of the bridge has not been considered because of missing data.

Block F

In this block, possible questions concerning the trial recommendation shown in Block 9 will be answered using a menu format:

1. (Q) What are the relative ratings of the five options at this stage, namely, rehabilitation, replacement, improvement, abandonment, and maintenance?

   *(A) Based on points, they are as follows:

Rehabilitate	9
Replace	10
Improve	8
Abandon	0
Maintain	3

2. (Q) How is the recommendation made if the rating of two options is equal at this stage?

   (A) The less expensive option is selected.

3. (Q) What is meant by "work priority"?

   (A) This factor is to be used as a "tie breaker" in the event that a choice has to be made between work on two bridges when funds are available for only one.

4. (Q) How important is missing data?

   (A) If primary data is missing, the recommendation at this stage is unreliable, and the missing data should be obtained before proceeding. If secondary data is missing, the recommendation is probably satisfactory, although the user should excerise judgment concerning the omission. When in doubt, obtain the missing data and rerun the procedure.

* NOTE: The points shown are only for the examples in this report. In general, they would be taken for the actual bridge as given in Block 8.

Block 10

In this block, the procedure for final screening is given; it essentially contains recommended "action" costs and available funds. As described in Block 4, there are six categories of funding for bridges to be replaced, rehabilitated, or improved. Thus all the bridges on the short list should be grouped into one of these categories, using the recommendation derived from Block 8.

Procedure 1:

Note the cost of the recommendation for the bridge in question from Blocks 3 and 8. Also list the work priority points, if any.

Procedure 2:

Note the costs of the recommendations for all the other bridges on the short list in its category from Block 11, along with any work priority points.

Procedure 3:

List all of the deficiency point ratings of all the bridges in the short list in its category from high to low. At the same time, list their recommended action costs and work priority points from Procedures 1 and 2. For bridges with equal deficiency point ratings, rank these in order of individual action cost (low to high).

Procedure 4:

Beside each bridge listing, ranked as in Procedure 3, note the deficiency points, the action cost, and work priority points for each bridge plus the total accumulated action cost including all the other bridges further up on the ranking list.

Procedure 5:

Take the total available Federal and State funds in its category from Block 4 and match it with the nearest accumulated action cost on the list. Note the three borderline bridges on either side of the cut-off figure.

Procedure 6:

Using the work priority points of these six borderline bridges as "tie breakers" or" kickers," the user is given the option here of replacing any or all of the three bridges above the available fund cut-off line with the three bridges below the line if the bridges below the line have higher work priority points, assuming the accumulated action costs of the replacing bridges fall above the total available fund cut-off line.

Procedure 7:

After optionally relisting the bridges as in Procedure 6, the final list of bridges for action that year are those above the available fund cut-off line.

Block G

This block is devoted to answering some possible questions regarding the procedure in Block 10. It can also be used to make changes in the procedure in Block 10. Some sample questions and answers in a menu format are as follows:

1. (Q) Can Federal and State money be used interchangeably?

   (A) No. There are many more restrictions on the use of Federal funds. In particular, Federal Bridge Habitation and Bridge Replacement funds are to be used on bridges with sufficiency ratings of 80 or less. Federal funds at 80% of cost must be matched with 20% State funds.

2. (Q) In an emergency, can additional funds be obtained?

   (A) Yes, at the discretion of the Governor, some extra funds are available, e.g., for disasters.

3. (Q) Are there special fund allocations to the interstate, primary, and secondary systems?

   (A) Yes

Block 11

This block contains the trial recommendations for all the bridges on the short list other than the one in question. To obtain these trial recommendations, the DOB Expert System has to be used in the same way as for the specific bridge in question, starting with Block 2 and proceeding to Block 9 for each bridge. In effect, no final recommendation can be made until all the bridges on the short list are examined. This is because available funds for bridge work are limited and bridge work must be prioritized based on relative need.

Block 12

In this block, the procedure stored in Block 10 is executed for all the bridges on the short list.

Block 13

In this block, several lists are displayed based on the procedures in Block 10. These are as follows:

1. List of all bridges on the short list in their respective categories, ranked by deficiency points. Also shown for each bridge are the deficiency points, action cost, accumulated action cost, and the work priority points. The bridge in question is flagged.

2. List of the Federal and State funds available in the six categories described in Block 4 for that year, along with their total.

3. List of the six bridges in the vicinity of the available fund cut-off line.

4. Rearranged list of the six bridges in #3 (optional).

5. Final list of the bridges recommended for action or work. Flag the bridge in question if it is above the cut-off line. Also, list exactly what the recommendation is for the bridge along with any comments or special conditions (from Block 9). Otherwise list it as not recommended for work in that year. Note that all bridges not in the final action list for that year are to be reevaluated for possible action in the next year. In the interval, they are to be routinely maintained.

Block H

This block contains some possible questions and answers related to the final recommendation in Block 13. A few sample questions and answers in menu format are as follows:

1. (Q) How final is the final recommendation?

   (A) Only in very unusual circumstances should the recommendation be overruled, and then only for good reasons.

2. (Q) Who has final authority on what bridges have work done on them?

   (A) Generally the District Bridge Engineer of the VDOT construction district in which the bridge is located.

3. (Q) What happens if several bridges end up costing more to rehabilitate or replace then originally estimated?

   (A) Work on some other bridges may have to be reduced in scope or deferred at the judgment of the District Bridge Engineer.

CONCLUSIONS

Although the proof of the operational usefulness of this DOB Expert System cannot be evaluated until the computerized system is up and running, the basic procedure described in this report appears to be both workable and programmable. In addition, since the rules used are those used by experts themselves, the recommendations reached should also be those of the experts. However, it is expected that some minor changes and refinements will be needed as this written procedure is converted to software. Finally, this report was reviewed by the original experts interviewed as well as by others, and their comments and corrections have been appropriately incorporated.

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