A MODEL-SYSTEMS APPROACH TO THE PLANNING AND CONTROL OF MAINTENANCE COSTS

By

JAMES HARVEY BULLOCK

Bachelor of Science in Business Administration
University of Arkansas
Fayetteville, Arkansas
1968

Master of Business Administration
University of Arkansas
Fayetteville, Arkansas
1969

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1974

A MODEL-SYSTEMS APPROACH TO THE

PLANNING AND CONTROL OF

MAINTENANCE COSTS

Thesis Approved:

Herman Bäer
Thesis Adviser

[signature]

[signature]

[signature]

D. D. Durham
Dean of the Graduate College

PREFACE

In this study, I have been concerned with the development of an analytical framework for the planning and control of maintenance costs, the specification of the accounting information requirements of certain basic maintenance decisions, and the means by which the accounting system and management accountant can facilitate the maintenance decision process.

I wish to express my especial appreciation to my committee chairman, Dr. Germain B. Böer for his guidance, assistance, and encouragement throughout this study. I am also grateful to my other committee members, Dr. G. Michael Crooch, Dr. James F. Jackson, and Dr. Wayne A. Meinhart for their invaluable assistance in the preparation of the final manuscript.

I am indebted to the management of the companies who helped make this dissertation possible by permitting me to conduct in-depth studies of the maintenance activity of their firm, to interview their supervisory personnel at length, and to have access to informational materials essential to the research effort.

I wish to express my thanks to Dr. Wilton T. Anderson, Head, Department of Accounting, for his guidance and interest throughout my enrollment in the doctoral program and for the financial assistance which I received--largely as a result of his efforts in my behalf. I am also grateful to the American Accounting Association for the

financial assistance which I received through their Fellowship Program in Accounting.

Finally, I am especially grateful to my wife, Wanda, for her understanding, encouragement, and many sacrifices during the course of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The maintenance activity is an important and costly consideration for enterprises with heavy investments in plant and equipment. As manufacturing plants have become more highly mechanized and equipment and tools have become more complex, skill requirements for maintenance personnel have steadily increased, resulting in rising payroll costs and heavy investments in maintenance equipment. These factors, along with the profit squeeze of recent years, have highlighted the need for improved planning and control of the maintenance function. Such improvements have been slow to develop as evidenced by the following observations from the literature:

> Maintenance represents a very significant portion of manufacturing expense and, yet, historically, it has been one of the hardest areas in which to develop realistic controls for establishing information for budgetary comparisons as well as actual cost reductions (44, p. 19).

> Maintenance has been viewed as a necessary evil of doing business and the associated cost has always been accepted without challenge. . . . very few companies bring to bear the necessary resources to control this portion of manufacturing costs (18, p. 40).

> . . ., experience indicates that such maintenance objectives are lacking in many companies due to management's own lack of interest and due to alleged difficulties encountered in planning, measuring, and controlling the maintenance function (55, p. 263).

> Accountants are often not familiar with maintenance information needs and accounting data is frequently not customized to assist in formulating maintenance policy (63, p. 12).

In May, 1964, the National Association of Accountants published NAA Research Report No. 41, Control of Maintenance Costs, one of the few extensive studies on the planning and control of maintenance activities (63). This study reported on the accounting techniques that the accountant can use to provide managers with information that will help them improve maintenance cost control. The methodology employed in conducting this study consisted of a review of the relevant literature and of a field study to collect information about current practices of forty companies. These companies were selected because initial inquiries indicated that they had well-developed and effective maintenance cost control programs and, therefore, could make positive contributions to the study.

The report findings indicated that the then current practices in maintenance cost control left much to be desired. The summary of findings section describes the "state of the art" as follows (63, p. 4-8):

> Maintenance policies have usually evolved from experience in rather haphazard fashion rather than being designed to implement specific maintenance objectives. Relatively few of the companies participating in this study have written maintenance policies. Existing largely in the minds of maintenance supervisors, uniformity and continuity in policies tend to be lacking. In part, this situation is attributable to lack of management attention to maintenance. A more important explanation may be found in the difficulties encountered in applying quantitative analysis to establish maintenance objectives.
>
> Basic techniques for controlling maintenance work include procedures for service requests, work orders, scheduling and dispatching of work orders. However, the available evidence indicates that these techniques are inadequately developed in many companies. . . .

> Budgeting practices observed in the field study serve to keep total expenditures for maintenance within predetermined limits, but they do so with little consideration regarding the effectiveness of work done.

Although the companies visited considered maintenance cost a significant problem, the field study showed a lack of clearly defined maintenance objectives with a consequent failure to develop the policies and procedures needed to effectively control maintenance cost. NAA researchers attributed this lack of objectives and policies to one or a combination of (1) lack of management interest and (2) difficulties encountered in quantitative analysis of the maintenance function.

> The field interviews suggest that the maintenance policies of the majority of companies visited could be improved if management would take a more positive attitude toward control of maintenance services and costs. The view that maintenance operations are not susceptible to measurement and control should be rejected and, by applying the fundamentals of policy formulation and work planning guided by cost data, effective control systems should be sought (63, p. 11).

> Experience and intuitive judgement are relied upon heavily in developing [maintenance] policies. Quantitative analysis is seldom used (63, p. 12).

Not only did the study find that managers held a number of misconceptions about the maintenance function, but the study also discovered that the accountant was not providing the information that managers needed to plan and control maintenance activities.

> The cost of maintenance and the need for effective control are viewed as significant problems by almost all the companies visited. Effective control over maintenance costs requires, among other things, information on costs of the varied activities encompassed by maintenance. It is the accountant's function to determine these costs in a manner conducive to the exercise of control.
>
> As a member of the management team, the accountant can assist in organizing the maintenance function and developing adequate control procedures. His analytical skills can also be employed advantageously in finding the most economical method when management is faced with alternatives which affect future maintenance costs (63, p. 4).

The accounting department supplied data in a few cases for engineering studies which were made to assist in formulating maintenance policy. However, the accountant's role is usually a minor one and often he does not participate at all. It seems reasonable to believe that the accountant could make a positive contribution to maintenance policy if he were more familiar with maintenance problems and if the cooperation between the two activities were improved. This contribution could take the form of specially designed cost reports and special studies to aid in maintenance planning and control (63, p. 12).

Purposes of the Study

The purposes of this study are (1) to develop an analytical framework for planning and control systems with special emphasis on decision characteristics, informational inputs, and accounting implications, (2) to develop a general model of the maintenance decision system, (3) to analyze conceptually certain maintenance decision settings and specify their accounting information requirements, (4) to present quantitative methods or decision models that are specifically applicable to maintenance decisions, and (5) to make recommendations, based on the foregoing, on how the contribution of the management accountant and the accounting system to the maintenance planning and control process can be improved.

A conceptual framework is necessary in order to isolate and define the relationships between the management decision function and the information function (accounting). From the discussion in the preceding section, it is apparent that planning and control of maintenance activities as currently practiced are generally not satisfactory. This is partially due to lack of management attention and to management misconceptions about the controllability of maintenance costs. One of the hypotheses of this research is that inadequate management accounting data contribute significantly to the lack of maintenance cost control.[1] Inadequacy of management accounting data is due largely to a preoccupation, in existing research studies, with control techniques for specific problems. A major effort directed toward a conceptual analysis of the relationship of accounting data to the optimization of maintenance decisions is not available. This study will attempt to develop such a conceptual framework.

Organization of the Study

The study contains an introductory chapter concerning the nature of the problem, and the objectives, significance, and limitations of the study. The second chapter reviews the relevant literature relating to the maintenance function.

In the third chapter, a framework for analysis of planning and control systems is presented which is oriented to managerial levels and decision characteristics. Presentation of the framework is preceded by a review of relevant literature in systems theory, management and organization theory, and decision theory. This review provides a supportive base for the framework and is synthesized in the framework. A model-systems approach is employed to provide a systematic rationale of the maintenance function. Accounting, as the basic information

---

[1]According to the AAA's Committee to Prepare a Statement of Basic Accounting Theory, "He [the management accountant] should understand the information requirements well enough to be an intelligent supplier of relevant data for use in the decision-making models if, indeed, not the originator and manipulator of these models (6, p. 40)."

system for maintenance management, is analyzed as an integral part of the model.

The fourth chapter consists of an examination of the maintenance activity, its goals, resources, and subsystems. A general model of the maintenance decision system is developed. Maintenance decisions are categorized in terms of specific decision settings and each decision setting is analyzed in terms of (1) a statement of the problem, (2) management's objectives in making the decision, (3) the alternatives available, (4) the decision variables and criteria, and (5) methods of analysis suited to the decision process. The information requirements for the decision settings are specified and the role of the accounting system in providing such information is delineated. A final section stresses the importance of (1) the recognition of cost behavior patterns attributable to different types of maintenance costs and (2) the use of appropriate cost concepts in maintenance decisions.

The fifth chapter reports results of field studies of current maintenance management practices in selected petroleum refineries. The field studies allowed an in-depth inquiry into the role of the accounting system in the maintenance planning and control functions and provided the researcher with a practical insight into operational maintenance systems.

A final chapter summarizes the research, makes recommendations about how the accounting system and the management accountant can better serve the informational needs of maintenance management, and makes recommendations for further research.

Methodology

The methodology includes library research, development of a conceptual framework, and an in-depth field study of the maintenance activity in selected petroleum refineries.

The purposes of the library research are (1) to provide the writer with a comprehensive background in the theory and techniques related to the topic; (2) to develop the essential requirements of an effective maintenance planning and control program; and (3) to provide a basis for the formulation of the conceptual framework.

The Conceptual Framework

The basic research strategy for development of the conceptual framework is the systems approach. The systems approach is characterized by: (1) definition of the system under consideration (i.e., when it is observed that a problem occurs in relation to a particular system, a study of that system must be preceded by a careful definition of its boundaries and content); (2) the systematic examination of objectives and of alternative ways of achieving these objectives; (3) data collection; and (4) model building (models are constructed to represent the system and assist in defining the relationships that exist within the system).[2]

This study views the firm as a system and develops models of selected subsystems within that system. The firm is defined in general

---

[2]For a detailed discussion of the systems approach, refer to Lee (46, p. 128-146) and Churchman (17). The applicability of the systems approach to research dealing with internally reported accounting information is discussed in the AAA's Report of the Committee on Accounting and Information Systems (5, p. 289-299).

terms as an open system interacting with its supporting environment. It is made up of a number of functional subsystems, each capable, in theory, of being isolated and defined for analytical purposes. The subsystems which form the primary focus of this study are the maintenance system and the accounting information system. The accounting system is a major component of the formal information system and its role in meeting the decision-making needs of maintenance management is investigated in detail.

The AAA's Committee on Accounting Theory Construction and Verification identified accounting as being the measurement-communication function of the decision process (2, p. 60). The committee stresses the interaction of the accounting function with decision models saying that, due to this interaction, there is in a sense no separate theory of accounting. The inference is that the accounting system is a part of a larger system and that neither accounting theory nor the structure of accounting systems can be isolated from the decision processes of the users.

In the development of the conceptual framework, a detailed specification of the decision settings faced by maintenance management is prepared. Primary attention is then directed to the information required for these decisions. Turban indicates that current accounting systems do not provide adequate cost data (83). He describes the conventional accounting system as being incomplete with regard to maintenance and lists the following shortcomings:

(1) Downtime losses are usually not computed.
(2) Costs of non-maintenance work done by maintenance workers are not segregated from true maintenance costs.
(3) Preventive maintenance expenditures and repairs expenditures are mixed.
(4) Cost centers of the conventional accounting system do not coincide with real maintenance cost centers.

(5) An average maintenance cost per hour is used regardless of the skill involved (83, p. 73).

Because of these weaknesses, this study includes a discussion of (1) cost concepts appropriate to planning and control of maintenance activities, and (2) the cost behavior attributable to different types of maintenance costs and the consequent implications for analysis and control. Wherever appropriate, these costs are included in the framework.

The Field Studies

The field studies were undertaken (1) to give the researcher a perspective of operational maintenance systems and (2) to provide him with an essential base for researching the decision needs of maintenance management. Unlike previous studies, the emphasis is on analysis of the overall maintenance planning and control system and the primary maintenance decision settings, rather than enumeration of deficiencies in maintenance management techniques.

The field studies focus on the systematic relationships among various functions within the organization, particularly the maintenance and accounting functions.

Information sources for the field study include company informational materials (policy manuals, procedural directives, budgets, performance reports, and the like), personal interviews, and observation. After obtaining the necessary permission to conduct in-plant studies at the refineries, a questionnaire (see Appendix A) was prepared and forwarded to each company. The purpose of the questionnaire was to indicate the subject areas to be discussed at the time of the field interviews. Different parts were addressed to personnel in various positions (e.g., maintenance superintendent, operations supervisors, stores manager, accountants, etc.) in the organization.

In order to obtain an adequate view of the maintenance activity within petroleum refineries, four refineries were included in the field studies. The refineries selected differed significantly in size, location, and organizational structure.

Reasons for Selection of Petroleum Refineries for Use in the Field Studies. Ideally, the empirical findings for this type of study should be drawn from in-depth studies of a broad cross-section of industrial organizations. Due to resource and time limitations on the part of the researcher, such an approach was not feasible. The alternative was to select a limited number of firms which were most likely to contribute positively to the research effort.

The field studies provided a means for comparing the conceptual framework with current maintenance management practices. It is reasonable to believe that such comparisons are more meaningful if related to companies having well-developed and effective maintenance programs than if related to companies which handle maintenance on a crisis-by-crisis basis. Petroleum refineries can be expected to have relatively well-developed, effective maintenance programs for the following reasons:

(1) Their maintenance costs are significant, amounting to about one-half the total spent on capital expenditures (52, p. 99). Hence, refinery management can be expected to emphasize maintenance planning and control. Such emphasis is evidenced by the trend in petroleum

refining to upgrade the maintenance function to major status in the plant (83, p. 3).

(2) Petroleum refineries are generally capable of bringing a full range of resources to bear on the maintenance problem.

Basic Assumptions of the Study

The underlying premises for this research are that (a) accounting is the measurement-communication function of the decision process, (b) the accounting system should serve as the basic information system for the planning and control functions and for the decision models and techniques used to implement these functions, and (c) the management accountant should be an active participant in, and contributor to, the management decision process by making cost studies, assisting in the implementation of quantitative decision techniques, and helping management to recognize and identify cost concepts and cost behavior patterns relevant to particular decisions.

Limitations of the Study

A broad framework is developed for planning and controlling maintenance costs, with a major emphasis on the relationship of accounting information to the optimization of maintenance decisions. An exhaustive treatment to each area within this framework is beyond the scope of this study.

Due to the qualitative nature of the research approach, the conceptual framework cannot be subjected to statistical investigation. The framework is not final; it is offered for testing through further research. It is emphasized that the purpose of the field study is not to "validate" the conceptual model. No individual can make a sufficient number of thorough investigations to provide an adequate basis for generalizing about all organizations. However, the cumulative evidence of a series of well-conducted investigations is a potential source of such generalizations.[3]

Significance of the Study

Currently, there exists no generalized framework for analysis of maintenance planning and control systems. Previous studies have presented techniques and procedures for dealing with specific maintenance problems. To the extent that this fragmented approach has contributed to the present unsatisfactory state of maintenance management development, a correlated framework offers definite possibilities for improvement. A unified and coherent framework will (1) provide a reference base for the evaluation of both maintenance management practices and the associated accounting system in its servicing of the maintenance decision process and (2) serve as a guide to development of improvements in the planning and control of maintenance costs.

---

[3]For an elaboration on this point, see Anthony (9, p. 157-167).

CHAPTER II

LITERATURE REVIEW

Introduction

A coordinated body of literature has not emerged in the area of maintenance planning and control programs. Numerous articles, some studies, and portions of chapters in recent books have been devoted to various aspects of the subject. There is, however, little evidence of the existence of a cohesive framework which attempts to correlate the total requirements of an effective maintenance system.

Publications have generally dealt with specific maintenance problems (i.e., maintenance scheduling, preventive maintenance, budgeting, and motivation) and with procedural techniques for dealing with such problems. Nonetheless, there has been an implicit recognition of the need for a correlated framework for planning and controlling maintenance costs. The NAA study stressed the need for cooperation and coordination of departments (production, maintenance, accounting, etc.) and for overall cost analysis to improve maintenance cost control (63, p. 7). Articles by Ludwig (51) and Sisson (76) are typical of many appearing in industry publications which stress the de-isolation of maintenance management.

In general, the literature may be broadly categorized into publications oriented toward the topics of: (a) accounting for maintenance and (b) maintenance management. Works dealing with maintenance management can generally be further subdivided into those emphasizing effective management practice and organization and those stressing quantitative or "operations research" applications.

Accounting for Maintenance

Aside from the NAA study discussed previously, there have been few publications aimed at providing an extensive coverage of the role of management accounting in serving the maintenance decision process. Numerous articles have been written which stress the importance of effective presentation of information by the accounting department as a key element in contributing to control of various types of maintenance costs. Knobloch, et al., (44) describe the accounting department's role in the Maintenance Work Authorization Control Program at the Babcock & Wilcox Company, Beaver Falls, Pennsylvania. Manthey (53) reports on a cost control system for routine and repetitive jobs. His system requires: (1) the use of a Time Task Range Technique to specify the manpower and material requirements, and the time range and cost of routine jobs, and (2) the employment of special maintenance accounts and reporting procedures by the accounting system. According to Manthey (53, p. 38), the system "is reasonable and responsive for most firms that do not have the means for a more precise and formalized system." More recently, Harding (32) has proposed a theoretical control system for maintenance scheduling which makes use of the computer to determine job assignments. He places responsibility on the accountants to provide assistance in establishing job priorities, measuring efficiency, and communicating cost and measurement data to operating management to aid in decision-making. Accordingly, he underscores the need for "accountants to prepare for an automated future."

Maintenance Management

A detailed study by Newbrough (66) in 1967 consists of a

> . . . review of those techniques and related principles that have proved highly satisfactory since their first application in 1929 and 1930 and which have since been applied to nearly every type of industry, including some of the largest industrial organizations in the United States (66, p. xi).

Newbrough's study emphasizes procedures and techniques deemed to be helpful to all levels of maintenance management. He gives little attention to the specific topic of accounting for maintenance costs or to maintenance cost behavior. The study is made up of eighteen chapters divided into three main sections entitled Organizing, Motivating, and Controlling. Included are two brief chapters dealing with maintenance cost budgets and target costs for maintenance control. Cost control for spare parts and maintenance materials is also given brief attention. A twelve-page chapter on the latter topic is devoted almost entirely to a discussion of such items as storeroom location, storeroom organization, and types of stores records suitable for small, medium, and large-size companies. Virtually no mention is made of cost control other than reference to use of the minimum-maximum basis as a common means of gauging the amounts of materials, supplies, and spare parts to be stocked.

In somewhat the same vein, an earlier book by Lewis and Pearson (49) was published in 1963. The preface of the book summarized its objectives as follows:

> The basic purpose of the book is to record some of the practices developed and used by government and private industry, and the way in which they can be used as guides for the reader in the application of his own daily maintenance management, to provide some general tested rules, and to establish some criteria to measure the effectiveness of the maintenance management function (49, p. iv).

It is interesting to note that the overall approach to maintenance control as recommended by the authors exemplifies the non-participation of the accounting department in the decision-making process--a condition which appears to be quite prevalent. In the very few instances where the accounting department is mentioned, its activity is confined to passively feeding data to the maintenance control group. The latter group then has the responsibility for preparing comparative and analytical reports for managerial decision needs. The apparent decrease in the relative importance of the accounting system as a provider of decision-making information is discussed more fully in Chapter III where consideration is given to the appropriate role of management accounting in serving the informational needs of management.

Also to be included among the publications that are fairly comprehensive in their coverage of the various aspects of the maintenance operation is one published by the American Management Association (7) in 1963. It is entitled Modern Maintenance Management and consists of a collection of fourteen articles (142 pages) written by maintenance managers of several large industrial firms. The AMA asked these managers to put their experiences in writing "in order to produce a practical and proven model of modern maintenance management (7, p. 6)." The topics covered include: Organizing maintenance operations, effective maintenance planning; improved maintenance scheduling;

application of critical path scheduling to maintenance; preparing the maintenance budget; the maintenance work order procedure; maintenance stores and spare parts control (four pages); maintenance training; upgrading skills; developing maintenance managers; measuring labor productivity; the development and use of labor standards in maintenance; measuring and appraising maintenance performance; the value of preventive maintenance; and using electronic data processing in maintenance. As indicated, the contributors in most cases describe problems encountered in their respective firms and discuss approaches taken to solve such problems. Others give detailed descriptions of aspects of their maintenance program. For instance, one article consists of seventeen pages devoted to a description of the preventive maintenance program in use at the writer's place of employment, including six pages of illustrative forms, reports and records. Such articles are no doubt quite useful and the experiences described may provide useful insights which are transferable to similar situations where the end result will be improved maintenance performance; however, the book falls short of its stated goal in that the articles are disconnected and do not result in a cohesive maintenance management framework.

Jardine (40) and Morse (60) provide examples of publications which stress the application of quantitative, or management science, techniques to maintenance problems. Jardine's book is a collection of twelve papers presented at the Operational Research in Maintenance Symposium held at the University of Strathclyde, Glasgow, in December, 1968. Most of the papers are basically of a case-study nature. They illustrate the use of mathematical models to solve a variety of problems (optimum crew-size, optimum overhaul policies, etc.) which are typically associated with the maintenance activity.

Morse illustrates the application of quantitative analysis to determine when preventive maintenance is advisable and the use of queuing models to optimize use of repair facilities and crew. Both Jardine and Morse emphasize the need on the part of their readers to recognize that the techniques illustrated apply to "common" types of problems even though operational environments may differ.

Other articles dealing with the theoretical optimization of certain types of maintenance decisions, such as spare parts provisioning and preventive maintenance scheduling, may also be found in the literature (50) (56).

Summary

The foregoing examples are representative of the traditional approach to the examination of the maintenance planning and control activity. The emphasis generally has been on procedures and techniques for coping with specific problems. Procedural aspects are indeed important; however, such an approach is unlikely to result in maximum cost-effectiveness for the firm as a whole. There is a need for a planning/control framework which will take into account: (1) the overall goals of the firm, (2) the subgoals associated with functional units within the firm, (3) the interrelationships between maintenance and other functional units, (4) the information requirements of maintenance decisions and the timely provision of such information, and (5) the consequent implications for optimization of maintenance costs.

Goldman and Slattery (30) have published a study along the lines of such a framework, but dealing with only a portion of the present topic. Their book represents "a first attempt to draw together in a systems framework the emerging principles of maintainability engineering (30, p. 7)." Although primary attention is given to improved cost-effectiveness of military systems, the authors do stress concepts and principles associated with maintainability engineering and maintenance strategies as opposed to presenting cookbook solutions to specific problems. In addition, their work includes some discussion of the economics of maintainability-related decisions, and the characteristics of optimal maintenance policies.

The foregoing discussion has pointed out the absence of a coordinated body of literature in the area of maintenance planning and control programs. The writer realizes that a comprehensive, detailed, treatment of all aspects of the maintenance function is impractical; however, a broad framework for analysis of the maintenance planning and control system is essential if maintenance-related decisions are to be optimized for the firm as a whole and if the accounting information requirements for such decisions are to be effectively determined. The following chapter is directed toward development of the requirements of such a framework.

CHAPTER III

AN ANALYTICAL FRAMEWORK FOR PLANNING AND CONTROL SYSTEMS

Introduction

The literature review in the preceding chapter pointed out the lack of a correlated framework for planning and controlling the maintenance activity. In this chapter a generalized framework for analysis of planning and control systems is presented and described. The framework is basically that proposed by Anthony (9) and employed subsequently to one extent or another in the works of Blumenthal (11), Deming (22), Ross (72), Sollenberger (77), and others. The initial sections of the chapter are devoted, however, to a brief analysis of the conceptual requirements of an analytical framework for planning and control systems--requirements which, it is proposed, are fulfilled by Anthony's framework. The requirements were determined by reviewing the literature in the subject areas of organization theory, decision-making, and information-communication theory. In addition, this chapter also contains an analysis of the role of management accounting in facilitating the management function.

The topics examined, in order of their presentation, are: (a) the systems approach to management and organization, (b) the organization as a system, (c) the role of management in the organization,

(d) information and the role of management accounting in serving managerial decision needs, and (e) a generalized framework for analysis of planning and control systems. The discussions in (c) and (d) include consideration of the decision-making process and its central position in both the management and accounting functions.

The foregoing sections are then summarized and synthesized into a generalized framework for analysis of planning and control systems. This framework is then applied in Chapter IV to the maintenance planning and control system.

Conceptual Requirements of an Analytical Framework For Planning and Control Systems

The Systems Approach to Management and Organization

Several concepts and theories have been proposed as a framework for management of organizations. Included among these concepts are decision theory, information and communication theory, and systems analysis. Also, one frequently reads of different "schools of management": the "operational" or "management process" school, the human behavior school, the operations research or management science school, and the like. Since each of these concepts and ideas is related to the management function, the ideal framework would permit the achievement of a total synthesis of all of them (and perhaps others not mentioned) as they relate to the management of organizations. Such an "ideal" framework does not presently exist, nor is it essential for purposes of this study. However, an approach to management is desired which is well-suited to the inclusion of a number of the concepts mentioned. Such an approach is suggested by Greenwood (31, p. iii-iv):

> Research of the decision-making literature has resulted in five major findings that are either common to most decision theories or processes, or constitute major changes in existing decision theories and practices. First among these, systems analyses and systems models are found to be a basic common denominator of all decision processes. Systems models provide prerequisite steps to the operations research information models presented in the annual planning decision sequence and for environmental, organizational behavior, and computer decision systems. The systems approach also emphasizes analysis of problems for the firm as a whole versus more specialized problems for which "closed" computerized mathematical models may be readily developed. Second, "information" is found to be the primary ingredient upon which all types of problem solving-decision making processes depend, requiring therefore the development of organizational management information systems. Communication-information input and output flows are integral to almost every step in the decision process, and we also find these information flows to be the essential ingredient in all operations-research, environmental, organizational behavior, and computer decision systems and models.

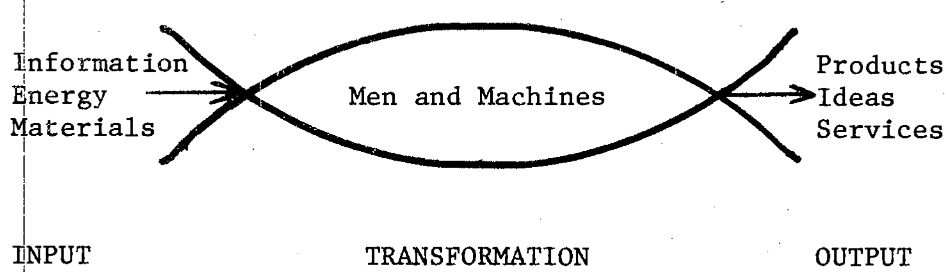
Although the emphasis in Greenwood's book is on decision theory, his remarks indicate that a systems approach to management and organization would facilitate consideration of the decision process as well as information and communication needs.

<u>The Systems Concept</u>. A system is "an organized or complex whole; an assemblage or combination of things or parts forming a complex or unitary whole" (42, p. 4). Emery (25, p. 1) and Anthony (9, p. 4) give similar definitions and, along with Lee (46, p. 9-20), make a distinction between natural and man-made systems. Lee defines four subclasses of the latter: procedural, physical, social, and conceptual. Churchman (17, p. 1-30), after defining a system as "a set of parts coordinated to accomplish a set of goals," outlines five basic

considerations which the scientist believes must be kept in mind when thinking about the meaning of a system:

1. the total system objectives and, more specifically, the performance measures of the whole system;
2. the system's environment: the fixed constraints;
3. the resources of the system;
4. the components of the system, their activities, goals and measures of performance;
5. the management of the system.

Johnson, et al., (41, p. 5) define a system as "an array of components designed to accomplish a particular objective according to plan." This definition, combined with the observations of Churchman, is particularly suitable for purposes of analyzing the complex business organization. It indicates the existence of objectives, a purposeful arrangement or design, and a plan of action for achieving the objectives. Johnson amplifies his definition by presentation of a model of a basic system (Figure 1).



Source: Johnson, R.A., W. T. Newell, and R. C. Vergin. Operations Management: A Systems Concept. Boston: Houghton Mifflin Company, 1972.

Figure 1. Model of a Basic System

It is readily seen that the resources and outputs listed in Figure 1 pertain in particular to business organizations. Other types of resources and outputs would be applicable to other types of systems. Any elementary system model will, however, be composed of combinations of three basic elements--input, conversion (or transformation), and output (54, p. 57).

Models. Inherent in the systems concept is the use of models. According to Starr (78, p. 31), "a model is a simplified representation of reality." Although there are many types or categories of models, the type which is used primarily in this study is the schematic model described by Hopeman (35, p. 33):

> Schematic models represent a greater degree of abstraction from real phenomena than physical models. Examples of schematic models are organization charts, flow charts, block diagrams, and other pictorial abstractions. Whereas physical models are constructed to represent objects in a system which are easily observable, schematic models offer greater flexibility in that they can represent relationships which are conceptual. An organization structure does not physically exist, a flow chart does not physically exist, and a block diagram does not physically exist, yet they provide meaningful symbolic representations of relationships which do exist even though they are not physical objects.

Such models are useful in depicting the boundaries of systems under study. They provide a means of expanding or contracting the level of detail in accordance with the need of the investigator. In general, models provide a means of abstraction which aids communication. The schematic model is employed in the following sections to conceptualize the important characteristics, relationships, and interactions of various systems and functions. Other types of models, particularly mathematical or "management science" models, are discussed in

Chapter IV in conjunction with specific decision settings where their use is indicated.

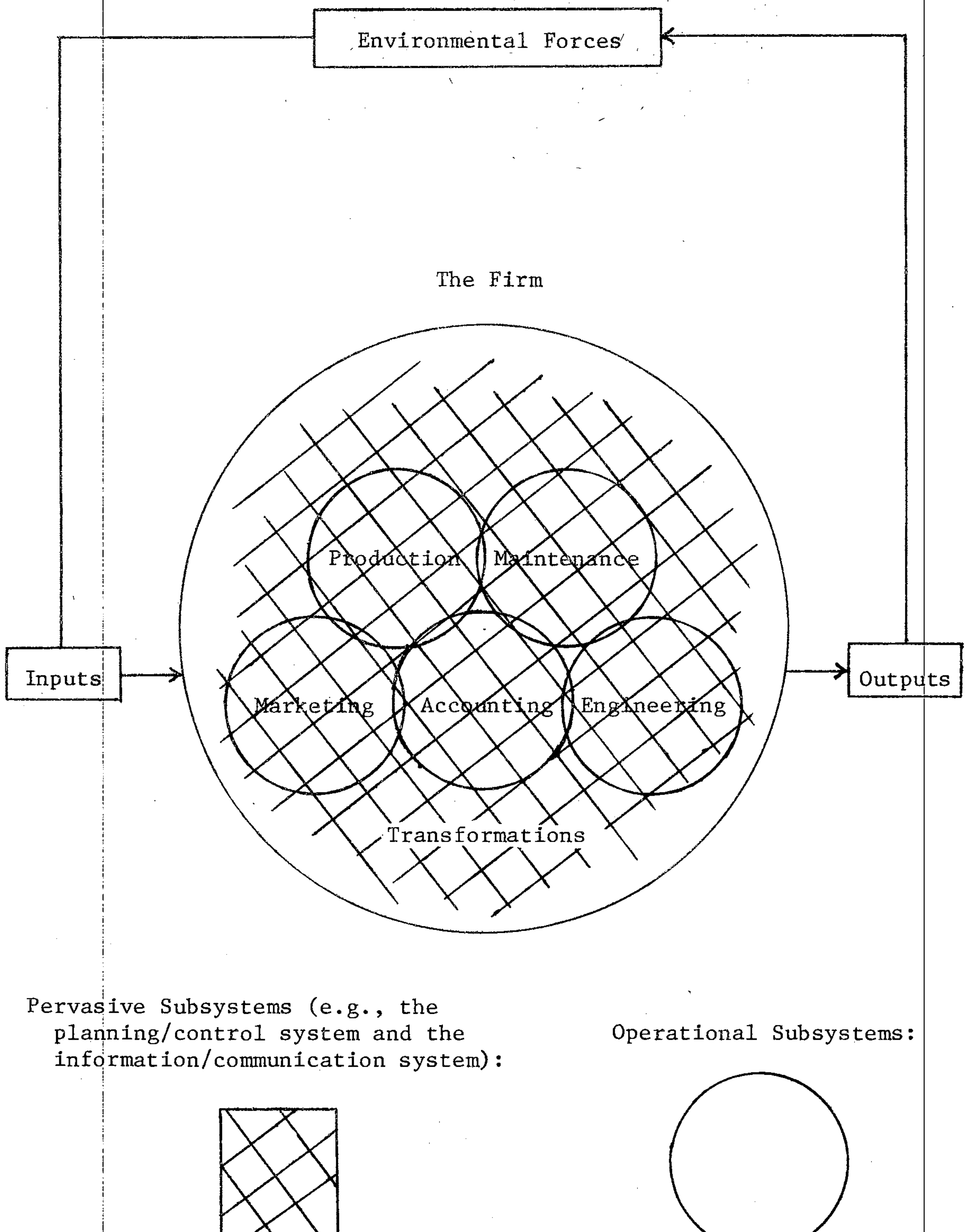
The Organization as a System

In viewing the business organization as a system, it becomes apparent that it really constitutes a collection of systems, or subsystems as illustrated in Figure 2.

A basic notion of the systems approach to management and organization is the interrelationship of the parts or subsystems of the organization. The starting point of the approach is a set of goals, and the focus is on the achievement of these goals and optimization of the input-output relationships for the system as a whole rather than for any single subsystem. The concept of management by system offers several advantages over the typical functional approach (discussed in the following section). First, explicit recognition is given to the total system (organization) as well as the separately definable subsystems. As shown by Figure 2, the latter includes both subsystems identifiable with particular activities or operations (e.g., production, marketing, engineering, accounting) and other subsystems which are not identifiable with a single operating function (e.g., planning/control systems, information and communication systems), but pervade the entire system--as indicated by the grid lines.[1] Second, the systems approach offers a means of accomodating the complexity of the

---

[1]The distinction between operating systems and pervasive systems is not clearcut in all cases. For example, the accounting system may be associated with particular operations (e.g., the collection and processing of data and transmission of reports), but it is also a part of the information system which pervades the firm.



Source: Original

Figure 2. A Conceptual Model of the Business Organization as a System

modern organization.[2] It provides a framework for systematic consideration of the hierarchy of systems, including the goal-subgoal relationships. Finally, the concepts of information theory and decision theory, which have themselves been proposed as a basis for management of organizations, can be readily incorporated into the systems approach. In other words, the systems approach to management embraces properly designed information systems for decision-making.

Basically, then, the systems approach implies a perspective in which the firm is viewed as a set of activities that must be coordinated. A complete expansion of this view implies that an analysis of any operation must include all other operations that relate to or influence the operation under study. Such an expanded analysis would be impractical. On a practical level, the systems approach does imply an investigation of an operation or system in as broad a context as possible. At some point (exactly when may have to be subjectively determined), further investigation becomes impractical because the benefits of such an investigation, as measured by improved systems effectiveness or efficiency, are insignificant.

Role of Management in the Organization

In the preceding section, it was mentioned that the systems

---

[2]The term "organization" as used hereafter applies to "administered organizations" as opposed to organizations viewed broadly as "any group of persons associated together." Anthony (9, p. 9) describes administered organizations as those having the following four characteristics:

(1) they exhibit sustained collective action,
(2) they are integral parts of a larger system,
(3) they have specialized, delimited goals, and
(4) they are dependent upon interchange with the larger system.

approach entails viewing the organization as a set of activities that must be coordinated. The "coordinating" is accomplished via the management function as indicated by the following quotations:

> Management involves the coordination of human and material resources toward objective accomplishment. . . .
> Management is the primary force within organizations which coordinates the activities of the subsystems and relates them to the environment (43, p. 6).

> Management is the process by which individual and group effort is coordinated toward group goals (23, p. 4).

> Essentially, management is the process whereby these unrelated resources [men, machines, and money] are integrated into a total system for objective accomplishment (42, p. 14).

> Basically, the task of management can be described as that of allocating the system's resources to its subsystems such that its goals are achieved (5, p. 297).

The overall job of the manager, then, is to create within the organization the environment which will facilitate the accomplishment of its objectives.

Two developments in the theory of management are of particular interest for purposes of this study. One of these is the classical view of management in which attention is focused on certain fundamental managerial functions which are considered essential if an entity is to attain its goals. The second development is associated with the systems view of the organization and the recognition that there are basic differences in the orientation of the managerial system at different levels in the organization.

Managerial Functions. Certain managerial functions have come to be regarded as more or less universal regardless of the manager's place in the organization structure or the type of organization in which the manager is engaged. These various functions or processes have been classified or identified in a number of different ways. The commonly listed functions include forecasting, planning, organizing, staffing, directing, coordinating, controlling, and communicating. Fayol (72, p. 35) listed five "elements" of management which he maintained were universal. They were: planning, organizing, commanding, coordinating and controlling. Lee (46, p. 119), on the other hand, names only one which is "always recognized," that being the element of decision-making. Anthony (9, p. 129-147) provides a summary of the various classificational breakdowns that have been employed by different students of management.

Although the number of functions listed may be expanded by some writers and reduced by others, the two functions of planning and control are virtually always included. Even those who would cover the entire process with the one concept of decision-making generally distinguish the planning and control processes in any analysis of managerial activities. As mentioned above, Lee (46, p. 120-129) takes this approach (listing decision-making as the one managerial function), but immediately follows up with a discussion of (a) planning decisions and (b) the decision-making aspects of control processes.

For purposes of this research study, an elaborate classification of managerial functions is not essential. There seems to be no good reason for deviating from the practice encountered most frequently in the accounting literature of giving primary emphasis to the twin functions of planning and controlling (55) (57) (58) (74). However, no concentrated effort will be made to maintain a precise use of terms in this regard. Explicit consideration of distinct managerial functions is not necessary for purposes of this study.

As noted above, the managerial functions are considered to be universal regardless of the managerial level. The orientation toward the functions, however, differs depending on the types of decisions faced by the manager. Since this study will ultimately focus on certain types of maintenance decisions, it is important that these differences in orientation be considered.

Managerial Levels. It has been recognized in recent years that there are basic differences in the orientation of managers toward the performance of their managerial functions depending on both their management level and the character of the decisions which they must make.

Kast and Rosenzweig (43) view the firm as an open socio-technical system. They identify three managerial levels in the hierarchical structure of the complex business organization: the technical, or production level, the organizational (managerial) level, and the institutional or community level. These levels are distinguished as follows:

> The technical system is involved with the actual task performance in the organization. In the business firm, the technical functions involve the actual production and distribution of the products or services--the task performance activities of the organization. The technical system is not just involved with physical work but includes many types of technical activities utilizing knowledge. For example, research and development, production control, market research, operations research, and many accounting functions are part of the technical system. . . .
>
> The second level, the organizational, coordinates and integrates the task performance of the technical system. A primary function of management at this level is to integrate the input of material, energy, and information to the technical level.
>
> The institutional level is involved in relating the activities of the organization to its environmental system. The organization must continually receive supporting inputs

> from the society in order to carry on its transformation activities (43, p. 129).

Kast describes the managerial system as spanning the entire organization by directing the technology, organizing resources, and relating the organization to its environment. He explains the differences in orientation at these three levels.

> The technical level is concerned primarily with economic-technical rationality and tries to create certainty by "closing the technical core" to many variables. Thompson says, "Under norms of rationality, organizations seek to seal off their core technologies from environmental influences. Since complete closure is impossible, they seek to buffer environmental influences by surrounding their technical cores with input and output components." The closed system view is applicable to the "technical core" of the organization.
>
> By contrast, at the institutional level the organization faces the greatest degree of uncertainty in terms of inputs from its environment over which it has little or no control. Therefore, management at this level should have an open-system view and concentrate on adaptive and/or innovative strategies. The organizational manager operates between the technical core and the institutional level and serves to mediate and coordinate the two. This level transforms the uncertainty of the environment into the economic-technical rationality necessary for input into the technical core (43, p. 129-130).

According to Kast, recognition of these levels permits a useful differentiation in the types of managers necessary at the three levels. These differences are classified in terms of the task performed, point of view, techniques employed, time horizon, and decision-making. Table I summarizes these differences. Note that Table I shows that the decision-making strategy differs for various managerial levels. As will be explained later in the context of Anthony's framework, this has significant implications for design of both the planning and control system and the accounting system.

TABLE I

THE MANAGERIAL SYSTEM: TECHNICAL, ORGANIZATIONAL, AND INSTITUTIONAL LEVELS

Type of Manager	Task	Viewpoint	Technique	Time Horizon	Decision-Making Strategy
Technical	Technical rationality	Engineering	Scientific management, operations research	Short run	Computational
Organizational	Coordination	Political	Mediation	Short run and long run	Compromise
Institutional	Deal with uncertainty, relate organization to environment	Conceptual and philosophical	Opportunistic surveillance, negotiate with environment	Long run	Judgmental

Source: Fremont E. Kast and James E. Rosenzweig. Organization and Management: A Systems Approach. New York: McGraw-Hill Book Company, 1970.

Decision-making. It has previously been suggested that decision-making is the most pervasive of the managerial functions. Further evidence of the prominence of decision-making in managerial activity is provided by the following quotations:

> Decision-making is the root process of all managing. It is the generalized activity--common to all management (78, p. 117).

> All managerial activity might be considered decision-making. . . . If all behavior results from decision making and if managing is a particular kind of behavior, then managing is decision making. Obviously there are other useful ways to view management--concentration on process or functions, for example. But decision making is one of the most important tasks of managers. It pervades the performance of all managerial functions (43, p. 344).

> Control, like administration and management, is subject to a variety of definitions or shades of meaning. Certainly it is one of management's most important functions, running a close second in importance to decision making (47, p. 2).

Cyert and March's A Behavioral Theory of the Firm (19) is in reality a theory of decision-making within business organizations. Given this primacy of decision-making, it is essential that specific consideration by given to decisions and the decison process in formulating the requirements of an effective planning and control system. In this regard, it is of interest to examine the definition of a decision, the factors which characterize a decision, and the conceptual phases of the management decision process.

A decision is a choice from among alternative courses of action (41, p. 21). The American Accounting Association's Committee on Foundations of Accounting Measurement lists five factors which characterize a decision:

(1) A <u>purpose entity</u> distinguishable from its environment, which possesses preferences for survival and achievement of its objectives;

(2) two or more <u>alternatives</u> open to the entity, which is capable of choosing and executing one of them;

(3) <u>states of nature</u> not controlled by the entity which influence the outcome of a selected alternative;

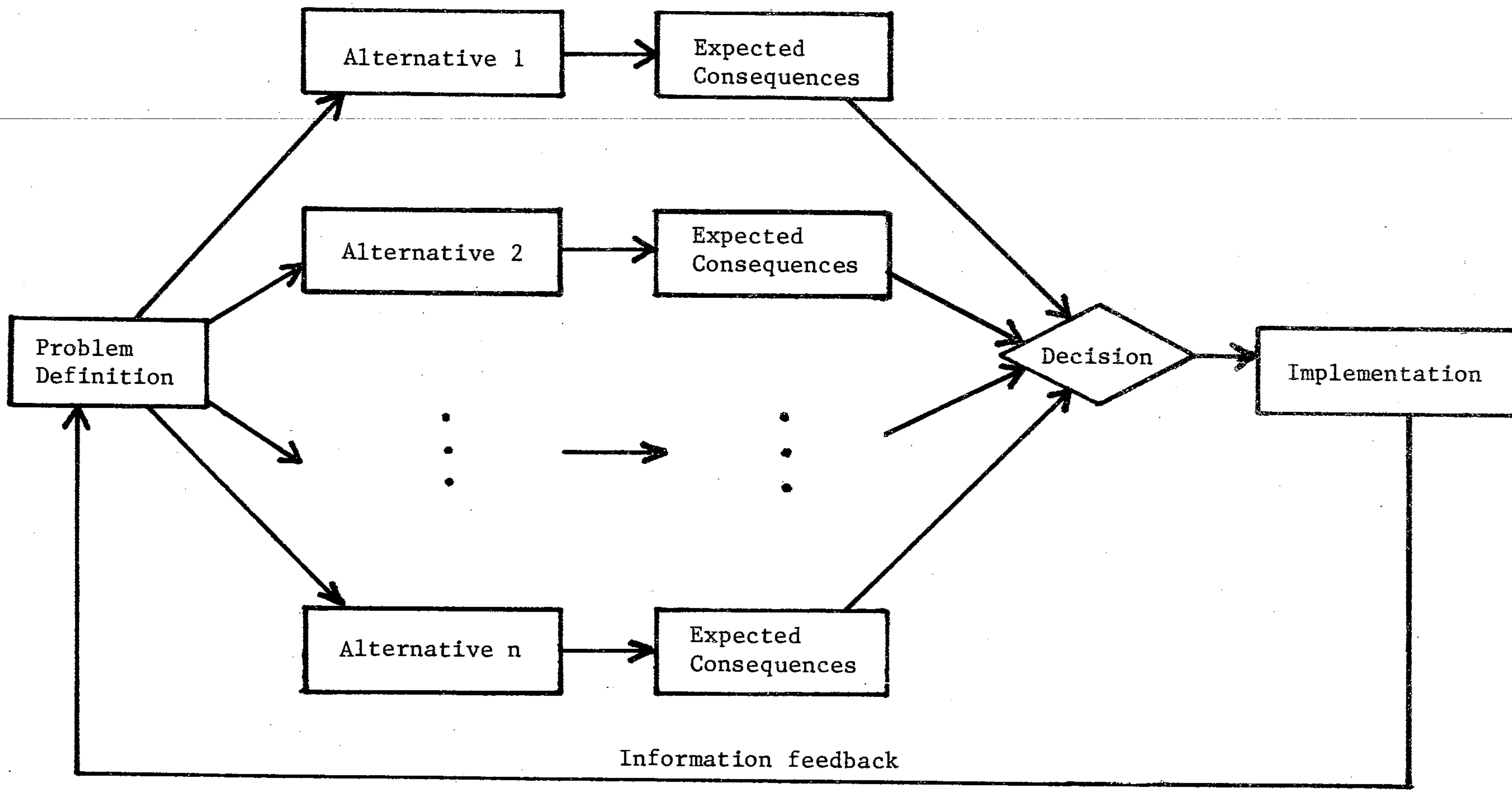
(4) <u>expected outcomes</u> which are the consequences anticipated after execution of an alternative; and

(5) <u>expected payoffs</u> which are the evaluation of outcomes based on the preferences of the entity (3, p. 12).

Decisions may also be characterized in terms of their degree of structure. Simon (75, p. 5-6) takes this approach, and categorizes decisions as programmed or nonprogrammed. Decisions are categorized as programmed "to the extent that they are repetitive and routine, to the extent that a definite procedure has been worked out for handling them so that they don't have to be treated *de novo* each time they occur." Nonprogrammed decisions are described as "novel, unstructured, and consequential."

Decision-making comprises three main phases: finding occasion for making a decision; finding alternative courses of action; and choosing among courses of action (75, p. 1). Johnson (41, p. 21) lists six elements in the decision process: (1) problem definition, (2) discovery of alternative courses of action, (3) evaluation of alternatives, (4) selection of course of action, (5) implementation of decision, and (6) information feedback of results. These steps are portrayed in Figure 3.

The American Accounting Association's Committee on Accounting Theory Construction and Verification (2, p. 63-66) has pointed out that prediction and prediction models are an inherent part of the decision process since decisions must relate to future actions. Thus,



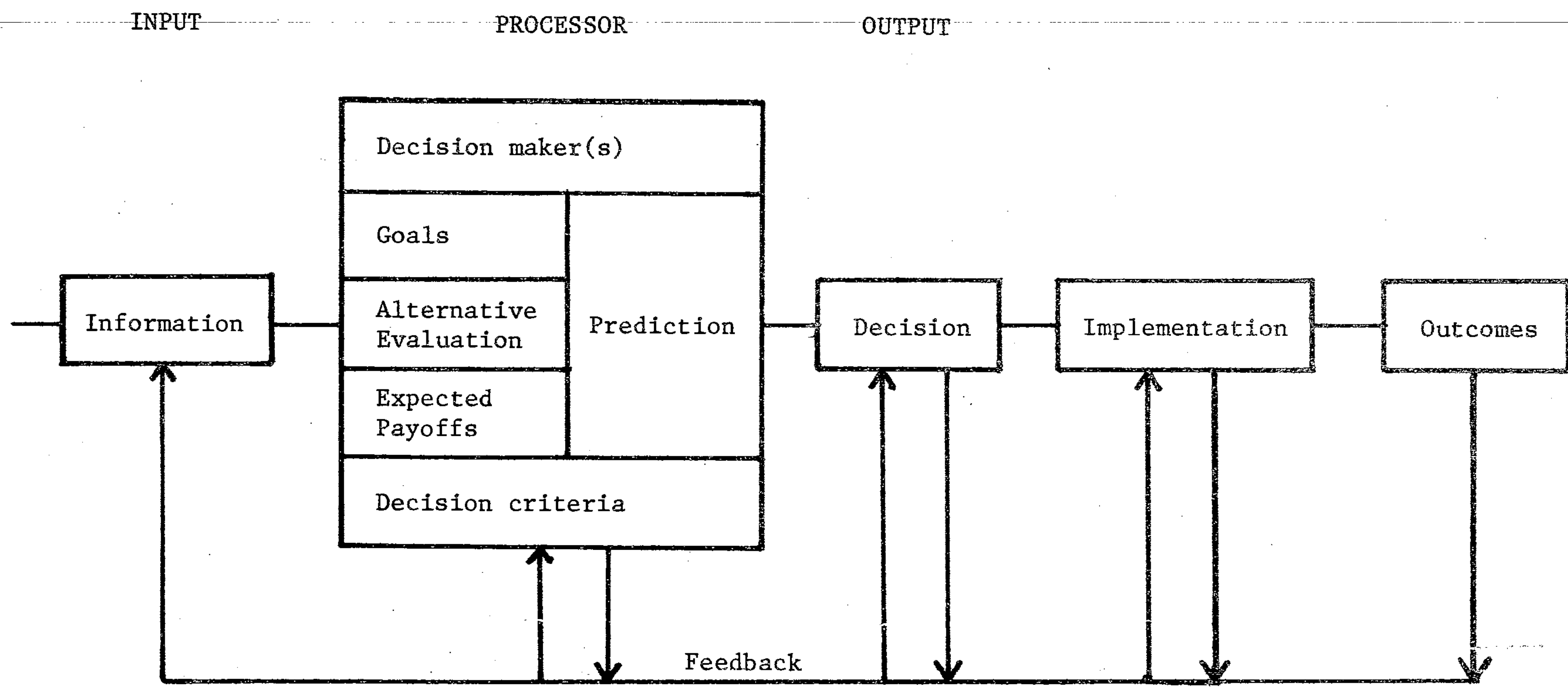
Source: Richard A. Johnson, William T. Newell, and Roger C. Vergin. Operations Management: A Systems Concept. Boston: Houghton Mifflin Comapny, 1972

Figure 3. Flow Diagram of the Decision-Making Process

a slightly expanded, but still quite simplified model of the management decision process might appear as in Figure 4. Observe that the decision-maker is viewed as the processor of inputs (information) and that the outputs are decisions. Actually, the decision maker, whether an individual or group, constitutes a "black box" (33, p. 29-33), and his complex inner workings are subject to a good deal of speculation. However, it is useful to recognize that prediction is a vital part of the decision-making process because information requirements, and the ease with which they may be satisfied, will differ depending on the types of predictions and decisions being made. Observe also that the diagram implies that decision-making is an iterative process rather than simply a chain of sequential activities. At any stage in the process, new information may arise and the feedback of this new information may result in changes or modifications at prior stages.

In addition to conceptualizing the decision process as in Figure 4, it is also useful to represent the decision process as a function. Ijiri, Jaedicke, and Knight (39) use this approach to concentrate on the role of accounting information in decision-making. They describe the decision process as characterized by decision inputs, decision outputs, and a decision rule. Decision inputs are the variables considered by the decision maker in making his decision. A decision rule associates inputs with decisions (outputs). Selection of a decision rule is made within the context of a set of objectives. Using as an example a decision with one assumed input, the decision rule, h, is represented symbolically as:

$$z = h(x)$$



Source: Original

Figure 4. A Model of the Management Decision Process

where x represents a variable for the input and z a variable for the output. Of course, there are typically several inputs to the decision--some of which are controllable and some noncontrollable. For this reason, the equation might be changed to read:

$$z = h(x,y)$$

The letter x represents all controllable, independent variables; y represents the noncontrollable, independent variables (external factors); and z, the dependent variable, represents the objective (usually the "optimum" alternative). If values are assigned to x and y, then the equation can be solved.[3]

For purposes of this study, recognition and specification of the controllable and noncontrollable independent variables (inputs) is important for two reasons. First, most functions are complex and dependencies exist among the independent variables. Consideration of these interrelationships enhances the probability of achievement of objectives. Secondly, there are significant accounting measurement problems associated with the assignment of values to the variables. In a theoretical clarification of the relationship between the accounting process and the decision process, Ijiri, et al., (39, p. 192-197) explore conditions under which accounting methods affect decisions. They point out that accounting data are generally surrogated decision inputs.[4] Their findings indicate that accounting

---

[3]The equation may be useful even where the variables cannot be quantified since it provides a systematic view of relationships.

[4]A principal input is one upon which the decision maker wants to base his decision ultimately. A surrogated input serves as a

information impacts not only on the quality of managerial decisions through its reliability as a surrogate, but may in some circumstances serve to define the goals and decision procedures of the manager(s). The manner in which accounting information impinges upon the decision maker and the decision process is at present poorly understood. Nevertheless, a systems approach to decision making should tend to minimize the dysfunctional consequences of accounting information. The emphasis on goal-subgoal relationships within the firm should serve to reduce the probability that accounting information might cause the decision maker to restrict his goals and alternatives to ones other than those which are most useful for the organization.

Information and the Role of Accounting in Serving Decision Needs

As seen in the preceding section, there is an indelible link between information and decisions.[5] Indeed information can appropriately be referred to as the fuel of the decision process. This research study is ultimately concerned with information requirements which are to be met by the accounting system, as opposed to those met by other parts of the firm's information system. In this context, it

---

substitute for the principal. As such, it is a decision input upon which the decision maker bases his decision only to the extent that the surrogate reflects a principal. For further elaboration, see Ijiri, et al., (39) pages 218-222.

[5] Davidson and Trueblood describe the tie between the accounting process and the decision-making process as basically one of information, saying, "In its broadest and most fruitful sense, accounting is an information or data-providing function--and information of one kind or another is required at each stage of the problem-solving process" (20, p. 578).

is necessary that assumptions be made as to the place of accounting as a part of the organization's formal information system and the appropriate role of the management accountant as a participant in the decision process. After defining and specifying the objectives of management accounting, these assumptions are set forth.

The Objectives of Management Accounting. According to McFarland (57, p. 2), "Management accounting encompasses the entire range of economic information needed by those who manage a business enterprise and by those who provide its capital." This definition implies that all accounting is management accounting and thus departs from the customary distinction between financial accounting and managerial accounting. McFarland (57, p. 93) does distinguish external reporting from internal reporting, but he prefers to view external reporting as an integral aspect of management accounting.[6] The American Accounting Association's Committee to Prepare a Statement of Basic Accounting Theory (6, p. 38) states that "the objective of accounting for internal use is to provide information to persons within an organization that enables them to make informed judgments and effective decisions which further the organization's goals." The Committee offers the following definition:

---

[6]The AAA's Committee on Foundations of Accounting Measurement (3, p. 3-12) distinguishes between "equity accounting" and "operational accounting." Operational accounting is viewed as a subset of management information systems and refers to accounting designed to aid management decision making as well as investment decisions by investors. It is also referred to as "accounting for resource allocation" or "accounting for economic decisions." Operational accounting focuses on the predictive value of information whereas "equity accounting" focuses on the reconciliation of various interested parties of the organization.

> Management accounting is the application of appropriate techniques and concepts in processing the historical and projected economic data of an entity to assist management in establishing plans for reasonable economic objectives and in the making of rational decisions with a view toward achieving these objectives (6, p. 39).

It is readily seen from the foregoing definitions and from perusing the initial chapters of textbooks on cost and managerial accounting (24) (36) (55) (58) (74) that the emphasis is on serving the informational needs of management brought about by the problems they face and the solution techniques they use. This emphasis forms the basis for consideration of the scope of the accounting information system.

The Accounting Information System. The American Accounting Association's Committee on Accounting and Information Systems, (5, p. 289-296) considered the question of how accounting fits into the firm's overall information system in their 1971 report. The committee points out that "developments in information and management theory and technology are making the boundaries between what is and what is not 'accounting' increasingly dim." On the premise that accounting does have some concepts, problems, and characteristics which differ from other information activities, they distinguish the accounting system as follows:

> The Committee considers the Accounting Information System to be that portion of the formal information system concerned with the measurement and prediction of income, wealth, and other economic events of the organization and its subparts or entities.

This viewpoint places some boundaries (however imprecise) on the accounting system and it is an adequate distinction for purposes of this research.

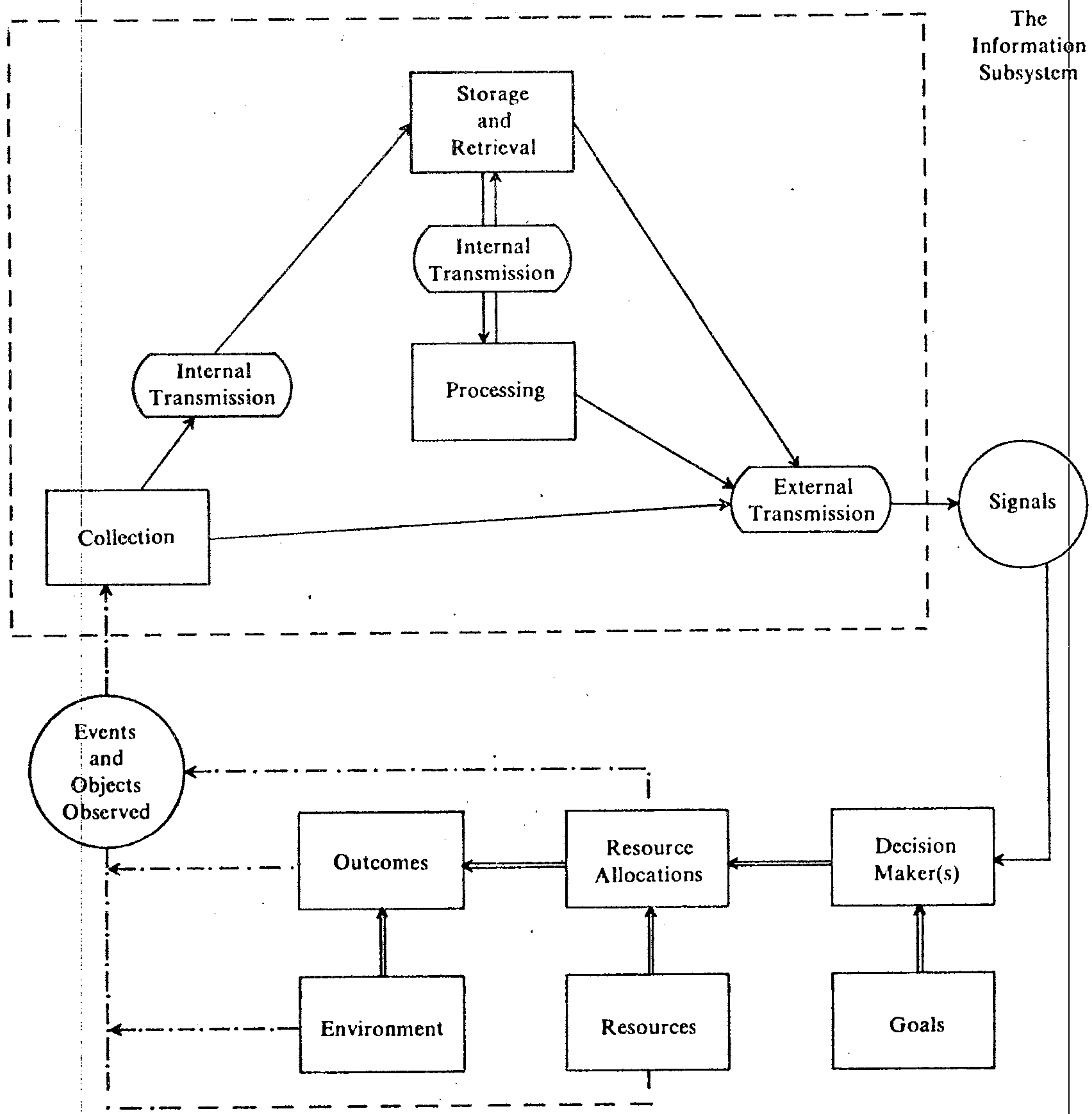
The committee (5, p. 298) also provides a simple model (Figure 5) which is useful for depicting the relationship between the accounting information subsystem and the remainder of the total system. The model, as developed by the committee, is applicable to any information subsystem; however, the only change necessary to make it apply specifically to the accounting system is to restrict the data collected (i.e., the events and objects observed) to that which is economic in nature.

In Figure 5, the information subsystem (bounded by the broken lines) consists of the activities of collection, processing, storage and retrieval, and transmission of data. The signals transmitted to the decision maker(s) comprise one input to the decison process. The committee (5, p. 298-299) describes the remainder of the system.

> Based on the information derived from these signals, his previous experience, and his goals, each decision maker selects resource allocations which are to be implemented. The resource allocations actually implemented and the environment at the time of these allocations determine the firm's outcomes. They also effect [sic] the resources available and the environment for future periods. The information system makes observations on some of the events and objects which make up the organization's resources, resource allocations, outcomes, and environment; it also records data which represent descriptions of what was observed.

They also point out that the process is repetitive, indicating the existence of a time dimension which is not depicted in Figure 5.

<u>Assumptions as to the Appropriate Role of the Management Accountant</u>. The appropriate function of accounting in the management planning and control process is not well defined and there are several different philosophies concerning just how active a role the management accountant should assume (3, p. 5-6). The AAA's Committee on



Source: American Accounting Association. "Report of the Committee on Accounting and Information Systems." The Accounting Review, Supplement to Vol. XLVI (1971), p. 298.

Figure 5. A Functional Model of the Information Subsystem and Its Role in the Total System

Accounting and Information Systems (5) lists six basic activities which have been included in the traditional concept of the accountant's activities and responsibilities.

1. Perform and facilitate the attest function.
2. Keep records on economic performance and related third party needs.
3. Provide an overall management control function.
4. Perform a number of operating duties involving financial management.
5. Design and manage information systems.
6. Provide information for a variety of decision-making purposes (5, p. 295).

The committee cites evidence indicating that the current information environment (which has resulted from developments in EDP and their impact on information handling; theoretical developments in systems analysis and control, communications theory, information economics, measurement theory, and decision theory; and the consequent elevation of the information system function in the organization) has dramatically decreased the accountant's importance in relation to the performance of the last three activities, all of which relate to management accounting. They call on the accounting profession to choose in a rational and informed manner the role it wishes to have in the developing area of information management. The inference is that failure to take an active role will result in further erosion of the accounting function.[7]

The basic assumption of this study is that the management accounting system is an important subset of the firm's formal

---

[7]The committee (5, p. 344-350) makes no explicit recommendation on this matter; however, it is made clear that "the Committee believes that accounting in the broad sense of the term can and should rise to the challenge and opportunities of the developing information technologies and take the lead in information management."

information system and should serve as the basic information system for the management planning and control functions and for the various decision models used to implement these functions. This is in accord with the AAA's 1966 Statement (6, p. 40) as emphasized in the following assertion:

> The breadth of management's scope and hence the requirements placed on information involve the management accountant not only in his own technology and in economics but in the behavioral and management sciences areas as well. Management is increasingly involved in using quantified data in areas where qualitative judgment prevailed a decade or two ago. When this requires measures and techniques based on other disciplines, the management accountant must be prepared to fulfill these needs. He should understand the information requirements well enough to be an intelligent supplier of relevant data for use in the decision-making models if, indeed, not the originator and manipulator of these models. At the minimum, the accounting system must provide the means to evaluate the appropriateness of the information needed and in no case should the accountant be merely the passive supplier of untreated data.

A Generalized Planning and Control Framework Oriented to Decision Characteristics

The preceding sections of this chapter have dealt with topics and considerations which should be taken into account in the design of an effective planning and control system and in the design of the accounting information system if it is to make a positive contribution to the management decision process.

The purpose of this section is to present a generalized planning and control framework suitable for application to large industrial organizations and to investigate the means by which the operation of the accounting system can be properly integrated into the planning and control system via consideration of decision characteristics. Primary reliance will be placed on Anthony's (9) framework for analysis of planning and control systems, the basic features of which are described below.

The elements of systems theory, management and organization theory, and decision-making which have been previously discussed support the Anthony framework and are synthesized in that framework, although the writer realizes that any brief presentation of supportive theory is likely to suffer some distortion by condensation. The discussion of information needs and the role of management accounting provide the basis for expanding Anthony's framework to suit the major objective of this study, i.e., the conceptualization of the role of the management accounting system in satisfying the information needs associated with different general categories of decisions and, ultimately, with specific decisions within those categories as they relate to the maintenance activity. Anthony attempted to provide a broad framework for analysis of planning and control systems which would enable the making of valid generalizations about managerial activities and decisions based upon the characteristics which distinguish those managerial activities and decisions. The writer's aim is (1) to apply that framework--expanded to include its implications for the accounting information system--to a particular operational system (maintenance) within an organization and (2) to investigate, within that framework, specific decision settings, specific information and communication needs, and specific means by which the accounting system can meet the informational needs associated with the decision process.

The Anthony Decision Framework

As a basis for examining the information requirements of managerial decisions, a framework is needed which incorporates the systems approach and which provides for decision classification according to type and managerial level. The conceptual framework developed by R. N. Anthony (9) fulfills these requirements. This is demonstrated in the systems emphasis referred to in the preceding paragraph and in the discussion which follows.

Anthony identifies three main processes in the planning and control hierarchy of the large organization: strategic planning, management control, and operational control (9, p. 1-23). The purpose of this section is to define each of these processes and describe briefly their essential characteristics.

> Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are to govern the acquisition, use, and disposition of these resources.
>
> Management control is the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives.
>
> Operational control is the process of assuring that specific tasks are carried out effectively and efficiently.

In general, these categories coincide closely with the three managerial levels identified by Kast and Rosenzweig and discussed previously on pages 30-32. Strategic planning represents the highest (institutional) level in the decision-making hierarchy, relating the organization to its environment and setting the course which the organization will pursue. The dominant managerial function is planning.

The persons involved in the decision process at this level are top management assisted by staff. The decisions they face are typically unstructured and irregular. Each problem is more or less unique. Information requirements are largely external and supplied on an *ad hoc* basis, specifically tailored for each plan or problem. Relevant measurement concepts are commonly marginal or incremental revenues and costs and opportunity costs.

At the organizational level, management control involves implementation of strategic planning decisions. The management control process is carried on within guidelines established by strategic planning. The focus is on the role of line managers. The management control process involves planning decisions, as well as control, but the plans are made within given objectives, facilities, organization structure, and the like. Hence, the decisions made at the management control level have different characteristics from those made at the strategic planning level. By the same token, the information needed for management control decisions is of a considerably different character than that employed in strategic planning. The decisions tend to be recurring in nature, following a somewhat regular timetable. The information needs are more readily determinable, and a substantial part of the information may be routinely accumulated in the accounts because it tends to be more internal and historical in nature. Decisions are arrived at subjectively since the optimum relationship between inputs and outputs cannot be specified. This subjectivity implies that a careful analysis of cost concepts (or other measures) is necessary to insure that the information system provides relevant information for decisions made at this level. Costs are generally categorized as "managed costs," whereas "engineered costs" are typical of the operational control process.[8] The management control process integrates the upper and lower levels in the system hierarchy by designing the means of implementing strategic planning and by formulating decision rules based on objectives and policies to serve as guidelines for operational control.

At the "technical level," the dominant managerial function is control, and emphasis is on single tasks or events.[9] Decisions are objectively determined, made within the context of precise decision rules or models, and information inputs are well-defined.

The framework, then, developed by Anthony provides for a three-way classification of the processes that fall within the broad term, Planning and Control Systems. This classification and the distinguishing characteristics of each process are summarized in Table II along with some of the implications for gearing the accounting system to serve each process effectively.

Accounting Implications

Examination of the processes of strategic planning, management

---

[8]According to Anthony (8, p. 22), "managed costs" is a term descriptive of those types of resources for which an objective decision as to the optimum quantity to be employed cannot be made. An important management function is to make judgments as to the "right" amount of managed costs in a given set of circumstances. "Engineered costs" are elements of cost for which the right or proper amount of costs that should be incurred can be estimated on an objective basis.

[9]Although the term, technical, is associated with Kast and others (43, p. 129-131), Anthony originally labeled his third main topic "technical control," rather than operational control, in his early work on the subject (8).

TABLE II

CLASSIFICATIONAL REFERENT FOR PLANNING AND CONTROL PROCESSES AND INFORMATION-DECISION CHARACTERISTICS

	DECISIONS			
PROCESS/LEVEL	Broad Context	Characteristics	Informational Inputs & Accounting Implications	Outputs
Strategic Planning Institutional Top Management and Staff	Goal Formulation Resource acquisition & allocation	Unstructured Environmental Orientation Many Variables Planning Emphasis Predictive	External Emphasis Unanticipated internal information Special staff studies and analyses	Goals Policies and precedents
Management Control Organizational Top and Line Management	Goal Congruence Resource Allocation	Rhythmic Constrained Subjective Internal orientation Planning and control emphasis	Internal emphasis Historical & predictive Regular & special reports Secondary measures Retrospective and prospective measures Managed costs Data bank approach	Decisions Implementation within policies & precedents Procedures and Rules
Operational Control Technical Line Supervisors, foremen, etc.	Task oriented	Stable Programmed Objective Control emphasis Constrained by procedures, rules	Internal events Transactions More non-financial measures Primary measures Engineered costs Real time	Execution

Source: Compiled primarily from Robert N. Anthony. Planning and Control Systems: A Framework for Analysis. Boston: Harvard University, 1965. Also, Sherman C. Blumemthal. Management Information Systems: A *Framework for Planning and Development*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

control, and operational control permits some initial generalizations about the demands that each process imposes on the accounting system, although this is discussed in greater detail in Chapter IV.

The unstructured, non-repetitive problems common to strategic planning depend largely on external information, subjective determination, and unique data arrangements. Internal information needed for strategic planning is normally unanticipated. Even where the problem is foreseen, it is unlikely that data collected regularly in a form useful for an occasional strategic decision will be worth the cost of collection. The accounting department may be called upon to participate in staff studies or prepare special analyses to assist in strategic planning. In general, however, if information required for a strategic planning problem is readily available in the accounting system it is due to either (1) a fortuitous data base selection or (2) the fact that the information requirements happen to be the same as those required for a management control or operational control decision for which data is routinely accumulated.

In subsequent chapters, it will be seen in examination of the maintenance function that strategic planning decisions are rarely encountered. The maintenance function is of the nature that it is associated with the ongoing activities of the firm. Maintenance considerations are, of course, included in some strategic planning decisions, such as, the acquisition of a major facility, or decision to construct a new plant. The maintenance planning and control system _per se_ is, however, concerned almost exclusively with decisions which are, by their character, associated with the management control and operational control decision categories. The strategic planning process is included here because it serves to complete the framework and, therefore, provide the appropriate context for consideration of the other two decision categories. Management control decisions, rather than operational control decisions, are accorded the major emphasis throughout this study because they (1) are more complex, (2) are less well-defined in terms of appropriate methods of analysis, and (3) have a greater impact on the effectiveness and efficiency of the maintenance activity because they set the procedures and rules within which the operational control decisions are made.

Some researchers into this topic have indicated that a consciously designed internal information system cannot be expected to routinely meet the needs of the strategic planning process because its information needs are too unpredictable (9) (11) (21). Others view strategic decision-making as the area having the most challenge for, and deserving of the most attention from, the information specialist and information technology (13). The eventual resolution of this question is of interest, but it has no significant bearing on this research since the strategic planning process does not form an important part of the subject matter of the remaining chapters.

Information needs of the management control process vary, but they are predictable. Information is typically internal and expressed in monetary units. The data needed may call for past, present, or future measures. Both special cost studies prepared on demand and recurring, summary reports are required. Because of the nature of decisions, the accounting system should be designed to allow a variety of analyses including some whose characteristics may be unknown. Thus, the accounting system should collect and process data in a relatively disaggregated form, i.e., a data-bank approach. This applies to the operational control process also, since management control systems derive much of their source data from operational control systems. With regard to the aggregation of data, the AAA's Committee on Foundations of Accounting Measurement (3) distinguishes primary and secondary measures. A primary measure is a number that is generated directly by quantifying the property of an object. A secondary measure is a number that is derived indirectly by an algebraic transformation of a set of numbers which are direct measures of some objects or their attributes. The committee (3, p. 26) then states:

> Because of the heterogeneity of decisions which operational accounting [defined on page 40] must serve, a measurement system must be developed which relies heavily upon primary measures and at the same time is capable of supplying secondary measures upon specific request or upon general demand.

In the context of Anthony's framework, the latter capability is most critical in supplying the needs of the management control process.

The information needed in the operational control process can be more clearly defined and quantified. Frequently, the decisions at this level are of the sort described by Simon (75) as programmed decisions and discussed earlier on page 34. Hence, the information requirements are well-defined, especially where mathematical models, or closed decision models, are employed. Operational control data are frequently nonmonetary, in real time, and related to individual events, whereas data in a manage-control system are either retrospective or prospective and summarize many separate events.

Summary

This chapter has presented a basic framework for classifying activities within the area of planning and control systems. A brief review of the literature in the areas of systems theory, management and organization theory, and decision theory was undertaken to provide theoretical support for the framework. The role of the accounting system was discussed in some detail for the purpose of relating it to the decision process in general and to the processes of strategic planning, management control, and operational control.

In Chapter IV, the framework is applied to the maintenance system. The systems approach is employed by initially identifying the maintenance system's environment, goals, and resources, and subsystems.[10] Subsequently, the major decision settings faced by maintenance managers are specified and examined. This includes classification of each major decision setting according to Anthony's framework, and a conceptual analysis of these decisions and their accounting information requirements.

---

[10] This corresponds to Churchman's conception of the systems approach as discussed earlier (p. 23).

CHAPTER IV

A CONCEPTUAL ANALYSIS OF MAINTENANCE DECISION SETTINGS AND ACCOUNTING INFORMATION REQUIREMENTS

Introduction

As noted in Chapter I, there is general dissatisfaction with the level of effectiveness of maintenance management. This condition is attributed to (1) lack of top management emphasis and attention, (2) misconceptions about the controllability of maintenance costs, and (3) inadequate management accounting data on which to base maintenance decisions. A review of the literature on maintenance in Chapter II established that there is no coordinated body of literature in the area of maintenance planning and control programs. Consequently, the need for a decision framework that looks at maintenance decisions in terms of their impact on the total organization was suggested. Such a framework would take into account the interrelationships between the maintenance activity and other functional units. It would also provide a reference base for the examination of the information needs (including accounting analyses) of maintenance decisions.

In Chapter III, the Anthony decision framework--expanded to include its implications for informational inputs and design of the accounting system--was described and advanced as the basic vehicle for analysis of the maintenance activity. In this chapter, such an analysis is undertaken. Anthony's framework has the advantage of being broadly applicable to large, human organizations. It was formulated to permit the making of valid generalizations about decision making regardless of the specific type of managerial activity. The application of this general framework to the maintenance activity allows for the integration of managerial considerations that are more or less unique to maintenance decisions.

The discussion which follows applies primarily to relatively large industrial organizations because their maintenance decisions are more complex than those of the small organization. The term "industrial," as used herein, refers primarily to manufacturing, or technically productive enterprises. This study is not directed toward the type of organization whose maintenance activities are primarily custodial in nature.

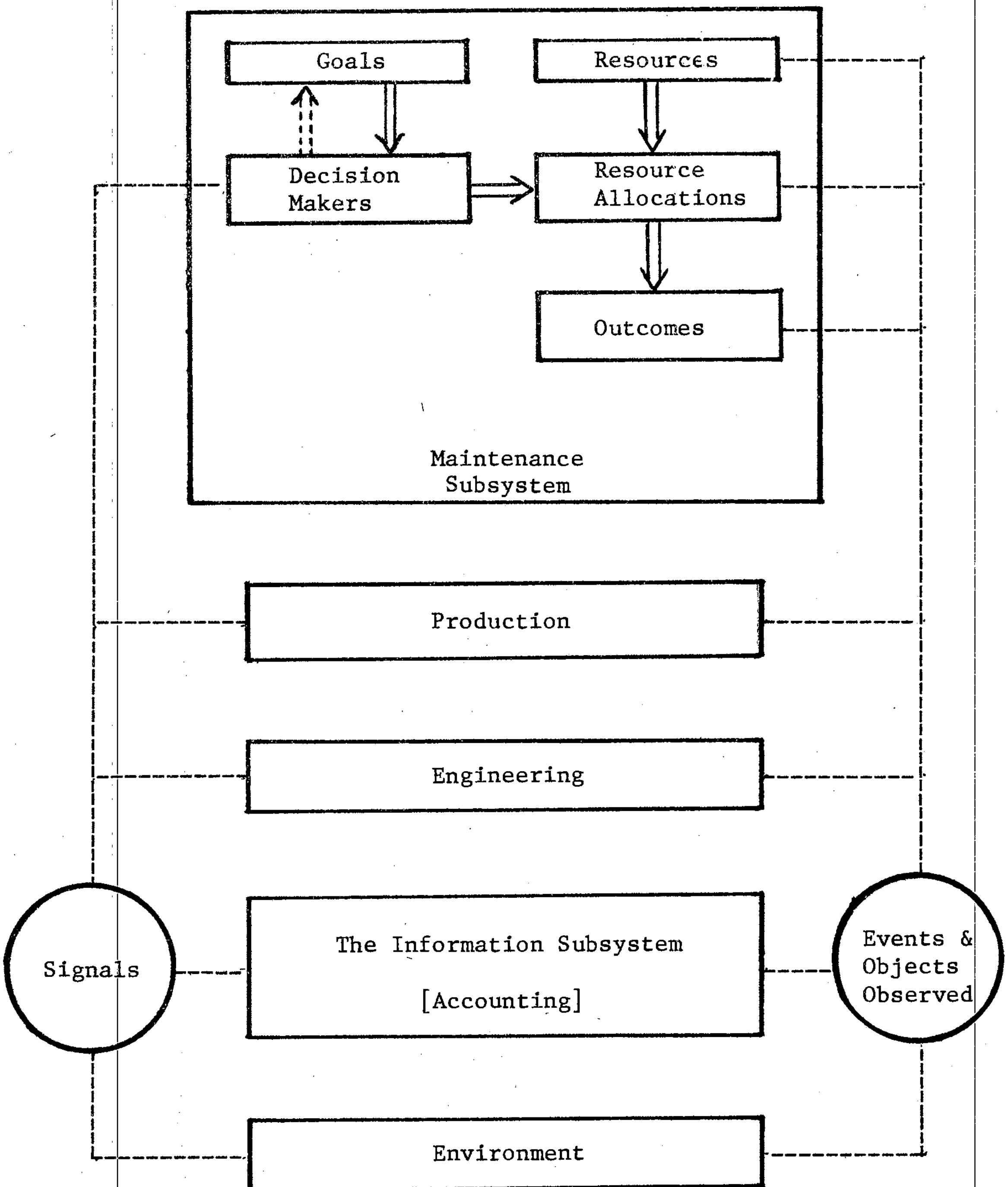
This chapter is divided into three main parts. First, the maintenance activity is described in systems terms. Its environment, goals and responsibilities, resources, and subsystems are set forth. Second, the major maintenance decision settings are examined along with associated objectives, alternatives, controllable and noncontrollable variables, and decision criteria, with the ultimate focus being the accounting information requirements. In the course of examining each decision setting, careful attention is given to (1) classification of the decision within the Anthony framework, (2) interdependencies among decision variables for a given decision, (3) interrelationships among maintenance and non-maintenance decisions, and (4) consideration of decision models or other analytical techniques which are suitable for resolution of the problem, given that their use is economically feasible in the circumstances. A final section stresses the importance of recognizing and identifying cost concepts and cost behavior patterns relevant to particular decisions.

The Maintenance Subsystem and Its Operational Setting

Figure 2 in the preceding chapter (p. 26) presented a conceptual model of the business organization as a system. In this model, the firm is viewed as an open system interacting with its environment. It is assumed that the objective of the firm is to maximize shareholder's wealth subject to ethical, social, political, and legal constraints. The firm consists of various functional subsystems. Through the management process the activities of the functional subsystems are coordinated to transform the inputs (human and material resources) into outputs in such a way as to accomplish the firm's objectives.

The main focus of this study is the maintenance subsystem and its interaction with other subsystems, particularly the accounting information system, in the accomplishment of objectives established in accordance with the objectives of the total organization.

A modified version of Figure 2 is presented in Figure 6 which emphasizes the place of the maintenance subsystem in the organization. The production, engineering, and information subsystems are specifically included in the model because they are the subsystems which more strongly influence, and are influenced by, the maintenance subsystem. Accounting is an integral part of the formal information system, and the provision of accounting information for management decisions is



Source: Original

Figure 6. A Functional Model of the Maintenance Subsystem and Its Role in the Total System

the major concern of this study. The accounting system depicted in Figure 6 is the particular element of the information system to which attention is directed. The environment affects resource availability, the manner of resource allocation, and the outcomes of decisions both of the maintenance activity and of the firm as a whole.

The following discussion is couched in general terms without regard to specific types of industrial firms or equipment configuration. Few maintenance problems are unique to a particular firm. There are "common types" of problems, although environmental factors, work loads, failure rates, costs, and the like may differ, the basic problems remain. By the same token, information requirements can be expected to have certain basic similarities even though the form and timing of reporting will differ among firms.

Maintenance Goals, Resources, and Subsystems

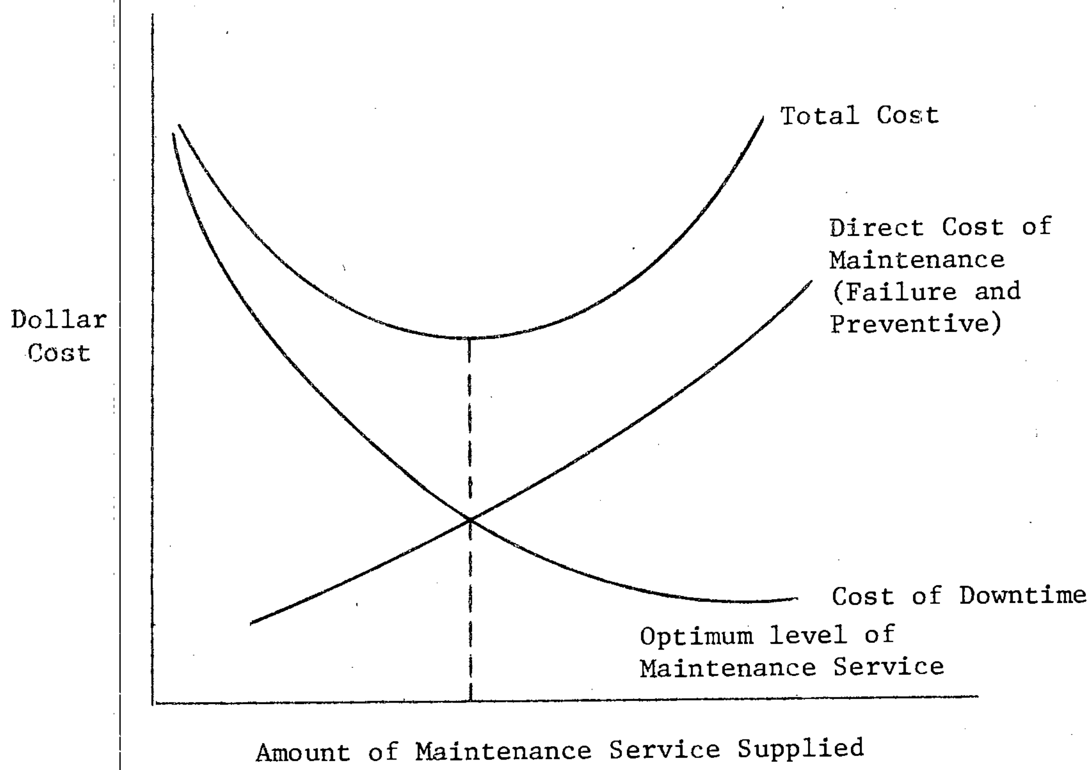
The chief responsibility of the maintenance activity is to further the objectives of the enterprise of which it is a part. If this is to be accomplished, maintenance objectives must be established within the framework of the overall objectives. This implies that the broad goals of the firm must be broken down into a number of operational subgoals that can be related to factors under the control of various individuals. Each goal must be associated with a means by which the goal may be achieved. Hence, objectives are expressed in broad and general terms at the strategic planning level and become more and more specific as they relate to the management control and operational control processes.

As mentioned above, the ultimate goal of the maintenance subsystem is to contribute to the achievement of the organizational goals, that is, maximization of shareholder wealth. Since the primary means of achieving the latter objective is through production and sale of the organization's products, the subordinate goal of maintenance is closely allied to production. The goals of the maintenance system and production system must be consistent. Broadly stated, the goal of the production system is to meet specified production schedules effectively and efficiently with respect to quality, cost, safety, and so forth. In order to do this, the physical production system must be maintained. The maintenance activity assists in achievement of production goals through its influence on effective capacity.

All productive facilities are susceptible to failure or deterioration due to effects of use or the natural process of age. Failure results in (1) costs to replace or repair the facility and (2) breakdown costs due to losses in output if equipment and personnel are idle and no slack capacity exists. Rather than rely on failure or breakdown maintenance, preventive maintenance--essentially, maintenance to prevent failure--can be undertaken. Preventive maintenance practices, if applied indiscriminately, may also result in excessive costs. Therefore, a basic problem of maintenance is the determination of the balance--in terms of both effectiveness and cost--between <u>prevention</u> of equipment failure and <u>correction</u> of equipment failure. There are, then, three basic types of costs that may be initially identified. These are the costs associated with preventive maintenance, failure maintenance, and production downtime. <u>Preventive maintenance</u> (PM) includes replacements, adjustments, major overhauls, inspections, and lubrications preplanned and scheduled on a cycle designated by the engineering, maintenance, or operating departments to maintain equipment and facilities in such condition that breakdowns and the need for emergency repair are minimized. <u>Failure</u>, or <u>breakdown</u> <u>maintenance</u> is that required to repair or replace or otherwise restore equipment or facilities to operational status after failure has occurred. <u>Downtime</u> <u>costs</u> are the costs which result from loss of machine or equipment operation time due to deficiencies in scheduled maintenance practices. They include the cost of lost production, delayed shipment, cost of scrap and re-work caused by faulty machinery, and cost of excessive deterioration of equipment.

The economic decision of determining the optimum level of maintenance is illustrated in Figure 7. The optimal level of maintenance is that point where the total costs of maintenance, whether preventive or failure, and downtime are minimized assuming a specified level of effectiveness.

Several aspects of maintenance management hinder the achievement of "true" optimization. First, as previously indicated, the effects of maintenance decisions cannot be separated from the effects of production and engineering decisions. Thus it is the combined effect of production, engineering, and maintenance decisions which must be assessed. From the standpoint of production, maintenance may be considered effective if it prevents breakdowns or restores failed equipment to service rapidly. The accomplishment of these goals may, however, be accompanied by the inefficient use of maintenance resources. Second, there is an interaction among decisions within the maintenance system as well as among decisions in the maintenance,



Source: Adapted from Howard L. Timms and Michael F. Pohlen. The Production Function in Business, Third Edition. Homewood: Richard D. Irwin, Inc., 1970.

Figure 7. Economics of Maintenance Costs

production, and engineering areas. For example, determination of maintenance crew size is related to preventive maintenance policy. Likewise, replacement decisions are related to overhaul frequency. Third, maintenance decisions are influenced by financial considerations, such as taxes and depreciation. Fourth, the existence of other objectives such as worker safety or reduction of personnel grievances must be considered. Finally, the determination of the extent to which "true" optimization has been attained is a very difficult measurement problem within itself. The methods of measuring maintenance effectiveness are, at best, imprecise.

For these reasons, it can be expected that some degree of sub-optimization will be experienced in solving "real world" maintenance problems.

Maintenance management is concerned with the general economic decision mentioned above, of determining the optimum level of maintenance. This is a broad statement of the maintenance decision problem, and it does not provide a suitable basis for analysis of the information needs of maintenance management. As a practical matter, it is essential for analytical purposes that this broad statement be broken down into several component decisions, or decison settings. It is then feasible to concentrate attention on these more specific decision situations for purposes of (1) isolating the decision variables and criteria, (2) selecting the method of analysis, and (3) determining the information requirements of each decision. As these decisions settings are examined more or less individually in the next section, their interrelationships with other decisions is emphasized.

The resources available to maintenance management consist of men, materials, and equipment. Management must attempt to allocate these limited resources among competing demands for maintenance services in such a manner as to make the maximum contribution to the profit objectives of the firm. In order to accomplish this, an organization is required that provides for some degree of separation of duties through the delegation of authority and the assignment of responsibilities. The organization of plant maintenance plays an important role in its successful operation. In order for the maintenance activity to provide the required services and meet its established objectives, it must be organized to fulfill the needs of its plant environment.

Physical layout of plant, size of facility to be serviced, and nature of the manufacturing activity will have a bearing on the way in which maintenance is organized. However, the advantages and disadvantages of centralization or decentralization, of craft or zone organization, and of placing the maintenance function under the engineering or production departments or giving it equal status with these departments is not discussed herein. This study is concerned with maintenance decisions and their information requirements and these are largely the same regardless of the organizational pattern.

The subsystems of the maintenance system which are generally identifiable are those associated with preventive maintenance, breakdown maintenance, replacements, manpower levels, job planning and scheduling, materials, and mechanical services (i.e., construction and alteration). These subsystems form the basis for analysis of the major decision settings which confront maintenance management.

The Maintenance Decision System

The basic maintenance decision situations may be categorized as:

(a) Breakdown versus preventive maintenance.

(b) Repair versus replacement of worn or defective parts or units.

(c) Provision of mechanical services.

(d) Determination of manpower levels and crew size.

(e) Use of contract versus use of company personnel.

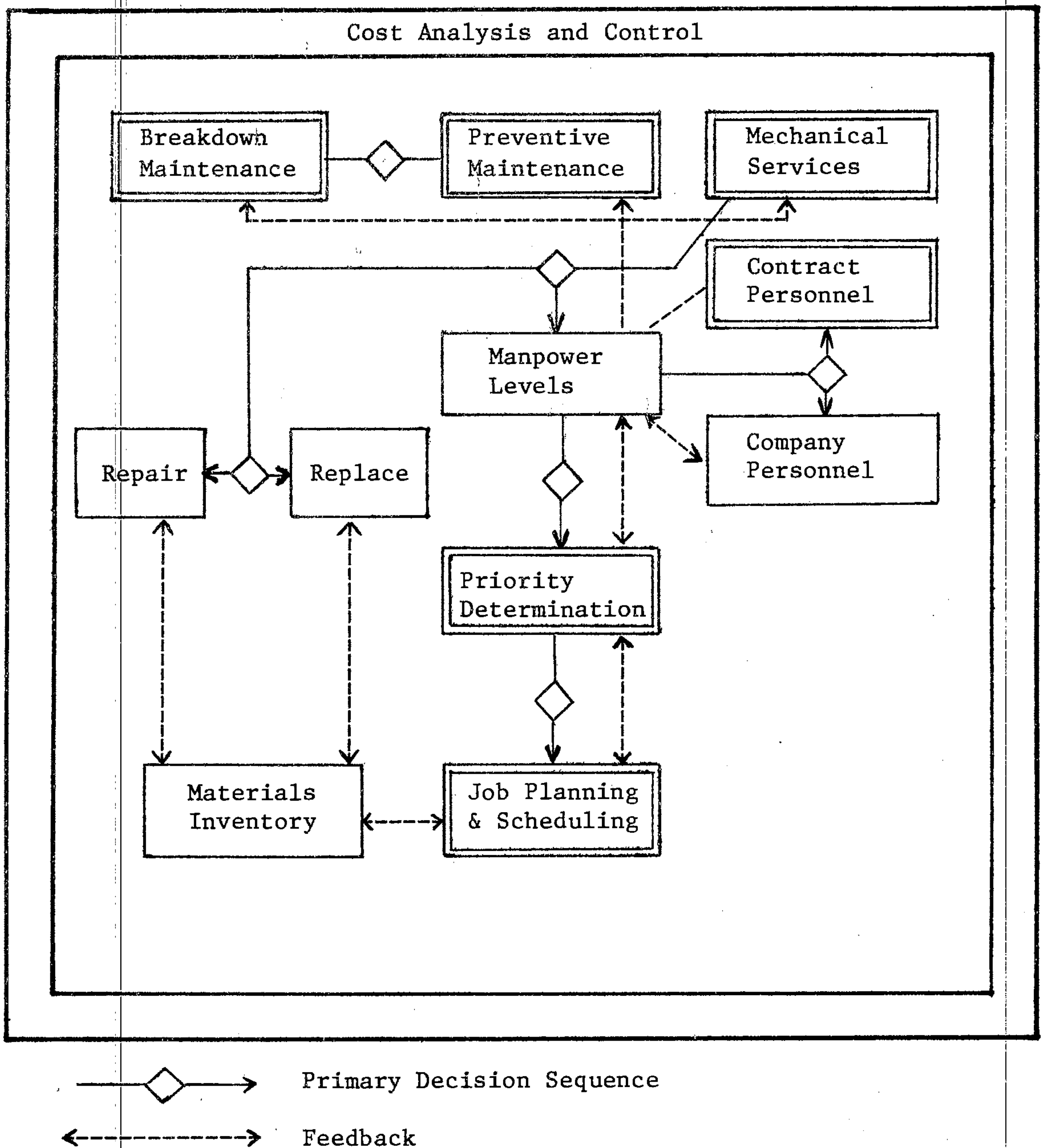
(f) Determination of job priorities, planning, and scheduling.

(g) Determination of optimal maintenance inventory policies.

Although this list is by no means complete, it includes the basic management control decision settings which characterize and are critical to most maintenance programs. Figure 8 depicts these decision situations as a maintenance decision system, hereafter referred to as "MDS." The MDS is composed of the major subsystems indicated in the figure. These subsystems, in combination with additional underlying decision networks related to operational control decisions constitute the total decision system for maintenance.

For a given item of equipment, a decision must be made as to whether to develop a preventive maintenance plan or to rely on breakdown maintenance. If it is determined, say, by analysis of failure patterns, that preventive maintenance is indicated, then subsequent analysis is necessary in order to determine the optimal preventive maintenance schedule and appropriate programs and procedures (inspection, lubrication schedules, etc.) must then be developed to implement the decision. The breakdown vs. preventive maintenance decision influences--and is influenced by--the repair-replacement decision. Also, when combined with consideration of the demand for mechanical services, the breakdown vs. PM decision has a major bearing on the determination of manpower levels.

Following the decision as to the desired manpower level, analysis is necessary to determine whether, in light of overall company objectives, these needs should be filled by internal personnel or by contract personnel. Decisions must also be made to determine how the manpower will be utilized. Job priorities must be determined and each



Source: Adapted, with significant modifications, from Ruddell Reed, Jr. Plant Location, Layout, and Maintenance. Homewood: Richard D. Irwin, Inc., 1967.

Figure 8. General Model of the Maintenance Decision System

job must then be individually planned and scheduled. Allowances must also be made for emergency work that cannot be planned in advance.

Inventories of spare parts and other maintenance materials must be coordinated with the repair-replace decisions and with the job schedule. Analyses are also required to make decisions as to the economic order quantities for individual items, reorder points, establishment of safety stocks and, in general, the estimation of the optimal investment in maintenance materials inventory.

Note that the decisions depicted in Figure 8 are interrelated. The MDS is a dynamic system. Feedback causes modifications in previous plans and decisions. Thus, although the unbroken lines are indicative of the primary decision flow, or sequence, decision-making is essentially an iterative process due to the continuous feedback of new information both within the MDS and from outside the MDS.

The interdependencies of the MDS with other systems in the organization is indicated in Figure 8 by the use of double lined rectangles. For example, the establishment of priorities for maintenance jobs is often the responsibility of the operations or production department although, such priorities may be modified from time to time through consultation between maintenance planning and operations. At the same time, the determination of job priorities is arrived at, in part, through consideration of cost information which is developed and supplied by the engineering department and/or the accounting system. As another example, the breakdown vs. preventive maintenance decision may depend largely on how production volume is affected, particularly when "onstream" preventive maintenance is feasible.[1]

Classification of the decision settings of the MDS according to the Anthony decision framework is undertaken as the decision settings are examined individually. It will be seen, as might be expected, that they generally fall in the management control category. It has been pointed out that there is a great deal of dissatisfaction with the level of success achieved in the planning and control of maintenance costs. Such a condition is more likely to exist in a situation where there is a predominance of management control decisions. Such decisions are more subjective than are operational control decisions and the decision variables, information requirements, and effectiveness/efficiency measures are not so easily specified or determined.

The Breakdown Versus Preventive Maintenance Decision

Given a process facility and an equipment configuration, maintenance management must attempt to devise a maintenance program that will minimize the costs of maintenance and downtime given some desired level of effectiveness. An initial concern is the determination of the extent to which preventive maintenance practices should be employed for various types of equipment. As seen in Figure 7, the total direct costs of maintenance are the sum of costs incurred for both preventive maintenance and failure maintenance. The maintenance cost

---

[1]Onstream maintenance is that which may be performed while the equipment is operating.

curve can be lowered by employing the optimal amount of each type of maintenance service. Few organizations can afford to rely on breakdown maintenance alone. Breakdown maintenance is expensive both in direct and indirect costs. Failure of one component of a facility may hasten the failure of related components. Failure may result in lost production, which, in turn, adversely affects the effectiveness of associated personnel. Major repair may be mandatory after failure whereas minor preventive maintenance actions might have avoided such repairs. Reliance on breakdown maintenance also imposes a greater burden on those charged with spare parts provisioning since equipment downtime is increased if spare parts are not on hand at the time of breakdown while spare parts required for scheduled PM actions can be planned and ordered in advance.

Figure 9 is a modification of Figure 7 to represent this decision situation. In Figure 9, the upward sloping cost curve represents PM costs only; direct costs of failure maintenance are now included with cost of downtime and the horizontal axis measures the amount of PM service supplied. As PM is increased, cost of breakdowns are decreased. Typically the rate of reduction in breakdown costs is more rapid initially than the rate of increase in PM costs. The objective is to find the level of PM which results in minimum total costs.

This decision setting is characterized by two related questions:

(1) For a given type of equipment, is PM appropriate?

(2) If PM is appropriate, what is the optimal PM frequency?

The foregoing questions are examined in depth by Morse (60), Goldman and Slattery (30), Reed (70), and Timms and Pohlen (82). The following discussion, especially as it relates to the application of quantitative techniques to these decisions, relies heavily on the sources mentioned. The ultimate aim in reviewing the quantitative methods is to specify the information requirements associated with their use.

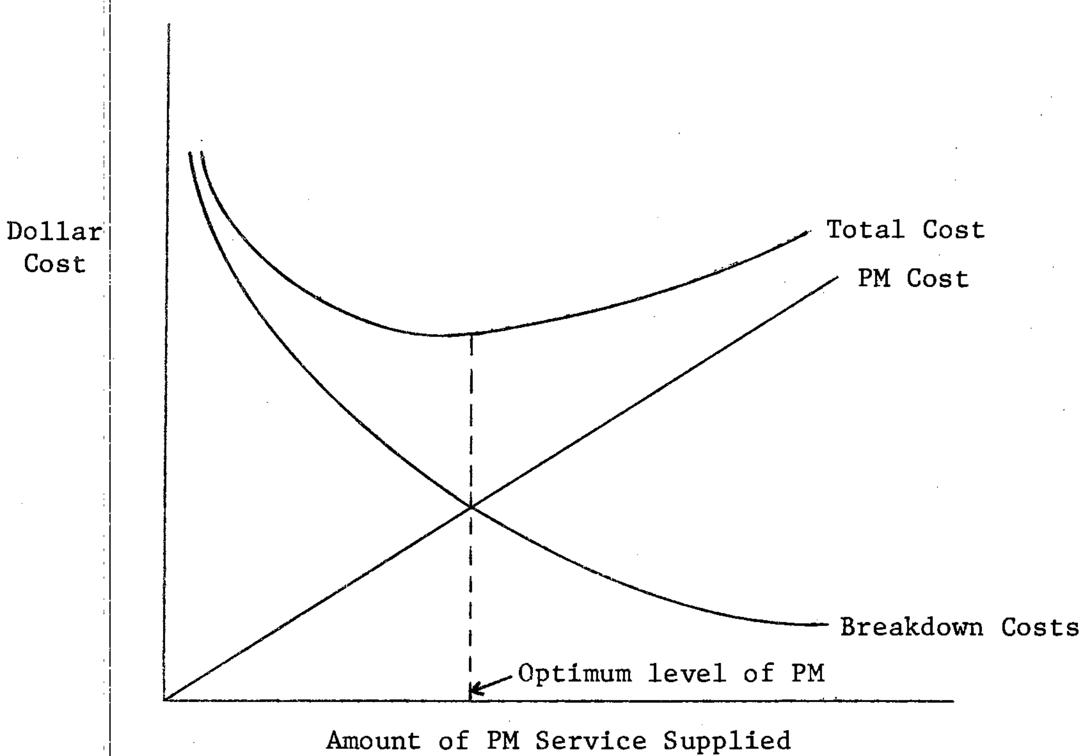
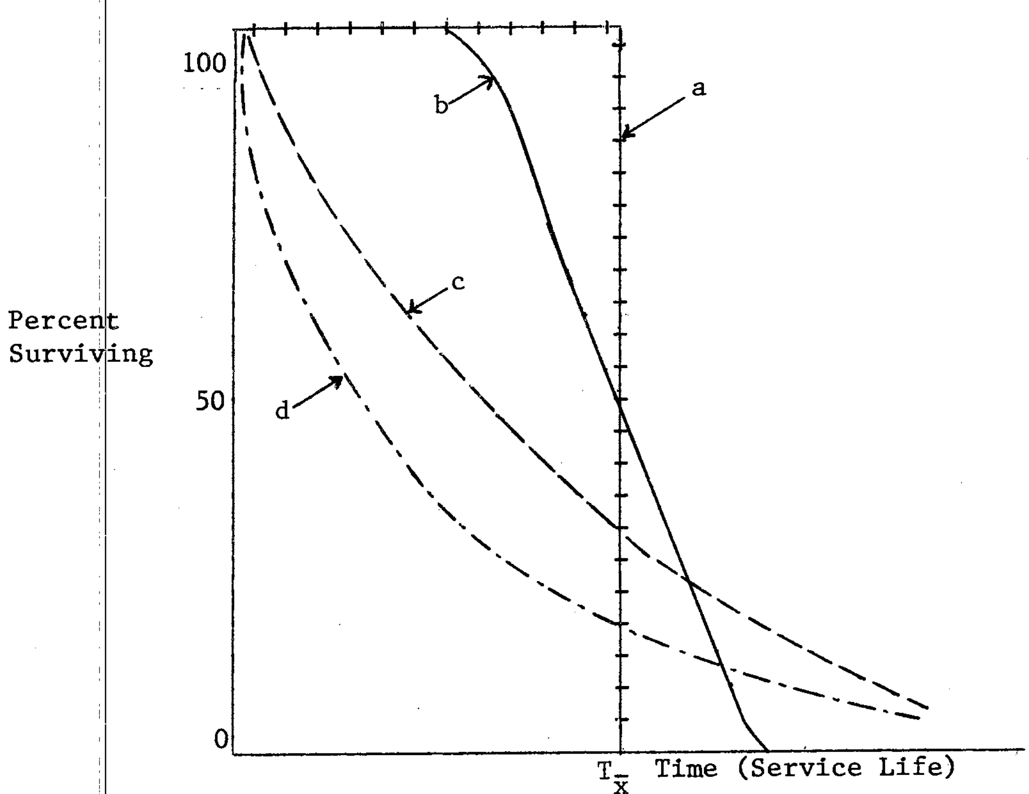


Figure 9. Economics of Preventive Maintenance

Some level of PM service will be beneficial for most types of equipment. For other types, however, PM is not appropriate. In order to determine whether PM is or is not appropriate (and subsequently to determine the optimum PM frequency), a variable of interest is the service life distribution of the equipment in question. If a reasonably accurate prediction can be made as to when a part is going to fail, the part can be replaced at some opportune time just prior to failure. The period of time from when a part is put into service until it fails is called its "service life." Service life, however, is not a constant for most types of equipment, nor is it the same for each component within a particular machine. It follows some sort of probability distribution about an average value. The distribution of the service life of a machine as a whole can be obtained by combining the distributions of service lives of its components. Figure 10 shows four different service life distributions. The functions represented by the letters a, b, c, and d denote types of equipment with increasing variability of service life, or failure time. Curve a depicts the unusual situation where service life is constant; each machine will operate the same length of time before it breaks down at time $T_{\bar{x}}$, the average service life.

Curve b represents a type of equipment characterized by wear-out failure only. No failures are observed in early time periods and very few will have high service lives. After some period of operation, failures begin to occur with increasing, and then decreasing, frequency. At $T_{\bar{x}}$, 50 percent will have failed. If the failure frequency were plotted against time for this type of equipment, the resultant pattern would be the typical normal distribution curve.

Service life distributions of machines with greater variability of breakdown time are depicted by curves c and d. In both cases, the machine may fail immediately after being returned to service (early failure) or, in the case of curve c, it is equally likely to fail at any given time thereafter. Curve c, an exponential distribution, represents a random failure situation; failures occur as a result of chance variations in stress and are independent of the age of the machine. Transformers, resistors, electron tubes, and most purely electronic parts would be included in the random failure category. As indicated in Figure 10, at time $T_{\bar{x}}$ considerably more than 50 percent of the machines will have failed. Machines with a service life distribution similar to curve d (hyper-exponential distribution) have an even greater variability of service life.



Source: Adapted from P. M. Morse. Queues, Inventories, and Maintenance. New York: John Wiley and Sons, Inc., 1958.

Figure 10. Service Life Distributions Expressed as Probability Functions, the Probability that Service Life Will Exceed any Given Time

It was previously mentioned that total maintenance costs could be decreased if management could make a reasonably accurate prediction as to when a machine or component will fail, and then provide for opportune preventive repair or replacement just prior to failure. The difficulty of prediction of service life increases with the variability of the service life. Hence, determination of the optimal preventive maintenance policy is much more difficult for equipment with high variability of service life. More important, in connection with the question as to when PM is appropriate, Morse (60, p. 160-167) demonstrates that PM is invalid for parts which do not have definite wear-out characteristics or those in the random failure category. He points out that PM will only be a clear advantage for machines with <u>less</u> variability of breakdown time than the exponential.

> The basic reason is not hard to seek: for exponential breakdown-time distributions, breakdowns occur at a constant rate whenever the machine is operating, being just as likely to happen just after repair or maintenance is completed as later. Consequently, the only way to reduce the number of breakdowns per month (say) is to run the machine <u>less often per month</u>; preventive maintenance <u>only reduces</u> breakdowns by reducing running time, in this case. This tendency is even more pronounced for machines with larger variability of breakdown time; here breakdowns are frequent <u>just after</u> the machine has been repaired, and if the machine survives these, it will run a long time (as explained earlier, this can be because the cause of breakdown is in some fine adjustment which, when right, stays right, but when a little off, goes bad soon). In this case preventive maintenance will usually <u>increase</u> the mean number of breakdowns per running time of the machine (60, p. 165).

Therefore the decision as to whether PM is worthwhile for a particular machine depends mainly on whether the failure pattern is predictable, and this pattern is generally associated with a wear-out type of service-life distribution.

The basic information needed by management in making this decision consists of a record of when failures occurred for a given piece of equipment. An equipment record should be maintained that will enable management, or the management accountant, to plot a survival curve and determine, either by inspection or by use of statistical techniques, how well the data fit a desired curve.

Of course, it may be that the manufacturer of a piece of equipment or a component can supply the necessary information as to service life and prescribe a PM schedule. On the other hand, the question of whether PM is appropriate may be fairly obvious since most mechanical and electro-mechanical equipment will be characterized to some extent by wearout failure.[2] Nonetheless, for those types of equipment with a less than exponential variability of breakdown time, knowledge about the failure pattern is useful since it is necessary to the determination of an optimal PM frequency--the second of the two questions mentioned earlier as characterizing the breakdown vs. preventive maintenance decision setting.

The objective of a preventive maintenance program is to reduce the total cost of providing a service. The optimal PM policy depends on the service life distribution average and how this characteristic interacts with breakdown and PM costs.[3]

---

[2]It should be noted that PM may not be warranted in many situations where it seems to be the logical strategy. Cason (12, p. 97) describes an experience where a PM program to replace bearings at fixed intervals seems to be indicated. Analysis of failure experience revealed a random failure situation, however, indicating that preventive replacement of bearings would have been a serious error.

[3]An associated problem is to determine optimum crew size, but this is discussed later in this chapter.

Reed (70, p. 163-165) illustrates an approach to the determination of optimal PM frequency by starting with a situation where the expected period maintenance total cost is first established given that no PM is practiced.[4] He then determines the optimal period frequency for PM by finding expected period costs for policies of successively increasing periods between preventive maintenance inspections/repairs until the minimum point on the total cost curve has been determined. In order to utilize Reed's approach, information must be available relative to:

1. Frequency of failure. The probability of failure in a given period if no PM is practiced must be reasonably determinable.

2. Cause of failure. If equipment is inoperative due to "administrative" downtime rather than deficiencies in scheduled maintenance practices, the "failure" would not enter into the analysis.

3. Cost of breakdown (including repairs, lost production, etc.). This would be the average cost expected to be incurred in a breakdown event.

4. Cost of PM to reduce or eliminate the failure. This would be the average cost associated with performing the PM task and would, in some cases, include the cost of lost production.

To determine the expected period cost of a policy of scheduling PM on an n-period frequency, Reed uses the following formula:

---

[4]Timms and Pohlen (82, p. 393-394), Goldman and Slattery (30, p. 71-90), and Morse (60, p. 165-167) use approximately the same approach to this problem as that employed by Reed. Goldman and Slattery present a more detailed discussion and illustration. They divide the costs of PM into costs of preventive inspection and costs of preventive repair. Their method of analysis also requires knowledge about the "deterioration probability" of an item of equipment rather than just the probability of failure. The deterioration probability is the probability that at a given inspection an item will be found to require preventive repairs. Morse provides a more advanced treatment (at least in terms of the mathematical analysis employed) of this problem, but the information requirements are essentially the same as those of the Reed method.

$$1/n\ [C_p + C_b F_n]$$

where,

$F_n = p_1 + p_2 + \ldots + p_n + F_1 p_{n-1} + F_2 p_{n-2} + \ldots + F_{n-1} p_1$ (the total expected failure rate for period n).

C_p = Cost of preventive maintenance.

C_b = Cost of failure.

p_n = Probability of a failure in period n.

To determine the expected period cost with no PM, the expected period maintenance total cost is computed by dividing the cost of failure (C_b) by the expected number of periods between breakdowns.

In summary, the breakdown vs. preventive maintenance decision setting is characterized as follows. The objective is to minimize total costs of preventive maintenance, failure maintenance, and downtime for some specified level of system effectiveness. The noncontrollable variable of interest is the service life distribution of the equipment or, alternatively, its probability of failure. The controllable variables are the amount of PM service to provide and the method of allocation of PM service. The decision criterion is reduction in total cost without loss of system effectiveness.

With regard to the information requirements associated with this decision setting (assuming the use of the methods of analysis discussed above), equipment records should be maintained showing:

(a) Dates of failure or breakdown--to permit determination of service life distribution or probability of failure in a given planning period.

(b) Cause of failure.

(c) Cost of each breakdown including materials, labor, and downtime (the latter amount can be determined accurately enough in most cases by multiplying the value of the output of the machine per hour of productive time by the number of production hours lost).

(d) Cost of each PM inspection and/or repair including materials, labor, and downtime (downtime costs may be associated with PM in cases where there is no opportune idle time period during which PM can be scheduled).

The breakdown vs. preventive maintenance decision setting falls in the management control classification of Anthony's decision framework. It involves the allocation of maintenance resources. It has a planning and control emphasis, an internal orientation, and it is subjective in nature. Although the quantitative techniques discussed above suggest the possibility of a programmed approach characteristic of operational control decisions, the inputs (estimates of probabilities and costs) are difficult to estimate reliably. The costs of PM services are "managed costs" in the sense that the optimum level cannot be objectively specified.

The accounting system should be designed so that the information requirements listed above are routinely accumulated and recorded for each critical type of equipment. Thus, the raw data are available to management when this sort of decision situation arises. The accounting system can further facilitate the management decision process through the use of computer programs to convert the raw data into the form needed for the quantitative analysis.

Repair Versus Replacement of Worn or Defective Parts or Units

In the event of equipment failure or detection of worn or defective parts during preventive maintenance inspection, a decision must be made concerning the nature and extent of maintenance work to be initiated. Basically, maintenance management seeks to select repair-replacement policies that will minimize total repair cost over the useful life of the equipment. Where the choice involves repair vs. replacement of defective parts or units, the costs associated with alternative policies must be predicted to allow selection of the lowest cost policy.

Within this decision context, there are several different types of problem situations. Some assets are subject to gradual deterioration over their useful lives and others fail suddenly and are either not subject to repair or repair is not undertaken because replacement is clearly more economical. This section discusses formulation of repair-replacement policies for both categories of assets. With respect to the first category, Reed (70, p. 156) lists the following basic principles of evaluation and decision under the replacement problem:

(a) Costs of prior investment for equipment, maintenance, or operation are sunk costs and do not influence the present decision.

(b) When comparing alternatives each alternative must be capable of satisfying process requirements for which it is being considered. If demands increase over the projected life of one alternative to a point that the alternative cannot satisfy demand the decision must be based upon replacement or supplementation to meet the excess demand at the time it occurs.

(c) First cost or initial cost of equipment is installed cost ready to operate.

(d) First cost of existing equipment is fair market value less removal cost plus any cost necessary to repair or convert to satisfy process demands.

(e) Decision is based upon average annual cost which is the sum of investment costs (depreciation and return on investment), operating costs (labor and maintenance), and associated overhead (including taxes and insurance).

(f) Value of production lost during change over (if not directly recoverable) is part of the first cost of the equipment causing the loss.

He also points out that when the question of repair or replacement arises, three alternatives exist, (1) the equipment may be left in its present condition, (2) repaired, or (3) replaced. Insofar as the economics of the analysis is concerned, the repair problem is treated in the same fashion as a replacement alternative. Therefore, where machinery and equipment is characterized by gradual wearout characteristics, management will have as its objective the formulation of the optimal replacement policy for such equipment.

<u>Replacement Policies for Equipment Subject to Gradual Wearout</u>. Both Reed (70, p. 166-168) and Morris (59, p. 56-95) discuss the equipment replacement problem under two different types of assumptions. On the one hand, it can be assumed that the existing equipment is to be replaced by equipment with approximately the same capability. In this case, the objective is to preserve the firm's productive capacity at its present level. Alternatively, the objective may be to expand the firm's productive capacity through replacement of existing equipment with superior equipment. The principles of evaluation listed previously apply under either the capacity preservation or the capacity expansion assumption. However, the capacity expansion decision involves a great deal more uncertainty. If management plans to

preserve current capacity, there is the implication of a continuation of somewhat the same activity, probably within the same policy structure. Generally, capacity expansion decisions involve relatively more uncertainty and have a greater impact on the firm as a whole. A capacity expansion proposal may originate with the marketing or long-range planning group. It may involve predictions of demand for new and existing products, perhaps in new marketing areas.

In establishing the information requirements for these types of repair-replace decisions, the capacity preservation decision model is discussed in some detail. Additional inputs required for the capacity expansion decision are also specified; however, the problems associated with demand and technological forecasting and the like are not discussed.

In the capacity preservation context, management faces the decision as to the best time to replace equipment. The formulation of appropriate replacement policies is important because it has significant economic consequences for the firm. Postponement of replacement, as is true with postponement of maintenance or neglect of preventive maintenance, may result in increasing production costs to the extent that the firm is unable to remain competitive.

Management's objective in formulating replacement policy is to estimate as accurately as possible the economic service life for a given asset which will result in minimizing the average cost per period of service. The decision rule as stated by Morris (59, p. 65) is:

> As long as the average cost is greater than the marginal cost of extending the life of the asset by one additional year, do not replace; as soon as the marginal cost of one additional year's service exceeds the average cost, the asset should be replaced.

The above rule assumes that the sum of the period costs (costs of ownership, operation and maintenance) are nondecreasing. For most machines, operating and maintenance costs will rise as the machine gets older. The problem is structured quantitatively, after Morris (59, p. 63-65), letting:

TC_n = the present worth of all future costs associated with an asset over n periods.

I = initial investment.

c_j = total operating and maintenance costs in period j.

i = rate of return.

S_n = salvage value at the end of n periods.

It is assumed that $c_j \geq c_{j-1}$ for j = 2, 3, . . . to indicate that operation and maintenance costs do not decrease with the age of the asset. Further, since the useful life of the existing asset and the replacement may not be the same, it must be assumed that there is a sequence of identical replacements that continues until the total time period is the same under either alternative.

Assuming a sequence of identical machines, each replaced after n periods,

$$TC_n = \frac{\left[I + \sum_{j=1}^{n} \frac{c_j}{(1 + i)^j} - \frac{S_n}{(1 + i)^n} \right] [1 + i]^n}{(1 + i)^n - 1}$$

This has the following interpretation according to Morris. The first pair of brackets in the numerator represent the present worth P of all the expenses associated with a given asset; $P(1 + i)^n$, then, is equal to the future worth of P after n periods. The denominator represents the interest rate for n periods. Hence, TC_n is the present value of an indefinite sequence of payments, $P(1 + i)^n$, at the end of every n periods.

The optimal service life N is that for which

$$TC(N + 1) \geq TC(N), \text{ and}$$

$$TC(N - 1) \geq TC(N)$$

If it is desired to use an equivalent annual cost basis for comparison, rather than the present worth basis, then the decision rule referred to previously on page 80 and expressed in terms of marginal vs. average cost would be employed.

Given values for the initial investment, salvage, and annual operating and maintenance costs for each alternative, equivalent present worths can be established.[5] Morris indicates that evaluations using the foregoing formula for TC_n are normally done by a computer in current applications, and that computer programs for this and other models are available.

In the capacity expansion context, management wishes to replace existing machinery and equipment items with models having improved capabilities. That is, the new machine is expected to perform more effectively, generally from the standpoint of cost, or increased capacity, or both.

Assuming that the increased capability is believed to be required at some time in the future, the decision becomes one of <u>when to replace</u>. Determination of the economic service life of the new machine

---

[5]Initial investment for the existing asset is its net realizable value plus repair cost; the initial cost for the replacement is its installed cost.

is also part of the problem unless a finite planning horizon is assumed.

The decision model in this case must incorporate in the period cost of the present model the cost of lost opportunity due to not having the increased capability of the replacement. The objective is to minimize total costs over the planning period consistent with the capacity and quality constraints. The decision rule is: replace the present model when the cost of extending its use for an additional year exceeds the savings which result from delaying the acquisition of the new model for one year.

The quantitative analysis for this decision setting is presented in detail by Morris (59, p. 65-71) and is not discussed here. The information requirements are much the same as for the capacity preservation problem just discussed. The capacity expansion decision model, however, calls for the initial investment, salvage value, and period operating and maintenance costs associated with both the present asset and replacement asset to be incorporated in one equation to arrive at the present worth of all costs.

Before specifying the information requirements associated with the repair-replace decision and either capacity maintenance or capacity expansion, several factors which enter into the decision and make it particularly troublesome should be mentioned. This decision setting requires management to make many estimates, some of which are extremely subjective. Assumptions must be made with regard to the length of the planning horizon. A number of forecasts must be made as to revenue, operating and maintenance costs, and salvage value for each asset. Also, forecasts of technological progress for classes of machinery and equipment are a vital element in the decision model--yet the factor of technological obsolesence is extremely difficult to quantify. In addition, in the model described in this section, some assumption is necessary with respect to an appropriate interest rate or rate of return. Further, scarcity of capital may further complicate the decision by necessitating careful evaluation and comparison of a number of competing projects, some similar and some dissimilar.

The information requirements for the repair-replace decision setting as it relates to equipment with gradual wearout characteristics are:

(a) The amount of the initial investment for both the existing asset and the replacement asset. Initial investment for the existing asset is its net realizable value (current market value less cost of disposal) plus repair cost. Initial investment for the replacement asset is its installed cost.

(b) Estimates of the period operating and maintenance costs for each asset. These amounts may be based in part on the maintenance and operating history of the existing asset and in part on manufacturer's estimates of cost patterns for the replacement machine.

(c) Estimates of the salvage value of each asset at the end of n periods.

(d) A specified interest rate or rate of return.

The characteristics mentioned previously place this decision setting in the management control category of Anthony's decision framework. There is an obvious planning emphasis. The measures employed are largely prospective in nature and highly subjective, even though based in part on historical records. Although one of the objectives of this decision is to calculate the optimal service life of the equipment, the methods of accomplishing this are by no means sufficiently objective to conclude that this decision setting is characterized by engineered costs. The informational inputs are not of the sort that are routinely collected or included in regular, summary reports (except to the extent that historical operating and maintenance costs provide a base for estimating future period costs). The management accounting system should provide the required informational inputs to this decision setting based upon special cost analyses and reports. Subsequent repair-replace decisions for a given class of equipment may become fairly routinized; however, replacement policy decisions should be reviewed periodically to ascertain whether new developments (i.e., technological and market changes, etc.) dictate a need for policy revisions. Information of the latter sort is not likely to be the responsibility of the accounting system. The accounting department should be cognizant of other developments such as significant changes in period costs associated with particular items of equipment and should bring these changes to management's attention.

<u>Replacement Policies for "Sudden Death" Components</u>. An additional aspect of the repair-replace decision setting has to do with those situations where units are subject to complete failure and are not subject to repair. This is true of such items as light bulbs, electron tubes, certain types of valves, bearings, and the like.

When equipment is down for repairs or preventive maintenance service, certain fixed costs are incurred in getting it returned to service. Likewise, fixed costs are incurred when replacement of certain failed items (such as light bulbs) is undertaken, even though no equipment downtime is involved. These fixed costs are associated with getting men, materials, and tools to the work site and may include the cost of lost production. The significance of such costs may be such that quantity replacement of both good and failed items may be more economical than a simple policy of failure replacement.

Actually, several policies can be employed in this type of decision setting:

(1) Replacement of failed units as they fail.

(2) Replacement of failed units as they fail, and any other units that have been in service a specified period of time in excess of, say, the average service life of the unit.

(3) Replacement of all units periodically.

The objective is to select the policy which will result in the lowest total cost (or lowest cost per period) and yet maintain system performance at an acceptable level. The problem, then, is to predict the total cost of each of the policies listed earlier, given some planning horizon. Two basic approaches to the solution of this problem are presented. Under either of these approaches, however, it should be noted that the information requirements for this decision setting parallel quite closely those listed for the breakdown vs. preventive maintenance decision discussed on pages 68 through 77. The first approach does, in fact, involve the use of the same analytical procedure. Using the formula and notation for determining the expected period cost of scheduling PM on an n-period frequency (p. 75-76), the expected period cost of replacing failed units as they fail (policy (1) above) will be equal to the expected period cost given that no preventive maintenance is practiced. Or, on a total cost basis, the problem is essentially one of predicting successive individual unit failures over some specified period of time [such as, the useful life of a motor (valves) or an electronic device (tubes)] and multiplying the number of failures times the average cost of replacing a single unit to get total cost under policy (1).

Expected period, or total cost, under policy (2) is determined in the same fashion as indicated for obtaining the optimal PM frequency since the cost of replacing a failed unit is C_b and the cost of periodic replacement of an operative unit is C_p. The prediction of total costs is complicated somewhat under policy (2) because the decision-maker has to predict the time of each successive failure and, also, the number of other units that have to be replaced because their service life exceeds the specified period of time beyond the average service life. The estimated number of units to be replaced and the cost of each replacement event enable the decision maker to build up the total predicted cost under this policy. Not only must records be maintained for the date of failure of each unit, but these records have to be coordinated with other records as to the length of operating time of each good unit at the time of a given failure. This is essential if all units which have been in service longer than the average service life (in hours, miles, etc.) plus, say, ten percent are to be replaced at each failure.

Under policy (3), prediction of costs depends on which of two basic situations prevail. If the situation is such that a single failure causes cessation of operation (as is the case when a tube goes out on an electronic device), the prediction of costs hinges on predicting when, following each total replacement, the first failure will occur. The number of these "first failures" multiplied times the average cost of each total replacement yields the total predicted cost. The resultant figure, when divided by the number of periods yields the expected cost per period under this policy.

On the other hand, if a single failure simply serves to diminish system performance, but does not cause cessation of operation, then management is concerned with predicting how long the interval between replacements can be without the system performance falling below minimum acceptable levels. Replacement of light bulbs fits into this situation. Here, management is concerned with setting the percentage decrease in lighting levels that can be allowed and still be acceptable as far as system effectiveness is concerned. In order then to determine the replacement frequency, the basic item of required information is simply the probability distribution for failure. If p_n is the probability of failure in period n, then the optimal policy is to replace all items when Σp_n is equal to the allowable percentage decrease in lighting levels.

Other policies in addition to those listed on page 86 can, of course, be proposed. A desirable policy might be to replace only failed units periodically.

In a given problem situation, the application of the approach just discussed may be impractical due to the complexity of the equipment configuration. In these more complex situations, it is extremely difficult to come up with a precise mathematical solution; hence, an alternative approach may be employed. This alternative involves a technique referred to as simulation. Simulation is an experimental method of analysis as opposed to a mathematical decision model which yields a precise answer to all problems which fall in a given category. The idea is to perform an artificial, rather than actual, experiment utilizing the same probabilities as those relating to the actual events. Hoffman (34, p. 243-245) gives an example of the use of simulation in connection with the determination of replacement policy for tubes in an electronic control device. In his example, the policies proposed are (1) replacement of failed tubes as they fail, (2) replacement of all tubes when any tube fails, and (3) replacement of failed tubes as they fail plus replacement of all other tubes that have been in service for 1,000 hours (the average service life of the tubes is 850 hours). As is true for the PM vs. breakdown maintenance decision, knowledge of the service life distribution of the critical component is essential. Given the service-life distribution plus the costs associated with replacement, Hoffman simulates the tube replacement situation to find the policy with the lowest expected cost. In his example, the required cost information includes the cost of each tube, the fixed cost of a breakdown, and the variable cost of replacement. Numbers are assigned based on the cumulative service-life distribution for a single electron tube. A computer program is then used to select these numbers randomly and simulate the failure pattern of the tubes, and thus artificially test the alternative policies. The results of the simulation yield, for each policy, the number of breakdowns and the number of tubes replaced. This information, combined with the cost data listed above, enable the analyst to derive the total expected cost of each alternative and select the least-cost policy.

Replacement situations may be more complicated than indicated by Hoffman's example; and, in fact, simulation may not be economically feasible if the equipment configuration is sufficiently complex. The service-life distribution of equipment consists of the service-life distributions of all its components. Some of these components may be quite dissimilar and have widely divergent service lives. Thus, the problem becomes one of simulating the sets of service lives of all critical components. This becomes quite complicated and the amount of data required for a solution may render the simulation approach to the decision process impractical even given the use of an electronic computer. However, given that simulation is judged to be an economically feasible decision process, the following general information requirements can be stipulated:

(a) The service-life distribution of the component.

(b) Fixed cost incurred due to breakdown.

(c) Variable costs of breakdown and replacement. This figure would include downtime costs, probably expressed on an hourly basis.

The accounting system should be designed to accumulate data from which the foregoing information requirements can be generated. Thus, the accounting system should maintain records showing:

(a) Dates of failure. This will permit determination of service-life distribution if such information is not available from the manufacturer.

(b) Cost of components.

(c) Time required to make replacements and cost per labor hour. This would need to be recorded separately for replacement of different numbers of components so that the average cost of replacement of successive numbers of components could be determined.

(d) Downtime cost per hour.

(e) Fixed costs associated with a breakdown event including setup time for the replacement.

In general, replacement decisions for "sudden death" components are management control decisions. In contrast to the replacement decision for equipment subject to gradual wearout, most of the information can be routinely accumulated in the accounting records. There is a planning and control emphasis. Subjective judgment is employed both in selecting the method of analysis and in estimating certain elements of the input information. Thus, the costs associated with this decision setting are managed rather than engineered costs. The one possible exception to the classification of replacement decisions as management control decisions is in the rather uncomplicated situation, such as light bulb replacement. Here, the overall level of objectivity is much greater, aside from the estimate of the allowable decrease in lighting levels, and a programmed replacement policy can be instituted.

It is apparent, in reviewing the foregoing discussion of the repair vs. replacement decision setting, that one particular decision situation may be further removed from the operational control classification than another.

Provision of Mechanical Services

Demands upon the maintenance activity arise not only from the need to perform "basic maintenance" (i.e., preventive and breakdown maintenance), but also from the need to perform other services not falling within these two classifications. The "other services," referred to herein as mechanical services, include construction and construction modifications, removal and installation of equipment, and rearrangement of facilities.

Management must decide both the amount and nature of mechanical services which will be provided by the maintenance activity.

This decision setting is introduced at this point mainly to indicate its place in the primary decision sequence in the MDS. Since it is not a concern here to determine whether or not a particular mechanical service is to be performed, but essentially, to consider by whom (internal or external personnel) it is to be performed, the methods of analysis and information requirements of this decision setting are included in a later section devoted to the consideration of using contract personnel versus using company personnel for maintenance (including mechanical services).

Any large company will have a continuing need for the performance of mechanical services. Whether to have this work done by the firm's maintenance department depends on both the nature of the service and the number of men required for its performance. Large construction projects may clearly call for use of an external contractor. Smaller construction and alteration projects may be more profitably assigned to the maintenance department because they absorb what might otherwise be idle time. These services tend to take up the slack which exists when there are fluctuations in the amount of preventive and breakdown maintenance work to be performed.

In a given case, however, it may be difficult to assess whether a job is too large, or too demanding in terms of technical specialization and the like, to be performed economically by internal maintenance personnel.

Management's objective in this decision setting is to minimize total costs of preventive maintenance, breakdown maintenance, and mechanical services. Two basic alternatives are available to management with respect to provision of mechanical services. One policy is to staff the maintenance organization based on assessment of the number of personnel needed to take care of preventive and breakdown maintenance requirements. Any such assessment must take into account the fluctuating demands for these services and it must be recognized that some idle time will be logged when demand is slack. Management in this case will call on maintenance personnel to supply mechanical services up to the point that they can achieve full utilization of the department's time. Any need for mechanical services in excess of this level will be contracted out. The alternative policy is to make permanent additions to the maintenance staff based on an evaluation of the amount of mechanical services that are generally required on an ongoing basis. Management will wish to set the manpower level at a point where close to 100 percent utilization can be attained. Again, any occasional demands for mechanical services that cannot be met by such an expanded staff will be contracted out.

In determining the amount of mechanical services to be supplied by the maintenance department, management will need to estimate the total demand for mechanical services over some planning period. These demands should be listed on a project by project basis when significant, with an allowance for miscellaneous small projects that can be anticipated. The portion of this total demand that cannot be met with the existing maintenance staff must be evaluated in terms of the estimated costs to be incurred if the maintenance staff is expanded and the mechanical services performed internally versus the cost of using external personnel. The differential cost of labor will be the main factor in determining the least-cost policy. Additional factors may enter the analysis. For example, the use of outside contractors may permit the firm to reduce its investment in inventories of spare parts.

As stated earlier, this decision setting is discussed further in connection with the determination of manpower levels and the use of internal versus external personnel. It is introduced at this point to put it in perspective insofar as the overall maintenance decision system is concerned, and to emphasize its interrelationship with the aforementioned decisions.

Determination of Manpower Levels and Crew Size

For most plants, labor costs constitute a significant percentage of total maintenance cost. The determination of the optimal size of the maintenance staff is, therefore, a very critical decision. Excessive costs can result from either understaffing or overstaffing the maintenance function.

The decision concerning optimal staffing of the maintenance activity is one which cannot readily be approached from an overall standpoint. Lewis and Pearson (49, p. 52) present an equation which can be used to determine the total number of maintenance workers which should be employed in a given plant:

$$X = \frac{MH}{2080 - (A + B + C)}$$

where,

X = number of maintenance personnel required (without separation by trade areas)

MH = man-hours of maintenance labor required on an annual basis (without separation of supervision, control, and clerical personnel)

A = allowed vacation man-hours

B = allowed sick-leave man-hours

C = allowed holiday man-hours

Such a formula answers only a part of the question; it ignores the very important consideration of the composition of the maintenance staff. The authors note that the formula can be applied to each trade requirement (i.e., plumbers, electricians, etc.) in building up the total man-power requirement. Maintenance work assignment may be highly inflexible due to special skill requirements and/or union agreement. Thus, the problem must be approached by deciding how many of each service skill to employ. An important consideration also is the number of support personnel (supervisors, planners, schedulers, clerical, etc.) that are required to complement the personnel involved in direct maintenance activities.

The objective of management in this decision setting is to obtain the optimum balance between the cost of maintenance staffing and the cost of downtime. In other words, management seeks to minimize total costs where total costs are equal to the sum of the cost of service plus the cost of service failure. This is true whether the decision involves the determination of the size of crew to be employed for a new plant or the making of adjustments in the crew size of an established plant. In either of these situations, management must predict the maintenance man-power requirements based on an assessment of the demand for basic maintenance and for mechanical services.

Reference to the MDS (p. 66) shows that in terms of the primary decision sequence, the staffing decision follows the decision concerning preventive vs. breakdown maintenance and, at least in part, the decision as to the amount of mechanical services to be provided internally.

In making the PM versus breakdown maintenance decision, and subsequently, the decision as to the optimal PM frequency, information must be available with regard to failure patterns of equipment and costs of both PM and breakdowns. In order to develop such costs, a necessary prerequisite is an analysis of the service to be performed. For instance, the cost of PM to reduce or eliminate a failure is defined as the average cost of performing the PM task (p. 75). Hence, the task itself must be studied in some fashion in order to determine the amounts of materials and labor that it requires and the costs thereof. The labor cost element of each PM task must include estimates of the number of man-hours required and the costs per hour. These estimates may be based on "off-the-cuff" conjecture or upon very careful studies in which the maintenance operation is carefully defined and manpower requirements based on time standards are established for each skill. In any case, the antecedent decisions require informational inputs that also enter into the staffing decision. This information as it relates to PM, to breakdown maintenance, and to provision of mechanical services can be combined to come up with a projection of the total numbers of men required for both direct and indirect maintenance activities. This projection is, of course, derived by adding the separate requirements for each maintenance skill plus requirements for supervisory, clerical, and other support personnel. Thus, an estimate of the annual man-hour requirement for maintenance work can be built up, appropriately classified according to man-hour requirements for each trade skill and each type of support personnel.

The foregoing analysis is not as simple as it may sound. The preventive maintenance activities and the provision of mechanical services can be preplanned and scheduled in a fairly accurate fashion. Breakdown maintenance, however, cannot be planned and scheduled--yet the plant must be staffed to handle such emergency maintenance.

In seeking to achieve the primary objective of minimizing the cost of service plus the cost of service failure, management seeks to achieve a high utilization of personnel (i.e., a low percentage of idle time) plus a high efficiency level during utilization. These are difficult goals to achieve even where time standards are employed for maintenance tasks, because the variances from standard time will tend to be greater than those normally experienced for production activities. Hence, even without the added complication of random failures, maintenance management may find it more difficult to achieve high utilization of personnel and efficiency of performance than might normally be the case for production management.

Two approaches (which may be used in combination) to the staffing, or crew size, problem are discussed in the following paragraphs. Again, these approaches involve quantitative decision models, one of which (the first to be discussed) is more deterministic than the other. Following presentation of the method of analysis in each case, the information requirements are specified.

Both approaches recognize the fact that the maintenance crew size problem has the characteristics of a queuing or waiting line problem. Under certain circumstances, the queuing situation may be amenable to direct mathematical solution through the use of probability theory. A second method of analyzing queuing problems is through the use of simulation. It may be desirable at times to combine these two approaches. A third approach, which is not discussed herein, is to experiment physically with the system. For instance, a maintenance supervisor might simply try varying the crew size for a given maintenance task, observe the results, and make a decision as to the best alternative.

Queuing theory or waiting line theory is primarily concerned with processes which have the characteristics of having random arrivals (i.e., arrivals at random time intervals), and the servicing of "customers" may also be a random process.[6]

---

[6] Arrival rates and service times may, of course, be uniform. If so the queuing situation is fairly easy to analyze. Uniform arrivals and service times are not likely to be encountered in maintenance.

If there are costs associated with waiting in line, and if there are costs of adding more service facilities, the objective is to minimize the cost of waiting and the cost of providing service facilities and personnel. This is precisely the objective as previously outlined for this decision setting (p. 95-96). In maintenance, the "customers" to be serviced are machines. "Arrivals" are the breakdowns or other demands for service such as preventive maintenance inspections and requests for mechanical services. The number of servicemen (maintenance personnel) to be supplied is the variable of interest in the current decision context. Computations lead to such measures as the expected number of machines waiting to be serviced or the expected waiting time of the arrivals. These measures can then be used in cost computations to determine the optimal number of servicemen which are to be provided.

PM and mechanical services are of such a nature that some control can be exercised over arrivals for service. This is not true, however, with respect to breakdowns. Therefore, the main concern in employing queuing analysis is in terms of breakdown maintenance. The time of breakdowns (one type of arrival) cannot be controlled. Arrival, or failure patterns, may be completely random for many service-type systems.[7] Failure patterns give rise to queuing or waiting line systems when they occur with some type of time distribution. Even though the failures are randomly distributed, their average can be calculated if a long enough time period is used.

---

[7] The arrival rate, or as it is referred to in the maintenance context, the failure rate represents the average rate at which breakdowns occur and require service.

Servicing time may also be randomly distributed. For a given situation, or type of repair, a machine may be repaired in ten minutes on one occasion, while the next repair may require two hours. Again, however, if the data are available, the servicing rate (rate at which maintenance personnel can handle the demands for repair) can be determined and expressed as an average rate per unit of time.

Waiting systems vary according to their characteristics. Wagner (85, p. 837-875) discusses these characteristics and how they may vary from one system to another. The more important of these characteristics, summarized in terms of their relationship to maintenance applications, include:

(1) The number of servicing units--variation exists in the number of maintenance personnel (and other maintenance facilities) that may be available to service failed equipment. If there is more than one server available, a <u>multiple-service channel</u> system exists. If a failed item must be serviced by two or more servers in sequence, the system is <u>multiple-phase</u>.

(2) The distribution of arrival times--failures may occur in a fairly predictable fashion or may follow a completely random pattern.

(3) The queue discipline, or the manner in which failed machines are to be serviced. In many queuing situations service is on a first-come, first-served basis. For similar machines performing the same function, this may be true in maintenance; however, it is more frequently the case that maintenance personnel are assigned to service failed equipment based on priorities recognizing the urgency of the servicing required. Priorities are

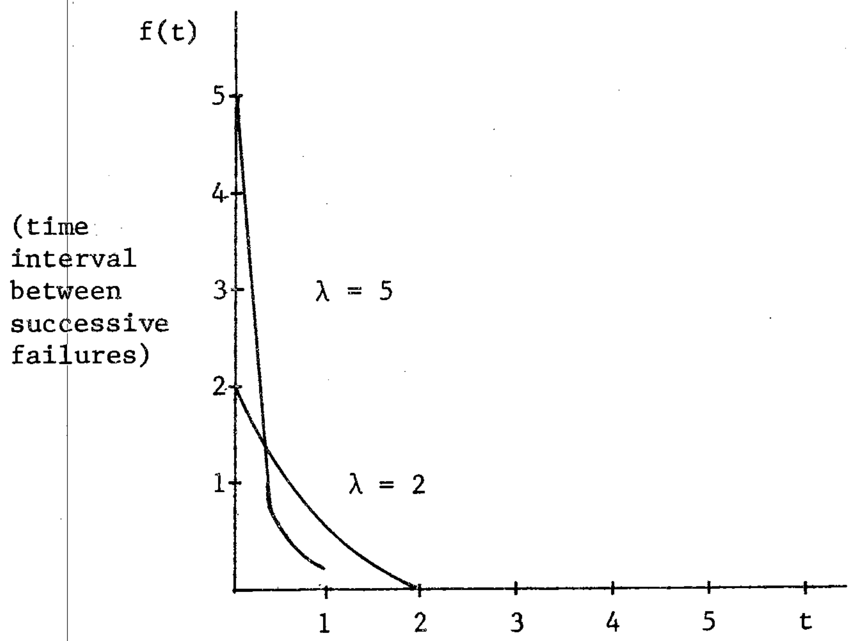
generally based on the critical nature of the equipment and the costs of downtime. One aspect of the queue discipline which is not generally encountered in maintenance is the situation where an arrival chooses not to join the queue because it is too long. Although, the situation may occur where management decides to send a failed item outside the plant for service because internal personnel cannot get to it quickly enough.

(4) The size of the population to be serviced. In many queuing situations the population is infinite (e.g., customers to be serviced by a gasoline station). Mathematical analysis is generally simplified if an infinite population can be assumed. Such an assumption may be feasible in maintenance where the population of machines to be serviced is quite large. If the population is small, the mathematical analysis is more complex because the size of the waiting line materially affects the arrival rate.

(5) The distribution of times required to perform the maintenance service.

Although a number of different patterns for arrivals and service time requirements may occur in practice, it is commonly assumed in illustrations of applications of queuing theory to maintenance problems that both failures and service-times follow a random pattern (41, p. 409) (34, p. 251) (82, p. 405).

A random pattern of failures, where the number of potential failures is quite large and each is independent of the others can be depicted by curves such as those shown in Figure 11.



Source: Adapted from Harvey M. Wagner, Principles of Operations Research, Englewood Cliffs: Prentice-Hall, Inc., 1969.

Figure 11. Exponential Failure Distribution $f(t) = \lambda e^{-\lambda t}$.

When the failure pattern is random, it simply means that the probability of a failure in the next time period is independent of the time the last failure occurred. As indicated by Wagner, when failures are assumed to be exponential, the number of failures in any given time period n is a random variable which follows the Poisson distribution, one of the most common distributions in probability theory.

The Probability distribution of the number of failures n in any interval of length T is Poisson (85, p. 846):

$$P\begin{bmatrix}\text{n failures in} \\ \text{any interval} \\ \text{of length T}\end{bmatrix} = \frac{(\lambda T)^n e^{-\lambda T}}{n!} \text{ for } n = 1, 2, \ldots$$

where,

λ = failure rate per unit of time

e = 2.718, the base of the natural logarithm

$1/\lambda$ = mean time between failures

Combining λ and T by multiplication yields the expected number of failures in any time period t. For example, if $\lambda = 3$ (the average number of failures per day) and T = one week, then the average number of failures per 7-day interval is $3 \cdot 7 = 21$. Also, $1/\lambda$ represents the mean time between failures, which in this case is 1/3 of a day (that is, one failure on the average every eight hours).

Random service times also follow the Poisson distribution with a mean rate per unit of time of μ (as commonly designated). If the unit of time T is 8 hours and μ is equal to 4 services or completed repairs, then the average service time $1/\mu$ is 2 hours or T/4.

As indicated earlier, the characteristics of waiting line systems vary considerably. In general, however, the variables of interest include: (1) the probability distribution of the number of units in the system and their waiting times, (2) the probability of all the maintenance servers being occupied or idle, (3) the probability distribution for the length of the idle and busy periods for each maintenance worker, and (4) the probability that the queue will exceed a specified length (85, p. 842). As necessary, then, formulas must be developed that will adequately describe the characteristics of the waiting line system.[8]

---

[8]For the mathematical development of such formulas, see Bierman, et al. (10, p. 348-351), Johnson, et al. (41, p. 411-414), and Wagner (85, p. 841-875).

To illustrate the application of mathematical analysis to a waiting line problem and to integrate the previous discussion in terms of a single illustration, an example developed by Reed (70, p. 169) is presented.

Reed gives an example of a simple type of waiting line problem (the more complicated the problem the less likely it will be amenable to direct solution by mathematical analysis). The assumptions underlying Reed's illustration are:

(1) Equipment failure follows a Poisson distribution with a mean failure rate λ.

(2) Machines are serviced on a FIFO basis.

(3) Servicing time by a fixed crew is a random variable z, following a negative exponential distribution such that

$$g(z) = \mu e^{-\mu z}, \quad z \geq 0$$

and μ is the average rate of service.

Given that there are N machines and k service crews, Reed uses the following formulas to make his probabilistic calculations:

(1) The probability of no machines waiting for or being serviced in an interval t is:

$$P_o = 1 - \sum_{n=1}^{N} P_n .$$

(2) The probability of n machines in the queue or being serviced is:

$$P_n = \frac{N!}{n!\ (N - n)} \left(\frac{\lambda}{\mu}\right)^n P_o, \quad o \leq n < k$$

$$Pn = \frac{N!}{(N - n)!\ k!\ k^{(n-k)}} \left(\frac{\lambda}{\mu}\right)^n P_o, \quad k \leq n \leq N.$$

(3) The expected number of machines in the queue or being serviced is:

$$E(n) = \sum_{n=o}^{N} np_n.$$

The expected hourly cost of downtime, C_d, is E(n) times the cost per hour of downtime per machine; the hourly cost of maintenance personnel, C_m, is k times the hourly maintenance labor rate times the number of men in the crew; hence, total cost, TC equals $C_d + C_m$. The optimum number of crews, k*, to serve N machines is that number which minimizes TC. Assuming six machines, a mean service rate of μ for one maintenance man, $\lambda/\mu = .1$, $C_d = \$32$, and $C_m = \$5$ per hour, the formulas yield:

TABLE III

PROBABILISTIC CALCULATIONS FOR EXPECTED NUMBER OF MACHINES WAITING FOR OR BEING SERVICED

n	P_n $k^+ = 1$	P_n $k = 2$	P_n $k = 3$
0	------------ 0.4845	0.5688	0.5702
1	------------ 0.2907	0.3413	0.3421
2	------------ 0.1454	0.0853	0.0855
3	------------ 0.0582	0.0028	0.0011
4	------------ 0.0175	0.0013	0.0001
5	------------ 0.0035	0.0003	0.0001
6	------------ 0.0003	0.0001	0

+k represents the number of maintenance men

Source: Ruddell Reed, Jr., Plant Location, Layout, and Maintenance. Homewood: Richard D. Irwin, Inc., 1967, p. 170.

To determine the expected number of machines waiting for or being serviced requires the use of formula (3) on the preceding page. For example, for k = 2, E(n) = 1(.3413) + 2(.0853) + 3(.0028) + 4(.0013) + 5(.0003) + 6(.0001) = .5276. Therefore, TC = $C_d + C_m$ = .5276 ($32) + 2($5) = $26.88 per hour. Similar computations for k = 1 and k = 3 yield $28.85 and $31.55 per hour respectively, indicating that the optimum number of maintenance men is 2.

As mentioned, the case described above involves several limiting assumptions and applies only in the simplest sort of waiting line situation. It involves, as do many maintenance problems, a special case. The assumption of random arrivals for service, given that there are a very small number of machines in the population complicates the probabilistic calculations even in this simple case. Such calculations become extremely cumbersome even using a computer when there is a large (but finite) number of machines to be serviced. This is due to the fact that anytime the source population is finite, then the rate of arrivals must decrease as the number of machines in the system (i.e., either waiting or being serviced) grows (41, p. 407). When the number of calls for service is limited due to there being a small number of machines in the population to be served, there are no well-defined general expressions for C_d, the cost of service failure, or, alternatively, the waiting line cost which is a function of the calls for service and the distribution of their service times. If the number of machines in the population is quite large, it may be feasible to develop the mathematical analysis as though the population were infinite. Otherwise, the task of determining C_d is extremely complex.

Reed's model, as well as more complicated models illustrated by others are useful in many cases because, although containing restrictive assumptions, they can be used to provide approximate quantitative information and some qualitative information about the behavior of more complex systems.[9]

In any situation where mathematical analysis is employed, the operating characteristics (e.g., the average number of machines in the system, the average waiting time, the probability that all service men are occupied, the order of service, number of service channels, etc.) must be carefully specified or approximated. Observations should be made to assure that the model conforms reasonably well to any assumptions about arrival and service-time distributions. If the arrival and service rates are not consistent with standard statistical distributions, or the queuing problem is otherwise so complex as to make mathematical evaluation via equations extremely difficult, then it may be desirable to employ simulation analysis, using Monte Carlo techniques, as discussed earlier, in the replacement decision setting.

Before summarizing the information requirements for the crew size decision, the simulation approach is outlined briefly.

For some waiting line problems, a mathematical model may be too complex or no mathematical algorithm may exist. In such cases, it may

---

[9]Illustrations of the application of mathematical analysis to several types of queuing situations are given by Wagner (85, p. A59-A73), Timms and Pohlen (82, p. 407-408), Hopeman (35, p. 248-250), and Morse (60, p. 157-174). These situations include (1) single machine, single channel (repair crew), (2) multiple machines, single channel, (3) multiple machines, multiple channels, etc. In general, the situations illustrated are based on assumptions of first-in, first-out service and exponential distribution of arrival and service times.

be feasible to formulate the relationships that characterize the problem so that the system's performance can be simulated with a model. Timms (81, p. 105) suggests that the most wide-spread decision systems that have been modeled and run as computer simulations are those involving queuing situations. Concerning maintenance in particular, he refers to a United Airlines project, begun in 1954, to simulate the "operation of the entire maintenance situation" at one of United Airlines' stations. In terms of the MDS, simulation, generally by the Monte Carlo technique, has been employed for determining optimal repair-replacement policies, for scheduling maintenance, for determining crew size, and for management of maintenance materials inventories.

In discussing the application of mathematical analysis of a queuing model for crew size decisions, it was indicated that such an analysis was feasible only in relatively simple situations. The further removed a problem is from the one-machine, one-crew situation, and from restrictive assumptions about the priority of service, the size of the population to be serviced, and the distribution patterns of failure and service times, the less likely it is that a deterministic mathematical model can be employed.

Vergin (84, p. 57) asserts that non-trivial maintenance problems have never been considered within a queuing environment. He lists the following barriers to building such a queuing model:

> First, two types of arrivals occur. Arrival times for [scheduled] maintenance are constance, requiring infinite phase Erlang distributions while breakdown arrivals would require an entirely different Erlang distribution. Second, since the number of machines (the arrival population) is finite, each machine must be identified with an individual arrival channel. Third, priorities in the service channel must be established for either preventive maintenance or repair. Fourth, switching from the preventive maintenance

waiting line to the repair line will occur if machines are kept operating after the scheduled maintenance period when the maintenance crew is busy on other units. Considering all of these factors, it does not appear that mathematical analysis of such a queuing model is possible until considerable advances in queuing theory emerge.

In spite of Vergin's position with regard to approaching the queuing problem, there is considerable support for the use of mathematical analysis via queuing models as indicated earlier on page 107. Such models, even though they involve restrictive assumptions, can provide information about the behavior of complex systems that will lead to better maintenance decisions than might be achieved using a "seat-of-the-pants" approach.

Simulation models can be effectively utilized in situations where the distribution of arrival and service times does not comply with one of the standard forms for which analytical solutions have been developed.[10] It can also be used for systems requiring special sequencing of service operations and for systems where priority of service is assigned on the basis of some decision rule.

Examples of maintenance simulation by the Monte Carol technique are given by Hoffman (34, p. 239-243), Reed (70, p. 175-179) and Vergin (84). Of these, Vergin presents the most complex model. His simulation model deals with a multi-machine maintenance-repair model and is aimed at determination of both optimal crew size and optimal maintenance scheduling.

---

[10] Vergin points out that computational procedures have been developed and may be found in the literature for several failure distributions including the normal, gamma, Weibull and Erlang distributions.

Rather than describe the simulation method for determining optimum crew size in detail, it is noted here that the minimum requirements for solution under this method are distributional data of the affecting factors and a table of random numbers. If studies are made of the distribution of times between failures and of the distribution of times required for service, then the Monte Carlo process can be employed to take random draws from these known distributions, thus generating a history of arrivals and service times in the same proportion as these events occur in the actual distributions. Having generated the arrival and service times by the Monte Carlo process, the operation of the system can be simulated for some selected period of time, say, 10,000 hours. Basically, this involves moving arrivals (failures or PM inspections) into the system, determining when they are serviced, and recording the characteristics of the system that are of concern (i.e., idle or waiting time of the failed machines, idle time of maintenance men, and the length of the waiting line).

The information requirements of this decision setting are basically the same under either the mathematical analysis or the simulation approach to solution of a given problem. Because of the wide variety of maintenance systems and work situations that may be encountered, only the general information requirements associated with the manpower level decision can be listed. These include:

(a) Dates of failure or breakdown for each machine and dates of preventive maintenance activity.

(b) Time required to return the machine to service after each failure or PM activity.

(c) Costs of maintenance service for each failure or PM activity. This may include some fixed element of cost of providing the service plus variable costs associated with the utilization of different numbers of maintenance men.

(d) Costs of service failure. Essentially, this is the cost of waiting for service, the downtime cost in terms of lost production, idle time of operators, etc.

The accounting system should be designed to accumulate and record on a continuing basis the data listed above if it is feasible to do so. The costs must be classified in a manner suited to the decision models presented above. Fixed and variable costs must be identified and recorded separately. For example, the variable cost of a PM event (for items such as lubricating oils, replacing worn components, etc.) or the variable costs of a breakdown event (including the average cost of material destroyed because of the breakdown), rather than just the total cost of the event should be available in the accounting records.

Again, some of the data requirements may not be routinely accumulated in the accounts. In the case of downtime costs, calculations can be made to determine the incremental profit for the output of the machine expressed as, say, X dollars per hour of productive running time.

The cost inputs listed in items (c) and (d) are necessary to determine the total costs associated with a given crew size. Items (a) and (b) above enable the determination of the failure distribution and the mean time between failures, and the service-time distributions as well as the average service time. The distributions may conform to a mathematically expressible distribution curve, such as the exponential, or they may not. In the latter case, simulation, as opposed to mathematical analysis will ordinarily by the preferable approach. Additional information may, of course, be required in a given case. For instance, some maintenance work may have to be performed in a specified sequence or on the basis of established priorities (to be discussed in a later section).

Determination of maintenance manpower levels and specific crew sizes is a management control decision. The costs involved are managed costs. Although quantitative models have been presented as a means of providing information to management to <u>aid</u> them in making manpower decisions, the models are not deterministic. The decisions are quite subjective; the optimum relationship between inputs and outputs cannot be specified. Emphasis is on both planning and control. Secondary, rather than primary measures predominate and these are derived from both regular, summary reports and from special cost studies and reports.

The interrelationships of the manpower decision with other maintenance and production decisions should be reemphasized at this point. The size and composition of the maintenance force depends on the total demand for maintenance service. The demand for maintenance services varies, however, depending on the decisions of management with respect to breakdown vs. preventive maintenance, preventive maintenance scheduling, and provision of mechanical services. These decisions have been considered in previous sections of this chapter. Other decision settings (see Figure 8, p. 66) yet to be examined also have an impact on manpower levels. Use of contract or external maintenance personnel may reduce the maintenance force requirement. The effectiveness and efficiency of job planning and scheduling also has a significant effect on manpower levels and costs.

Use of Contract Versus Use of Company Personnel

Closely related to the determination of optimal crew size is the decision concerning the use of internal or external maintenance personnel. Mentioned earlier in the discussion of provision of mechanical services, this decision generally is made with respect to specific maintenance activities. It is unlikely that the large industrial plant will find that it is either economical or practical to try to get by with no permanent in-plant maintenance force. At the same time, it may not be desirable to follow a policy of using only internal personnel. The goal of maintenance management is to provide required services at the lowest cost. In order to meet this objective, use of a combination of internal and external maintenance personnel may prove most economical.

Certain uncontrollable factors may restrict management in this decision setting. For example, they may simply have no alternative with respect to the use of contract personnel due to the fact that such personnel are not available. This may be true with respect to the supply of contract personnel in general or it may apply only to the availability of specific types of services or skills in the local area. Union agreements may also limit management in their freedom to use external personnel. However, given that such an alternative does exist, management will generally make separate evaluations in terms of individual projects or types of maintenance activities and the type and amount of maintenance skill involved. In any case, the costs associated with each alternative should be identified, gathered, and summarized before the decision can be made.

In the discussion of manpower levels in the preceding section, it was assumed that optimal crew sizes were determined based on analysis of labor costs associated with use of internal personnel. Costs derived from this type of analysis must still be compared with costs of having the service provided externally.

Generally, the differential cost of labor will be the most critical factor, but the accounting information requirements--assuming negotiations pertain to a continuous contract--of this decision include the following:

(a) Costs of internal maintenance labor, including both direct and indirect costs. Wage rates, fringe benefits, additional record-keeping costs, additional support personnel (planners, general clerical, etc.), and the like enter into the determination of this cost element. Only costs which will differ between the alternatives should be considered. If maintenance supervision will be the same for both in-plant or external servicing then such costs are not relevant to the analysis.

(b) The differential costs of maintenance materials inventories, tools, and construction equipment. If contract maintenance is used, the firm may be able to reduce its investment in spare parts inventories and eliminate the associated handling and ordering costs; the investment in tools may be less because the contractor supplies his own tools; expenditures for construction equipment may be reduced if, say, the contractor provides the equipment on a rental basis.

(c) Differential costs of downtime. Use of external personnel may involve more delay in initiating repair following a breakdown. On the other hand, total downtime may be minimized by use of contract maintenance if the contractor can supply extra men on an around-the-clock basis if necessary.

(d) Obsolescence costs. Reed (70, p. 156) describes the circumstances under which this particular type of cost must be considered:

> With certain equipment (particularly data processing equipment) rental and service are often combined in a single contract. If the equipment is purchased not only must the normal costs of owning and maintaining the equipment be compared to the rental and service cost, but consideration must be given to the probability of improved equipment becoming available which should be secured (but if secured would result in a significant loss on the present equipment). One method of allowing for this is to estimate the probable loss if present equipment is obsoleted and multiply this by the estimated probability of obsolescence in any year as the estimate of that year's cost of ownership due to the risk of obsolescence.

(e) Costs of deferred maintenance due to differences in flexibility of maintenance scheduling. If a firm has a fixed number of maintenance personnel, it may be impossible, say, to follow an "optimal" PM schedule because the required number of men is not available at the time a particular shutdown and PM repair should be performed. Deferring the PM activity increases the probability of a breakdown and incurrence of costs in excess of those which would have otherwise been experienced. Under contract maintenance, the necessary number and type of craftsmen can perhaps be supplied on demand, scheduling is more flexible, and costs of deferring maintenance work may be avoided.

The cost elements mentioned above, when compared with the costs to be incurred under the contract provisions, provide management with a major informational input on which to base their decision.

This is a management control decision characterized by subjective estimates of costs and subjective judgements concerning qualitative factors, such as the impact of the decision to use contract maintenance on the morale of the in-plant force. The emphasis is on both planning and control. From an accounting standpoint, the cost information outlined above must be provided by means of special reports based on studies and analyses of the costs relevant to each specific decision. Some of the basic data exists in the historical records. For instance, hourly wage rates and fringe benefits of in-plant personnel enter into the decision. This information, appropriately modified for known or anticipated changes, combined with managerial estimates of personnel reductions to be achieved through use of contract maintenance contributes to development of the costs referred to in item (a).

Most of the cost information, however, is not routinely accumulated in the accounting records. Records of downtime costs and costs of deferring maintenance are seldom maintained. Such costs, along with the costs of obsolescence, are difficult to quantify. In any case, the management accountant should be aware of the fact that this is a decision which rests upon an analysis of certain differential costs and he should be able to identify and develop these costs. He will, or course, have to rely on managerial estimates of the magnitudes of certain changes under a given alternative and be able to express the effect of such changes in terms of costs.

Other qualitative factors will be considered by management in reaching a final decision. The problem of the effect on morale of the in-plant force was mentioned earlier. Also, management may be concerned about the proper motivation and effective utilization of contract maintenance workers (65).

Determination of Job Priorities, Planning, and Scheduling

Any plant has available only a limited amount of maintenance resources. These resources must be allocated among numerous demands for service. Management must have some means of assigning priorities to requests for maintenance work in order to allocate their maintenance resources (men, materials, tools, and equipment) in such a way as to best facilitate plant operation and to do so at minimal overall cost.

Priorities for maintenance work may be assigned by production, by maintenance, or by consultation between the two (49) (63) (65). The topic of priority determination has received relatively little attention in the literature. It is discussed to some extent by Newbrough (66, p. 299-318) and Harding (32, p. 37-38), but the approach observed in most published materials on the subject is to assume the existence of priorities without giving consideration to how such priorities should be established.

This is a management control decision which requires individual cost studies. The decision is also influenced by subjective considerations such as safety factors.

Harding presents the following formula for calculating the scheduling priority of a machine (32, p. 37):

$$SP = PP(PD - IOH) + DT(IPW + OC)$$

Where:
- SP = Scheduling priority
- PP = Product Profit (incremental contribution to earnings)
- PD = Product demand
- IOH = Inventory on hand
- DT = Down time (required for the overhaul)
- IPW = Idle production workers (hourly basis)
- OC = Overhaul cost (on an hourly basis, craftsmen and material cost)

He describes this scheduling priority as giving the relative value of each machine--the higher this value, the higher the priority. Assuming that tools, parts, and materials are available for, say, any two tasks being considered, work will be authorized first on the machine having highest priority. Harding also discusses the situation where a machine breaks down, and the decision must be made to determine if a maintenance job already in progress should be interrupted in order to work on the breakdown, or whether the breakdown should just be placed in the schedule according to its priority. This particular decision requires a comparison of the scheduling priority (as calculated by the preceding formula) of the down machine with costs incurred in stopping work on the machine currently being serviced or repaired. The latter cost is calculated as follows (32, p. 38):

$$DCEBI = PPMUC\ (PD - IOH) - PPMBO\ (DR + DTMUC + 2TBT) + (IPW)$$

Where: PPMUC = Product profit (incremental contribution to earnings of machine under consideration)
PD = Product demand
IOH = Inventory on hand
PPMBO = Product profit of machine being overhauled
DR = Down time remaining (on equipment being interrupted)
DTMUC = Estimated down time of machine under consideration
TBT = Time to break off work on the equipment being overhauled and transfer the men, materials and tools to the breakdown equipment
IPW = Idle production worker (cost of equipment being interrupted)

If the downtime cost (or scheduling priority) of the equipment broken down exceeds the cost associated with interruption of the in-progress work, then the job being worked on should be discontinued in order to assign men, materials, tools, etc., to work on the breakdown item.

Newbrough describes a quantitative ranking index for maintenance expenditures (RIME) derived from computing numerical values for (1) each piece of equipment or unit in the organization and (2) each maintenance job or project to be done.

Each machine or unit is ranked on the basis of three factors: (1) percent utilization, (2) percent profitability, and (3) a process factor based on how much other equipment is affected by downtime on the item under consideration. The percent utilization factor is based on the assumption that the more an item of equipment runs the more important it is. Percent profitability is the item's incremental contribution to profit expressed as a percentage of total plant profit dollars. The process factor is included to make sure that the ranking index takes into account possible downtime on other equipment.

The relative ranking of each job or project is determined by rating:

(1) deferred maintenance cost increases

(2) lost-production costs

(3) excess labor cost

(4) quality cost

(5) safety factors

The numerical factors obtained by ranking the equipment and the project are multiplied together to get the RIME index which sets the priority for maintenance jobs.

The decision techniques described above are but two of many possible approaches to the assignment of priorities to maintenance demands. Any approach must take into account as a basic determinant, the downtime cost per hour connected with each maintenance job. This cost has been discussed previously; its main components are the cost of lost production and costs of idle time for production workers. Costs of deferring maintenance may also be an important factor. The foregoing costs should be developed as they pertain to each type of maintenance request so that appropriate priorities may be established.

Another factor is the time required to complete the maintenance job. Consider, as a simple example, the situation where machines A and B break down at approximately the same time. Repair of either machine requires the same number of maintenance men and the same skills are involved. Downtime cost per hour of machine A is $600 and for machine B, it is $1,000. The expected repair time is six hours for machine A, 20 hours for machine B. Management must decide which machine to repair first. Based solely on comparison of downtime costs per hour, machine B should be repaired first. However, given the disparity in repair times, machine A should be repaired first because this would result in additional downtime costs of only $6,000 (6 hours at $1,000 per hour) over what will be experienced anyway. If machine B is repaired first, then machine A will be idle for 26 hours rather than six hours. The additional 20 hours of downtime results in additional downtime costs of $12,000 (20 hours at $600 per hour).

Proper planning and scheduling of maintenance activities are vitally important to the control of maintenance costs. Since maintenance resources are limited, they must be used efficiently to attain the desired level of service at least cost.

Since planning and scheduling of maintenance activities rely heavily on information requirements which are generated in response to other decisions discussed in this chapter, they are discussed only briefly here.

As indicated in Chapter I, maintenance is commonly thought of as not being susceptible to planning and scheduling because demands for service are unpredictable. It is true that a maintenance schedule cannot be followed with the same degree of precision as is achieved with production schedules, but a major portion of maintenance work can be planned and scheduled in a highly accurate fashion. Breakdowns, by definition, cannot be scheduled (although as has been pointed out, breakdowns may occur in a predictable pattern). Plans can be made for their occurrence, however, and management must take this into account in scheduling, in setting manpower levels, and in establishing inventory requirements for tools, spare parts, and other maintenance materials.

The work that can be planned and scheduled includes preventive maintenance, mechanical services, and major maintenance projects such as annual overhauls and turnarounds. The more work that can be planned and scheduled the more likely it is that manpower will be utilized effectively (less idle time, less "make-work"), and that materials stores control will be improved.

Scheduling problems differ widely among plants and different types of scheduling problems will typically be encountered within a single plant. A master schedule may exist for major maintenance projects planned during the year, while day-to-day schedules may be prepared for purposes of assigning men to specific jobs.

Prerequisites for successful scheduling include (1) an effective work order system, (2) an effective stores control system, and (3) effective manpower assignment control, including coordination of crafts.

For each job, scheduling will be facilitated if certain basic data are routinely compiled for each item or equipment. These information requirements include:

(a) Equipment description, number, and location.

(b) Planned or desired maintenance intervals.

(c) Actual dates of inspections, PM, or overhaul.

(d) Estimated time for each maintenance task.

(e) Estimated time and sequence of each separate step in the performance of the maintenance task.

(f) Manpower requirements expressed in number of hours per skill classification.

(g) Priority of the machine.

Scheduling accuracy will also be increased by the employment of work standards for those jobs where the development of engineered time standards is feasible.

In addition to accumulation by the accounting system of the information listed above, the management accountant should be capable of assisting the maintenance manager through his familiarity with a number of technical aids to scheduling, including Gantt charts, critical path planning (CPM or network analysis), and PERT/Cost. Such technical aids are not discussed here since they have received exhaustive treatment elsewhere in the literature (7) (41) (55) (80).

Determination of Optimal Maintenance Inventory Policies

In order to insure that maintenance activities can be carried out in a way that will facilitate the production function, inventories of maintenance materials, tools, and spare parts must be maintained. The costs associated with management of maintenance inventories are much the same as those for raw materials or finished goods inventories. Management's objective in this decision setting is to minimize the total of two opposing types of costs--the cost of carrying plus the cost of not carrying adequate quantities of inventory. The topic of inventory management has received a great deal more attention in the literature than have many of the decision settings discussed previously in this chapter. Although the literature mentioned is generally not directed specifically to maintenance inventory management, the methods of analysis are the same. A thorough coverage of these methods is available from numerous sources (34) (35) (36) (41) (55) (60)

(85), and will not be presented in detail here. However, the overall problem is summarized in the following pages prior to classification of the decision setting and specification of the accounting information requirements.

As mentioned above, management is basically concerned with minimizing the sum of two types of costs. The cost of carrying inventories typically includes the cost of capital, related taxes, incremental insurance costs, warehousing, ordering costs (the latter consists of such elements as the incremental cost of related clerical, receiving, and handling activities along with such elements as the impact of quantity discounts and freight differentials), and spoilage and obsolescence. The cost of not carrying adequate inventories includes costs of stockouts, lost sales and customer goodwill, foregone quantity discounts, uneconomic production runs, and extra purchasing, handling, and transportation costs due to "rush" orders. These are the cost figures, then, which management should have available in facing this decision setting.

The problem boils down to answering two fundamental questions: How much to order? When to order?

To answer the quantity question, the costs of ordering (identified above as part of the carrying costs) must be balanced against the remaining cost of carrying inventories at the necessary service level. Thus, good inventory management attempts to minimize the total of these two sets of costs. The methods employed to achieve this goal vary from the very crude "rule-of-thumb" approach to models of intermediate sophistication to probabilistic models involving complex dynamic programming algorithms such as those described by Wagner (85).

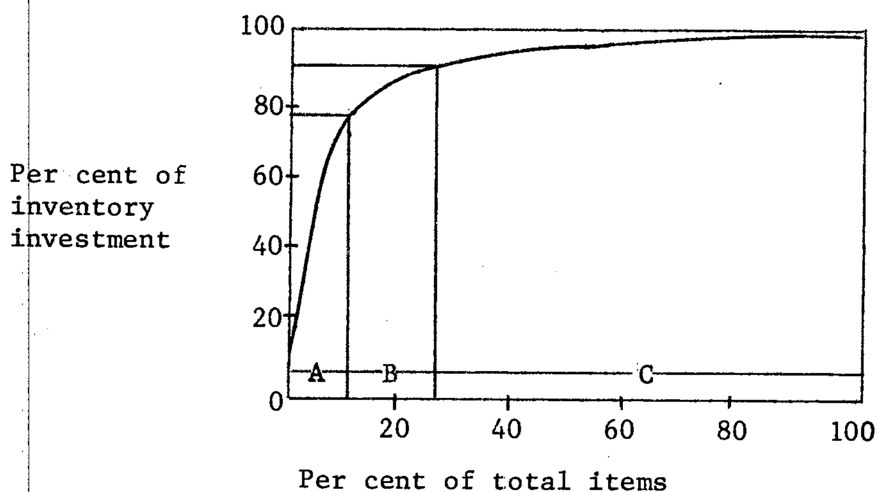
A typical rule-of-thumb approach is illustrated by the following decision rule: When the inventory of a given item is down to what is considered a one month's supply, order a three months' supply. A model of intermediate complexity is the economic order quantity (EOQ) model which is frequently found in use even though it involves a number of limiting assumptions about inventory demand, forecast errors, and the like (41) (55). The answer to the second question of when to order depends on the rate and variability of usage (demand), the replenishment lead time, and the desired level of service. These elements, when considered in combination, lead to the establishment of the reorder point (ROP).

The EOQ model may be of questionable validity because it assumes, among other things, that (1) the rate of usage is known and constant, (2) purchase price is independent of quantity purchased, (3) ordering of the product is independent of ordering other products, (4) lead time or replenishment time is known, and (5) capital resources are unrestricted. Adjustments can be made in the model to allow for situations where some of these assumptions are violated. For instance, the model can readily be expanded to allow for quantity discounts. On the other hand, the EOQ model may be unworkable if ordering of the products is not independent (i.e., if economies can be gained by combining orders for several products from the same supplier). Likewise, in this situation, reorder points are not reached independently.

It is readily apparent that the determination of the optimum investment in inventory can be quite complicated and it involves a great deal of uncertainty. In practice, it is quite common to find a company employing different inventory control methods for different inventory items. Since the method used to exercise control over an item must be economically feasible, more attention will be given to control of high value or critical items than to low value items. ABC analysis is a device for separation of inventory items for forecasting, planning, and control purposes. This concept reflects the need to consider the dollar volume of individual inventory items in relation to the dollar volume of total inventory. Inventory management is improved by varying attention and effort in relation to the importance of the items in inventory. Importance is normally identified in terms of annual usage and dollar volume.

The ABC inventory value classification is based on the fact that most companies have a distribution of annual dollar usage of inventoried items similar to that portrayed in Figure 12. Commonly, 10 to 20 percent of the items in inventory account for 75 to 80 percent of the investment in inventory. These are the A items. The 70 percent or so of items falling in the C category may account for only 10 percent of the annual dollar usage. In this example, the remaining 10 to 20 percent B items constitute 10 to 15 percent of the dollar value of inventory. Since dollar volume is related directly to inventory costs, potential savings are greatest in the A classification. Hence, better inventory control procedures are used for this category, while the least costly inventory policies are used for C items since close control is not so essential.

There are, however, items that are functionally critical to operations regardless of their cost. For instance, the lack of an inexpensive pump part, required infrequently, may cause significant losses in production. In control of maintenance inventories, importance is more likely to be identified in terms of stockout cost rather than high dollar volume of usage. Regardless of the criterion for determining importance, the ABC categories define the items of greatest economic impact and indicate where varying control procedures may be appropriate. A simulation model may be used for critical items while a simple "two-bin" system may be used for C items.[11]



Source: Richard A. Johnson, William T. Newell, and Roger C. Vergin. Operations Management: A Systems Concept. Boston: Houghton-Mifflin Company, 1972.

Figure 12. ABC Inventory Classification System

---

[11] The two-bin system is one in which predetermined quantities of a given stock item are placed in two separate bins. When one bin is emptied and usage from the second bin is begun, a purchase order is written for a new supply. The second bin contains a sufficient quantity to allow for normal usage between the order and delivery date plus the safety stock.

As mentioned at the beginning of the discussion of this decision setting, management's objective is to minimize the sum of the costs of carrying inventories plus the costs of not carrying adequate inventories (subject to resource constraints and operating objectives). A review of the composition of these two costs as listed on page 124 reveals a number of cost estimation problems. Among the costs of carrying, the incremental costs of insurance, taxes, and warehousing may be estimated quite accurately. The cost of capital, or the cost associated with the funds tied up in investment in inventory, is more difficult to determine. This is an opportunity cost--some value must be associated with the lost opportunity of using the inventory funds in other ways. The determination of this cost requires the use of some interest rate--generally either the current borrowing rate or the expected rate of return on investments. Obsolescence and deterioration costs, in addition to being difficult to estimate, may vary widely among different items of inventory. Perhaps the most ill-defined cost input is the cost of stockouts (a cost of not carrying adequate inventory), particularly where it is necessary to estimate lost sales and loss of customer goodwill. For maintenance inventories, however, this particular cost may be more realistically determined than for finished goods inventories. Costs to be considered include costs of downtime on the equipment involved, loss of labor productivity, cost of rush orders, and the like. Additional complicating factors in this decision setting are (1) many of the cost inputs are not available from the accounting records, and (2) costs which are included in the accounting records and reports may not be properly classified for decision purposes. Among others, the accounting records will not reflect the opportunity cost of investments foregone because capital is tied up in inventory, the costs of stockouts, and the cost of foregone quantity discounts. These costs must be estimated on the basis of special studies and analyses.

Costs derived from the accounting records may be misleading due to the fact that accounting costs are developed for income determination and reporting under generally accepted accounting principles. Costs developed for inventory management decisions require classifications that differ from costs collected for external reporting. For example, the accounting records may reflect costs in the aggregate while for decision purposes the cost should be classified into fixed and variable components. Many of the costs listed on page 124 are incremental costs and, as such, they may not be reflected separately in the accounting records. Thus, total insurance, clerical and receiving costs may be shown in the accounts, but for a single item, only the incremental insurance, clerical, and receiving costs are relevant to decision-making. Fixed costs, for instance, cannot be changed by an EOQ decision; hence, they should be disregarded. The EOQ concept is based upon marginal analysis, and the relevant costs are those which will change because of the EOQ decision.

To obtain the optimal quantity in terms of cost minimization, it is necessary to minimize the total incremental cost. The equation which leads to the determination of total incremental costs (TIC) is:

$$TIC = \frac{EOQ}{2} C + \frac{R}{EOQ} S$$

Where: EOQ = Economic order quantity
C = Inventory carrying cost per unit per year
R = Annual required units
S - Procurement costs per order

To answer the question then, of how much to order--to determine the EOQ--the first derivative of the TIC function is taken, set equal to zero, and solved for EOQ yielding:

$$EOQ = \left(\frac{2RS}{C}\right)^{\frac{1}{2}}$$

As mentioned on page 125, this simple equation can be expanded to allow for some situations which are not in accord with its limiting assumptions.

To answer the question of when to order, information must be available on (1) the usage rate, (2) the variability of usage, (3) the replenishment lead time, (4) the variability of lead time, and (5) the desired levels of customer (or maintenance) service.

The reorder point is generally fixed at that amount which is the expected usage during lead time plus the safety stock necessary to allow for the variability of usage, lead time, and the desired level of maintenance service. Historical records combined with expectations are essential in determining what this quantity should be.

The EOQ and ROP models may have to be modified to include probabilistic inputs in circumstances where there is considerable uncertainty. For spare parts inventories in particular, usage rates may be so variable that the linearity assumption of the ROP model is not representative of the physical system. Lead times may also be subject to significant variation. In such cases, it is useful to have a frequency distribution of the occurrences with measures of the mean and standard deviation. Records should therefore be maintained concerning the usage rates and lead times so that the probabilities associated with their occurrence can be determined. These probabilities would also be part of the required inputs for inventory control using Monte Carlo simulation (41, p. 52-58).

From the foregoing discussion, it is apparent that the information requirements for inventory control decisions vary depending upon the sophistication of the decision model used. It is also characteristic of this decision setting that most of the informational inputs are based upon forecasts or are provided by means of special cost studies or analyses for individual items or classes of items. Special studies are required to develop the cost of carrying inventory, the cost of ordering, and the cost of stockouts. Components of these costs were listed on page 124; problems associated with their estimation were discussed beginning on page 128. The management accountant should be prepared to make such cost studies as are necessary. Some of the inputs, such as forecasts of usage, must be obtained from other personnel. Other cost elements can be determined by analysis of the accounting records. For example, the incremental insurance costs associated with carrying additional quantities of an inventory item can be developed by analyzing the insurance account to see how costs behave in response to changes in the amounts (or dollar values) of inventories carried. Historical records should be kept in sufficient detail to enable the development of the desired cost estimates. For example, records should be maintained on quantities of spare parts, components, materials, and tools on hand along with their location and costs, quantities used and dates of usage, and quantities received along with the dates ordered and dates received. The latter two items enable the analyst to determine the probability distributions of usage rates and lead times.

All inventory records must be constantly updated as parts, materials, tools, etc., are issued and returned so that the status of each item is known. This is, of course, a king-size job and it is best handled with an on-line computer system. Such records are essential in order to:

(1) Issue purchase requisitions as quickly as possible for all parts and materials not available in the quantity needed.

(2) Assure that tools, materials and spare parts availability is coordinated with the work schedule.

(3) Notify management of downtime losses due to not having materials available when needed for either scheduled or nonscheduled work.

This decision setting, then, is characterized by subjective estimates, an internal orientation, and emphasis on both planning and control. The informational inputs are both historical and predictive, and rely heavily on special cost studies. It falls within the management control category of Anthony's decision framework. Once the decisions have been made for a given item or class of items, the subsequent activities, such as reordering, become operational control decisions susceptible to a programmed approach according to the procedures and rules developed at the management control level. In other words, as long as the system is monitored to detect the need for changes, a computerized system can be used not only to maintain quantity records, but also to optimize inventory levels and to automatically issue purchase orders at programmed reorder points.

Maintenance Cost Classification and Behavior

It is commonly recognized that cost classifications which are suitable for costing products and for financial statement presentation are often not appropriate for the decision needs of management. In the literature on cost and managerial accounting, one finds repeated emphasis on the need to distinguish costs based on whether they are controllable or uncontrollable, direct or indirect, fixed (capacity) or variable, joint or separable, etc. McFarland (57, p. 81) expresses it this way, "In order to plan and control the costs assigned to him, each manager needs to know the sources from which costs arise and how these costs should behave in response to major independent variables." Consideration of cost behavior patterns is as important for maintenance decisions as for production or other decisions. Although distinctions of this sort have been stressed at various points in the preceding analyses of maintenance decision settings, there are certain characteristics of maintenance costs that need to be specifically noted.

First, one of the major cost-influencing factors is the production level of the plant and many costs are appropriately classified as variable or fixed depending on how they respond to changes in the level of output. Some maintenance costs may not behave in this same fashion, however, because of the tendency to postpone or defer certain maintenance activities, especially those which require shutdown of equipment, during periods of high production. It is not unlikely that maintenance costs in total will decline during peak production periods and increase due to catch-up efforts when production slacks off.

Analysis may reveal that, although total maintenance costs drop during a period of high production, some types of costs, such as PM inspections and "onstream" repairs actually increase, but the increase is more than offset by the fact that shutdowns and overhaul of machinery are deferred. It is useful to divide certain maintenance costs into fixed and variable components, but such a distinction is likely to be based on specific jobs rather than the level of plant output. For instance, replacement of failed items entails fixed costs (set-up costs), but other costs vary depending on the quantity of items to be replaced. Analysis of alternative policies (see discussion, p. 85-91) to determine the optimal replacement policy requires that the fixed and variable cost components be distinguished. The accounting system should provide for appropriate classification and accumulation of such costs.

Second, because maintenance costs are illusive and benefits difficult to gauge accurately, they are commonly thought of as fixed and uncontrollable costs. Many companies, in fact, rely entirely on fixed budgets for maintenance (63). As indicated in the previous sections of this chapter, maintenance costs are controllable and management policy and an effective information system are the most important determinants of maintenance cost-effectiveness.[12]

Finally, it is essential that decision-makers and management accountants be careful to take into account incremental (marginal) costs and opportunity costs. The incremental costs may not be

---

[12]Finley (28, p. 86) estimates that as much as 70 percent of maintenance costs are controllable costs, and can be reduced by management without decreasing performance.

obtainable directly from the accounting records, while opportunity costs generally are not recorded at all. The management accountant should be prepared to develop such costs when necessary.

Summary

This chapter has described the maintenance system, its interdependencies with other systems, its goals, resources, and subsystems. The basic maintenance decision system (depicted in Figure 8) was shown to consist of a number of interrelated decisions which fall in the management control classification of the Anthony decision framework. Each decision was analyzed in terms of (1) management's objectives in making the decision, (2) the decision variables, and (3) quantitative decision models or other analytical techniques suited to aid the maintenance decision process.

Information requirements were specified for the various decision models, and the role of the accounting system (and the management accountant) in providing such information was delineated.

Chapter V consists of a description of field studies of maintenance activities in selected petroleum refineries. The field studies were conducted by the writer in order to obtain a background knowledge of operational maintenance systems. This background knowledge provided an essential base for researching the decision needs of maintenance management.

CHAPTER V

SUMMARY OF FIELD STUDIES OF SELECTED PETROLEUM REFINERIES

Purpose of the Field Studies

In the previous chapter, the maintenance activity was described in terms of its goals, resources, and subsystems. The maintenance decision system was shown to consist of several major interrelated decision settings. These decision settings were examined individually, giving consideration to management goals, decision variables and criteria, and methods of analysis. Based upon this examination, the decision settings were characterized in terms of the Anthony decision framework and the accounting information requirements of each decision setting were specified.

In order for the writer to gain the necessary insight into industrial maintenance activities, in-depth field studies were conducted at selected petroleum refineries. The field studies served the following purposes:

(1) They provided the researcher with a perspective of operational maintenance systems and their relation to the organization as a whole.

(2) They provided an exposure to current practices in maintenance management and decision-making.

(3) They enabled the researcher to investigate the role of the accounting system in facilitating the maintenance planning and control functions.

As indicated in Chapter I (pages 10-11), petroleum refineries were selected for use in the field studies because they have significant maintenance costs, and they generally have substantial resources to use in coping with the maintenance problem. Hence, they can be expected to have relatively well-developed and effective maintenance programs. Given the objectives of this research project, and the purposes of the field studies as listed above, a limited number of studies of effective maintenance management systems could reasonably be expected to make the maximum contribution to the research effort given the time and resource constraints on the researcher.

In this chapter, the maintenance management practices employed in the refineries are described. The purposes in doing so are:

(1) to describe, in terms of the major decision settings set forth in the preceding chapter, the approaches to decision-making which were observed in the refineries.

(2) to indicate in particular the extent to which quantitative decision models such as those discussed in Chapter IV were being employed in the decision process.

(3) to point out the types of information which were made available to maintenance management for the purpose of serving their decision needs, and the extent to which such information coincides with that specified in the conceptual analyses in Chapter IV.

(4) to note the role of the accounting system and the management accountant in supplying information to maintenance management.

No attempt is made to evaluate on a comparative basis the efficiency and effectiveness of the maintenance management of the refineries studied.

The following section sets forth the approach used in conducting the field studies. This is followed by a general description of the refineries included in the studies (i.e., their size or productive capacity, organization, etc.). Later sections describe the methods used in making the types of management control decisions analyzed in Chapter IV and depicted in Figure 8. Attention is directed in each case to the informational inputs employed in the decision context and how and by whom the information is supplied.

Design of the Field Studies

Studies were conducted at four petroleum refineries (each operated by a different company) in three different states. Telephone calls and correspondence with company officials were used to obtain permission to conduct the field studies. The time spent in studying the individual refineries varied from a maximum of approximately ten days to a minimum of two days. The most time was spent in the first refinery studied due to the need for the researcher to gain familiarity with refinery operations, the refinery maintenance activity, and to structure the field study procedure so that it could be conducted more efficiently in other refineries.

A refinery maintenance questionnaire (See Appendix A) was developed and used in the last three refineries studied. This questionnaire was mailed out in advance of the visit to the refinery. The questionnaire was accompanied by a list of informational materials (see Appendix A) which the refinery was requested to supply. In two cases, some of these informational materials were mailed to the researcher in advance of the field visit. This facilitated the subsequent interview procedure in that the writer was already familiar to some extent with the refinery and its maintenance organization.

Subsequent to the first field study, then, the following procedure was used in conducting the remaining studies:

(1) Arrangements were made via correspondence and telephone calls to obtain permission to conduct the study and to set dates for the visit to the refinery. Company officials were assured that information obtained would be treated as confidential and that the research report would not identify either the companies or the individuals participating in the study in any way.

(2) The refinery maintenance questionnaire and the list of informational materials desired were mailed to either the refinery manager or the mechanical superintendent at the refinery.

(3) The researcher requested that the informational materials be provided in advance of the field visit if possible.

(4) The researcher requested that an interview schedule be arranged with personnel in specified positions of responsibility in the maintenance, operations, and accounting

divisions. Permission was requested to record the interviews on tape.

Refinery officials were in all cases most cooperative. With few exceptions, requested information was made available. In some cases, blank copies of forms--cost reports or budgets, for example--were provided, but for security reasons, reports detailing actual cost elements and relationships were withheld. In any case, figures revealed in the following sections are in most cases approximations. Descriptive or other information which would tend to identify a specific refinery is omitted.

General Description of the Refineries

As indicated previously, four refineries were included in the field studies. In the following sections, these refineries will be referred to as refineries A, B, C, and D. Selected comparative figures for the refineries are presented in Table IV. The refineries varied in size from a crude capacity of 100,000 to over 350,000 barrels per calendar day. Total manpower varied from 755 to 2,160. The number of hourly maintenance employees ranged from 185 to 740 men. The percentage of maintenance hourly workers to total manpower was 21.4%, 34.5%, 24.5%, and 34.3% for refineries A, B, C, and D respectively. Such percentages cannot be interpreted meaningfully, however, because of variations in the use of contract maintenance. Also, the maintenance unit of one refinery serviced an adjacent chemical unit owned by the company and another refinery made use of a "roving" maintenance group that serviced facilities other than those of the refinery proper.

TABLE IV

REFINERY CAPACITY AND MANPOWER DATA

Refinery	Crude Capacity b/cd	Total Manpower	Total Maintenance Hourly Manpower	Total Maintenance Supervisory Personnel
A	120,000	1,170	250	60
B	150,000	1,275	440	50
C	100,000	755	185	45
D	350,000+	2,160	740	107

Maintenance Objectives and Organization

In contrast to the findings of the NAA study referred to in Chapter I, the refineries included in this study were found to have well-defined organizational responsibilities based on established maintenance objectives and policies.

Objectives for the maintenance activity as a whole were set forth in general terms only. Written objectives at this level were available at three of the four refineries. To illustrate, a general objective of refinery A was to maintain refinery units in a condition adequate to fulfill refinery processing and safety goals.

Refinery D objectives included (1) maximizing the run-lengths of units, (2) performing maintenance work in such a way as to meet process timing (getting gasoline, heating fuels, etc., when needed), and (3) maintaining safety standards. In connection with the foregoing objectives, refinery D had established goals based on the number of maintenance men required to maintain the facilities investment. Charts were available indicating the number of men required to maintain each $1,000,000 of plant investment (corrected to dollars of a base year). During the past five years, this refinery had achieved a reduction of approximately 50 percent (from 2.95 to 1.50) in the number of maintenance men required to maintain each million dollars of plant investment. The improvement goal was set at attaining a three percent reduction per year. Maintenance cost goals for this refinery were to reduce maintenance and services costs as a percent of plant investment. Charts indicated that during the past four years, this figure had been reduced from approximately 4.5% to 2.9%, while the plant investment (defined as the refinery's investment today expressed in terms of what the same facilities would have cost in base year dollars) had increased by approximately fifteen percent. An additional index was maintained on materials costs as a percent of investment. Goals on each of these performance indices were projected through 1976. Another refinery used similar indices, but they were based on unadjusted book value of plant investment.

At one refinery, the overall maintenance objective was simply "to try to do the job to the best of our ability, and as economically as possible."

Refinery and mechanical department organization charts were available in all refineries. Figures 13 and 14 are examples of "representative" organization charts for a petroleum refinery and a petroleum refinery maintenance division, respectively. These charts are not directly identifiable with any of the refineries participating in the field studies. They are presented to depict common organizational and authority relationships in petroleum refineries.

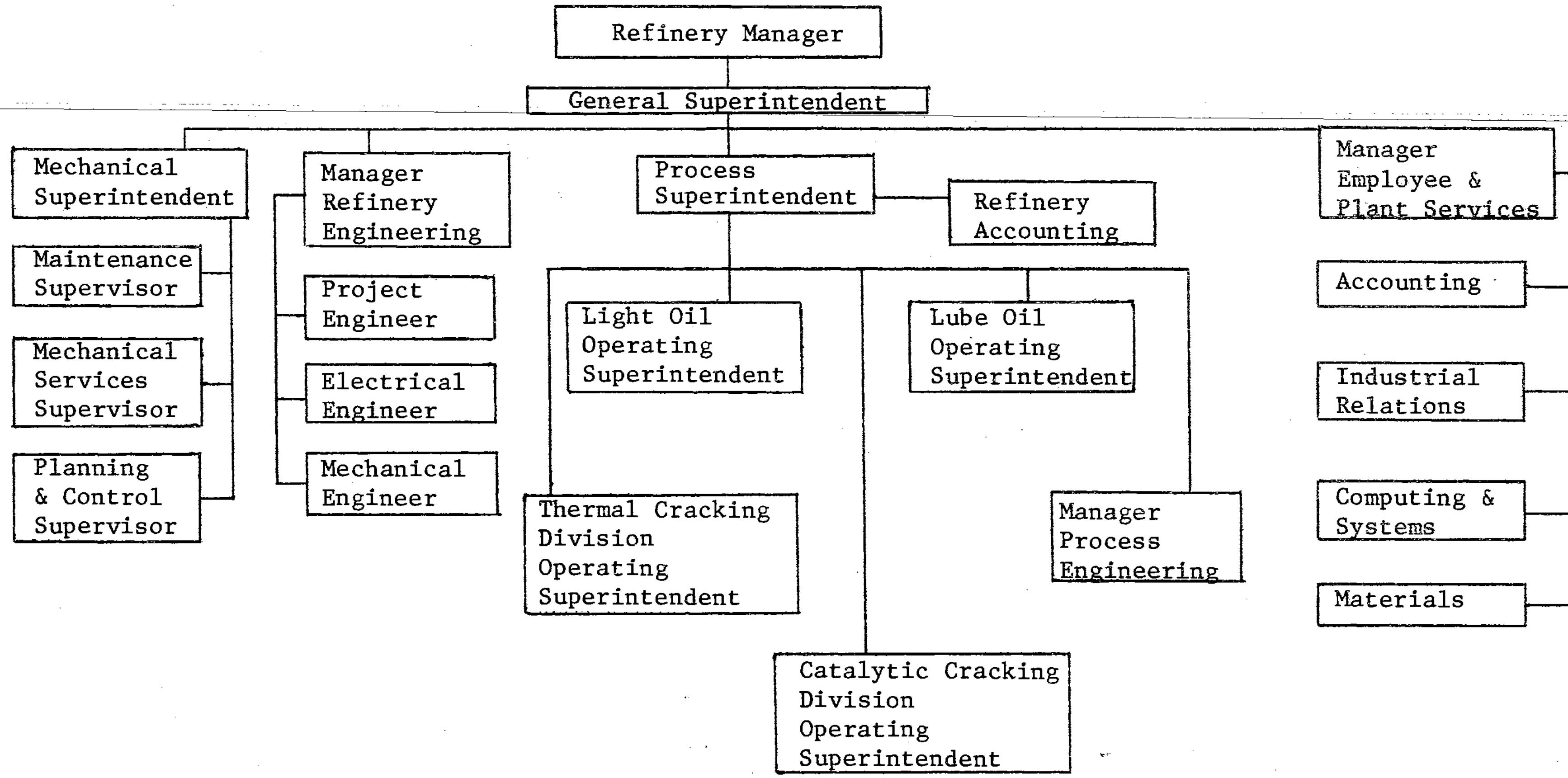


Figure 13. Organization Chart--Petroleum Refinery

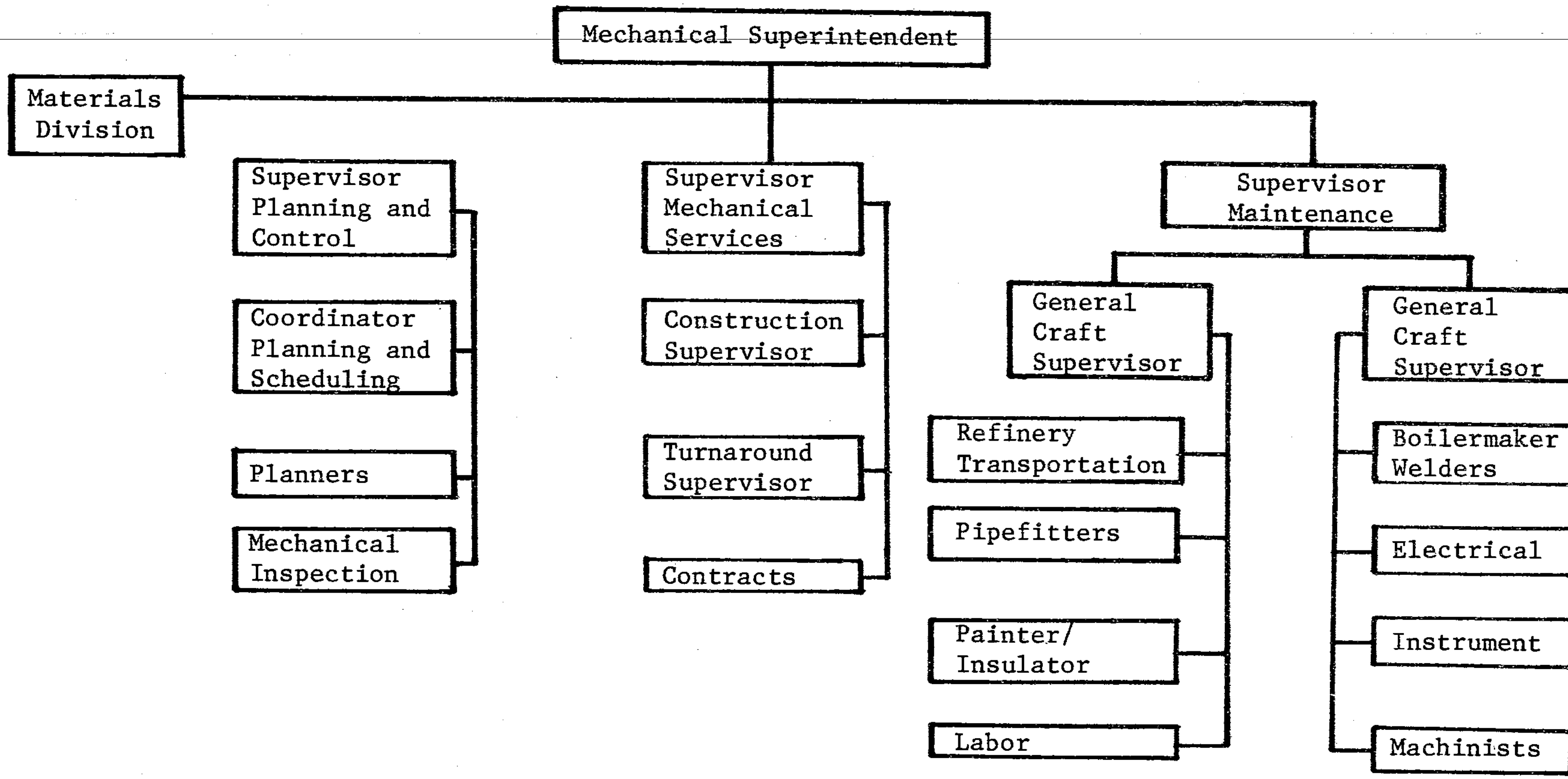


Figure 14. Organization Chart--Maintenance Division

Although some distinct differences were observed in the organizational patterns of the refineries, in no case did the mechanical (maintenance) division report to either the process division or to engineering. The same general pattern existed in all refineries in that the mechanical superintendent reported to a general superintendent (referred to variously as a plant superintendent, operations manager, or facilities manager) who, in turn, reported to the refinery manager. The process and mechanical superintendents appeared to occupy the same authority level in each refinery.

Three of the refineries were organized primarily by zone; refinery B was organized by craft and did not use the philosophy of zone or area foremen at all.

Materials stores management was under the jurisdiction of the mechanical department in refineries B and C. In refineries A and D, materials stores reported to an administrative manager or plant services.

Other differences in organizational patterns were observed, but will not be discussed at this point.

Written job descriptions detailing the functions and responsibilities of mechanical department supervisors were available in three of the four refineries. The descriptions ranged from very brief outline statements listing principal functions to extensively detailed job descriptions such as the illustrative job description presented in Appendix B for the coordinator of planning and control at refinery B.

Written policies and procedures to facilitate the planning and control of maintenance costs exist in each refinery. Again, the attention to detail varied significantly among refineries and with respect to the particular policy or procedure involved. Refinery A, for example, had developed a three page itemized procedure for the writing of work orders. This form specified step-by-step the manner in which the work order is to be filled out (from the time originated until closed) and included an illustration. This procedure was supplemented by (1) a four page policy statement regarding the procedure for writing work orders by priority assignment, (2) a policy statement regarding emergency maintenance procedures, and (3) inter-office correspondence letters regarding authorization and approval of work orders and other instructional details.

The Refinery Maintenance Decision System

The purpose of this section is to describe the methods used in the refineries to plan and control maintenance costs. This is accomplished through a consideration of each of the major decision settings analyzed in Chapter IV and depicted in Figure 8 (page 66) as constituting the maintenance decision system. Since these are management control decisions requiring a great deal of subjectivity and judgment, a variety of approaches and attitudes were observed in connection with certain decisions. In other decision settings, however, a great deal of consistency in both approach and attitude was evident. As each decision setting is discussed the following questions will be considered:

(1) What decision techniques or methods of analysis are employed?

(2) What informational inputs are available?

It was apparent in each of the refineries participating in the study that a strong emphasis was placed on having "quality" people in the management and supervisory positions. As would be expected in management control decisions which require the exercise of a great deal of informed judgment, there was heavy reliance on individual managerial initiative, ability, experience, and "common sense."

Although the role of the accounting system may be referred to occasionally as each decision setting is considered, a later section of this chapter summarizes the extent to which the accounting system and the management accountant contributed to the maintenance decision process in the refineries.

The Breakdown Versus Preventive Maintenance Decision

All refineries employed preventive maintenance to some degree to insure against mechanical breakdown. There was no uniform interpretation of what constitutes PM. In refinery B, PM was viewed as including those activities directly or indirectly intended to support the self-insurance program, prevent disaster and breakdown, prolong runs safely, diagnose condition of equipment, minimize overhaul work on rotating and reciprocating equipment, and otherwise prolong equipment life. This interpretation conforms rather closely to PM as defined for purposes of this study (p. 60-61). In refinery C, most of the foregoing were considered "routine" maintenance; they included under PM the work of only one may who serviced heat exchangers, motors, pumps, and engines.

Concerning the question of whether PM is appropriate for a particular type of equipment, only one refinery reported making a formal study of the service-life distribution of an item of equipment in trying to arrive at the answer to this question. This study concentrated on electric motors and was incomplete at the time the writer conducted the field interview.

The value of such studies was thoroughly discounted by two interviewees, while several others questioned on this point felt that such studies might prove beneficial, but had not been undertaken. An inspection group in refinery A was responsible for making service life predictions on equipment, but apparently such predictions were made on the basis of physical inspections, vibration checks, and the like, rather than by calculating a service life distribution based on failure rates.

Even though not based on service-life studies, decisions had been made to discontinue PM on certain types of equipment in refineries B and D. In refinery D, for example, the mechanical facilities head stated that they had simply become convinced that PM didn't pay off for pumps and motors. Replacement of bearings in rotating equipment on a regular schedule had also been discontinued. One interviewee observed that bearings might be replaced and then burn out thirty minutes later. It was decided that if bearings on a piece of rotating equipment had been performing well over some period of time, it was best to leave the equipment alone and run the bearings and mechanical seals until they failed. This same refinery had also discontinued regular compressor overhauls. On compressors, they made a 4,000 hour check and took action if necessary; some compressors had operated 100,000 hours without requiring overhaul. Basically, these decisions were based on experience and judgment.

Refinery B had concluded that PM (in the sense of taking a motor out of service and rebuilding it) on small electric motors was economically unsound. They were quite concerned, however, about the appropriate PM policy for, say, a 400 horsepower motor. When should it be taken out of service, cleaned up, bearings replaced, and the like? When should money be spent on PM to prevent a more costly breakdown? In other words, management had decided that a regular PM policy on electric motors depended on the size of the motor. For large motors, it was appropriate and economical; for small motors, it was not. Their conclusions, then, were not in agreement with those of refinery D's management. In this situation, a study of the service-life distribution of such motors should provide evidence as to which is the better policy in terms of cost-effectiveness.

The second problem in this decision setting is to determine the optimal PM frequency.

All refineries studied employed some type of regular PM scheduling program. Management did not, in any refinery, make use of a formal type of quantitative analysis such as that described in Chapter IV (pages 75-76). No attempts were made to calculate service-life distributions or determine the probability of failure in a given time period.

Reasons given for not using formal techniques to determine optimal PM frequencies included the following:

(1) It is difficult to assess the value of such an approach. How do you know if the results obtained justify the use of the complicated decision model?

(2) Refineries have too few identical pieces of equipment. One interviewee stated that, except for their reciprocating compressors, most of their equipment consisted of individual, tailor-made items.

(3) An elaborate system is not that essential since it is desirable to have flexibility in PM scheduling. PM can be shuffled around as needed to handle emergency work and balance workload.

In refinery C, one man was charged with the responsibility of setting PM schedules based on equipment history and with scrutinizing the schedule continually for needed adjustments.

In all refineries, the dominant practice was to set PM schedules based on judgment, experience, and equipment history. Heavy reliance was also placed on analytical tools or devices such as vibration analyzers (rotating and reciprocating equipment), ultrasonic devices (checking metal thicknesses), X-ray inspection devices, and temperature checks on heat exchangers.

Refinery D has a strict PM program for turbines, mainly as a safety factor, and for equipment safety valves. Both of these items are on a computer updated system; computer reports are generated detailing when, for instance, safety valves on pumps and turbines need to be taken off, checked, and replaced.

In refinery A, the PM responsibility is shared by several groups. The machine craft supervisor is responsible for scheduling PM on gears and compressors; refinery engineering compiles and keeps current lubrication schedules showing equipment frequency and type of lubrication to use. Industrial engineering prepares a schedule for checking bearings, and the power distribution system, electric motors and instruments are under a PM plan set by the instrument and electrical craft supervisors. In this refinery, PM carries a sufficient priority to insure scheduling of maintenance people to perform the work.

Even though quantitative decision models were not employed to any appreciable extent in the breakdown versus preventive maintenance decision setting, maintenance management in each refinery has a wealth of information with which to work. Ample computer facilities are available for handling the needs of each refinery and each company has systems people to assist the mechanical department in recording data and obtaining reports in such detail as they request.

The information required for this decision setting in Chapter IV (page 76-77) is largely available in each refinery under present reporting methods. The basic document for this information is the work order. Figure 15 shows the work order form used by refinery A (areas enclosed by bold lines contain information to be keypunched).

The work order is generally designed so that it shows the date and cause of failure (perhaps identified by a failure code), and identifies the unit involved. The work order serves as a basis for collecting a historical record of maintenance costs charged to a particular unit.

In the context of this decision setting where the objective is to minimize the total cost of PM, breakdown maintenance, and downtime, without loss of system effectiveness, the cost element which is not routinely collected is the cost of downtime. Maintenance people were not involved in determining product or production losses due to downtime of equipment. Although downtime costs were not routinely

AUTHORIZATION FOR EXPENDITURE

REQUESTED BY | AFE NO. | SUB

A1A TO | ZONE & AREA | JOB PRIORITY | BLANKET 'X' | DATE

EQUIPMENT NO.	CATEGO-RY	MAJOR	MINOR	UNIT NUMBER				SUB UNIT	MKT. P&C FUNC-TION	BUDG. OR PLNR RESP.	ANAL.	
				CON-TROL	CLASS	PRE-FIX	UNIT				I	II

REVIEW AFTER ESTIMATE | FAILURE CODES | LATEST START | LATEST FINISH

PROCEED WITH WORK

A2A DESCRIPTION

INSTRUCTIONS

APPROVED BY | DATE | APPROVED BY | DATE

CRAFT	CODE	'X' STD	FIELD M-HOURS	'X' STD	SHOP M-HOURS
A3A					
A3A					
A3A					
A3A					
A4A TOTAL					

PREPARED BY | DATE

ESTIMATED COST | LABOR | MAT'L | TOTAL

MATERIAL AVAILABLE

CLOSEOUT | BY MAINTENANCE | BY OPERATOR | DATE

Figure 15. Work Order Form - Refinery A

calculated, the operating, or process people, made estimates of these costs and, in two of the refineries, claimed to have accurate estimates for all important units of the dollar cost per hour for each hour the machine or unit was out of service.

Equipment records in each refinery were quite detailed and efforts were being made to improve or extend the data file. For example, an interviewee at refinery D observed that they currently had computer printouts on maintenance data for centrifugal pumps and turbines. They were in the process of adding to this list motors, compressors and heat exchangers. Their goal is to have an equipment records program that will eventually print out maintenance data on each identifiable major piece of equipment. They did not yet have built-in flagging techniques for costs, and were, in fact, having trouble getting cost data into the program. At the time, they had data on number of failures, reasons for failure, recurring-type things like number of seals replaced, and the like. They were working on getting the materials and labor costs into the program. Primary assistance in such efforts came from the computing and systems division.

Repair Versus Replacement of Worn or Defective Parts

Replacement policies for sudden-death components were not discussed with interviewees in the field studies. The general feeling was that this was a type of decision situation rarely encountered in petroleum refineries.

The decision to repair or replace equipment with gradual wear-out characteristics was generally made on a "rule-of-thumb" basis.

Quantitative analysis such as that discussed in Chapter IV (pages 78-85) was not found to be in use in the refineries.

The informational requirements for this decision setting were of the sort which must be obtained by special cost studies; hence, they would not be expected to be readily available in the maintenance reporting system.

Maintenance costs were found to be a significant factor in the repair-replace decision. In refinery C, one interviewee described their policy as one of noting when maintenance costs were becoming excessive on a piece of equipment and immediately putting the problem item under study. For instance, if a pump began causing trouble (operationwise, downtime losses, maintenance costs, etc.) the computer would be set up to print out a monthly cost summary card on a cumulative basis. If it became apparent that the cost of upkeep was exceeding the cost of replacement, then the pump was replaced.

Refinery A maintains complete records on equipment condition in the refinery engineering department, the maintenance machine shop, and the inspection department. The engineering department has a computer program whereby pumps, motors, etc., which are experiencing excessive maintenance are set out and flagged. This program, which is run each six months, reveals when a piece of equipment has exceeded its original cost by 20 percent in one year and 50 percent in three years. Table V shows the form of the printout. Equipment showing up on this report becomes a candidate for replacement based on further study.

Determination of Manpower Levels and Crew Size

In Chapter IV (pages 94-113), the decision concerning optimal

TABLE V

REFINERY A MAINTENANCE SYSTEM:
EQUIPMENT REPLACEMENT ANALYSIS

REPORT NO. 1
PAGE NO. 2

EQUIPMENT NUMBER	COST LAST YEAR NO ORDERS	LABOR $	MATERIAL $	TOTAL $	% REPLACEMENT	COST LAST THREE YEARS NO ORDERS	LABOR $	MATERIAL $	TOTAL $	% REPLACEMENT
P4920	2	119	0	119	29.3	2	119	0	119	29.3
P4917	1	139	0	139	37.5	1	139	0	139	37.5
P4903	1	131	0	131	39.6	1	131	0	131	39.6
P4888	1	76	0	76	23.0	1	76	0	76	23.0
P4886	2	294	0	294	99.6	2	294	0	294	99.6
P4854	2	240	0	240	193.5	2	240	0	240	193.5
P4850	1	185	0	185	162.2	1	185	0	185	162.2
P4839	2	323	0	323	54.7	2	323	0	323	54.7
P4808	1	164	0	164	37.6	1	164	0	164	37.6
P4807	1	163	0	163	37.3	1	163	0	163	37.3
P4798	2	714	0	714	136.0	2	714	0	714	136.0
P4773	2	322	0	322	25.5	2	322	0	322	25.5
P4753	4	229	0	229	70.4	4	229	0	229	70.4
P4752	1	196	0	196	20.4	1	196	0	196	20.4
P4751	1	193	0	193	20.1	1	193	0	193	20.1
P4749	1	311	0	311	116.4	1	311	0	311	116.4
P4740	2	867	0	867	89.8	2	867	0	867	89.8

staffing of the maintenance activity was discussed. Manpower and crew size determinations were seen to be highly interrelated with other maintenance decisions and with decisions outside maintenance, such as, production and capital expenditure decisions. The decision is also affected by such uncontrollable variables as the local labor market. A firm may be very limited in its options to use contract or casual labor to supplement its regular maintenance force.

It is extremely difficult to gauge the effectiveness of the staffing policy, once it is adopted.

Conceptually, the approach proposed in Chapter IV for this decision involved the prediction of manpower requirements based on an assessment of the forecast demand for maintenance services. Such a forecast requires that tasks be studied in order to estimate labor requirements in terms of both hours and skills. Information developed in this fashion can be combined to estimate total manpower needs for work that can be readily forecast and which can be scheduled on a fairly accurate basis. A major complication is the unscheduled work--breakdowns--and how to estimate the additional manpower needed for such work.

Two quantitative decision models (waiting line analysis and Monte Carlo simulation) were discussed in Chapter IV as being suitable for use in this decision context, particularly with respect to the estimation of manpower needs for unscheduled work. Such models are rather difficult to adapt to particular circumstances; they necessarily contain restrictive assumptions, yet they may result in information that will lead to better maintenance decisions.

All of the refineries studied made forecasts in varying degrees of detail of work to be done during the year. Also, maintenance tasks of a recurring nature were commonly studied in order to develop estimates for labor hours and materials requirements. Refinery A uses a purchased system consisting of standardized manpower and time increments for each job to which the system can be applied. Approximately 35 percent of their maintenance jobs are covered by such standards. In three of the refineries, the maintenance procedures for such recurring tasks were written up step-by-step and bar-charted to indicate sequencing of job steps. Detailed historical records were also maintained on turnaround (TA) jobs on major units. Hence, a substantial body of information was available in each refinery on which to base predictions of manpower requirements. However, as has been previously pointed out, none of the refineries made formal studies on equipment to arrive at failure patterns and probabilities, distributions of time between failures, distributions of times required for service, and the like. Such information is essential to the use of queuing techniques and/or simulation methods. Therefore, no refinery participating in the study used such quantitative methods in solving the manpower and crew size problem.

In each refinery, staffing of hourly maintenance personnel was determined primarily by analysis of the volume of work backlog. Of course, as one interviewee expressed it, adequate manpower levels must be achieved in regard to attainment of an "adequate maintenance level" in the refinery, and what constitutes adequate maintenance is not well-defined. An official of refinery C outlined a procedure for assessing where a refinery stood in reaching an adequate maintenance level.

First, he felt that the operating departments, through their requests for maintenance services, would request the services necessary to insure an adequate level of maintenance. Second, the planning department would process these work orders and estimate the manpower requirements by crafts. They had found that skilled planners could estimate the majority of the work orders they process within plus or minus 20 percent of the manhours actually used, and that on an overall average their estimates came remarkably close to 100 percent on all work orders processed.

The manpower estimated on the processed work orders other than emergency type work, work which must be started within 36 hours, preventive maintenance work, turnaround work, and standing work orders is a part of backlog for the particular maintenance department involved.

If the backlog under these conditions runs from 6 to 8 weeks with emergency work and work which must be started within 36 hours no greater than 2-4%, on the average, of total maintenance manhours worked, then this provides assurance that an adequate level of maintenance is being achieved.

If emergency and Priority No. 1 work shows a consistent increase, then consultations between maintenance and operations are called for to determine the cause. If a realistic analysis shows that operations is becoming overanxious in requesting this type of work, then this can be remedied by closer policing by operating department management.

If, however, increase in this type of work is due to breakdowns because requested maintenance services have not been performed, or are being poorly done, then an adequate maintenance level is not being maintained and the situation must be corrected.

The actual staffing policy for refinery C was to set the size of the manpower staff on a long term basis, using volume of work backlog in total and by craft to insure proper staffing by classification. They received a weekly computer report on their maintenance weekly work force and backlog status. This report provided information both in total and by labor or craft classification for the following items:

(1) Number of Employees.

(2) Number of employees assigned to non-scheduled work.

(3) Expected absences, upgrades, and vacations.

(4) Man-days available for work.

(5) Anticipated emergency and write-in work.

(6) Anticipated Priority No. 1 work.

(7) Man-days of backlog in total and by craft for: (a) each area or zone, (b) shops, (c) standing work orders, (d) work orders awaiting material, and (e) all work orders--sum of (a) through (d).

This refinery achieved flexibility in manpower usage through use of a roving crew of about 100 people available for work as needed in any of the company's plants in the area. They also had agreements whereby they could work men across crafts to a considerable degree.

The staffing philosophy of refinery B was to supply sufficient permanent people to cover maintenance needs plus approximately one to two percent of capital and mechanical services project work. Their hourly personnel staffing in each department was determined by analysis of mechanical work load, review of mechanical work backlog, unit turnaround staffing needs, and amount of emergency work and overtime experienced. A mechanical work backlog was computed weekly; the figures provided were somewhat inaccurate because remaining time on jobs in progress was not included. Nevertheless, the figures were used as a guide for planning revisions to staffing of various crafts.

Refinery A aimed at holding a three-week backlog which management felt was "normal" for balanced optimization of their manpower. They receive weekly computer reports on backlog by craft (See Table VI) and by open work orders.

At refinery D, estimates were made at the beginning of each year of the number of men needed for regular maintenance during the year. This estimate was based on planned turnarounds and other planned or known maintenance work. Estimates also were made of manpower needs due to unscheduled downtime. Comparisons of actual manhours worked with estimates were made by week and year to date. The head of the maintenance department observed that at the end of the preceding year, reports indicated that their index of manpower usage would be 1.25 men per million dollars of plant investment. The goal was 1.21, a difference from "actual" of .04, or sixteen manyears of maintenance over the goal. This was considered to be very close considering size of maintenance force (approximately 750 men).

This refinery maintains a record of construction backlog, maintenance work backlog (reviewed monthly), and a minor capital order (replacements and renewals) backlog. They were maintaining between 40,000 and 60,000 manhours of maintenance backlog and 20,000 to 40,000 manhours of backlog in minor capital orders. Based on past experience, management felt that these were satisfactory levels. To achieve flexibility, this refinery maintained a buffer of approximately

TABLE VI

REFINERY A MAINTENANCE SYSTEM:
WEEKLY BACKLOG SUMMARY REPORT - OPEN WORK ORDERS

	Craft	Field	Shop	Total
662	Equipment	1073.6	18.8	1092.4
801	Pipe Fitters	3661.8	746.7	4408.5
802	Machinist	1067.5	861.5	1929.0
803	Boiler Makers	704.2	152.0	856.2
806	Welders	798.9	245.0	1043.9
808	Refinerymen	1615.9	35.9	1651.8
809	Electricians	1086.7	279.7	1366.4
811	Building Crafts	3344.3	372.9	3717.2
814	Tool Room	24.0	.0	24.0
831	Instruments	231.4	264.4	495.8

200 people for construction activity. By pulling these people off construction work for turnarounds and the like, they were able to deal with the peaks and valleys in their maintenance manpower needs.

In refineries participating in this study as well as other refineries with which certain interviewees were familiar, no specific formula was known to be in use to determine optimum numbers for maintenance staffing. Failure to use such formulas to predict manpower needs in advance was attributed to the belief that such formulas, or quantitative methods (e.g., queuing techniques or simulation models as presented in Chapter IV) are either (a) too complicated for practical use or (b) they would produce no better results than methods currently being employed because of the forecasts and estimates involved. Another deterrent to their use was lack of knowledge about how such models could actually be implemented.

Characteristically a management control decision, maintenance staffing was found to be commonly based upon judgment after evaluation of maintenance work backlog, trends in mechanical overtime, number of emergency work orders, and frequency of equipment malfunction with resultant unit downtime.

Use of Contract Versus Use of Company Personnel

All refineries participating in the study utilized contract maintenance to some degree. Little specific information was obtained about the economic analysis on which contracting decisions were based.

Refinery C had a policy of using contract maintenance as little as possible. Management had made no attempt to formally measure cost differences for in-plant versus contract work, but estimated that they could do the work with their own men at about one-half the cost to contract. Based on their experience with contract maintenance, they believed it to be not only expensive, but inefficient. The only jobs contracted were those requiring specialized equipment (e.g., high-pressure cleaning of heat exchangers), or involving significant safety problems.

In refinery B, contract forces were used regularly in-plant to handle specialty jobs, such as painting, earthwork, and major refractory jobs. Contract people were also used for large and infrequent maintenance jobs and about 98 percent of all capital and mechanical services project work. The maintenance contract work was considered expensive; productivity was estimated at 50 percent of permanent forces, however this had not been studied. Hourly contract rates were higher than in-plant rates and contractors apply to the hourly rates an average percentage markup of approximately 8 percent for insurance, 8 percent for taxes, 10 percent for overhead, and 12 percent for profit.

Management at this refinery feels that contract work is necessary because the demand for the sort of work contracted is not consistent enough to justify an expansion in permanent forces. Most contract work is firm bid. Generally, the plant furnishes all materials. Local contract forces are not readily available; nevertheless the contract labor climate was described as good.

In refinery D, the decision to use contract work was based on the make-up of work crews (i.e., selection, training, and number of people involved) and the type of work. Janitorial work, painting, scaffold work, and refractory work was contracted. One official indicated that much of the contract work was of the sort that in-plant people did not want to do anyway. Management felt that contract work was generally fairly effective with variations in quality depending on the type work.

One interviewee voiced the opinion that the refinery would probably have to go to more contract work in the future as plant construction begins to slow down (the plant employs almost 200 people for construction activity and uses these people for handling fluctuations in their needs for maintenance services).

Determination of Job Priorities, Planning, and Scheduling

Job priorities were set by operating supervisors in three refineries. In refinery D, priority assignments were jointly determined by process (operations) and the mechanical department.

Priority determinations are based on losses of production or product, quality considerations, safety, or some other type of monetary loss. Table VII shows the priority categories of maintenance work in refinery A. Although neither of the two quantitative approaches to priority determination described in Chapter IV (pages 117-120) were found to be in use, downtime costs (costs of lost production and costs of idle time for production workers) and costs likely to be incurred by deferring maintenance were taken into account. The writer was unable to determine the exact source or means of estimation of such costs; operations supervisors rather than maintenance management were apprised of the amounts. In one refinery, downtime costs were apparently based on studies by refinery engineering. In another estimates were developed jointly by operations and process engineering.

TABLE VII

REFINERY A: CATEGORIES OF MAINTENANCE WORK PRIORITY

PRIORITY	DESCRIPTION
E	Emergency. Limited to work that, if not accomplished immediately will result in immediate and significant loss of production, product, or will endanger life.
1	Essential non-deferrable repair jobs where production, quality, safety, or a substantial monetary loss is currently being sustained.
2	Essential but deferrable jobs. Jobs where monetary losses are currently being sustained, but the magnitude is relatively small. Also, items on which there is danger of a shutdown or loss of capacity.
3	Designates desirable but deferrable jobs. Number 3 priority jobs will be used to build up a backlog of work.
4	Designates items that are required, but which can be held for a specific shutdown or turnaround.
5	Work orders for long delivery of material, contract jobs, or jobs that can be deferred for a prolonged period.

The percentage of "emergency" maintenance work in the refineries ranged from 15 to 25 percent. Work other than emergency work is planned and scheduled to some degree. Each refinery has a carefully prescribed work order system. In refinery B, for example, larger mechanical jobs are preplanned by the division engineers for their division, smaller mechanical jobs are planned by planners in the mechanical department. Planning includes labor and material cost estimates, required crafts with numbers of men and time, and properly sequenced job steps. The planner also selects materials and prepares materials lists for jobs planned. Standard job plans have been developed for approximately 100 repetitive type jobs. These standard jobs are bar-charted to indicate manpower sequencing (e.g., if a pipefitter is needed on a job, but not until, say, four hours after the job is started, then the pipefitter is scheduled to arrive at the job site at the time when his services are needed). A schedule of mechanical jobs to be done the following day is issued daily. A schedule of labor assignments is also issued daily and is accessible to laborers entering plants so they can proceed to their work locations without confusion. Schedule format is by craft, job control number, location, unit, and brief job description. Numbers of men and hours required for job steps, and craftsmen or laborers assigned to each job are shown.

Other refineries have a similar system for daily scheduling. Refinery D schedules manpower with an on-line system. They utilize a cathode ray tube installation to reassign employees on a day-to-day basis. The senior staff planner decides which job, and the CRT is used to effectively move the employees from one supervisor to another. It also serves the planner in other ways. For instance, if he needs to know how many machinists are in the maintenance department on a given day, who they are, and where they work, or, if he needs vacation and absence figures, department manpower totals, craft totals, and the like, this information is at his fingertips.

Turnarounds are planned and scheduled in even more careful detail. In refinery A, all operating units are scheduled offstream at predetermined intervals for inspection and repairs. The shutdown intervals are established by operating management and a 12-month schedule issued. This schedule is reviewed monthly and adjusted to stock situations and operating needs and an additional month added to the end, thus making it a 12-month rolling schedule. The maintenance planning section formulates a mechanical work list well in advance of the shutdown, indicating each piece of equipment to be worked on with a sequential list of steps to be performed. Work orders are issued for each major piece of equipment in order that jobs can be planned under their purchased standards system where applicable and for subsequent equipment history records. The entire turnaround is planned on a Planalog board to determine the critical path, number and length of shifts, and to optimize manpower by crafts.

The Planalog method is also used by refinery B. The Planalog is a rather uncomplicated mechanical device consisting of a slotted board laid out with a time scale fitted with small blocks. The job is written on each block, and the length of the block represents the time the job will take. Blocks are shuffled back and forth to organize the jobs according to the shutdown job list. The blocks are then organized by craft and a master board is prepared by the shutdown planner and reviewed by operations, maintenance and engineering. After final approval, the board is used as the master plan during the shutdown. The board is updated daily and blocks pushed along if a job slips, or removed when a job is completed. This technique appears to work very well. The mechanics and supervisors find it much easier to visualize than a computer printout, and they consult it frequently during the day so they know what is going on currently, what job is next, and what jobs are on the critical path.

Arrow diagramming is used at refinery C. Refinery D uses a method similar to Planalog. They analyze turnarounds in detail, lay the job out on a large chart, and use this means to evaluate progress. One interviewee indicated that they had used straight CPM techniques in the past and found that their jobs were not too adaptable to it. Most of their turnarounds are one or two week jobs and application of CPM was not considered necessary. On an eight week job they did lay out the critical path, bar charts, and the like. They had abandoned use of critical path scheduling by computer, however, because they had found that they could not feed the information into the computer and get it back in time for it to be useful. Other refineries have experienced this same problem, but a fairly significant percentage of refineries do use CPM by computer for their turnaround projects (65, p. 53-57).

Determination of Optimal Maintenance Inventory Policies

Management of maintenance materials inventories varied considerably among the refineries.

The stores function was a responsibility of the mechanical department at refineries B and C. At refineries A and D, stores was under the jurisdiction of an administrative or plant services manager.

Refineries C and D had all inventories on the computer; refinery A was in the process of converting to an EDP system at the time of the field study. Refinery B used a manual system.

The values of the maintenance materials inventories ranged from approximately $700,000 at refinery C to $3,000,000 at refinery D.

Only refinery D used economic order quantity and re-order point computations. This refinery had been on an EDP-based system since 1955 and had installed a real-time system in 1969. Under their system, withdrawals were recorded on real-time, withdrawal reports by job were available, re-orders placed automatically, and records were maintained on microfiche of the availability of all items stocked for a unit. To illustrate the detail of their inventory control records, their system was set up to provide a materials printout on request for each inventory item. This materials printout showed, among other things, the following information:

(1) Item description and symbol number.

(2) Unit price.

(3) Lead time.

(4) Bin location and quantity.

(5) Usage center.

(6) Minimum inventory.

(7) Order quantity.

(8) Reorder point.

(9) Number of stockouts for the current and two preceding years.

(10) Standard package quantity.

(11) Date of issue, date of receipt, quantity ordered, and unit price for the last five purchase orders.

(12) Comparison of issues for the last three years by maximum quantity issued, frequency, and total issues.

(13) Monthly issues by frequency and quantity for last six months in which issuances were made.

In refinery A, where conversion to a full EDP materials control system was in process, they had previously been carrying about 1500 line items on the computer. This was described, however, as "primarily an accounting record--not available for inventory control, but more or less a money type thing for financial management." In cataloguing items for the new system they had already found that duplications in spare parts were running about 16 percent. This resulted from the fact that different equipment items had common parts which were not cross-referenced. Hence, the same spare part was being stocked in four to six different places.

The warehouse supervisor indicated that they had discontinued use of EOQ formulas "because they had learned that it cost money to warehouse these things." This statement implied that the supervisor did not understand that inventory carrying costs are taken into account in the EOQ determination.

In refinery B, the warehouse supervisor determined what items should be stocked and in what quantity. Decisions were based on stock item usage data obtained from a stock card file. The stock file was reviewed quarterly to control stocked quantities and check items for obsolescence. Stockouts occurred occasionally which, although not considered serious by warehouse management, were felt to be a serious problem by field supervision.

In refinery C, all inventory was on the computer. Maximum and minimum quantities were set based entirely on experience. They assigned one man full-time to this task and he worked closely with supervisors to determine quantities.

Role of the Accounting System in Maintenance Planning and Control

In general, the participation of the accounting department and management accountants in the maintenance planning and control process was minimal--at least in terms of potential involvement. As indicated in the previous sections, maintenance management was, as a rule, assisted by computing and systems personnel in arranging for the recording and reporting of maintenance data in such detail as was desired. Special cost studies and analyses by the accounting department were rarely made. Downtime costs were developed by operations and engineering people. Accounting was not involved with the economic analysis of contracting decisions (although this may have been primarily due to the fact that management commonly made contracting decisions based on convenience, safety, or other factors, and arrived at the decision without any formal consideration or analysis, say, of the differential cost of labor).

The pattern, then, that existed in each refinery was much the same. The interaction between maintenance and accounting was limited. Operations, engineering, and computing and systems personnel, rather than the accounting division, were most instrumental in providing maintenance management with the information they needed to plan and control the maintenance activity.

The following paragraphs re-emphasize this condition to some extent, but several situations are also described where the accounting division assumed an active role in supplying maintenance management with needed information. Such active involvement appeared, however, to be the exception rather than the rule.

In refinery C, interviewees in the maintenance department stated that it was not part of the accounting department's function to keep the historical records on equipment which were used to plan and control costs. Accounting reported costs, but others (mechanical and engineering) maintained equipment records. Accounting was described as remote and totally unconnected with their computer information system. The maintenance division dealt directly with the computer center about information needs without going through any part of accounting. According to the maintenance division supervisor, they received no single specially designed report from accounting that assisted in the planning and control of maintenance costs. Accounting department records for the refinery itself were described as being for budgeting purposes only. At the time of the field study, the maintenance department did not have an actual budget to perform under or try to meet. On shutdown work, they likewise did not work under a cost control budget for a given unit. Their procedure was to work with labor hours and materials rather than deal with costs.

In refinery A, a very extensive computerized reporting system was in use. Cost reporting was handled by the office services department (a part of the accounting organization) under the direction of the manager of plant services. However, the manager of refinery engineering was responsible for the computer program that monitored maintenance costs for refinery mechanical equipment. The computerized work order system appeared to provide adequate and timely information on maintenance work. Among other things, it generated the following reports:

(1) Weekly closed work order performance and summary report. This report shows actual times and costs versus standard times and costs broken down by craft, area, and zone.

(2) Weekly backlog report of open work orders by craft.

(3) Weekly aging of open work orders by location. This report shows all open work orders by area and zone, job number, unit identification, number of days open, and backlog hours remaining.

(4) Transaction report for all jobs opened the previous week.

(5) Time reports showing all craft time charged the previous week and to what charged.

(6) Closure report for all work orders closed the previous week.

(7) Printout of backlog manpower needs for all maintenance work based on assigned priorities.

Analyses of costs were performed by mechanical and engineering personnel.

At the time of the field study, one budget was prepared by the supervisor of office services and it covered the entire refinery. No separate mechanical department budget was prepared, although plans were in process to make the budgeting system much more comprehensive in the future.

In refinery B, the accounting system basically supplies historical cost information. Accounting does not participate to any significant extent in making cost analyses or studies, nor do they participate in budgeting of maintenance costs.

Refinery D appeared to have had the most success in terms of co-operative efforts between accounting and maintenance to improve the utility of accounting information for maintenance management.

Their computerized reporting system has been developed extensively. Most of the reports generated for the mechanical department have been prescribed by maintenance management and the computing and systems division has worked with them to see that the required data are accumulated and reports generated as requested on a timely basis. For example, at the end of each week the cost reporting system for mechanical work intercepts all the data for the last week. This includes all the labor distribution that was turned in, all payables, and all materials invoices, and summarizes this data into weekly cost reports. Tapes are maintained which add the weekly data to the previous year-to-date totals, and new year-to-date figures are included in the cost report. This is before the data ever gets to the accounting department.

At the end of the month, all intercepted data is compiled into a monthly run, and by the seventh working day of the following month, total costs are known for the previous month by unit, by job number and by other classifications. Certain reports, however, had been developed in consultation with the accounting department.

The head of the maintenance department described their earlier maintenance management philosophy as being one of emphasizing control of labor rather than emphasizing control of costs. This was based on the theory that by controlling manpower, costs would automatically be controlled also. This idea had not been discarded because in many ways it was effective, especially because many of the mechanical people interpret data expressed in terms of numbers of men better than that expressed in terms of dollars of cost. Recently, however, they had been looking at what was available to them from accounting to help pinpoint costs, recognize major cost contributors in maintenance work, and help effect cost savings. Prior to this, accounting had developed the system to suit their needs from an accounting standpoint. The system was quite inadequate from a cost control standpoint. The interviewee indicated that there were still many shortcomings in the system and that they still met some resistance from accounting personnel when they advised them that certain information, which perhaps was good for accounting purposes of collecting costs, was worthless to maintenance from the standpoint of recognizing and controlling costs. He then cited instances where, on the other hand, accounting had made significant contributions toward the improvement of reports for maintenance management. For example, the mechanical department, with help from a special study group in accounting had developed a weekly performance report for each first-line supervisor showing how much money the supervisor had spent on various kinds of maintenance, how much manpower he had used to do it, and the total spent to date. Table VIII shows the format of the report. The goals listed in the report are established with full participation by the supervisor. The deleted portion of the report relates to certain non-maintenance items. Lines 2, 3, and 4 of the report relate respectively to minor maintenance (less than $1,000 cost), regular maintenance (over $1,000 cost), and other mechanical (minor capital orders). Lines 10 through 16 relate to contract work (regular and capital) broken down into maintenance work, turnaround projects, construction, and overtime incurred.

TABLE VIII

REFINERY D: MECHANICAL COST REPORT BY AREA SUPERVISOR

AREA

01120

LN	WORK DESC	WEEK EQ MEN	YTD EQ MEN	GOAL EQ MEN	WEEK LABOR $	YTD LABOR $	GOAL LABOR $	WEEK MAT $	YTD MAT $	GOAL MAT $	WK-TOT$	YTD-TOT$	GOAL-TOT $	ZONE
1	TEMP SUP	.0	.0	.0					19225			19225		11
2	MIN MAIN	9.4	9.4	8.2	2035	3645	3205	63	1104	2080	2098	4749	5285	11
3	REG MAIN	.0	.4	1.8		168	703		406	1148		574	1851	11
4	OTH MECH	.0	.0	.8			312			180			492	11
5	TURNARND	.0	.0	.0					6786			6786		11
SUB	TOTAL	9.4	9.8	10.8	2035	3813	4220	63	27521	3408	2098	31334	7628	
10	CON MN R	.0	.0	.2						195			195	11
11	CON TA R	.0	.0	.0										11
12	CON CN R	.0	.0	.0										11
13	CON OT R	.0	.0	.0										11
14	CON MN C	.0	.0	.0										11
15	CON CN C	.0	.0	.0										11
16	CON OT C	.0	.0	.0										11
SUB	TOTAL	.0	.0	.2						195			195	
AREA	TOTAL	9.8	10.7	11.0	2121	4159	4220	63	27576	3603	2184	31735	7823	

Similar mechanical cost reports are generated weekly for each area and zone.

A joint effort by accounting, computing, and operations resulted in a system of controllable cost reports for the operating divisions. This is not a report used by the mechanical department. It illustrates, however, the objective of the company, as expressed by an interviewee from the accounting division, of trying to tailor reports for specific purposes or individuals so that it will not be necessary for them to have to take general reports and make modifications or additional computations to find out what they need to know in order to perform their functions more effectively.

The following general observations relate to additional findings from the field studies:

(1) Such reports as were furnished by accounting to the mechanical department were frequently not supplied on a timely basis. For example, in one refinery, a closed work order report by WO order number detailing unit codes, hours worked, cost of plant labor, cost of outside labor, cost of materials, and total costs, was disseminated 30 to 60 days late; it was not cumulative, and maintenance had to combine it with back reports to get total job costs. At another refinery, accounting furnished schedules of extraordinary expense for maintenance and for mechanical services. The reports showed the job number, description, unit codes, charges carried forward, charges for the current month (for labor, material, and contracts), charges for year-to-date, and comparison of total job costs to date with estimates. The report was distributed approximately 45 days following the end of the month to which it pertained.

(2) Reports and budgets generally did not separate variable and fixed costs or otherwise distinguish costs based on cost behavior patterns.

(3) The accounting division provided no assistance to maintenance management in the use of technical aids to scheduling such as Gantt charts or critical path techniques.

(4) The internal audit division was all but unknown to the maintenance division except in one refinery where the internal audit staff made regular checks to insure compliance with established policies and procedures for approval of budgets; authorization, approval and writing of work orders; and authorization, approval and writing of supplemental work orders on over-expended items. They did not concern themselves with the accuracy of budget, job, or project estimates, or with the effectiveness of maintenance policies, work performance, or decision methods.

Summary

This chapter has summarized the results of field studies of the maintenance activity of selected petroleum refineries. The approaches to decision-making by maintenance management observed in the refineries were reported and discussed in terms of the maintenance decision system set forth in Chapter IV. The role of the refinery accounting systems in providing information for maintenance decisions was also described.

The following chapter will summarize the research, make recommendations about how the accounting system can better serve the informational needs of maintenance management, and present recommendations for further research.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Problem

A major problem facing many industrial organizations today is the effective management of the maintenance function. Maintenance is an essential activity for business enterprises and it must be carefully planned and controlled in order (1) to protect the facilities investment of the enterprise, (2) to support the productive activities of the enterprise, and (3) to accomplish the foregoing at a minimum cost.

A review of previous research studies on maintenance of articles in industry and accounting periodicals revealed (1) that there is no coordinated body of literature in the area of maintenance planning and control programs and (2) there is general dissatisfaction with the level of effectiveness of maintenance management. The former condition results from the fact that published materials generally concentrate on individual aspects of the maintenance activity. There is little evidence of the existence of a cohesive framework which integrates these individual aspects into a total maintenance decision system. The latter condition is attributed to (1) lack of top management attention and emphasis, (2) difficulty in evaluating the performance of maintenance activities, (3) misconceptions about the controllability of maintenance costs, (4) difficulties encountered in the use of quantitative methods or decision models in maintenance decision-making, and (5) inadequate management accounting information on which to base maintenance decisions.

Purpose and Approach of the Research

The central purpose of this study was to make a conceptual analysis of maintenance decision settings, to specify the accounting information requirements of such decisions, and, based on the foregoing, to develop recommendations concerning the means by which the management accountant and the accounting system can contribute to the optimization of maintenance decisions.

To this end, in-depth field studies of the maintenance activities of selected petroleum refineries were conducted. The field studies gave the writer an exposure to operational maintenance systems and provided an essential base for researching the decision needs of maintenance management.

A review of the literature in the subject areas of systems theory, management and organization theory, and decision-making provided the basis for adaptation of the Anthony decision framework for use in analyzing the maintenance planning and control system. The Anthony framework incorporates the systems approach and provides for the classification of decisions according to type and managerial level. Anthony (9, page 1-23) identifies the following processes in the planning and control hierarchy of the large industrial organization:

> Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are to govern the acquisition, use, and disposition of these resources.

> <u>Management control</u> is the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives.
>
> <u>Operational control</u> is the process of assuring that specific tasks are carried out effectively and efficiently.

The decisions associated with these processes differ significantly in their characteristics. As explained in Chapter III, strategic planning decisions are those associated with the highest level in the decision-making hierarchy and are not of the sort encountered by maintenance management. Maintenance decisions, then, fall in either the management control or operational control classifications. The decision characteristics, expanded to include informational input characteristics and associated accounting implications, of these two classifications are extracted from Table II and shown in Table IX on the following page.

This study concentrated on management control decisions, rather than operational control decisions, because the former (1) are more complex, (2) are less well-defined in terms of information requirements and methods of analysis, and (3) have a greater impact on the effectiveness of the maintenance activity since they provide the procedures and rules within which the operational control process is carried out.

The systems approach to management and organization was employed to focus on the role of maintenance in the total system and its interaction with other subsystems, particularly the accounting information system. A general model of the maintenance decision system was developed. This model (see Figure 8, page 66) depicts the basic maintenance

TABLE IX

CLASSIFICATIONAL REFERENT FOR THE MANAGEMENT CONTROL AND OPERATIONAL CONTROL PROCESSES AND INFORMATION-DECISION CHARACTERISTICS

PROCESS/LEVEL	DECISIONS			
	Broad Context	Characteristics	Informational Inputs & Accounting Implications	Outputs
Management Control Organizational Top and Line Management	Goal Congruence Resource Allocation	Rhythmic Constrained Subjective Internal orientation Planning and control emphasis	Internal emphasis Historical & predictive Regular & special reports Secondary measures Retrospective and prospective measures Managed costs Data bank approach	Decisions Implementation within policies and precedents Procedures and rules
Operational Control Technical Line supervisors, foremen, etc.	Task oriented	Stable Programmed Objective Control emphasis Constrained by procedures, rules	Internal events Transactions More non-financial measures Primary measures Engineered costs Real time	Execution

decision settings which fall within the management control category of the Anthony decision framework.

Summary of the Conceptual Analyses of Maintenance Decision Settings and Information Requirements

The goal of the maintenance subsystem is to contribute to the organizational goals by achieving the optimum level of maintenance at minimum cost. Such a broad statement of the maintenance decision problem is not amenable to analysis either for specification of decision criteria or of information requirements. Therefore, this broad statement was broken down into several component decision settings, each of which was shown in Chapter IV to have the characteristics of a management control decision.

These basic maintenance decision settings were classified as follows:

(1) The breakdown versus preventive maintenance decision.

(2) Repair versus replacement of worn or defective parts or units.

(3) Provision of mechanical services.

(4) Determination of manpower levels and crew size.

(5) Use of contract versus use of company personnel.

(6) Determination of Job priorities, planning, and scheduling.

(7) Determination of optimal maintenance inventory policies.

The foregoing decision settings were examined individually in terms of: (1) a statement of the problem, the alternatives available, and management's objectives in making the decision, (2) the decision variables and criteria, (3) conceptually desirable method(s) of analysis, and (4) information requirements. Table X illustrates the form of this analysis for the breakdown versus preventive maintenance decision setting.

For each decision setting, interrelationships with other maintenance and non-maintenance decisions were emphasized by reference to the maintenance decision system.

The significance of the framework developed in this study rests upon its usefulness as a reference base for the evaluation of existing maintenance management programs and as a guide to development of improvements in the planning and control of maintenance costs.

The Role of the Management Accountant and the Accounting System

The ultimate aim in examining the decision settings was to specify their accounting information requirements. The basic assumptions of this study are (1) that accounting is the measurement-communication function of the decision process and (2) that the accounting system should serve as the basic information system for the management planning and control functions and for the decision models and techniques used to implement these functions. The management accountant should, at a minimum, understand the information requirements well enough to supply the relevant data for use in the decision-making models. Preferably, he should be able to originate and manipulate these models rather than be simply a passive supplier of untreated data. The accounting system should be designed to facilitate the management decision process by conversion of raw data into a form suitable for

TABLE X

DECISION SETTING: BREAKDOWN VERSUS PREVENTIVE MAINTENANCE

Problem:	To determine the extent to which preventive maintenance practices should be employed.
Objective:	To find the level of PM which results in minimum total costs of providing maintenance services (sum of breakdown plus PM costs).
Alternatives:	To rely on breakdown maintenance or establish PM program.
Basic questions:	(1) For a given item of equipment, or class of items, is PM appropriate? (2) If PM is appropriate, what is optimal PM frequency?

Basic question (1)	Basic question (2)
Decision Variables: Service-life distribution of item	Decision Variables: (a) service-life distribution of item, (b) amount and cost of PM service, and (c) cost of breakdown--including downtime losses.
Method of Analysis: Plot service-life distribution (survival curve) for item and determine, either by inspection or statistical techniques, how well the data fit a particular curve.	Method of Analysis: Calculate the expected period cost of a policy of scheduling PM on an n-period frequency.
Decision Criteria: Service-life or failure pattern must be predictable. If the failure pattern is random (indicated by an exponential or hyper-exponential distribution), PM is not appropriate.	Decision Criteria: Adopt policy that results in lowest total cost of PM, failure maintenance, and downtime, without loss of system effectiveness.
Information Requirements: Dates and cause of failure for the equipment item(s).	Information Requirements: (a) Dates and cause of failure for the equipment item(s). (b) Cost of each breakdown including materials, labor and downtime. (c) Cost of each PM service including materials, labor and downtime.

direct use in the decision models. Management should not have to take accounting reports and make modifications or additional computations in order to arrive at the information which they need in order to perform their functions more effectively.

To illustrate the foregoing in the context of Table X, note that the information for determining the optimal PM frequency for a given equipment item, or for a bank of similar equipment items, includes (among other things) a record of dates of failure and certain downtime costs. The management accountant, as an active participant in the decision process, should structure the accounting system, perhaps by development of computer programs, to supply not the raw data (dates of failure), but the service-life distributions and failure probabilities which must be generated from the raw data before it is suitable for use in a decision model such as that presented on pages 75 and 76. In addition, since downtime costs are not routinely accumulated in the historical accounting records, the management accountant should conduct cost studies to develop downtime costs (i.e., costs of lost production, idle labor costs, etc.) per hour for each critical equipment item.

Identification of the accounting information requirements of each of the management control decisions listed earlier provides a basis for for evaluating the adequacy of existing accounting systems in meeting the information needs of maintenance management. Of course, if the decision approach used by maintenance management differs significantly from that proposed on the basis of the conceptual analyses in Chapter IV, then the accounting system must be evaluated in terms of how well it provides the information required by the decision approach actually used. The adequacy of the management decision approach is a separate question; however, to the extent that the management accountant is aware of the existence of potentially superior decision models or methods of analysis, he should advise management of the alternative methods in order to promote improvement in the planning and control of maintenance costs.

It should be emphasized at this point that the accounting information is but one of the inputs to a maintenance decision. Decisions may be made on the basis of other information or considerations. In some cases, such other considerations may preclude the need for provision of accounting information. For example, if certain maintenance jobs are contracted out because they involve significant safety hazards, then economic analysis need not be undertaken. Similarly, if work is contracted out because the economics of the decision are obvious (e.g., when the work recurs infrequently and requires expensive and specialized equipment), then cost studies need not be developed. In most cases, however, accounting information is an essential input in order to enable managers to make informed economic decisions. In these cases, it is the responsibility of the management accountant to insure that the accounting information is adequate and that it is provided on a timely basis.

Additional Findings

The field studies were conducted for the purpose of providing the writer with a perspective of operational maintenance systems and a base for researching the decision needs of maintenance management. They were not in any sense an attempt to "validate" the framework developed or the conceptual analyses of the maintenance decision settings. The field studies were limited to only a few companies in one industry; hence, the researcher recognizes that the findings of the field studies cannot be assumed to be representative of conditions in industrial organizations in general. Nevertheless, the following findings were noted as being of particular interest from an accounting standpoint:

(1) The management accountant and the accounting system played only a minor role in serving the decision needs of maintenance management. Cost studies prepared by the accounting department were a rarity. Maintenance management consulted with the computing and systems group, rather than the accounting division, for the purpose of determining the form, content and timing of reports. Reports furnished by accounting were frequently not timely and were not in a form suitable for direct use by maintenance decision-makers. Such findings are in agreement with previous research in this area (63) (83).

(2) Reports and budgets generally did not distinguish costs based on cost behavior patterns.

(3) The accounting division did not provide assistance to maintenance management in the use of decision models such as the economic order quantity determination, or the use of technical aids to scheduling such as Gantt charts and CPM.

(4) The internal audit staff did not involve itself at all with the maintenance department in three of the refineries. In one refinery, the internal auditors checked compliance with accounting procedures related to such things as proper approval of budgets; authorization, approval, and preparation of work orders; capital and expense guidelines; and proper submission of supplemental work orders on overexpended items. They were not concerned with such things as

appraising the accuracy of budget estimates or the effectiveness of maintenance policies, performance, or the appropriateness of management decision methods.

(5) Quantitative decision models were seldom used in maintenance decisions. Reasons given for not using such techniques included:

(a) It is difficult to assess the value of such methods in terms of improved cost-effectiveness.

(b) The methods, in many cases, are considered too complicated to be practicable.

(c) Some of the methods are not considered adaptable to situations encountered in refinery maintenance.

(d) Equipment configuration in refineries is not such as to justify the use of such decision models.

Recommendations for Further Research

The following recommendations for further research are proposed as a result of the findings from this study:

(1) The framework developed and conceptual analyses of the maintenance decision settings are tentative; they are offered for testing through further research. Ideally, this would be done through depth studies of a broad cross-section of industrial organizations. Due to the demands of such an approach in terms of time and resources, an alternative would be to test by means of a properly designed questionnaire with appropriate statistical analyses of the responses.

(2) This study was based on the basic assumptions that (a) accounting is the measurement-communication function of the decision process, (b) the accounting system should serve as the basic

information system for the planning and control functions and for the decision models and techniques used to implement these functions, and, (c) the management accountant should be an active participant in, and contributor to, the management decision process by making cost studies, assisting in the implementation of quantitative decision techniques, and helping management to recognize and identify cost concepts and cost behavior patterns relevant to particular decisions. This conception of the role of accounting is in accord with that of many other accountants (2) (6) (57).

Findings of the field studies, combined with results of studies by Turban (83) and the National Association of Accountants (63) indicate that this conception may be inaccurate. It is recommended in this connection that research be undertaken (a) to assess more precisely the role of the accounting system in serving the management planning and control functions and the extent to which the accounting system has been supplanted as other information systems and information specialists have arisen to serve operating management, and (b) to determine how accurately the role of the management accountant as perceived by the American Accounting Association's Committee to Prepare a Statement of Basic Accounting Theory and as assumed in this study coincides with the actual role of the management accountant in business organizations (6). How active is the management accountant in the management decision process and does his role differ significantly depending upon the industry, or the managerial orientation of the enterprise? If the management accountant is not involved to an appreciable extent in the implementation and use of quantitative decision models (e.g., linear programming, EOQ determinations, queuing analysis, statistical analysis of costs, simulation models, etc.), then there are definite implications for reorientation of accounting education requirements.

(3) It is also recommended that research be undertaken with regard to the expansion of the role of internal auditors to include appraisal of the appropriateness of management approaches to decision-making and structuring of audits to reveal the adequacy of the information system in serving the decisions actually being made.

(4) Study the implementation problems of decision models, including behavioral considerations.

(5) An objection to the use of quantitative decision models is that it is difficult to assess the value of such methods in terms of improved cost-effectiveness. Research into the cost and value of information models such as those described in Chapter IV is needed in order to develop means of determining the validity of this objection in a given situation.

(6) An additional area of research involves the development of measures of performance for individual maintenance jobs and the development of evaluation indices for the maintenance activity as a whole.

Conclusions

This study represents an effort to provide a correlated framework for the planning and control of maintenance costs. The framework rests upon a conceptual analysis of management control decisions which were set forth as representing the nucleus of the maintenance decision system. The significance of the framework is dependent upon the validity of the conceptual analyses and the utility of the framework as a practicable approach to maintenance management.

The framework should provide a basis for evaluating and improving a firm's existing maintenance program and serve as a guide to the installation of maintenance programs in new firms. Each organization will have individual characteristics which must be taken into account in the design of its maintenance planning and control system. Nevertheless, a program designed to encompass the basic decision settings contained in this framework in a systematic fashion will aid the organization in achieving greater cost-effectiveness from its maintenance activity.

This study has resulted in the delineation of the information requirements of the basic management control decisions faced by maintenance management. Many of the informational requirements are of the sort which can be routinely accumulated in the historical accounting records. The identification of such information requirements provides a base for designing the accounting system to accumulate, classify, and report maintenance data, both financial and non-financial, in such a way as to make the maximum contribution to the planning and control of maintenance costs. Such a system would require a data bank approach with master programs for retrieving desired information in the form requested (e.g., total costs, variable and fixed cost elements, controllable costs by cost center, and the like) on a timely basis.

Other informational inputs to maintenance decisions are not available from the accounting records and must be provided by means of special reports based on studies and analyses of costs relevant to each specific decision. To the extent that this study has identified such costs (e.g., differential costs of downtime in the contract maintenance decision or incremental and opportunity costs in the inventory decision), it will prove useful to the management accountant charged with making special studies related to these decision settings.

BIBLIOGRAPHY

(1) Ackoff, Russell L., and Maurice W. Sasieni. Fundamentals of Operations Research. New York: John Wiley and Sons, Inc., 1968.

(2) American Accounting Association. "Report of the Committee on Accounting Theory Construction and Verification." The Accounting Review, Supplement to Vol. XLVI (1971), pp. 51-79.

(3) American Accounting Association. "Report of the Committee on Foundations of Accounting Measurement." The Accounting Review, Supplement to Vol. XLVI (1971), pp. 1-48.

(4) American Accounting Association. "Report of the Committee on Non-Financial Measures of Effectiveness." The Accounting Review, Supplement to Vol. XLVI (1971), pp. 165-211.

(5) American Accounting Association. "Report of the Committee on Accounting and Information Systems." The Accounting Review, Supplement to Vol. XLVI (1971), pp. 289-350.

(6) American Accounting Association. A Statement of Basic Accounting Theory. Evanston, Illinois: American Accounting Association, 1966.

(7) American Management Association. Modern Maintenance Management. New York: American Management Association, 1963.

(8) Anthony, Robert N. "Framework for Analysis." Management Services, I (March-April, 1964), 18-24.

(9) Anthony, Robert N. Planning and Control Systems: A Framework for Analysis. Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1965.

(10) Bierman, Harold, Jr., Charles P. Bonini, Lawrence E. Fouraker, and Robert K. Jaedicke. Quantitative Analysis for Business Decisions. Homewood: Richard D. Irwin, Inc., 1965.

(11) Blumenthal, Sherman C. Management Information Systems: A Framework for Planning and Development. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

(12) Cason, Roger L. "Will PM Help or Hurt?" Hydrocarbon Processing, L (January, 1971), 95-97.

(13) Churchill, Neil C., J. H. Kempster, and Myron Uretsky. Computer-Based Information Systems for Management: A Survey. New York: National Association of Accountants, 1969.

(14) Churchill, Neil C. and Andrew C. Stedry. "Some Developments in Management Science and Information Systems with Respect to Measurement in Accounting." Research in Accounting Measurement. Evanston, Illinois: American Accounting Association, 1966.

(15) Churchman, G. West. The Design of Inquiring Systems. New York: Basic Books, Inc., Publishers, 1971.

(16) Churchman, G. West. Prediction and Optimal Decision. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1961.

(17) Churchman, G. West. The Systems Approach. New York: Dell Publishing Company, 1968.

(18) Cozzolino, Joseph M. "Maintenance Cost Controls." Management Accounting, LII (February, 1971), 40-43.

(19) Cyert, Richard M. and James G. March. A Behavioral Theory of the Firm. Englewood Cliffs: Prentice-Hall, Inc., 1963.

(20) Davidson, H. Justin and Robert M. Trueblood. "Accounting For Decision-Making." The Accounting Review, XXXVI (October, 1961), 577-582.

(21) Dearden, John. "Can Management Information Be Automated." Harvard Business Review, XLIII (March-April, 1964), 128-135.

(22) Deming, Robert H. Characteristics of an Effective Management Control System in an Industrial Organization. Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1968.

(23) Donnelly, James H., Jr., James L. Gibson, and John M. Ivancevich. Fundamentals of Management: Functions, Behavior, Models. Dallas: Business Publications, Inc., 1971.

(24) Dopuch, Nicholas, and Jacob G. Birnberg. Cost Accounting: Accounting Data for Management Decisions. New York: Harcourt, Brace and World, Inc., 1969.

(25) Emery, James C. Organizational Planning and Control Systems. New York: The Macmillan Company, 1969.

(26) Emshoff, James R., and Roger L. Sisson. Design and Use of Computer Simulation Models. New York: The Macmillan Company, 1970.

(27) Field, John E. "Toward a Multi-Level, Multi-Goal Information System." The Accounting Review, XLVI (July, 1969), 593-599.

(28) Finley, Howard F. "How Cost-Effective is Your Maintenance Organization?" Hydrocarbon Processing, LI (January, 1972), 81-86.

(29) Fisher, Gene H. Cost Considerations in Systems Analysis. New York: American Elsevier Publishing Company, Inc., 1971.

(30) Goldman, A. A., and T. B. Slattery. Maintainability: A Major Element in System Effectiveness. New York: John Wiley and Sons, Inc., 1964.

(31) Greenwood, William T. Decision Theory and Information Systems. Cincinnati: South-Western Publishing Company, 1969.

(32) Harding, George G. "Mechanized Maintenance Scheduling." Management Accounting, LIV (March, 1973), 36-38, 42.

(33) Hare, Van Court, Jr. Systems Analysis: A Diagnostic Approach. New York: Harcourt, Brace and World, Inc., 1967.

(34) Hoffman, Thomas R. Production: Management and Manufacturing Systems. Belmont: Wadsworth Publishing Company, Inc., 1967.

(35) Hopeman, Richard J. Systems Analysis and Operations Management. Columbus: Charles E. Merrill Publishing Company, 1969.

(36) Horngren, Charles T. Cost Accounting: A Managerial Emphasis, Third Edition. Englewood Cliffs: Prentice-Hall, Inc., 1972.

(37) Hromish, M. "Maintenance Cost Data for Analysis and Control." Management Accounting, XLIX (October, 1967), 40-46.

(38) Ijiri, Yuji. Management Goals and Accounting for Control. Amsterdam: North-Holland Publishing Company, 1965.

(39) Ijiri, Yuji, R. K. Jaedicke, and K. E. Knight. "The Effects of Accounting Alternatives on Management Decisions." Research in Accounting Measurement. Evanston, Illinois: American Accounting Association, 1966.

(40) Jardine, A. K. S. Operational Research in Maintenance. New York: Barnes and Noble, Inc., 1970.

(41) Johnson, Richard A., William T. Newell, and Roger C. Vergin. Operations Management: A Systems Concept. Boston: Houghton Mifflin Company, 1972.

(42) Johnson, Richard A., Fremont E. Kast, and James E. Rosenzweig. The Theory and Management of Systems, Second Edition. New York: McGraw-Hill Book Company, 1967.

(43) Kast, Fremont E., and James E. Rosenzweig. Organization and Management: A Systems Approach. New York: McGraw-Hill Book Company, 1970.

(44) Knobloch, J. J., D. C. Schindler, and J. R. Blotzer. "Maintenance Work Authorization and Control." Management Accounting, LI (May, 1970), 19-22.

(45) Koontz, Harold, and Cyril O'Donnell. Principles of Management, Third Edition. New York: McGraw-Hill Book Company, 1964.

(46) Lee, Alec M. Systems Analysis Frameworks. New York: John Wiley and Sons, Inc., 1970.

(47) Lemke, B. C., and James Don Edwards. Administrative Control and Executive Action, Second Edition. Columbus: Charles E. Merrill Publishing Company, 1972.

(48) Levin, Richard I., and R. P. Lamone. Quantitative Disciplines in Management Decision. Belmont: Dickenson Publishing Co., Inc., 1969.

(49) Lewis, Bernard T., and W. W. Pearson. Maintenance Management. New York: John F. Rider Publishers, Inc., 1963.

(50) Lifsey, J. A. "Optimization of Maintenance Resources." Operations Research, Vol. 13, No. 6 (November-December, 1965), 1007-1019.

(51) Ludwig, Ernest E. "What the Maintenance Engineer Needs to Know About Process." Hydrocarbon Processing, LI (January, 1972), 87-88.

(52) "Maintenance, Special Report." Hydrocarbon Processing, XXXXIX (January, 1970), 99.

(53) Manthey, Philip S. "Time Task Range and Maintenance Account Technique." Management Accounting, LII (August, 1970), 35-38.

(54) Matthews, D. Q. The Design of the Management Information System. New York: Auerbach Publishers, 1971.

(55) Matz, Adolph, D. J. Curry, and Milton F. Usry. Cost Accounting: Planning and Control, Fifth Edition. Cincinnati: South-Western Publishing Company, 1972.

(56) McCall, J. J. "Maintenance Policies for Stochastically Failing Equipment: A Survey." Management Science, II (March, 1965), 493-524.

(57) McFarland, Walter B. Concepts for Management Accounting. New York: National Association of Accountants, 1966.

(58) Moore, Carl L., and Robert K. Jaedicke. Managerial Accounting, Third Edition. Cincinnati: South-Western Publishing Company, 1972.

(59) Morris, Willaim T. The Capacity Decision System. Homewood: Richard D. Irwin, Inc., 1967.

(60) Morse, P. M. Queues, Inventories, and Maintenance. New York: John Wiley and Sons, Inc., 1958.

(61) Mundel, Marvin E. A Conceptual Framework for the Management Sciences. New York: McGraw-Hill Book Company, 1967.

(62) Murdick, Robert J. Business Research: Concept and Practice. Scranton: International Textbook Company, 1969.

(63) National Association of Accountants. Control of Maintenance Cost, NAA Research Report No. 41. New York: National Association of Accountants, 1964.

(64) National Association of Cost Accountants. Planning, Controlling, and Accounting for Maintenance, N.A.C.A. Accounting Practice Report No. 2. New York: National Association of Cost Accountants, 1955.

(65) National Petroleum Refiners Association. 1972 NPRA Question and Answer Session on Refinery Maintenance. Tulsa: The Petroleum Publishing Company, 1972.

(66) Newbrough, N. T. Effective Maintenance Management. New York: McGraw-Hill Book Company, 1967.

(67) Optner, Stanford L. Systems Analysis for Business Management, Second Edition. Englewood Cliffs: Prentice-Hall, Inc., 1968.

(68) Palmer, Roger R. "Operational Auditing of Maintenance Cost and Control." The Internal Auditor, XX (Summer, 1963), 66-72.

(69) Rappaport, Alfred. Information for Decision Making: Quantitative and Behavioral Dimensions. Englewood Cliffs: Prentice-Hall, Inc., 1970.

(70) Reed, Ruddell, Jr. Plant Location, Layout, and Maintenance. Homewood: Richard D. Irwin, Inc., 1967.

(71) Rigby, Paul H. Conceptual Foundations of Business Research. New York: John Wiley and Sons, Inc., 1965.

(72) Ross, Joel E. Management By Information System. Englewood Cliffs: Prentice-Hall, Inc., 1970.

(73) Seiler, Karl, III. Introduction to Systems Cost-Effectiveness. New York: Wiley Interscience, 1969.

(74) Shillinglaw, Gordon. Cost Accounting: Analysis and Control, Third Edition. Homewood: Richard D. Irwin, Inc., 1972.

(75) Simon, Herbert A. The New Science of Management Decision. New York: Harper & Row Publishers, Inc., 1960.

(76) Sisson, Bill. "What the Maintenance Engineer Needs to Know About Operations." Hydrocarbon Processing, LI (January, 1972), 88-90.

(77) Sollenberger, Harold M. Major Changes Caused By The Implementation of a Management Information System. New York: National Association of Accountants, 1968.

(78) Starr, Martin K. Management: A Modern Approach. New York: Harcourt Brace Janovich, Inc., 1971.

(79) Starr, Martin K. "Planning Models." Management Science, XIII (December, 1966), B115-B141.

(80) Starr, Martin K. Systems Management of Operations. Englewood Cliffs: Prentice-Hall, Inc., 1971.

(81) Timms, Howard L. Introduction to Operations Management. Homewood: Richard D. Irwin, Inc., 1967.

(82) Timms, Howard L., and Michael F. Pohlen. The Production Function in Business, Third Edition. Homewood: Richard D. Irwin, Inc., 1970.

(83) Turban, Efraim. Some Determinants of the Use of Mathematical Models in Plant Maintenance. Chicago: Albert Ramond and Associates, Inc., 1966.

(84) Vergin, R. C. "Scheduling Maintenance and Determining Crew Size for Stochastically Failing Equipment." Management Science, 13, No. 2 (October, 1966), 53-67.

(85) Wagner, Harvey M. Principles of Operations Research. Englewood Cliffs: Prentice-Hall, Inc., 1969.

APPENDIX A

STUDY INSTRUMENTS

RESEARCH STUDY

PLANNING, CONTROLLING, AND ACCOUNTING FOR MAINTENANCE COSTS

REFINERY MAINTENANCE QUESTIONNAIRE

PURPOSE OF THE RESEARCH STUDY: The major purpose of the study is to develop a conceptual framework for the planning and control of maintenance costs with special emphasis on the information requirements of maintenance decisions and the role of the accounting system in providing such information.

PURPOSE OF THE QUESTIONNAIRE AND INTERVIEWS: This questionnaire is designed to serve as a guide for interviewing personnel responsible for various aspects of maintenance management in selected petroleum refineries.

The purpose of the interviews is to provide information about the current maintenance management practices in the refineries. Interviews will be conducted with maintenance, accounting, and operating supervisory personnel; therefore, those questions which are not applicable to the individual being interviewed should be disregarded. Written answers to the questions which do relate to the individual's functions and responsibilities are not necessary. While most of the questions require specific answers, others are somewhat general and are included to give an idea of certain areas of interest which may be discussed in the interview.

CONFIDENTIAL: Information obtained in these interviews will be treated as confidential; replies to questions are restricted to the researcher and members of his advisory committee at Oklahoma State University. Material appearing in the written research report will not be identified in any way with companies or individuals participating in the study.

I. GENERAL:

1. What is the status of maintenance* management in the refinery? To whom responsible?

2. Is the maintenance division organized by craft or by zone or by combination thereof?

3. Do you qualify maintenance personnel in more than one craft?

4. Are maintenance men unionized? If yes, how does this affect operations (with respect to crew size, promotions, overtime experience, use of contract maintenance)?

5. How is the size of the overall maintenance crew determined?

6. Who is chiefly responsible for the level of maintenance and for maintenance costs? Operating or maintenance people?

7. What percentage of maintenance hours are spent on capital work (i.e., construction of new facilities, etc.)?

8. What percentage of the total maintenance budget is used for contract maintenance?

9. What factors enter in to the decision to use contract maintenance? What types of services are performed regularly by contract maintenance?

10. What is your evaluation of contract maintenance? In terms of effectiveness? Economy?

11. Insofar as maintenance work is concerned, what is the primary concern of the internal audit staff (i.e., are they primarily concerned with ascertaining the extent of compliance with established policies or with reviewing and appraising the effectiveness of performance under such established policies)?

12. How has your company approached the problem or responsibility overlap and interdepartmental friction? Is this a significant problem?

13. What has been the trend of maintenance costs for the refinery over the past ten years (as a percent of operating expenses, capital expenditures, current value of equipment, or some other measure)? To what may this trend be attributed?

*Maintenance, for purposes of this study, is defined on page 5.

II. PLANNING AND SCHEDULING:

1. What method do you use to plan and schedule Turnaround jobs (Is there an up-to-date master plan for all large jobs indicating planned starting date, duration, and completion date, by craft and with manning clearly indicated and including cost estimates)?

2. Can downtime be scheduled in such a way as to avoid losses in production?

3. Who determines priorities for maintenance work?

4. Is there a work-order priority system for all work?

5. Do you have a craft-time breakdown on each work order prior to accomplishment of task?

6. Do you have a day's planned work for each craftsman, one-half working day in advance? Approximately how many craftsmen is each planner responsible for?

7. How do you determine length of backlog policy? Is manpower control tied in to this determination? Do you have periodic backlog measurement by craft? What length of backlog is considered optimal?

III. PREVENTIVE MAINTENANCE:*

1. Does the refinery have a formal, written preventive maintenance plan? If so, what equipment does it cover?

2. How do you determine amount and frequency of your preventive maintenance?

3. Do you have any data that show the influence of different amounts and frequencies of preventive maintenance on the rate of machine failure (breakdown)?

4. How much of your maintenance time is devoted, on the average, to preventive maintenance activities and how much to repairing equipment after it has broken down?

*Preventive maintenance, for purposes of this study, is defined on page 5.

IV. RECORDS:

1. Do you have an "equipment card" for every piece of equipment (showing preventive maintenance schedule, stores inventory and spare parts requirements, inspection schedule)?

2. Do you have a "cost record card" for major pieces of machinery and equipment (showing repairs and charges for labor and materials costs)?

3. Do you keep a record of downtime? How do you calculate losses due to downtime?

V. COST ANALYSIS:

1. Have you developed historical patterns of maintenance costs? For what purposes?

2. What system of cost estimation and cost control is used for shutdown work?

3. How are cost estimates made for individual work requests?

4. Do you occasionally estimate costs of deferring maintenance jobs?

5. When considering the acquisition of new equipment, what attention (in terms of formal analysis) is directed to the maintenance-reliability trade-off (determining the reliability and associated maintenance program which will minimize the sum of the costs of reliability, maintenance, and downtime)?

6. How do maintenance costs enter in to lease-or-buy decisions?

7. How do maintenance costs enter in to replacement decisions?

8. What type of economic evaluation is used to determine the adoption of an instrumentation technique as an aid to maintenance (for instance, how do you determine if it would be economically feasible to acquire a vibration analyzer)?

9. What is the extent of the accounting department's participation in the economic evaluation and justification of projects?

VI. BUDGETING:

1. What types of budgets are utilized for maintenance?

2. Are costs grouped according to behavior or control features for budgeting purposes (i.e., are fixed costs separated from variable costs? Are separate budgets prepared for those segments of the maintenance function having distinctly different authority relationships)?

3. Do you distinguish between repetitive, project, and unscheduled work in budgeting maintenance costs?

4. If fixed budgets are used, are they set up by cost elements or by items of equipment or equipment groups?

5. In developing budgets, how are the budgeted amounts determined? How does the accounting department participate in the budget development process?

6. In budgeting projects, do you budget a lump sum and review individual proposals for expenditures as they arise during the year? Or do you build up the annual project maintenance allowance by planning individual projects to be undertaken during the year?

7. What types of budget reports are regularly made? Frequency? Timeliness? Who is responsible for corrective action?

VII. MATERIALS STORES:

1. What is the approximate value of the spare parts inventory?

2. Do you have an EDP-based stores record system?

3. How is the spare parts and maintenance materials inventory level determined? Do you have controlled stores levels (order points, quantities)?

4. What percentage of your maintenance material stores consists of safety stocks or back-up items for which the inventory must be maintained at a given level?

VIII. <u>WORK ACCOMPLISHMENT</u>:

1. What types of performance measures and techniques do you use in evaluating (in terms of both effectiveness and cost) the maintenance activities under your jurisdiction?

2. Do you employ work measurement standards? What type?

3. What percentage of maintenance work is covered by work measurement standards?

IX. <u>MISCELLANEOUS</u>:

1. Do you accrue maintenance expense? Do reports to maintenance management reflect such accruals?

2. Is the maintenance department charged with general factory overhead?

3. How are maintenance costs charged to divisions or departments?

4. How does the accounting consideration of whether a job or project is to be expensed or capitalized influence the approval, priority, or budgeting of a job or project (e.g., is it easier to get a job approved if it can be expensed currently)?

<u>DEFINITIONAL</u>:

<u>Maintenance</u> - is defined broadly as "what maintenance personnel do." Different practices exist from one company to another, but maintenance activities may well include repair work and overhaul of operating and service facilities and equipment, removal and installation of equipment, construction modifications, rearrangement of buildings and equipment, servicing of machinery, equipment and tools to minimize breakdown and maximize service life, and certain capital expenditures projects.

<u>Preventive Maintenance</u> - is viewed as replacements, adjustments, major overhauls, inspections, and lubrications preplanned and scheduled on a cycle designated by the engineering, maintenance, or operating departments to maintain equipment and facilities in such condition that breakdowns and the need for emergency repairs are minimized.

LIST OF INFORMATIONAL MATERIALS DESIRED FOR FIELD RESEARCH ON REFINERY MAINTENANCE:

(1) Organization charts
  (a) for refinery
  (b) for maintenance unit

(2) Plant staffing report

(3) Job descriptions (functions and responsibilities)
  (a) for Maintenance Division supervisory personnel
  (b) for Operating Division superintendents (for one or two divisions only; for instance, that part of the job description of the Operating Superintendent-Light Oil Division which describes his responsibility for the level of maintenance and for maintenance costs in his division would be sufficient).

(4) Maintenance objectives, policies, and procedures

(5) Summary of annual refinery operating expenditures for the last three years

(6) Periodic maintenance budgets

(7) Accounting bulletins to Maintenance Divison

(8) Accounting reports provided to Maintenance Division

(9) Backlog trends or reports

(10) Work order performance reports

(11) Other performance reports related to maintenance (e.g., Report of actual vs. estimated total work done by craft, etc.)

(12) Trend reports (e.g., relating maintenance costs to total costs, value of equipment, etc.)

(13) Sample copies of forms (filled in, rather than blank, forms are desired if available)
  (a) Work order
  (b) Warehouse material order
  (c) Mechanical or Maintenance Division Daily Work Schedule
  (d) Work Order Priority List
  (e) Other forms used in Maintenance management

APPENDIX B

SAMPLE JOB DESCRIPTION

FUNCTION AND RESPONSIBILITIES OF THE COORDINATOR--PLANNING AND CONTROL

Function

Responsible for the administration, supervision, and work execution of the planners and clerical group. To assist and perform administrative work of the Mechanical Department as directed by his supervisor.

Organizational Relationships

Reports to the Mechanical Superintendent.

Works primarily with the Mechanical Division superintendents, senior planner, mechanical yard office clerical group, fire and safety division clerk, area coordinators, division superintendents, warehouse supervisors, Manufacturing Accounting, craft supervisors, and various staff groups.

Responsibilities

1. To supervise all phases of office work, check all reports for accuracy, assign work, and assist clerical personnel in routine and special work.

2. To assist the Mechanical Superintendent and his staff in various capacities where services are required.

3. To assume special duties such as analysis of costs, profit objective forecasts and special work which may be assigned.

4. To assist all divisions in the interpretation as to class of work which is to be performed with respect to accounting procedures and regulations.

5. To make or secure decisions as to accounting procedure on conditions in question.

6. To notify all concerned of any changes in the Controller's and/or Manufacturing Departments Accounting Bulletins.

7. Responsible for preparation of budget tabulations for maintenance and mechanical services budgets annually for all divisions in the refinery. Prepare budget comparison report against actual expenditures.

8. To assist mechanical personnel to prepare budget items and to help justify budget items with necessary supporting data. This includes maintenance, mechanical services, capital, furniture and fixtures, and automotive budgets.

9. Responsible for preparation of all Authorization for Expenditures for the refinery.

10. Responsible for preparation of all completion reports for Authorizations for Expenditure.

11. To prepare all supplemental A. F. E.'s.

12. Responsible for the preparation and distribution of sickness and/or nonoccupational accident reports for salaried personnel.

13. Responsible for the preparation of time reports for salaried personnel.

14. Responsible for calculating vacation allowables per craft for all mechanical hourly personnel.

15. To prepare and maintain records of vacations for all salaried supervisors.

16. Responsible for updating the refinery distribution code book, approved list to sign warehouse material, and weekend duty schedule.

17. Responsible for the assigning of work order numbers, processing and issuing of work orders, and typing and distribution of work orders as scheduled including the keeping of records.

18. Responsible for the typing and distribution of all daily work schedules, turnaround schedules.

19. Supervises the preparation and distribution of sickness and/or nonoccupational accident reports and the transferring of all hourly personnel to and from the Mechanical Division.

20. Handling various phases of Pilot tests, such as giving tests, keeping records, etc.

21. Supervises the recording of expenditures against capital, maintenance and mechanical services work.

Authority

The Coordinator--Planning and Control has the authority to carry out his responsibilities within the limits of Refining and Company policies and is expected to take affirmative action in carrying out these responsibilities.

VITA

James Harvey Bullock

Candidate for the Degree of

Doctor of Philosophy

Thesis: A MODEL-SYSTEMS APPROACH TO THE PLANNING AND CONTROL OF MAINTENANCE COSTS

Major Field: Business Administration

Biographical:

Personal Data: Born in Lucas, Arkansas, December 29, 1936, the son of Mr. and Mrs. H. S. Bullock.

Education: Graduated from Mansfield High School, Mansfield, Arkansas, in May, 1955; received Bachelor of Science degree in Business Administration from the University of Arkansas in 1968 with a major in Accounting; received Master of Business Administration degree from the University of Arkansas in 1969; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in July, 1974.

Professional Experience: Assistant Director of Personnel and Director of Industrial Safety, Harding Division of Fourco Glass Company, Fort Smith, Arkansas, 1957-66; graduate assistant, Department of Accounting, University of Arkansas, 1968-69; Instructor (part-time), Department of Accounting, Oklahoma State University, 1969-72; Assistant Professor of Accounting and Finance, Department of Accounting and Finance, New Mexico State University, Las Cruces, New Mexico, 1972-74.