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REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-OM-2

REMR MANAGEMENT SYSTEM

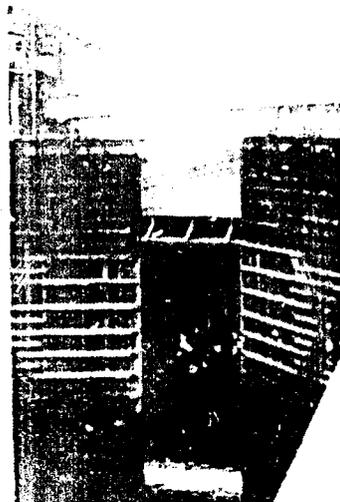
by

H. Thomas Yu and Anthony M. Kao

US Army Construction Engineering  
Research Laboratory

DEPARTMENT OF THE ARMY  
US Army Corps of Engineers  
P.O. Box 4005, Champaign, Illinois 61820-1305

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
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TOP Port Allen Lock and Dam, New Orleans, LA.

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→ The REMR Management System is designed as a planning tool and an information system for project-level management. It provides procedures for condition inspection and evaluation, data management, and economic analysis.

These procedures can be used to prioritize REMR activities based on condition, select maintenance and repair (M&R) alternatives based on performance, and compare the cost of various M&R alternatives based on life-cycle costs. The REMR Management System promotes faster, more objective, condition-oriented performance of REMR work.

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PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Operations Management problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32337, "Implementation of the REMR Management System," for which Dr. Anthony M. Kao is Principal Investigator. Mr. Jim Crews is the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. is the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. Jim Crews, and Dr. Tony C. Liu serve as the REMR Overview Committee; Mr. William F. McCleese, US Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Kao is also the Problem Area Leader for the Operations Management problem area.

This work was conducted by the US Army Construction Engineering Research Laboratory (USA-CERL) under the general supervision of Dr. R. Quattrone, Chief of Engineering and Materials (EM) Division. The Technical Editor was Gloria J. Wienke, Information Management Office.

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## REMR MANAGEMENT SYSTEM

### PART I: INTRODUCTION

#### Background

1. As a growing number of Corps Civil Works structures are reaching their design life, the task of maintaining the structures in a safe and efficient working condition is of particular concern. Approximately half of the Corps' inventory of more than 600 major structures will reach their 50-year design life within the next 20 years (Scanlon et al. 1983). Although many of these aging structures are capable of functioning well beyond their design life, they will require significant repair, evaluation, maintenance, and rehabilitation (REMR) measures for continued operation. The demand for REMR is expected to accelerate in the next decade as fewer new construction starts are authorized.

2. The effectiveness of a computer-aided maintenance management system in improving the overall efficiency of operation, including reduced maintenance cost, has been successfully demonstrated by PAVER (Shahin and Kohn 1981), a maintenance management system for pavements. PAVER introduced the use of the Pavement Condition Index, or PCI, to establish the need for maintenance and repair (M&R) measures. The PCI provides consistent, objective information about the existing condition of the pavements. With better information, better planning is possible, and the operational efficiency improves.

#### Objective

3. The objective of this research was to develop a REMR management system for Civil Works structures which includes procedures for data management, condition evaluation and rating, and economic analysis.

### Approach

4. The REMR Management System is designed with a major emphasis on District-level management. The District is a logical unit on which to base the management system because (a) the actual maintenance and repair work is either performed or managed by District personnel, (b) most of the information required for REMR management is relevant only to the District that maintains the particular structure, and (c) a District-based system is a necessary building block in constructing a higher level management system.

5. Most of the data stored in the system will originate from the District offices and the District personnel will require most frequent access to the system. Therefore, the strategy proposed for implementing the REMR Management System is to first successfully implement the District-based system and then implement the higher level management systems.

### Scope

6. This report provides an overview of the REMR Management System. The report includes a brief discussion of the management system concept, a description of the modules contained in the system, and the hardware requirements. The REMR Management System consists of three modules: Basic Functions Module, Condition Evaluation and Rating Module, and Consequence Modeling Module. The Basic Functions Module, which includes procedures for data management and life-cycle cost analysis, is described in detail. The descriptions of the Condition Evaluation Module and Consequence Modeling Module are limited to presentation of the concepts. The details of these modules will be reported separately.

## PART II: OVERVIEW

7. The REMR Management System is both a planning tool and an information system for managing REMR activities of Civil Works structures. It provides procedures for condition inspection and evaluation, data management, and economic analysis. These procedures can be used to prioritize REMR activities based on condition, select M&R alternatives based on performance, and compare various M&R alternatives based on life-cycle cost. The REMR Management System promotes faster, more objective, condition-oriented performance of REMR work.

### Terminology

8. The term "Civil Works structure" refers to a wide variety of different structures. A Civil Works structure is typically a large, complex structure, comprised of many disparate components. A component is any part of a structure which is easily identified as a unit by consistency in material composition or function. The components of a Civil Works structure are often themselves structures of considerable complexity.

9. In this report the term "component" refers to a structure such as a miter gate, lock wall, or guide wall, which is a constituent part of a large, complex Civil Works structure (such as a lock and dam). Also, the identifier "type" is used to denote a class (or category) of structures, for example:

- "Marseilles Lock and Dam" refers to a specific structure of the type "Lock and Dam."
- "Upper Service Gate" refers to a specific structure of the type "Service Gate," which may in turn be of the type "Miter Gate," "Tainter Gate," or "Sector Gate."

The type identification is necessary in the REMR Management System because the system determines which data and procedures are relevant to the structure based on the structure type.

### System Description

10. Conceptually, the REMR Management System is similar to PAVER. Both systems use the condition index (CI) to prioritize REMR activities, estimate future condition, and plan budgets. The CI is determined by the data collected during periodic inspections. The records of REMR activities are stored in the system. The system also provides data on repair alternatives and the procedure for comparing the life-cycle cost of various alternatives. One important difference between PAVER and the REMR Management System is that while PAVER is designed specifically for pavements, the REMR Management System is designed for Civil Works structures in general.

11. Figure 1 shows the schema of the REMR Management System. The Basic Functions Module contains the procedures for data management and Life-Cycle Cost Analysis (LCCA). The Condition Evaluation and Rating Module contains a collection of procedures for evaluating various types of structures. The Consequence Modeling Module contains procedures for optimizing REMR policy for various types of structures. The Basic Functions Module contains general procedures which apply to all structures; whereas, the other modules contain specialized procedures which apply only to specific structure types.

12. The Modules in the REMR Management System are organized to allow staged development. The process of developing a condition index evaluation or consequence modeling procedure is both expensive and time consuming. Therefore, it may not be feasible or practical to develop these procedures for all structure types. The REMR Management System is organized to allow these procedures to be developed separately and added to the system as they become available. The data management and LCCA functions are provided for all structure types by the Basic Functions Module.

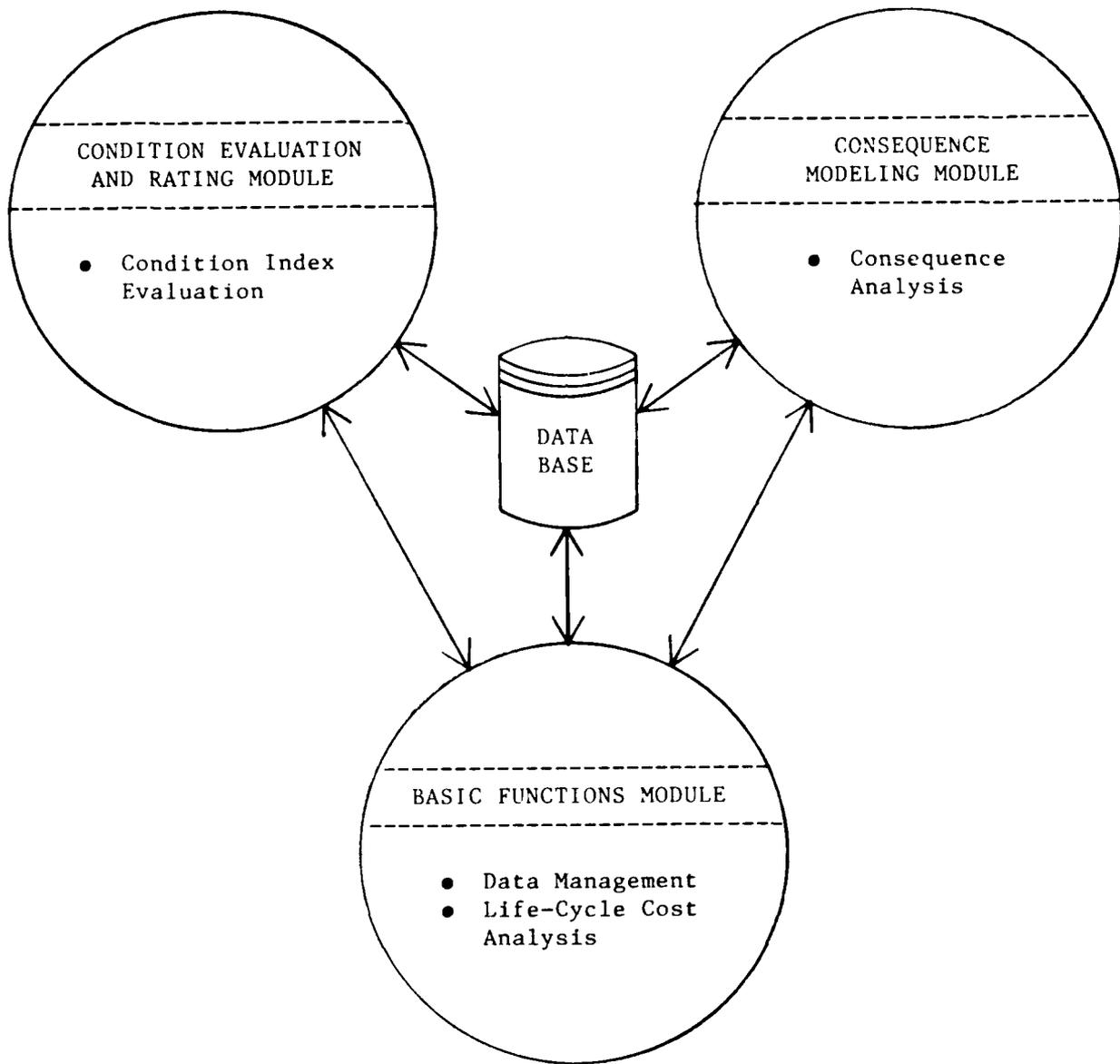


Figure 1. REMR Management System

### PART III: BASIC FUNCTIONS MODULE

13. The Basic Functions Module contains the procedures for data management and life-cycle cost analysis and serves as the control module for access to other modules. Details of data management and life-cycle cost analysis procedures are presented in this section.

#### Data Management

14. The data management procedure provides the means for storing and retrieving data necessary for REMR management. The procedure manages two types of data: historical data which include structure inventory data, M&R history, and accident reports, and data associated with structure types, such as possible problems and M&R alternatives.

#### Data organization

15. In designing the data management procedure, it was assumed that the two most common requests for reports would be for information about various components within a particular Civil Works facility and a particular type of structure or component. The relationship between various components of the structure were preserved in the data base so that the data for the structure could be examined at different levels of detail. The data organizational model which best fits the requirements for the REMR data base is the hierarchical model.

16. The hierarchical model organizes data records into a series of parent-child relationships (Figure 2). Figure 3 illustrates how a lock structure may be represented in the data base. This figure shows only the major components of the lock structure for illustration; the branching process can continue downward to allow detailed representation of the structure.

17. Hierarchical organization is not limited to representing the relationship between components. The method can also be used to identify possible problems relating to the component (Figure 4) and M&R alternatives which can solve the problems. For example, the component Miter Gate is at the top, or root, of the tree in Figure 4. The next

level shows the list of possible problems the component may encounter. The M&R alternatives which can be applied to correct the problem are shown at the next level. The hierarchical data organization allows the relationship between different components of the structure, between the component and possible problems, and between possible problems and M&R alternatives to be preserved in the data base. This arrangement of component/problem/M&R alternatives is beneficial to REMR management

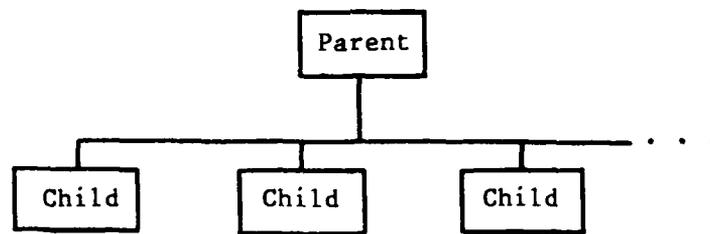


Figure 2. Hierarchical data organization

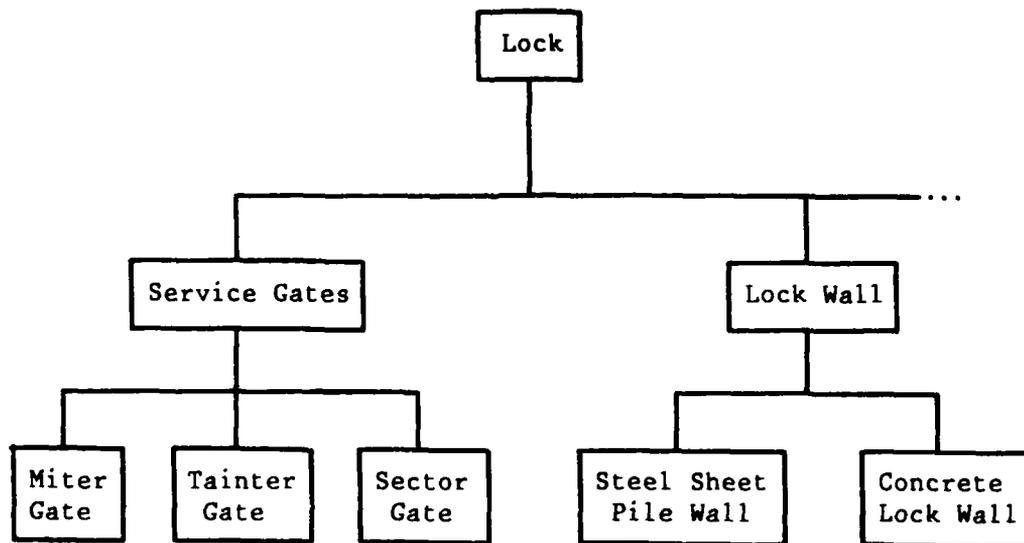


Figure 3. Example representation of the lock structure in hierarchical format

because it focuses the manager's attention on the problems relevant to the component and the M&R alternatives relevant to the particular problem.

18. Note that in Figure 4, the M&R alternatives for the problem Misalignment are listed in general terms only. This is because at this gross level, the exact cause and specific location of the problem cannot be determined. If more information is available, the problem can be examined at the next level of components in more detail. In the actual implementation, the miter gate will be further divided into subcomponents (skin plate, beam, pintle assembly, gudgeon pin and bushing, etc), and the possible problems relating to the subcomponents will be listed in the data base. Thus, hierarchical data organization allows the problems to be examined at different levels of detail.

19. While a hierarchical model is most suitable for organizing the REMR data base, it is not the only model that will work. A relational approach would offer more flexibility in data manipulation, but the relational model is best suited to organizing data which is in a tabular form. The component data shown in Figures 3 and 4 is naturally in a hierarchical form which is difficult to represent using the relational model. Although it can be done, the performance is significantly compromised and considerable data duplication (in the data base) occurs.

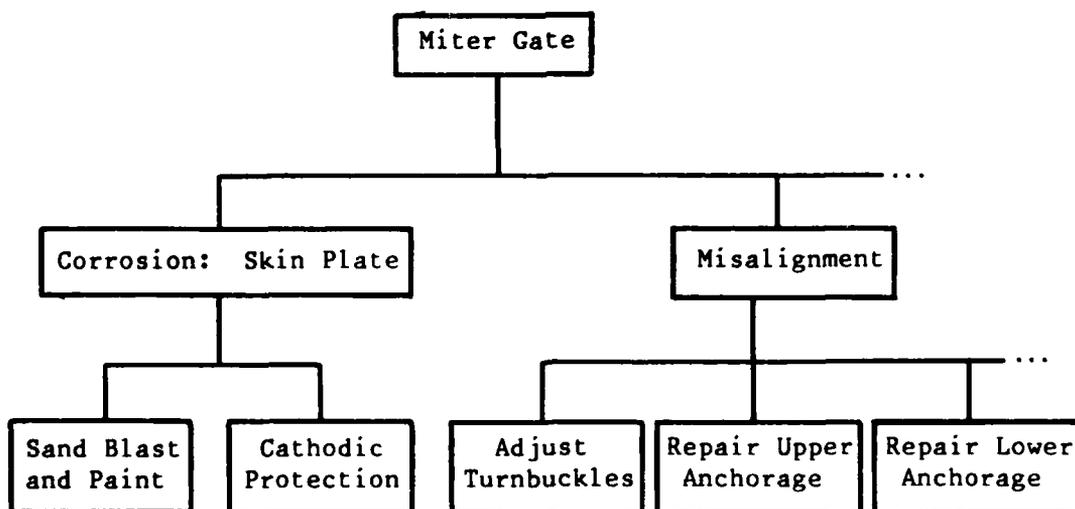


Figure 4. Hierarchical representation of problems and M&R alternatives

20. In the hierarchical approach, the flexibility in data manipulation is somewhat compromised, but this is not a major problem for the REMR application. The data management procedure can produce reports for a particular component or a component type in virtually any combination. The procedure will be able to produce all of the reports usually requested. Any unusual reports can be extracted from existing reports by sending the data to a file and manipulating the file.

REMR data base

21. The data stored in the REMR data base can be classified into three basic categories (Note: The symbols T and S show whether the data item is associated with a component type or a specific component, respectively.):

a. Structure Description Data

- (1) master structure data (T)
- (2) individual structure data (S)

b. M&R Data

- (1) problem list (T)
- (2) M&R alternative list (T)
- (3) M&R record (S)
- (4) condition index (S)
- (5) accident record (S)

c. Inspection Data

- (1) inspection form (T)
- (2) inspection data (S)

22. The structure description data is the inventory information which is used in the data management procedure to organize M&R data. Structure description data is essential information for data manipulation in the data management procedure, and is discussed in detail in the next section.

23. The M&R data items are associated with either a component type or a specific component. The problem list contains all possible problems which a particular type of component (note the T label) may encounter. The M&R alternative list (also marked T) contains the list of M&R methods which can be used to correct the associated problems. The M&R record is a

historical record of M&R performed on the component. The condition index is also historical data. The results of a periodic inspection are reduced to a CI and stored in the data base. The accident record is historical data of accidental damage sustained by the component.

24. The inspection data is currently not manipulated by the data management procedure because different types of components require different data for condition evaluation (i.e., inspection forms are component type-specific) and because it is not used directly by the M&R management system. The CI is determined from the inspection data and is used in the REMR Management System as the indicator of the structure condition. The REMR Management System does not refer to the data directly to assess the current condition of the components. Therefore, the inspection data is managed by the procedure which determines the component's CI. The final version of the management system will contain a limited inspection data handling routine to manage the inspection data for components which do not have a condition evaluation procedure.

#### Structure description

25. The structure description data is the key to the data base organization. Structure description is the process of dividing the structure into manageable components and storing this information in the data base. A typical Civil Works structure consists of many disparate components whose deterioration characteristics and REMR requirements differ widely. Because of the differences in component behavior, the data for each component type must be maintained separately.

26. The structure description process creates "slots" in the data base where the data for each component is stored. The process is analogous to inserting dividers in a file drawer and attaching index tabs so information related to a particular item can be kept together and easily located later. The component of interest is located by traversing the component list, a procedure similar to flipping through the index tabs to locate a file in a manual filing system. Once the component is located, the user can store or retrieve data for it. All access to the data is handled by traversing the component list in the REMR Management System.

27. In the REMR data base, the structure components are identified by name and type description. The name identifies a specific component, the type description identifies a group of components. The data associated with any specific component is identified by the component's name. The component type description establishes what data needs to be collected, which procedure should be used for condition evaluation, how the economic analysis should be conducted, what problems may occur, and which M&R alternatives are relevant. Assigning names to the components allows unique identification of the components when more than one of a given component type is present in the structure.

28. It is possible to construct an imaginary structure whose component list is the complete list of the type of components that may be found in all the structures of a particular type. The structure thus created is actually a general physical description of a class of structure. An example of this is shown in Figure 5. The figure shows the component types which may be found at a lock and dam. This figure is equivalent to the following verbal description:

A Lock and Dam structure consists of the two components Lock and Dam. A lock structure consists of the components Guide Wall, which may be of the type Steel Sheet Pile Wall or Concrete Guide Wall; Lock Wall, which may be of the type Steel Sheet Pile Wall or Concrete Lock Wall; and Service Gate, which may be of the type Miter Gate, Tainter Gate, Sector Gate, Roller Gate, or Vertical Lift Gate. A Dam structure . . .

The term "Master Structure" is used to refer to the imaginary structure which describes an entire class of structures in the REMR Management System.

29. As discussed in the "Data Organization" section, the Master Structure data is organized into a series of parent-child relationships (Figure 6). The hierarchical representation of the structure shown in Figure 5 is actually only an expanded version of the simple parent-child representation. The lock structure is shown at the top of Figure 6 as the structure which consists of components such as Guide Wall, Lock Wall, and Service Gate. When the constituents of these components are listed, it looks like the top portion of Figure 5.

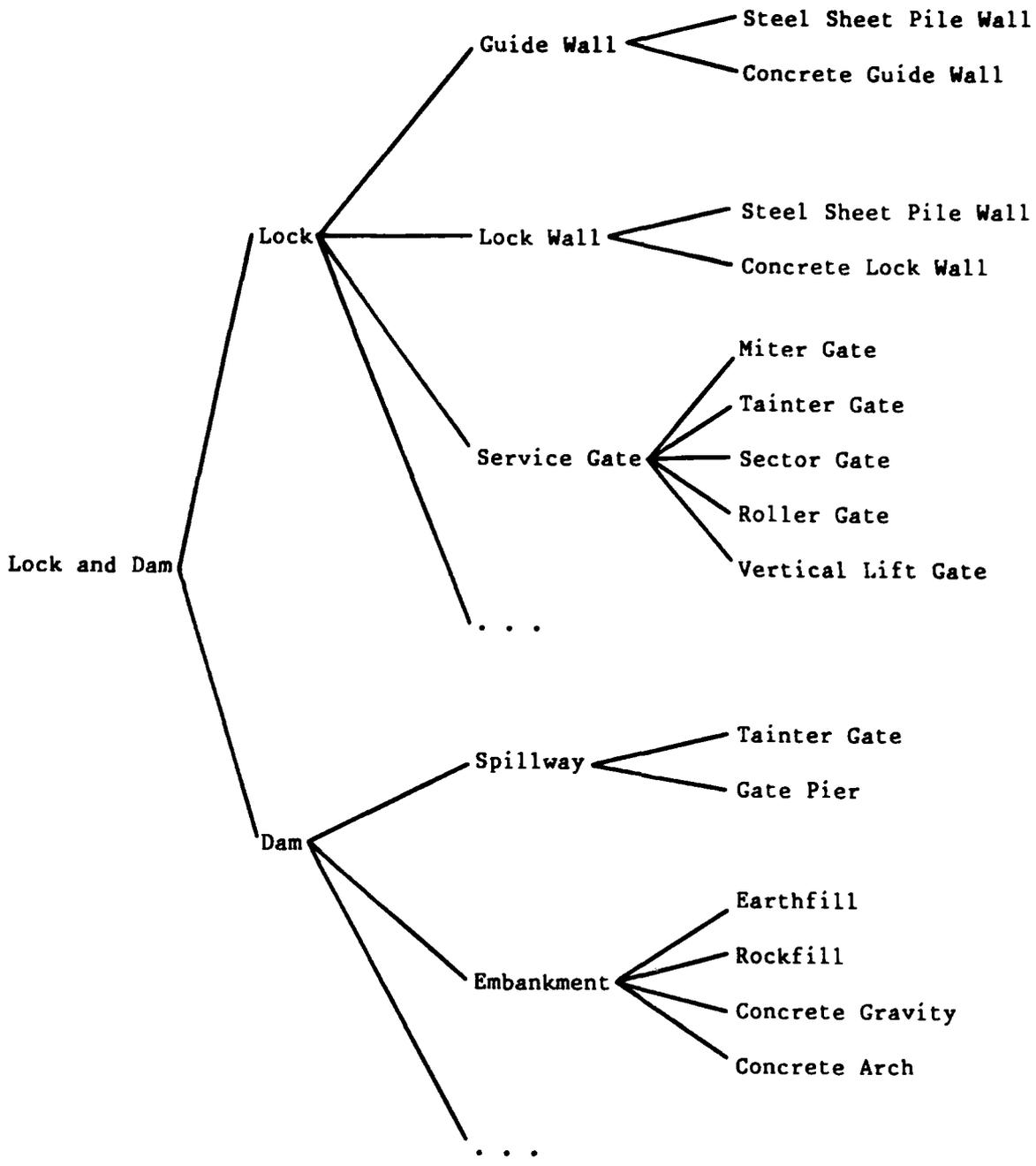


Figure 5. Master Structure example of a lock and dam

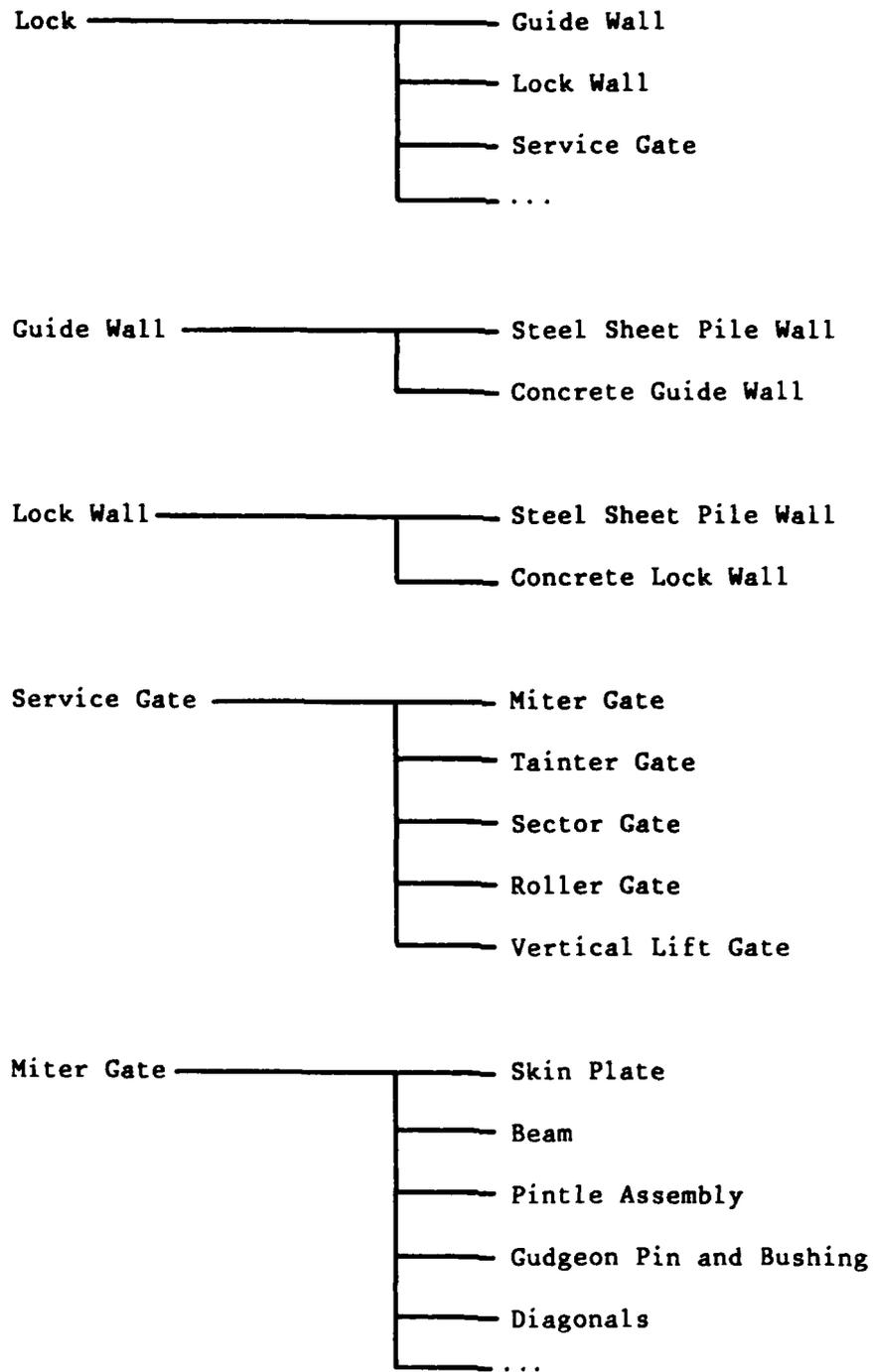


Figure 6. Data organization of Master Structures

30. The hierarchical method of data organization is useful for creating Master Structures. A Master Structure is always represented as a component and its subcomponents (parent-child) in the data base. The internal representation of any structure is the same in the data base regardless of the number of subcomponent levels. This allows a structure to be described in any level of detail. All the structures shown in Figure 6 are Master Structures; the Lock structure has three levels of subcomponents, and the Pintle Assembly of the Miter Gate has zero, but the internal representation of the components is same for both of these structures. The parent-child pairing of the components is performed automatically by the data management procedure; the representation the user sees when entering a Master Structure into the data base is the tree representation illustrated in Figure 5.

31. The parent-child representation of data also speeds up the structure description process. The parent-child pairs form Master Structure modules which can be assembled to form a new Master Structure. This is illustrated in Figure 6. The Master Structure "Lock" is an assemblage of Master Structures Guide Wall, Lock Wall, and Service Gate. In the process of editing a Master Structure, if the user enters the name of an existing Master Structure as a subcomponent of a new Master Structure, the existing Master Structure is attached to the new Master Structure as a subcomponent. Therefore, any Master Structure need only be entered into the system once.

32. Once the name of a Master Structure is entered, the other information relevant to the structure can be entered. This includes the descriptions and measurement units (up to four) that will be used to describe the size of the structure, list of possible problems, and the M&R alternatives that will correct the problems.

33. The use of Master Structures greatly facilitates the structure description process. Once the Master Structures are created, the structure description process is reduced to assigning names to the components. The decision of how the structure should be divided into components need only be made once when creating the Master Structure.

34. The structure description procedure can be summarized as follows:

a. Create Master Structures:

- (1) Decide how the structure will be divided.
- (2) Enter name for the component type.
- (3) Enter the description and the unit of measure which will be used to describe the quantity of the component. Up to four measurement descriptions can be entered.
- (4) Enter M&R alternatives and possible problems for the component.
- (5) Repeat items 1 through 4 until all component types for the structure are entered.

b. Enter the structure description information for individual structures into the data base:

- (1) Determine the structure type--the system provides a menu of available Master Structures to choose from.
- (2) Enter the structure name, district, location, and other background information (such as year built and contractor) as prompted by the system.
- (3) Enter the components--first select the component type from the menu, then assign a name to the component and enter the measurements as prompted by the system.

Figure 7 illustrates structure of the type "Lock and Dam," called "Lock and Dam No. 1." The component type description is shown in parentheses.

#### Life-Cycle Cost Analysis

35. LCCA is a method for systematically investigating the cost of various alternatives by comparing the total cost and benefit of the alternatives over a set time period. Alternatives with markedly different cost patterns can be compared objectively.

#### Policy on economic analysis

36. The Department of Defense requires LCC economic studies to be conducted as an integral part of the design process (which includes modification design) for all projects in the Military Construction Program

(Headquarters, US Army Corps of Engineers 1982). Army Regulation (AR) 11-28 "Economic Analysis and Program Evaluation for Resource Management" (Headquarters, Department of the Army 1975) contains the basic criteria, guidelines, and standards for all economic studies conducted by and for the Army. Regarding Civil Works projects, however, AR 11-28 states only the following:

For Civil Works projects, economic analysis, as well as related social, environmental, and institutional analyses, will conform to Presidential and congressional directed standards, criteria, and guidelines.

One such standard is established for economic studies of water resources projects by the Water Resources Council (WRC). The WRC guidelines (US Water Resources Council 1983) contain the official policy on economic analysis for all federally funded water resources projects. However, a uniform policy on economic studies for all Civil Works projects does not exist.

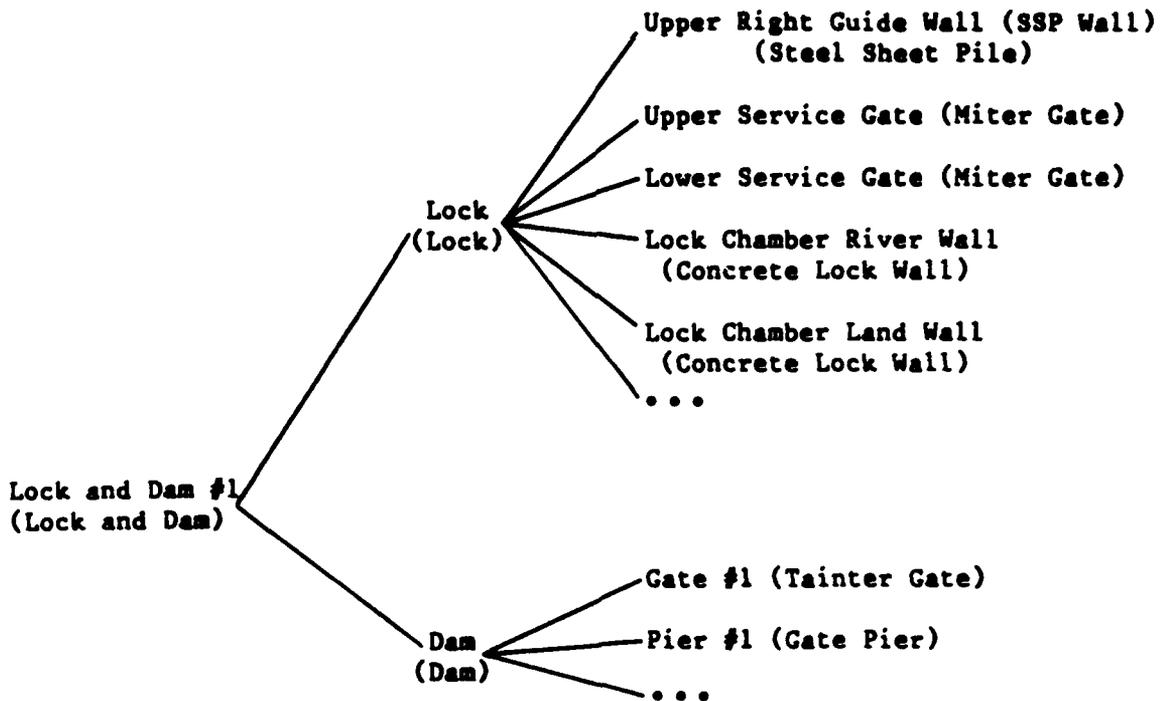


Figure 7. Example structure: Lock and Dam No. 1

### Current practice

37. Detailed economic studies for Civil Works projects are requested only for new constructions and major rehabilitations. For these activities, environmental impact studies and LCC economic studies (which include user cost/benefit analysis) are carried out in detail. However, economic analyses are seldom performed for normal repair and maintenance operations (i.e., all REMR activities other than major rehabilitations) because the REMR measures are taken due to necessity, not by choice. AR 11-28 allows the economic analysis to be omitted if the benefits to be gained from it are not worth the effort required to do the analysis, or when the DOD instruction/directives prescribe equipment replacement criteria (by age or condition).

38. However, the rationale for performing an LCCA under these circumstances is best presented in the following paragraphs from AR 11-28:

It should be understood that all analysis need not require the same level of effort. The degree and depth of analysis should be commensurate with the complexity of the action proposed, the issues involved, and the magnitude of resources involved. In some cases, the analysis may involve only an hour's research, but it provides the basis for a more informed decision.

The alternatives include not only the various options for a particular task, but also the alternate scope of work. For example:

If a lock guide wall is damaged due to a barge impact, it needs to be repaired without delay for safe operation of the lock; however, if it is a recurrent problem, corrective measures other than just the repair of the damage, such as construction of a protection pier or extension of the guide wall, should be considered.

The economic benefit of such activities as modifying the structure or performing maintenance to prevent the problem can only be assessed through an LCCA economic analysis.

### REMR LCCA procedure

39. The LCCA procedure included in the Basic Functions Module of the REMR Management System is a simple, computer-aided tool for performing LCCA. It is a general procedure applicable to all Civil Works structure

types. The procedure completes the mechanics of LCCA, but leaves all of the "thinking" to the user. The user estimates the cost of each item included in the analysis (including the user cost) and ensures that all necessary cost items are included. The user must also set the analysis parameters before each analysis according to the governing policy. The parameters include:

- a. Current date. The date used as the "present time" in present worth calculation; usually the date of analysis.
- b. Interest rate. The interest rate to be used in the analysis.
- c. Inflation rate. The differential inflation rate (rate of rise in material cost above general rate of inflation).
- d. Analysis period. The time period covered by the analysis.

The procedure takes the user input and determines the life-cycle costs for each alternative.

40. The procedure performs the analysis by component. The user first selects the structure to be analyzed, and then, by traversing the component list, selects the first component for LCCA. For the selected component, the system provides the user with the list of possible problems. When the user selects a problem, the system displays the M&R alternatives that will correct the problem. The display includes an estimate of expected life, variation of the expected life, and a rough estimate of the cost. When the analysis is completed for the component, the user may select the next component. The procedure produces the LCCA report for the structure by combining the LCCA results of constituent components.

41. The ability to produce the cost and performance data for the available M&R alternatives is the most useful aspect of the REMR LCCA procedure. The most difficult and time-consuming aspect of LCCA is collecting reliable data on cost and performance of M&R alternatives. The analysis itself is a relatively simple procedure of summing the present value of costs incurred at different times within the analysis period. The difficulty of gathering reliable data for LCCA is discussed in

Neathammer (1983). In the REMR Management System, performance data for M&R alternatives is maintained as a part of historical data.

42. The expected life data is automatically updated from M&R records. The user inputs the M&R record to the data base. The M&R record includes the problem being corrected and the M&R alternative used to correct the problem. The system "knows" which problems the implemented alternative solves due to the hierarchical structuring of the data. The next time the component experiences a problem which the last implemented alternative had solved, the system calculates the elapsed time. This process produces an estimate for the expected life of the alternative. The system stores the average value and the standard deviation of the estimates. As more data is collected over time the estimates become more accurate.

43. The cost data is not as reliable as the expected life data because it is very difficult to describe quantity information to an automated system. The repair cost depends not only on the size of the component, but also on the extent of damage. Therefore, the system only provides the "ballpark" cost figures of cost for small, medium, and large components. If the alternative's cost can be expressed as unit costs (e.g., dollars per square foot) the system provides an estimate of the unit cost. For these alternatives, the user must provide the required quantity information.

44. The LCCA procedure provides quick estimates and performs economic analysis for those component types for which the consequence modeling procedure is not developed. The more sophisticated procedures for economic analysis which include prediction models for estimating future condition, expected operating condition (traffic or usage consideration), and user cost are provided in the Consequence Modeling Module for selected component types. These procedures are necessarily component type-specific. It is not possible for such an "intelligent" procedure to handle all Civil Works structure types in general. (The details of the consequence modeling procedures are presented in Part V.)

#### PART IV: CONDITION EVALUATION/REMR CONDITION INDEX

45. Periodic inspection of Corps' Civil Works structures began in 1965 with the implementation of Engineer Regulation (ER) 1110-2-100 (Headquarters, US Army Corps of Engineers 1983). The ER specifies the guidelines for periodic inspection and requires Civil Works structures to be inspected at regular intervals by a team of experts. The needs for repair, further evaluation, maintenance, or rehabilitation are identified during periodic inspections.

46. While much useful information is collected during periodic inspections, the evaluation results are not always in a form useful for comparing the condition of one structure to that of others. Because the ER does not specify the inspection and evaluation procedures in detail, but relies on the judgment of experienced engineers to interpret the data, the evaluation results can vary from year to year and from district to district. The REMR Management System employs more systematic inspection and evaluation procedures which produce more objective and consistent results.

47. The Condition Evaluation and Rating Procedure in the REMR Management System specifies how the condition of a particular type of structure shall be inspected, evaluated, and represented. A simple step-by-step procedure for inspection and condition evaluation is developed with information provided by experienced engineers for various types of structures. The condition evaluation results are summarized on a numbered scale which relates to the structure's ability to perform its intended function.

#### REMR Condition Index

48. The Condition Index (CI) as used in the REMR Management System is defined as follows:

The REMR Condition Index is a numbered scale, from a low of 0 to a high of 100. The numbers indicate the relative need to perform REMR work due to general deterioration of the structure or functional and safety considerations.

49. The CI is produced from any measurable or observable characteristic or attribute that can be related to the physical condition, function, or safety of the structure. The procedures for producing the CI must be standard, objective, repeatable, and must be simple enough to be successfully applied by those without a high level of training and experience.

50. The REMR CI scale (Figure 8) is a continuous scale ranging from 0 to 100. The scale is divided into seven condition ranges and the CI ranges are grouped into the three zones that indicate the type of action the condition warrants. Although it can be interpreted that structures with CI ratings that fall in the same range are in comparable condition, small differences in the CI of structures do not necessarily reflect the corresponding differences in the actual conditions of the structures. The process of CI evaluation involves reducing a fair amount of data into a single number (or a few numbers) that represent the condition of a structure. The small differences in CI is meaningless; a more meaningful way of interpreting what the CI is saying about the condition of the structure is to look at the CI range the structure is in.

51. The CI is a rough indicator of the structure's general condition level. The CI is intended as a guide to focus management attention on those structures which warrant immediate repair or further evaluation. The CI is also useful for monitoring changes in the general condition of a structure over time and for comparing the condition of different structures.

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	<b>EXCELLENT</b> - No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	<b>VERY GOOD</b> - Only minor deterioration or defects are evident.	
2	55 to 69	<b>GOOD</b> - Some deterioration or defects are evident. Function is not impaired.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	<b>FAIR</b> - Moderate deterioration. Function is not seriously impaired.	
3	25 to 39	<b>POOR</b> - Serious deterioration in at least some portions of structure. Function is seriously impaired.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	<b>VERY POOR</b> - Extensive deterioration. Barely functional.	
	0 to 9	<b>FAILED</b> - General failure or failure of a major component. No longer functional.	

Figure 8. REMR condition index scale.

## PART V: CONSEQUENCE MODELING

52. A consequence modeling procedure is an automated management tool designed to help plan, budget, and manage REMR activities. There are tradeoffs among evaluation, maintenance, repair, and rehabilitation which need to be accounted for in order to efficiently maintain the Civil Works facilities. There are also tradeoffs in allocating resources among various structures in a network of facilities with competing needs. In analyzing these tradeoffs, one must weigh the value of an activity versus the cost of performing it, the benefit versus the penalties of deferring an activity, and interactions among activities (e.g., could, or should the performance of several activities coincide?). The consequence modeling procedure interactively weighs the various factors which affect the operation of a facility to recommend the optimal REMR policy for the facility.

### Approach

53. The design of the consequence model is based on an LCCA of each facility through some analysis period. Analyzing facilities requires a new approach to looking at facility performance and the factors which influence costs throughout its service life (Markow 1986). This approach is termed "demand responsive," in that the performance of a REMR activity is viewed as a response to the demand for the REMR measure. The demand for work arises through both a physical dimension (the condition of the facility), and a policy dimension (standards of initial design and construction, and the quality standards for REMR).

54. Treating REMR actions as demand-responsive activities requires that three additional elements be introduced into planning and management models. The first is that the estimates of future resource requirements and costs must be based on predictions of structural and operational deficiencies caused by use, environment, and age. The second is that the models must be sensitive to the implication of different policies (some policies may define what REMR activities must follow). The third is that new relationships must be identified between the "as maintained" state of

the civil facility and the impacts to both the Corps and the users, providing a measure of the benefits of each policy at the costs computed above. Organization of these ideas within a unified structure is shown in Figure 9.

#### Example Cost Streams

55. Cost streams (for both agency costs and user costs) are shown schematically for two facility strategies in Figure 9. It is assumed that environmental factors are identical in both cases, but that initial facility design and subsequent performance differ in response to capital investment and maintenance policy.

56. Strategy 1 (in Figure 10) entails higher agency costs for construction, maintenance, and rehabilitation, and lower user costs. Strategy 2 presents the opposite pattern, with lower agency costs and higher user costs. Strategy 1 may be interpreted, for example, as that of a facility built and maintained to very high standards to ensure premium service throughout its life. Strategy 2 may represent a conventional facility maintained adequately but not exceptionally.

57. From an agency perspective, Strategy 2 is the lower cost alternative and perhaps would be preferred. From a total cost viewpoint, however, the savings in agency costs in moving from Strategy 1 to Strategy 2 are offset by the increase in user costs. Therefore, one strategy cannot be said to be better than the other without a closer look. The discounted present value of the total costs (user cost plus agency cost) for each strategy must be compared to determine the desirable option consistent with the agency's policy (sometimes the agency may be interested only in the agency cost).

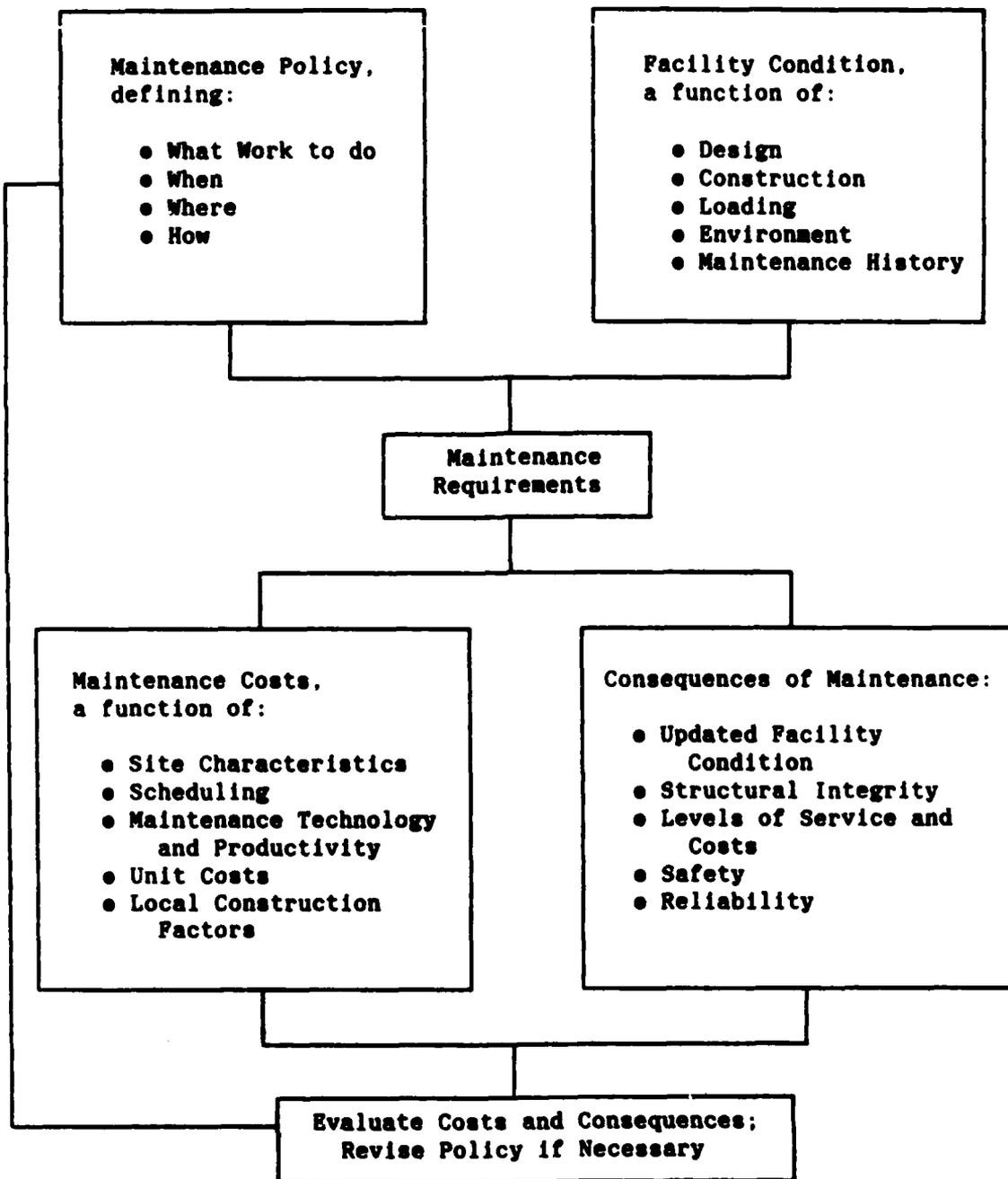
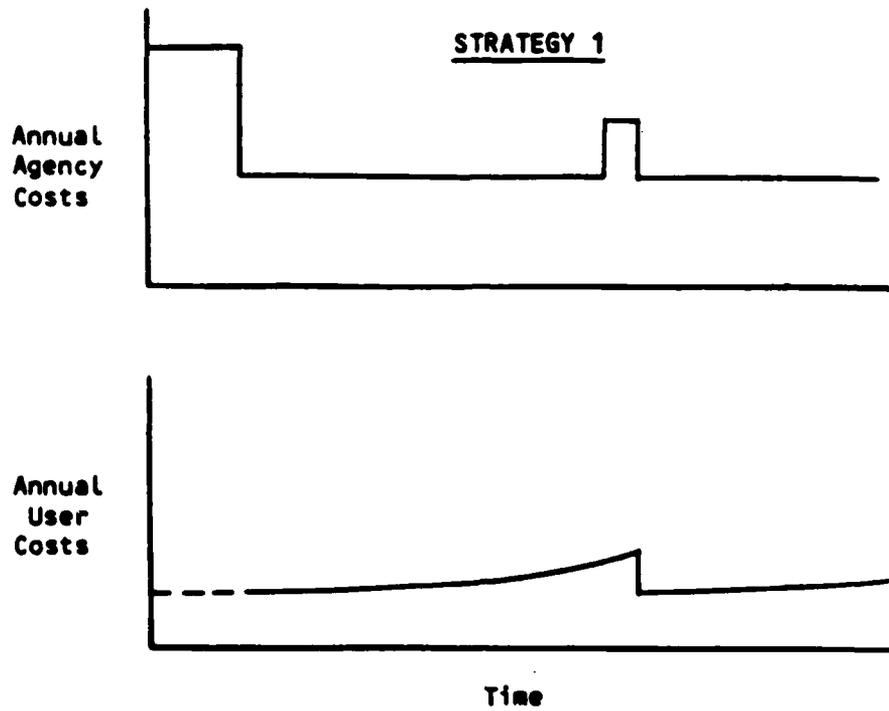


Figure 9. Approach to maintenance planning



(Costs Not to Scale)

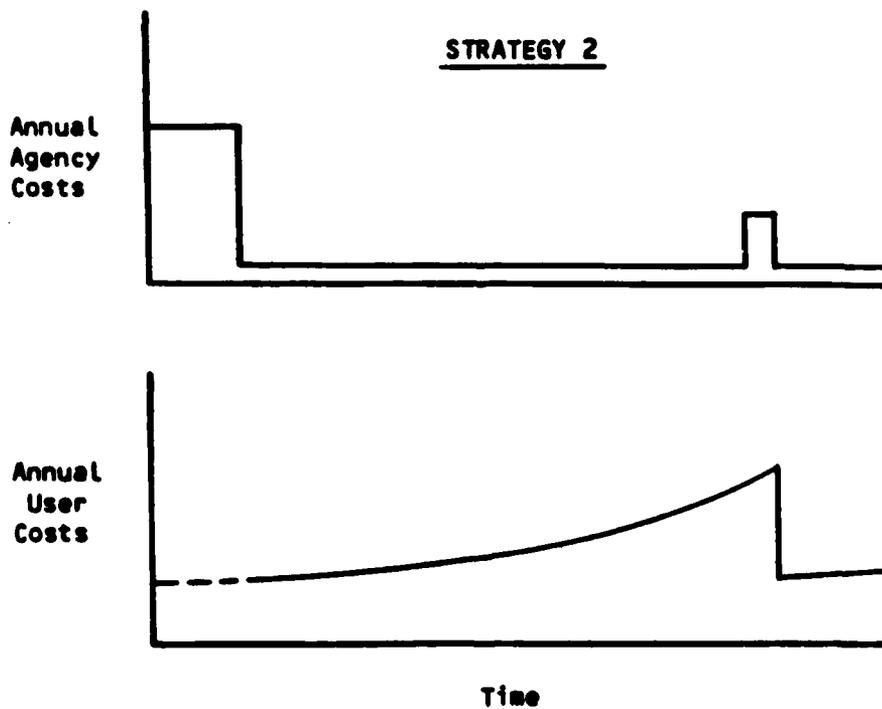


Figure 10. Schematic cost streams for two REMR policies

### Optimal REMR Policy

58. To illustrate the determination of optimal REMR policy, assume that cost streams similar to those in Figure 9 have been calculated for several potential REMR strategies or policies, and that all cost streams have been discounted at an appropriate rate. The strategies can be organized in terms of ascending costs to the agency and plotted. The impacts or consequences of each strategy can be represented in monetary terms (as in user cost) and plotted on the same graph. In general, if REMR policies are sensibly defined, more expensive policy should yield more advantageous impacts (i.e., greater reduction in costs associated with safety, or travel time), leading to the diagram in Figure 11.

59. Identification of the most advantageous policy now becomes a question of minimizing the total cost. In the absence of budget constraints, the appropriate policy is shown in Figure 11 as  $P^*$ , since the total costs (agency cost plus user costs) are minimized at this point. If a budget constraint is imposed, the best policy that can be funded lies at  $P'$ .

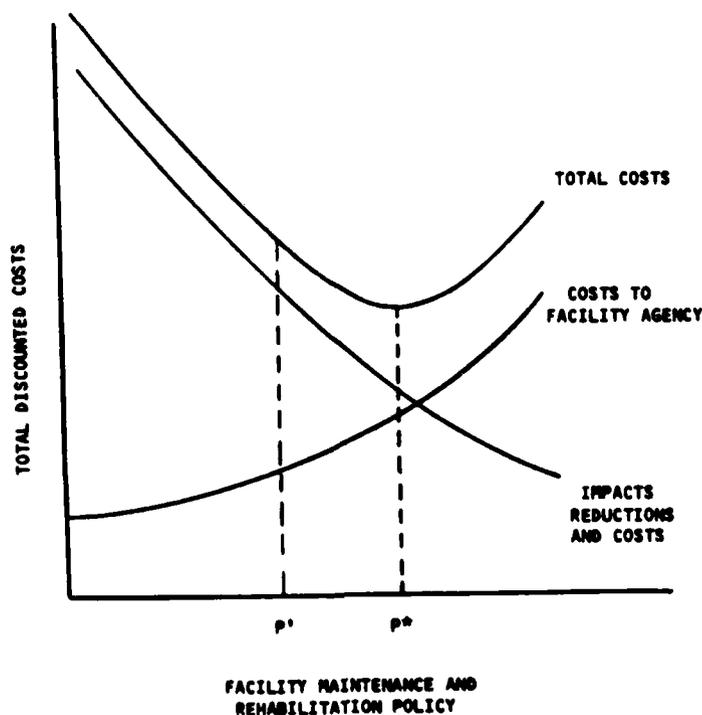


Figure 11. Example determination of the optimal REMR policy

## PART VI: HARDWARE REQUIREMENTS

60. The prototype REMR Management System is designed to run on an IBM-compatible personal computer (PC) under the MS-DOS® operating system, with at least 10 Mb of hard disk and 640k RAM. The size of the mass storage unit required depends on the amount of data that needs to be stored. The system performance on the PC is satisfactory.

61. The prototype is designed as a single-user system. However, a multiuser capability must be considered for the final version. One way to satisfy the requirement for multiuser support would be a PC network with file server, which would allow many users to share the data base. An alternative would be the use of a multiuser computer.

62. The data management system, as well as the rest of the M&R management system, is written in C language for portability. With minor effort, the entire system could be recompiled to run on any computer supporting the UNIX operating system. In this approach, the program and the data base would reside on the multiuser computer and terminals would be used to access the system.

63. The two methods for providing multiuser support are equally acceptable for the REMR Management System. The PC network option can be adopted with very little program modification because the prototype system is developed on the PC. The advantage of adopting the multiuser computer option is that it is better suited for supporting remote (dial-up) users. The PC network option is the preferred method for implementation, since the Corps District offices will have the PC network for general use in the near future.

## PART VII: SUMMARY

64. This report describes the REMR Management System, a computer-aided system for managing of REMR activities for Civil Works structures. The system consists of three modules: the Basic Functions Module, Condition Evaluation and Rating Module, and the Consequence Modeling Module.

65. The Basic Functions Module contains the procedures for data management and life-cycle cost analysis. The data management procedure allows the user to store and retrieve data. The procedure handles the structure inventory data, problems data, M&R alternative list, M&R history data, and accident records. The life-cycle cost analysis procedure provides the user with the tool to compare various alternatives on a life-cycle cost basis.

66. The Condition Evaluation and Rating Module contains a collection of condition evaluation procedures for various types of structures. A condition evaluation procedure specifies how the condition of a particular type of structure shall be inspected, evaluated, and represented. The condition index is a numeric scale ranging from the low of 0 to high of 100. The CI represents the relative need for REMR measures.

67. The Consequence Modeling Module includes tools useful for long-term planning. A consequence modeling procedure interactively weighs the various factors which affect the operation of a facility (the conditions of various components of the facility, performance of various M&R alternatives, and user consideration) and the budget to recommend a REMR policy for the facility.

68. The Basic Functions Module is described in detail in this report. The description of the Condition Evaluation and Rating Module, and the Consequence Modeling Module is limited to presentation of the concepts. Details of these modules will be reported separately.

## REFERENCES

- Headquarters, Department of the Army, 1975. "Economic Analysis and Program Evaluation for Resource Management," Army Regulation (AR) 11-28, Washington, DC.
- Headquarters, US Army Corps of Engineers, 1982. "Economic Studies", Engineer Technical Letter (ETL) 1110-3-332. US Army Corps of Engineers, Washington, DC.
- Headquarters, US Army Corps of Engineers, 1983. "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures", Engineer Regulation 1110-2-100, Washington, DC.
- Markow, M. 1986. "Management System for Repair, Evaluation, Maintenance, and Rehabilitation of Civil Works," Cambridge, Mass.
- Neathammer, R. 1983. "Life-Cycle Cost DataBase: Volume I, Design," Technical Report P-139, US Army Construction Engineering Research Laboratory, Champaign, Ill.
- Scanlon, J., et al. 1983. "REMR Research Program Development Report," US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Shahin, M. Y. and Kohn, S. D. 1981. "Pavement Maintenance Management for Roads and Parking Lots," Technical Report M-294, US Army Construction Engineering Research Laboratory, Champaign, Ill.
- US Water Resources Council. 1983. "Economic and Environmental Principles for Water and Related Land Resources Implementation Studies," Washington, DC.