AN INTEGRATED FACILITY OPERATION PROCESS MODEL

by

Moris M. Guvenis

Report of Research Sponsored by
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February 1989

Computer Integrated Construction Research Program
Department of Architectural Engineering
The Pennsylvania State University
University Park, PA 16802
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C I C

COMPUTER INTEGRATED CONSTRUCTION

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FOREWORD

The Computer Integrated Construction (CIC) Research program at Penn State was started in 1987 with a large grant from the National Science Foundation. This grant enabled the research team to develop the fundamental process models defining the scope of the activities required to provide a facility. The research team comprised up to twenty researchers at various stages of its life. It included faculty and research assistants from Architectural and Industrial Engineering, an academic advisory board from five of the leading research schools in the country and a five member industrial advisory board representing experts in each of the phases of the facility life cycle.

In this report, Moris Guvenis, the principal author has defined the roles and essential functions required to operate a facility. This report is a stand alone document focusing on operating and maintaining a facility after its construction, but also complements the other six technical reports defining the remainder of the research undertaken by the team to provide the facility as a whole.

Other complimentary work resulting from this work will be detailed in subsequent technical reports issued by the CIC research program.

Victor Sanvido
Assistant Professor of Architectural Engineering
Director of CIC Research Program
ABSTRACT

This report presents a process model for operating a facility. The model describes the functions which are required to operate the various systems in a facility and to provide the users of the facility with an environment that will enable the facility to meet its intended purposes. This includes anything from operating and maintaining the mechanical systems to providing services such as cleaning, grounds work, security, communication, etc. In addition to identifying the functions required to operate a facility, the model defines different levels of detail, and places each function in the appropriate level. The functions are tied to each other by information elements which are essential in carrying them out. The basics of the modeling tool which is used for this purpose, IDEF0, are described in the first chapter which also exhibits the context of the model. The following chapters explain the scope, methodology, the details of the model, case studies which were conducted, and a discussion on the potential benefits of the model.
ACKNOWLEDGEMENTS

The author wishes to thank everyone who has assisted in the development of this model and technical report: I would like to thank the personnel of the companies / organizations whose practical experience added to my knowledge on the subject and enabled me to observe it from different viewpoints. These companies and organizations include: The International Facility Management Association (IFMA), The Pennsylvania State University Office of Physical Plant, Baltimore Gas and Electric Company, The Johns Hopkins University School of Medicine, Camp Hill State Correctional Institute, HRB-Singer, Inc., and First Pennsylvania Bank (Philadelphia). Specifically, I would like to thank Nancy Minni of IFMA and Patricia McEvoy of Baltimore Gas and Electric Company for their effort and time they gave in reviewing the initial stages of the model and providing contacts for interviews and case studies. I would also like to thank the CIC Project Industry Advisory Board, specifically Skip Neely, for their contributions to the development of the model and for reviewing this report. Finally, I would like to thank the project team: In particular, the principal investigator Dr. Victor Sanvido for his constant effort and academic support, Charles Claar for providing contacts for case studies, and Dr. Deborah Medeiros and Dr. Soundar Kumara for their feedback throughout the development of the model.

The author also wishes to show his appreciation to National Science Foundation and The Department of Architectural Engineering for funding his graduate studies at the Pennsylvania State University through the CIC project.
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Chapter 1

THE COMPUTER INTEGRATED CONSTRUCTION PROJECT

1.1 INTRODUCTION

The National Science Foundation has funded a fourteen member interdisciplinary team together with ten advisors, to explore methods to enhance the use of computers in all phases of the life of a constructed facility. The objective of this Computer Integrated Construction (CIC) project is to provide an open information architecture to support the provision of a facility. The team comprises Penn State Architectural and Industrial Engineering researchers together with McDonnell Douglas and selected industry professionals. The intent is to benefit from the pioneering work related to Computer Integrated Manufacturing (CIM) done at Penn State by applying similar approaches to construction.

As the first major thrust of the project, we are developing an integrated process model that accurately represents the essential functions required to manage, plan, design, construct, and operate a facility. To date, the models have been successfully used on four different projects.

The second half of the project, which has just started, is to define the information and its attributes that are required to drive the system. The major benefit of this exercise is the development of a generic dynamic process and information model that can be applied on a specific project to develop and link the everyday models used to provide a facility. Examples of these models are: the architectural program, schematic drawings, CAD detailed drawings, contracts, CPM schedules, budgets, space planning models, energy management simulation, organizational charts and contracts.

IDEFO [3] was selected as the most appropriate modeling tool. A schematic representation of the drawing format (figure 1.1), and a graphical representation of how the model is decomposed (figure 1.2) is included.
FUNCTION: An activity, process, operation, or transformation.

INPUT: Elements (resources or data) that are transformed through a process or an operation to form the outputs.

OUTPUT: Elements that result from the function being performed.

CONTROL: The elements that influence or determine the process of converting input to output. May limit the activity or allow the activity to occur without being affected.

MECHANISM: The elements used to perform a process or operation, such as a person or machine.

Figure 1.1: Schematic representation of the IDEF₀ drawing format (adapted from ICAM Function Modeling Manual, June 1981).
1.2 AN INTEGRATED BUILDING PROCESS MODEL

The Integrated Building Process Model (IBPM) is explained in two drawings. The first drawing (figure 1.3) is an overview titled "Provide Facility" that defines the boundaries of the model in general terms. The second drawing (figure 1.4) divides "Provide a Facility" into five subprocesses. These drawings offer increasing levels of details. Figure 1.3 has the least detail and is known as the level F model.

The model was drawn from the perspective of an observer outside the whole process. It is an abstraction from observation of many building projects by the project team, advisors and other reviewers. The actual mechanisms used in the execution of the functions will depend on the project delivery method. This generic model, when completed with the appropriate mechanisms, should account for all delivery options.

1.2.1 The Level F Model "Provide Facility"

The level F process flow model (Figure 1.3) consists of a single block showing the inputs (facility idea, resources), the controls (external, and project participants constraints), the mechanism (free enterprise economic system and facility champion), and the outputs (operational facility, facility experience, and the impact on environment). Three elements will be tunnelled, shown as an arrow with parentheses on one end. In this case they are the free enterprise economic system, the external constraints, e.g., weather, and the impact on the environment. This tunnelling of arrows means that they will not be shown at the next level of detail - they essentially add nothing to the model and clutter the drawing. These will reappear when their influence is specific to an activity.

1.2.2 Components of "Provide Facility"

The level F model breaks down the process of "Provide a Facility" into the five subprocesses shown in Figure 1.4. These are: Manage Facility, Plan Facility, Design Facility, Construct Facility, and Operate Facility. Detailed definition of these subprocesses follow.
Purpose: This model describes idealized owner's functions and their relationships in a construction process.

Viewpoint: The owner/User

Figure 1.3: F-0, "Provide Facility"
FIGURE 1-4: F. Provide Facility
Manage Facility includes all the business functions and management process required to support the provision of the facility from planning through operations. These activities focus on converting a facility idea, time and money into a facility team, facility management plans, documents and contracts, and resources to support the project. This function runs for the duration of the facility life. It is controlled by two major factors - performance information about the facility as a whole and information to optimize subprocesses within the facility e.g., constructibility information.

Plan Facility encompasses all the functions required to define the owners needs and the methods to achieve them. These activities translate the facility idea into a program for design, a project execution plan, and a site for the facility. Major controls are constraints imposed by project participants (e.g., the owner or engineer), the facility plan, the contract and optimization information. Other outputs include facility planning knowledge and information on the performance of the team.

Design Facility comprises all the functions required to define and communicate the owner's needs to the builder. These activities translate the program and execution plan into bid and construction documents and operations and maintenance documents that allow the facility to meet the owner's needs. Controls or constraints include program and site information, the contract, facility planning knowledge transferred to the design team, the PEP and the design plan. Again, facility design knowledge and information on the performance of the design team is another output.

Construct Facility includes all functions required to assemble a facility so that it can be operated. These activities translate resources (e.g., materials) in accordance with the design into a completed facility. Typically appropriate facility operations and maintenance documents are generated. As a result, facility construction knowledge and information on the performance of the construction team is generated. Controls include bid and construction documents and criteria, the PEP, facility design knowledge transferred to the team, the contract and the construction plan.
Operate Facility comprises all of the activities which are required to provide the user with an operational facility. In addition, operating knowledge, and information on the performance of the team is generated. This process is controlled by the facility construction knowledge available to the team, the facility operating and maintenance documents, the PEP, the operating plans and the contract.

1.2.3 Evolution of the Model

The IBPM has been developed through extensive interviews with experts and practitioners; eight site visits; and multiple reviews by each of a five member academic panel and a five member industry panel. Over 40 experts have reviewed this model for its completeness. The model has been extended four levels below the F level model. This has led to simplification and verification of the upper levels presented in this paper.

While the drawings may seem obvious and simple, they differ radically from those first assembled by the project team. The first model included technical and management functions and was heavily influenced by who performed the function. A second model treated each of the four functions, viz. planning, design, construction and operations & maintenance as combined business and technical functions. The third revision, on the other hand, separated the management functions for each group and combined them into one generic management function called "management of the facility." The other four functions named above, focus on technical functions only. Finally, at lower levels, the model recognizes that there are planning and control, service acquisition and resource acquisition functions that are done at both the facility level and the subfunction level.

The following chapters of this report focus on the operation of a facility. The "Operate Facility" function which is referred to with the node "O" (see figure 1.6) is decomposed into its subfunctions at two more levels. The "Operate Facility" model is presented with explanations regarding its components, as well as case studies which were used to build and modify it.
Chapter 2

SCOPE OF WORK / METHODOLOGY

The post-construction phase of a facility life cycle is the most costly of all phases and thus requires special attention. It covers the operations of a facility and of its systems and services, managing the changes which occur due to the existing or projected requirements of the environment inside or surrounding the facility, consequent installations, renovations, and other minor construction accompanied by planning/replanning, designing, budgeting, etc.

2.1 OBJECTIVES AND SCOPE OF WORK

The primary objective of this report is to develop a process model focusing on the operation of a facility which is part of the post construction phase. The model will classify and identify major functions which are needed to operate a facility, and the flow of generic information elements which support these functions. The model will constitute part of the Integrated Building Process Model (IBPM) mentioned in the previous chapter, and thus will be consistent with the information elements which flow into the "Operate Facility" function from the other functions in the IBPM. The model will be generic in order to be suitable for different facilities, system types, maintenance functions, and building services. It will present the functions and their inter-relationships from an outsider's viewpoint.

The "Operate Facility" model will cover the functions necessary to provide the facility to its users with an environment desired to fulfill its purposes. This includes the operations of the various systems in the facility, their maintenance, and the services provided in the facility. Other functions such as space planning, budgeting, minor construction, etc. are not within the scope of this report because they already exist in different parts of the IBPM. The term "operate" is preferred to "operate and maintain" since maintenance is part of operating a facility, and distinguishing between "operate" and "maintain" is usually subjective.
2.2 METHODOLOGY

2.2.1 Process Analysis through Literature Search

The first step which was involved in conducting this research was studying and understanding the processes which make up the post construction phase of the life cycle of a facility, with a focus on the operations of its various systems and the provision of services to its users. This was done through a literature search on current journal articles and books as well as facility management guidelines/handbooks. Special attention was given to those sources of information which approached the subject through some way of modeling that attempted to represent various aspects.

2.2.2 Brainstorming for Building / Modifying the Model

After a considerable amount of literature was collected, periodical sessions with the project team were arranged for learning the basic techniques of the modeling method (IDEF_0), as well as for building, discussing, and modifying the model. The aim was to obtain as many different opinions and comments on the author's approach as possible through brainstorming. Industry Advisory Board meetings provided expert opinion and valuable feedback on the status, rigor, and correctness of the model at its various stages. In addition to the meetings, visitors from various companies/associations provided information on how they perceive the processes which are related to the operation and maintenance of a facility.

2.2.3 Testing the Model

After the model reached a relatively sound form, the next step was to obtain more information from current practitioners (consultants, facility managers, maintenance and operations supervisors, etc.). Therefore, case studies were arranged for testing and evaluating the model, and modifying it if necessary. The main consideration in selecting the facility types was that they had to be different in size, content (people, systems, and equipment), and intended purpose (main function of the facility). The facility/company types which were selected were:
1. A large scale university campus,
2. A power company,
3. A medical school,
4. A correctional institution.
(More information about the above facilities is given in chapter five).

During the interviews, special attention was given not to introduce the model directly, in order not to structure the thoughts of the interviewee, and thus obtain a potentially different viewpoint. Case #2, Baltimore Gas and Electric Company was an exception to this approach since the contact person was involved in the case study during the earlier stages of the development of the model, and the model had briefly been introduced to her.

The initial stage of the case studies included obtaining general information about the company / facility, and the role of facility management or operations and maintenance in its organizational structure. This was followed by information on the organizational structure of the facility management department itself. The questions which were related to the processes involved, had the following general structure:

*How* is a task done?
This related to how the specific organization handled its operations and maintenance as far as classifying the various tasks was concerned. The pattern that was followed was from general to more specific; i.e., from operating the overall facility to controlling operations information flow, to maintaining specific systems, and so on. This provided the author with an idea on how the tasks which were related operations and maintenance were arranged in that certain facility.

*What* is to be done in a specific task?
Together with the *how* questions, the answers to *what* questions helped understand the pattern of functional breakdown of tasks, i.e., what specific activities a constitute a certain maintenance task, what is needed in order to perform it (materials, information, etc.), what the results / end products of the tasks are, etc.
Who /what performs the task?
The answers to such questions helped relate the tasks to the structure of the specific organization. They also gave information on the equipment which is used to carry out certain activities. The information obtained from these questions were compared with the "mechanisms" of the model.

What are the constraints on performing the tasks?
This part was mostly related to the requirements of the various types of users and of specific purposes that the facility is designated for, environmental limitations, codes, budget, long/short term plans, etc. The information obtained from these questions were compared with the "controls" of the model.

Special forms were prepared for summarizing the interviews in such a way that the information could easily be compared with the model. Appendix C shows the forms which were used for case #3, The Johns Hopkins University School of Medicine. It can be noted that each page represents one function of the model at its second level (0.1 to 0.6). Each function is shown as a matrix. The rows represent the subfunctions (third level), and the columns represent the four different types of arrows (input, output, control, mechanism) which are used in the model. As the conversations were carried, items / answers which were applicable to the elements of the matrix were noted in the appropriate boxes. Additional information and comments, which were found to be important but could not be mapped to the matrix, were also noted on the same page as footnotes (see Appendix C).

2.2.4 Finalizing the Model

The last step was to finalize the model, and to suggest potential uses or possible further development that would facilitate its implementation. The final form of the model includes the functions at different levels of breakdown, and detailed identification of its information elements. The terminology used for these elements are defined in a glossary (Appendix B) in order to avoid potential misunderstanding.
Chapter 3

LITERATURE REVIEW

Although many articles point to the fact that managing the post-construction phase of a facility life cycle is at least as important as the construction phase itself [Kimmel, 1986; Dent, 1986; Simons-Forbes, 1987; Sutherland, 1987; IFMA, 1984,1986; Carroll,1986; Sena & Teicholtz, 1986], not many of them approach the operation of a facility as an item by itself. It is usually seen as part of managing a facility; that is, as a complementary function to space planning, budgeting, real estate, long-range planning, A/E services, etc.. These articles have been found to be helpful in understanding the relative importance of operating a facility with respect to the other functions, identifying different types of operations and maintenance tasks, and how they fit in as part of facilities management.

Those articles that do approach operating a facility as an item by itself [Humphries, 1987; Tomlingson, 1988; Rawlings, 1987; Johnson, 1987] give a better understanding of the function and its breakdown. However, they concentrate on specific facility types, or specific aspects of operations and maintenance. A summary of this key literature which helped define the "Operate Facility" model follows.

3.1 Humphries's Article

Humphries [1987] presents five performance measures which are claimed to be effective in achieving goals in planning maintenance. The maintenance planning function is defined as a key factor in achieving reliable operating schedules and reduced material stocks. It is added that success with maintenance planning largely depends on judicious use of carefully chosen performance indicators that measure a program's progress towards reaching its objectives, and that realistic but aggressive maintenance planning goals should be set.
The first performance measure is *direct activity*. Direct activity is defined as the proportion of time that craftsmen spend on actual execution of maintenance tasks. Direct activity times provide an outstanding way to track the impact of planning on the maintenance work force as well as a way to quantify labor cost reductions. Their most important benefit, however, comes from information collected from activities that impede workers from performing direct work. The initial results of a work sampling study can reveal opportunities for improvement that can be achieved easily through maintenance planning. The tools necessary to support maintenance planning may include preventive maintenance program upgrades, document and drawing control improvements, prepackaging of repetitive job plans, installation of computerized maintenance management packages, and training of maintenance planners.

The second and third performance measures are *planned* and *emergency work*. As emergency requests decrease, the proportion of work orders that can be planned increases. This indicates less urgency overall in maintenance requests. These improvements are the result of better execution of preventive maintenance and integration of maintenance planning needs into routine facility operations. Planned and emergency work orders can be monitored easily and almost continuously with a good work order system. However, it is imperative that clear definitions of the terms "planned" and "emergency" be established in the context of the work order system.

*Schedule compliance*, the fourth performance indicator, is the most powerful and important measure of a planning program’s success. The ultimate objective of planning is to provide craftsmen with the resources they need when they need them. Daily schedules must allocate all available labor time to planned jobs because the amount of time expended on emergency or unplanned repairs cannot be predicted reliably. When emergency jobs consistently interrupt planned work or if most maintenance work is unplanned and therefore unscheduled, the effectiveness of the planning function is questionable, regardless of the quality of the work plans developed. *Schedule compliance, therefore, measures the overall effectiveness of the planning function as the proportion of assigned time that is worked as scheduled. The planning function must focus on planned-versus-actual variations as a feedback mechanism for improvement of labor estimates, and good labor estimates are essential for*
effective budgeting and planning. However, schedule compliance is a more useful measurement of the overall effectiveness of the maintenance planning program than planned-versus-actual variations.

The last performance indicator, \textit{planned material}, measures the contribution of maintenance planning to a just-in-time inventory of maintenance materials. The structure of the planned materials indicator ignores material costs and the number of line items on a requisition or a purchase order.

These five performance measures provide a valuable feedback to those involved in a formal maintenance program.

3.2 Tomlingson's Article

Tomlingson [1988], based on his own experience as a consultant, details the concept of maintenance: Maintenance is seen as a service which contributes to plant profits. This can be achieved by setting the primary objective of maintenance as the repair and unkeep of production equipment to ensure that it is kept in a safe, effective, as-designed, operating condition so that production targets can be met on time and at least cost. A secondary objective is to perform approved, properly engineered, and correctly funded non-maintenance work (such as construction and equipment installation) only to the extent that such work does not reduce the capability for carrying out the maintenance program. In addition to the two main objectives, the maintenance function must operate support facilities (such as power or steam generation), but must ensure that necessary resources are allocated within its authorized work force and are properly budgeted. The maintenance function must also monitor the satisfactory performance of maintenance contract services.

Tomlingson's article also presented a list of workload terminology, distinguishing between different types of maintenance. Following are the nine maintenance types which are defined:
**Maintenance Work:**
The repair and upkeep of existing equipment, facilities, buildings, or areas in accordance with current design specifications to keep them in a safe, effective condition while meeting their intended purposes. It includes the following:

1. **Scheduled maintenance:** Extensive major repairs requiring advanced planning, lead time to assemble materials, scheduling of equipment shutdown to ensure availability of maintenance resources including labor, materials, tools and repair facility space, and management of the job from inception to completion.

2. **Unscheduled repairs:** Unscheduled, non-emergency work of short duration that can be accomplished within approximately one week with little danger of equipment failure in the interim.

3. **Preventive maintenance:** Equipment inspection and non-destructive testing to determine future repair needs and their urgency. This includes tasks such as lubrications and minor adjustments to prolong equipment life, cleaning, adjusting and minor component replacement to help ensure dependable operation.

4. **Emergency repairs:** Immediate repairs needed as result of failure or stoppage of critical equipment during a scheduled operating period. Imminent danger to personnel and extensive further equipment damage as well as substantial production loss will result if equipment is not repaired immediately. Scheduled time must be interrupted and overtime, if needed, would be authorized in order to perform such repairs.

5. **Routine maintenance:** (repetitive work) Janitorial work, buildings and grounds work. Often applied to personnel who perform highly repetitive work such as tool sharpening, etc.

**Non-maintenance work:**
A maintenance department may also be called upon to perform construction, equipment installation, relocation, or modification. This work is applicable
equipment buildings, facilities, or utilities. It is usually capitalized. It includes the following:

6. **Construction**: The creation of a new facility or the changing of the configuration or capacity of a building, facility, or utility.

7. **Installation**: The installation of new or rebuilt equipment.

8. **Equipment modification**: The major changing of an existing unit of equipment or a facility from original specifications.

9. **Equipment relocation**: Repositioning major equipment to perform the same function in a new location.

This terminology is pretty precisely defined; however, it is applicable to production plant type facilities only.

### 3.3 Rawlings's Article

A probabilistic approach to modeling maintenance is presented by Rawlings [1987]: The maintenance element of the project life cycle is seen to be an essential contributor to life cycle costing, both in terms of project viability as a result of the costs of maintaining the facility, and in terms of the optimization of design to account for maintainability and reliability requirements. The model is claimed to encompass the whole range of mean time between failures and the mean time between repairs that may be experienced, and the influences exerted on them by external events, that can provide answers to management questions at both design and operation phases. Examples at the design phase are:

1. tradeoffs between reliability and maintainability,
2. provisions for redundancy or backup components,
3. requirements for maintenance resources and their location,
4. development of a maintenance plan,
Examples at the operation phase are:

1. identification of subsystems or resources that contribute most to downgrading operational ability,
2. establishment and upgrading of maintenance schedules and policy,
3. determination of system/subsystem condition, given specific component failures,
4. how best to modify the maintenance system in response to accumulating operational experience and changing operational requirements.

The input that is required for the model may include items such as:

1. failure occurrence data,
2. failure correlation data,
3. repair time data,
4. policies and schedules,
5. repair crew availability and schedules,
6. spares inventory data,
7. unit costs and rates for manpower, equipment and spares.

The simulation logic of the model is set for:

1. the interrelationship of system components with respect to the ability of the whole system to perform according to specification,
2. the influence of weather on the system and/or the performance of repair crews,
3. preventive maintenance cycles according to predetermined policies and schedules,
4. component failures,
5. supply of spares,
6. configuration schedules and location of repair crews.

The output data of the simulation may include items such as:

1. the distribution of system performance times, giving the percentage of time the system performs according to the given availability criteria,
2. the distribution of times that failed components wait for repair both for all failures and critical failures,
3. performance times for each component or subsystem,
4. utilization of repair crews and facilities,
5. range of maintenance facility costs and the impact on the life cycle costs.

It is claimed that any element of the model can be interrogated in terms of criticality, utilization, contribution to cost, etc., and then the model is accessible for "what-if" gaming to determine the effect on the life cycle costs alterations to maintenance policies, design changes, parts availability, or other parameters, according to the wishes of the project management team.

3.4 Johnson's Article

The importance of preventive maintenance is emphasized by Johnson [1987]: The purpose of scheduled preventive maintenance is to find and replace any components that might be subject to failure and and prevent good components from failing prematurely. A good maintenance program fulfills both of these qualifications and will greatly reduce the risk of unplanned downtime. This will help the facility run at maximum efficiency with minimum production loss and downtime.

Johnson's article also includes a suggested list of preventive maintenance items. (However, it is limited to the electrical maintenance of motor control centers only). It is also added that preventive maintenance steps should be followed before the equipment is initially put into service, periodically thereafter, and at any time a modification is made to control center, such as adding or moving control units.

Although routine scheduled maintenance may require some time and effort to complete, those efforts will be repaid with higher plant efficiency, less chance of unscheduled downtime, and fewer instances of lost production.
The existing literature was found to be helpful in understanding the concepts and providing the model with a general background. For building the model, however, information collected from interviews with/presentations of current practitioners, site visits, case studies, and group discussions was put together with pieces of knowledge obtained from those articles.
Chapter 4

THE "OPERATE FACILITY" MODEL

4.1 THE EVOLUTION OF THE MODEL

The "Operate Facility" model is intended to be as generic as possible so that the functions which make it up are valid for different facility types, sizes, systems, and services which are provided. In order to understand the model and the reasoning behind it, it is necessary to review the approaches through which the model evolved.

4.1.1 First Approach: Manage Facility - Preventive / Corrective Maintenance

Figure 4.1 shows the first approach. The post-construction phase is viewed as managing a facility, and the function breakdown includes space planning, operating, and preventive & corrective maintenance.

Problems in this approach are:

1. The distinction between preventive and corrective maintenance is subjective, and differs from one facility type to another. Likewise, the distinction between "operate" and "maintain" is hard to define.

2. The housekeeping services (janitorial, mail, trash removal, etc.) are not included.

4.1.2 Second Approach: Manage Facility - Plan / Execute Work

Figure 4.2 shows the second approach. Instead of separating preventive maintenance from corrective maintenance, two new functions are defined: Plan Operations & Maintenance, and Execute Operations & Maintenance. A management function is also added to coordinate and acquire resources for the other functions.
Figure 4.1: First Approach to "Operate Facility"
Problems in this approach are:

1. Space planning is found to be redundant. It is a subset of "Plan Facility" model since the overall "Provide Facility" model considers the entire life cycle; "Plan Facility" must be generic enough to cover space planning.

2. Further breakdown of Plan/Execute Operations & Maintenance (O&M) create similar problems to those in the first approach.

4.1.3 Third Approach: Operate/ Monitor/ Inspect/ Maintain

The third approach is illustrated in figure 4.3. The "management" function is extracted from the facilities management section, and the name of the model is changed to "Operate & Maintain Facility". An attempt is made to separate operations from maintenance with complementary functions like "monitor" and "inspect" both systems and services in a facility.

The main problem with this approach is that "Inspect" is of less importance compared to other functions although they all appear at the same level.

One modification to the 3rd approach was made: "Inspect" is considered to be part of the "Monitor" function at this level. For the next level, a breakdown according to system types is planned, but three problems are encountered:

1. The breakdown for "operate" and "maintain" functions will be the same, and each system type will be parallel to another, whereas the "monitor" function follows a sequential pattern. In addition to this type mismatch, the system-by-system approach adds no value to the process model, and avoids breakdown to further levels.

2. It is very difficult and subjective to define or classify system types. Some systems cannot be definitely classified as one type. For example, a fire protection system can be considered as a safety system, a communications system, an electrical system, or a mechanical system.
Figure 4.3: Third Approach to "Operate Facility"
3. Building services such as cleaning, trash removal, waste disposal, etc. do not fit into the system-by-system breakdown; furthermore, they can sometimes be considered as maintenance items.

4.1.4 Fourth Approach: Analogy to the Decision Making Process

The problems discovered through the previous approaches have showed the necessity for a totally new approach. An analogy to Simon's decision making model (Ahituv and Neumann, 1987) is found to be appropriate when supported by a management type function. This has lead to the final version of the model. A detailed description of this fourth and final approach to the model follows.

4.2 AN OVERVIEW OF THE MODEL

Information about the modeling tool (IDEFO) and a summary of the first level of the Integrated Building Process Model (IBPM) are presented in Chapter 1. This section gives an overview of the function "Operate Facility" which in the IBPM is referred to with the node "O".

When observed in the IBPM context, the "O" model has the boundaries which are shown in figure 4.4. The terms which are used are defined in the glossary (Appendix B).

Figure 4.5 shows the node tree which summarizes the functional breakdown of the model and its different levels (this tree is only one branch of the overall IBPM).

The breakdown follows a pattern that is analogical to Simon’s decision making model which consists of the following four stages:

(a) Intelligence,
(b) Design,
(c) Choice, and
(d) Implementing solution.
The functions O.2 and O.3, namely "Monitor Facility Condition and Systems" and "Evaluate Conditions and Detect Problems" are analogous to stage (a); O.4 (Develop Solutions) to (b); O.5 (Select Plan of Action) to (c); and O.6 (Implement Plan) to (d). There is an additional function called "Manage Operations" (O.1) which has a supportive role for the other five functions to exist. A graphical representation of the analogy is shown in figure 4.6.

The second and the third levels of the model are explained in more detail in sections 4.3 and 4.4 respectively.

Figure 4.4: The boundaries of "Operate Facility"
4.3 "OPERATE FACILITY" – Second level

The model applies to a facility which is either at its initial start-up phase or already operating. An IDEF0 diagram for the overall "Operate Facility" model is shown in figure 4.7. The following paragraphs provide brief explanations for the functions.

4.3.1 Manage Operations (O.1)

This function is parallel to the other five functions at this level, and it provides short-term planning and management for meeting the required operating standards of the facility and for its maintenance. This includes scheduling and acquiring necessary services and resources to support all operations and maintenance functions that are related to the facility. The function generates the execution plan to the other functions, and the operations knowledge to the overall IBPM. The operations team which is shown as a mechanism is also an output since the same team (or part of it), together with other resources, is assigned or distributed to the rest of the functions.
Figure 4.7: The Breakdown of "Operate a Facility" (Node: O)
4.3.2 Monitor Facility Condition and Systems (O.2)

This function oversees the various systems and the required environment defined by the facility. This includes recording operations data and other information that is specific to the facility. The main input is the physical performance information which can be through inspection or an automated system. The output is the same information, but it is sorted, classified, or simplified in order to be used by other functions.

4.3.3 Evaluate Conditions and Detect Problems (O.3)

The monitored information at this stage is evaluated with regard to standards, user requirements, and the operations plan. Problems, if any, are located and identified. For example, the monitoring information can state that the water temperature for a heating system is x degrees. The O.3 function determines whether or not this is a problem, and if so, it locates the source and identifies the reason. It does not develop solutions.

4.3.4 Develop Solutions (O.4)

Once a problem is identified, several alternative plans are developed by people with sufficient technical knowledge and expertise, or by automated mechanisms (computers, control panels, etc.).

4.3.5 Select Plan of Action (O.5)

When a number of plans are developed to solve a problem, the non-technical aspects are also considered. However, the plan to be implemented is usually selected by someone else who is usually from an upper level of management. There are exceptions to this of course, and in most cases it is a function of the size of the facility or the organization managing it. The smaller the organization the more likely that less people will be involved in the functions O.2 through O.5. Another exception is an automated monitoring system which can oversee and evaluate the operations, and within certain limitations develop solutions and implement them.
4.3.6 Implement Plan (O.6)

This function is the actual carrying out of the physical operations and maintenance functions. In cases of breakdowns, action is taken in accordance with the selected plan. If there are no problems or breakdowns, the implementation is of the execution plan (scheduled or periodical maintenance, cleaning, turning systems on and off, etc.)

The following section gives more information about functions O.1 through O.6 by decomposing them to subfunctions and briefly describing them.

4.4 "OPERATE FACILITY" – Third level

This section takes a closer look at the six functions described in section 4.3 by defining their subfunctions. Each function is presented with a page of definitions and notes, and its IDEF₀ diagram.

4.4.1 Manage Operations (O.1)

The IDEF₀ diagram of O.1 is shown in figure 4.8. Brief descriptions of the subfunctions follow.

O.1.1 Review Data:
Reviewing the operations data and historical data - these data (as past experience) can always be helpful in developing plans and schedules.

O.1.2 Plan Operations:
The planning/replanning and scheduling that is necessary for implementing the Operations plan, and for the maintenance to support the operations.

O.1.3 Acquire Operations Services and Resources:
The acquiring of all the resources and services needed by all operations and maintenance functions.
It is important that this function not be confused with "Manage Facility" (node "M") in the IBPM. This function deals only with operations, short-term planning, and the acquisition of resources for the related tasks, whereas "Manage Facility" has a broader scope, longer range of planning, and the acquired resources are actually the facility managers, contractors who conduct the "Operate Facility" function.

4.4.2 Monitor Facility Condition and Systems (O.2)

The IDEF₀ diagram of O.2 is shown in figure 4.9. Brief descriptions of the subfunctions follow.

O.2.1 Select Critical Points/Areas to Monitor:
Select points/areas which would best represent the section(s) of the facility to be monitored.

O.2.2 Select Monitoring Mechanism:
Select the mechanism/system which will carry out/assist in the monitoring process. This mechanism can be an automated system, an inspection team, the user, etc.

O.2.3 Collect Data:
Collect all the information related to the operations of the systems in the facility.

O.2.4 Reduce to Information in Correct Format:
Transform the monitoring data to information in a format which can be understood and/or further processed by all mechanisms.

The selected points are usually the most critical ones for testing the effectiveness of the systems and services. The selected mechanisms are different for each monitoring point or purpose. For example, for the exterior look of a building, the best mechanism is an inspector, whereas for a hot water system a suitable mechanism is a thermometer.
Figure 4.9: Node O.2 - Monitor Facility Condition & Systems
4.4.3 Evaluate Conditions and Detect Problems (O.3)

The IDEF₀ diagram of O.3 is shown in figure 4.10. Brief descriptions of the subfunctions follow.

O.3.1 Evaluate Information Against Standards:
The phase in which the information is reviewed and compared with the critical or expected performance values; also includes the determination of whether or not there is a problem.

O.3.2 Locate and Identify Problems:
Find out where the problem is and determine what the problem is.

O.3.3 Notify Problem Solving Mechanism:
Once a problem is located and identified, a mechanism is notified for developing a solution or even implementing it. The mechanism may be an operator, a device, or even the user.

User requirements and standards have the main influences on defining the environment to be maintained in a facility. There are also tolerances to which these requirements can be extended. This function determines whether or not the actual status of the operations is within the tolerance limits of the desired standards or user requirements. If necessary, it locates and identifies the problem, and notifies a mechanism to find a solution.

4.4.4 Develop Solutions (O.4)

The IDEF₀ diagram of O.4 is shown in figure 4.11. Brief descriptions of the subfunctions follow.

O.4.1 Understand the Problem:
Understand the problem area and generate the necessary information to develop solutions.
Figure 4.10: Node O.3 - Evaluate Conditions and Detect Problems
Figure 4.11: Node O.4 - Develop Solutions
O.4.2 Determine Necessary Information and Skills:
Determine the information and skills needed to solve a problem.

O.4.3 Assemble Necessary Information and Skills:
Collect/ put together the information and skills needed to solve a problem.

O.4.4 Develop/Design Solutions:
Design a technical solution for a problem.

O.4.5 Analyze Implications:
Analyze the aspects of the problem solving plan which are not directly related to
the operations and maintenance of the facility, such as business operations,
disturbances, availability, etc.

O.4.6 Present Alternatives:
After a plan is developed, it is communicated to a selecting mechanism as a set
of alternatives.

The following notes supplement the above explanations:

1. A full understanding of the problem is necessary in order to develop effective
   solutions.
2. The implications of the technical solution (cost, disruptions, availability,
   codes, etc.) should not be overlooked.
3. A good presentation of the alternatives will provide a good understanding of
   the problem and the solution.
4. The way that the presentation is made may affect the selection.

4.4.5 Select Plan of Action (O.5)

The IDEF₀ diagram of O.5 is shown in figure 4.12. Brief descriptions of the
subfunctions follow.

O.5.1 Understand Alternatives and Their Implications:
Understand the alternative problem solving plans and their implications in order
to make the most suitable selection.
O.5.2 Select Alternative:
Consider the direct consequences of the suggested alternative plans and their indirect impacts/implications, and select alternative(s).

O.5.3 Commit Services and Resources:
Allocate the people, materials, equipment, contractor, etc. to implement the selected plan.

The following notes supplement the above explanations:

1. In the case that none of the alternatives are suitable for the problem, there is a feedback (referred to as "problem feedback") for new alternatives to be developed.
2. A full understanding of the alternatives and their implications is essential for selecting the best solution.
3. Selection of a plan can be subjective. The preference of the selecting mechanism may be different from that of the developing mechanism.

4.4.6 Implement Plan (O.6)

The IDEF_0 diagram of O.5 is shown in figure 4.13. Brief descriptions of the subfunctions follow.

O.6.1 Distribute Resources:
Giving the resources necessary to carry out the designated operations or maintenance work, to the mechanism performing it.

O.6.2 Do the Work:
The actual implementation of the physical work, i.e. turning on/off switches, replacing or repairing parts, cleaning, etc.

O.6.3 Inspect Work:
Includes the inspection of the maintenance; the checking of whether or not the work was done properly, or whether or not the implemented plan was an appropriate one.
The following notes supplement the above explanations:

1. The term plan refers to both the initial "execution plan" and the "problem solving plan" which is reactive to a breakdown, malfunction, etc..
2. "Inspect Work" should not be confused with the inspection which is a mechanism for monitoring the systems (O.2).
3. The "Physical Performance Information" is an input to O.2.1 for continuous monitoring, and to O.1.1 (Review Data) to be used as historical information for planning.
4. O.6.1 distributes the resources which are provided by the O.1 function (Manage Operations). The distribution is done according to the plans, and resource requirements of different activities.

4.5 DISCUSSION

These diagrams depict generic functions required to operate a facility. Two major points to be highlighted are as follows:

1. The IDEF₀ diagram is time independent. The functions do not have to follow this specific order. Depending on the type of the facility and the point in time in which the process is being observed, any one of the six boxes in the diagram can be the starting point.

2. In many cases functions O.2 through O.5 (and even O.6) can occur simultaneously, or some of the functions in the chain can be skipped. An Automated system is an example to such a case: When a certain space in a facility gets relatively cold, the cold air can activate a thermostat which is set on a temperature range according to certain requirements or codes. This can operate a heating unit until the space reaches the desired temperature, and heating is stopped again by the thermostat.
Chapter 5

CASE STUDIES

Since the existing literature only provided background for understanding the basic functions related to operating and maintaining a facility, more detailed information was needed for understanding the relationship between them and for the model to be generic. The following three advantages of case study strategies as stated by Benbasat, Goldstein, and Mead (1987) were found to be helpful for this purpose:

1. Study the subject in a natural setting and develop from the knowledge captured from the practitioners,

2. Understand the nature and the complexity of the processes taking place, and

3. Research an area in which few previous studies have been carried out.

Four cases were selected for the study. Special care was given to the point that the cases would be significantly different in nature so that they could set a better basis for validating the model. The facility types chosen for the study were:

1. A large scale university campus,

2. A power company,

3. A medical school,

4. A correctional institution.

In order not to structure the interviewees' answers, the model (in its current state) was not introduced immediately, but later in the conversation(s). The answers were summarized on a matrix form which consisted of functions as
rows, and constraint types (input, output, control, mechanism) as columns. Additional comments were also recorded on the sheet. More on the data collection methodology, and examples of such forms prepared for the interviews can be seen in Chapter 2 and Appendix C respectively.

The following sections give detailed information about each case and how they fit the "Operate Facility" model.

5.1 Case 1: PENNSYLVANIA STATE UNIVERSITY (PSU) - Office of Physical Plant

Office of physical plant is the main body which carries out the operations, maintenance, design, planning, construction, and various services on the PSU University Park campus. It also controls the planning and design of other campuses around Pennsylvania.

University Park is the largest PSU campus with over 30,000 students, and contains different facilities, from offices to classrooms, laboratories, housing units, concert halls, sports facilities, etc. Therefore there is a very wide spectrum of systems and environments which have to be operated and maintained, and services which have to be provided to the users of those facilities. Consequently, there is a variety of users and a variety of constraints on the operations of the systems.

Comparison with the Model

Figure 5.1 shows the organizational chart of the PSU physical plant. It can be seen that the maintenance and operations is separate from other functions, with its own planning and implementation.

There is personnel dedicated to preventive maintenance, and they follow a detailed route of totally planned and scheduled maintenance. The maintenance types are classified and prioritized. These functions are all part of the O.1 box in the model. The personnel is the mechanism to the O.6 box (operations team). The maintenance schedule can be modified according to the information
obtained from inspections and historical operations data. This can specifically be seen in the O.1.1 box of the model.

In case of corrective maintenance, the request can come from many sources, e.g., departments, inspectors, preventive maintenance staff, janitors, etc. There is a 'contact person' who forwards this request to the 'service desk'. This whole procedure can be classified as part of the O.2 and the O.3 boxes in the model: The information is collected from various areas through different mechanisms (sources) and the problem solving mechanism is notified. The clerk at the service desk determines the maintenance priority (judgement criteria depends on the urgency of the repair), assigns the job to a specific maintenance crew. This is parallel to the O.1.2 (O.1.2.4) box of the model. At the same time the request is recorded in the computer files for control purposes (part of "collect data" (O.2.3), can be shown at a further level of function breakdown).

Figure 5.1: The organizational chart of the PSU Office of Physical Plant.

5-3
Inspection is done basically for evaluating the need for the maintenance of the interior or the exterior (sidewalks, roofs, floors, etc.). In the model, inspection is considered as a mechanism for monitoring the facility condition and systems (box O.2).

A computerized system called the Central Control System (CCS) allows a centralized monitoring of the operation of the building systems throughout the campus. Power or machinery failures, temperature readings, etc. can be received through the system. The related operator or maintenance staff can then be informed to take necessary action. Furthermore, operation commands can be given through the computer terminal directly to the system. A historical data of operation is kept continuously. This central control system actually covers most of the "Operate Facility" model: All or some of the functions O.2 through O.5 are done simultaneously, and in many cases O.6 (the implementation of a solution) is taken care of through the same system.

The Maintenance and Operations department acquires its own resources; however, the related budget is external. A stock room is kept for all basic tools, additional equipment can also be acquired through the 'Project Management' department. 'Support Services' department can help provide professional help (engineers to act as consultants) as part of the human resources.

In general, main constraints for the planning of the operations are budget, required standards, and the maintenance priorities, whereas for the implementation they are budget, work schedule, and staff & tool availability. (In the model, budget is part of the project execution plan [PEP]).

5.2 Case 2: BALTIMORE GAS & ELECTRIC COMPANY

Baltimore Gas & Electric Company is the major power supplier of Baltimore and vicinity. Figure 5.2 shows the breakdown of the responsibilities of the facilities management department.
Figure 5.2: The Organizational Chart of Baltimore Gas & Electric Co., Facilities Management Department

The administration for the whole department is done through 'Real Estate & Planning'. The total staff numbers 410 and the distribution for each responsibility is as follows:

Security Operations  150
Real Estate & Planning  40
Project Control & Management  40
Operations & Maintenance  180
The Operations and Maintenance Department deals not only with office space of the company, but also with the maintenance of power plants, and power distribution systems.

**Comparison with the Model**

Managing the overall operations (O.1) is heavily constrained by the user/customer demands and the budget. The revision of the operations data (O.1.1) is usually used not for short term planning, but for determining future operations and maintenance needs. Acquiring the resources (O.1.3) is affected by the budget and the resource availability.

The monitoring and trouble shooting functions (O.2, O.3, and O.4) occur almost simultaneously, and they are performed by the same mechanism which can be operators, users, computers, or other control devices. System types and the specific function of the section of a facility to be monitored help define/select the critical areas (O.2.1). Selecting the monitoring mechanism (O.2.2) depends on the monitoring requirements and the type of the system, the availability of the selected mechanism, and the budget.

Trouble shooting is usually initiated by an input from the user, and the main factor influencing this user information is the anticipated operations standards. The problem solving mechanism can be notified (O.3.3) through various means of communications.

In developing a solution (O.4), a trouble shooting guide is used for understanding the problem (O.4.1). The same guide, along with established procedures, the experience of the problem solver, and the budget, determine and assemble the necessary skills and information (O.4.2, O.4.3), and develop solutions (O.4.4). Brainstorming is often used for this function. There may be various implications of the solution such as time and budget constraints, staffing, availability of specific skills, and relative priority of the job which often turns out to be subjective.
Selecting an alternative (O.5) is heavily influenced by its cost, ease of implementation, and implications. The experience of the person who selects the plan is also important.

Committing and distributing the resources (O.5.3, and O.6.1) are influenced by the cost of the resource and the available funds, staffing constraints, and knowing the contractor if the job is to be contracted. Doing the actual work (O.6.2) is a function of how good the plan is and to what extent field conditions allow it to be implemented properly. Therefore, verification of drawings and inspection of the existing conditions are crucial during the planning phase. Codes and user requirements are the main considerations for work inspection (O.6.3). The mechanism for this function is the quality control people or the same mechanism that does the work.

5.3 Case 3: THE JOHNS HOPKINS UNIVERSITY - School of Medicine

The Johns Hopkins University Medical School is one of the leading medical research institutions in the country. Since there are specific differences between the operations requirements of the school of medicine and the rest of the university, and since the school is not located on the main university campus, it has its own facilities management department to carry out the operations, maintenance, and other services of the facility. The facility occupies 1,000,000 sq.ft. which consists of public, research, and teaching space. The staff consists of 16 people.

Comparison with the Model

Environmental requirements for a medical school are much higher and more critical than those of many other facilities. Therefore, the planning of the operations and the maintenance (O.1.2) is very important. It has to be reasonably precise in order to support the direct research in the facility. There are a number of factors influencing or constraining the planning. The most important is the user requirements. Those requirements are listed as objectives, and the adaptability of those objectives to the system is optimized.
with respect to their availability (O.1.2.1, O.1.2.3, O.1.2.4). Staffing can also be a constraint during this optimization process. The work is scheduled (O.1.2.2) according to the priority level of the task. External constraints can be departmental or administrative. Practicality is another issue that has to be considered: awareness of changing technology, the existing or changing conditions of different sections of the facility is typical to a medical school, and is an important factor which influences the planning.

Most of the monitoring is done through inspection and user feedback (observation reports and user reports). All of the subfunctions of "Monitor Facility Condition & Systems" (O.2.1 through O.2.4) happen simultaneously. The operation and the condition of the systems are evaluated against the codes and the user requirements. The standards and the environmental requirements for the laboratories are high and the tolerances are low. The changes in codes have to be followed for they are frequent and they often set up additional constraints. Once a problem or a need for a change is identified (O.3.2) and understood (O.4.1) solutions are developed based on procedures and technical feasibility (O.4.2, O.4.3, O.4.4). The implications which have to be analyzed (O.4.5) are usually the limitations which are related to the designated function of the facility or the section of it. For example, animal welfare department must be continuously ventilated and the temperature must be strictly controlled no matter what the maintenance in that section requires. Similar requirements due to scientific reasons are also in effect for most of the laboratories.

Functions O.2, O.3, and O.4 are performed by the same people. In many cases they occur interactively or simultaneously. However, selecting a plan of action (O.5) is done by other people who have more experience and executive authority. For that reason, the role of presenting the alternatives (O.4.6) is significant, and the way in which they are presented may affect the decision. The person who designs the alternatives usually has a preference, and this can be seen in the way that they are presented. Selecting the appropriate plan (O.5.2) is a function of cost, the degree of fulfilling the needs, its practicality/ease of implementation, the indirect aspects (implications), various codes and the related changes, and the considerations for future demands.
It was commented that the person who selects an alternative must understand the plan (O.5.1); however, the implications must be known to him. Therefore, he must be aware of the implications rather than understand them. Committing the services and the resources is affected by staffing and the budget. Staffing problems become apparent when there is excessive need for specific skills or when there is deferred maintenance. This is usually considered in the planning phase since the department cannot tolerate or handle a long list of deferred maintenance items. The budget is predominantly an 'operations' budget and not a 'replacement' budget. In other words, the desired situation is that there will be no need for replacing a system or even part of it due to a breakdown, and that the preventive maintenance will be sufficient for its proper operation.

Distributing the resources (O.6.1) is constrained by the availability of manpower, materials, tools and equipment. The schedule which usually reflects job priorities can also become a factor which influences the distribution of the resources. The physical work that is actually performed (O.6.2) consists of the operations and the control the systems, and their maintenance. The maintenance work can be of two types: the work-order type as in cases of breakdowns, requests, or complaints, and the preventive maintenance type which is principally pro-active and scheduled. When a specific task cannot comply with the schedule, it is referred to as 'deferred maintenance'. Work inspection (O.6.3) is done by the same person who performs the task or by his superiors. The codes and the quality requirements make up the main considerations for the inspection.

5.4 Case 4: CAMP HILL STATE CORRECTIONAL INSTITUTION, Pennsylvania

State Correctional Institution in Camp Hill, PA (SCIC) is a minimum security prison. Due to the nature of the facility, environmental requirements and user standards are different from those of an office or a medical laboratory, whereas the security system requirements are much higher and critical.
Figure 5.3: Organizational chart of the Trade & Maintenance Department

Comparison with the Model

Figure 5.3 shows the organizational chart of the trade & maintenance department. The responsibilities include not only the maintenance of the utility plants and systems, but also grounds work, minor construction, building maintenance, etc. However, the work follows the logic of the model.
A five-year program is developed, and after state approval is obtained for finance, short-term trades are planned, scheduled in detail for implementation and are managed (O.1). The revision of historical data (O.1.1) is important for fulfilling future demands such as the sufficiency of the boiler plants, their capacities versus the expected use, etc. However, issues like growth of the number of prisoners, prison capacity are not reviewed in S.C.I.C. The main constraint on planning the operations (O.1.2) is the design of the item to be fixed or constructed, and the needs of the user. Budget and staff availability becomes a constraint while acquiring the necessary resources (O.1.3). (Usually there is no lack of manpower, but for certain tasks professional help i.e., engineers are required)

Monitoring the operations is as important as performing them, and this is done mostly through inspection. Selecting critical points / areas to monitor (O.2.1) is not done since almost anything is to be inspected. The main considerations for selecting the monitoring mechanism (O.2.2) are the technical specifications / the error rate of the systems to be monitored, and the purpose of the detection system. Collecting the data (O.2.3) depends on the level of automation of the system. For most systems history cards are filled on a periodical basis. For more sophisticated systems like the security/alarm systems there is minute-by-minute data recording by a printer. All of the data which are collected are put together and summarized as monthly reports for control and future reference (O.2.4).

Evaluation of the monitoring data is influenced by the requirements of each function and the allowed tolerances. The evaluation (O.3.1) and problem location (O.3.2) are mostly done by the user, and the problem solving mechanisms are notified (O.3.3) through work orders. For the security/alarm system, the allocation and notification are not when the when the system is down, but when the alarm is activated. The source of the alarm is located electronically on a control board, and action is taken directly.

Work orders are the main inputs to the "Understand the Problem" function (O.4.1) which is perceived to be important for the correct solution to be developed and implemented properly. Determining and assembling the necessary information and skills (O.4.2, O.4.3) are influenced by the complexity of the problem and by the budget.
In developing a solution (O.4.4), procedures and the experience of the individual play the most important role, but the implications of the solution are just as important as the solution itself. Aspects like additional expenses, disruptions, security, etc. have to be considered rigorously when selecting a solution plan (O.5.1; O.5.2). The main constraints and guidelines for committing the needed services and resources to each task (O.5.3) are the organizational chart, the priority of each task, and the availability of the resources.

Job priority and resource availability are also constraints on the distribution of the resources (O.6.1). Doing the actual work (O.6.2) is influenced by budget and overtime. (Overtime is parallel to the "execution plan" and the "problem solving plan" in the model). The work inspection is performed by the same person who does the work. The input for the inspection is the completed work, and the constraints are the work orders and quality requirements.

5.5 CHAPTER SUMMARY

This chapter has summarized why case studies were used for testing and modifying the model, on what basis the cases were selected, and how the relevant data were collected. This has been followed by details of the four cases, including general information about the company/facility, how operations and maintenance are carried out, and a comparison to the functions, inputs, outputs, and the constraints (boxes and arrows) of the "Operate Facility" model. The cases have been found to fit the model or parts of it. As expected, certain differences were noticed due to the significant dissimilarity of the cases.

The following chapter summarizes the whole technical report, lists the conclusions regarding the status of the operations and maintenance in current practice, and the potential benefits of the model.
Chapter 6

SUMMARY AND CONCLUSIONS

This report presented a generic process model for operating a facility. In order to give the reader a better understanding, various approaches which were taken and the related obstacles were included. Case studies which were used to help evaluate/modify the model were summarized. A glossary was added to avoid the misunderstanding of the terminology used.

The study which was conducted to build the model lead to the following conclusions regarding the status of the operations and maintenance in current practice:

1. Each company, organization, or facility has established operations and maintenance programs based on its own procedures, past experience, or preferences. Most of the decision making involved is not structured; it is carried out by individuals - intuitively, or based on their experience in the field. Due to the variety of facility types there is a lack of common 'operations and maintenance' structure among companies and organizations.

2. The concept of operations and maintenance differs from one aspect to another. An engineer's point of view is very different from that of an owner which is different from that of a user, etc.

3. The function "Manage Operations" (node O.1) is essential for the effective operation of a facility. It is not a repetition of the "Plan Facility" function (node P of the IBPM). It involves issues like coordination of planning, scheduling, and quality assurance, which cannot be considered at the facility planning level.

For various organizations, this lower level planning can appear more than once, allowing different disciplines to involve separate planning. The actual execution of the tasks in different disciplines can be performed by the same mechanisms: a certain individual, a subgroup, or even an automated system may perform a set of tasks on the same item, or a certain task on different
items. The coordination and integration of different disciplines can be carried out by upper levels of the organization.

The feedback from the case study interviewees and the project team addressed the following potential benefits of the model:

1. It can be a good educational tool for:
   • the owner to be able to understand the operations structure of its facility;
   • new employees to be trained in a facilities management firm, or a similar department of any company/organization;
   • students in order to be given a generic understanding of the operations of a facility.

2. Although the model does not consider the concept of time, and the functions seem too general, it is capable of being adapted to various organization types, and to the specific needs of the owner or the facility.
Appendix A

BIBLIOGRAPHY

1. An Introduction to SADT Structured Analysis and Design
   Technique, SofTech, Inc., Nov. 1976
   - Model building, structure decomposition
   - Constitution of an SADT model
   - Application of SADT
   - System development

   - How and why the facility manager entered the field of FM
   - Staff size, factors affecting it
   - Positions in FM: Levels, responsibilities, qualifications, place in the organizational structure
   - Organizational patterns:
     • Organization of responsibilities (general tasks)
     • Different aspects of management organization (three models)

   Description of a function model representing the functions of a system or environment; main concepts, elements of the model, and the approach.

   - Introduction to FM (General and statistical):
   - FM's responsibilities, profiles concerning types of industries and space distribution among different types of usage, finance, computers in FM, high and low churn responsibility groupings

Decision making model, decision types, degrees of uncertainty, information systems evaluation.


Determination of the cost effectiveness of some of the ECMs (Energy Conservation Measures) in two office buildings in MA is detailed. Topics covered: Determining the energy baseline, analyzing the economics of the ECMs, monitoring and feedback.


An approach to facilities planning with an emphasis on user requirements as a basis.


- The owner's need for services after the project is completed
- FM's role in the 'services' market and in development
- Computer software support.


- Responsibilities of FM
- The relationship between the FM and the architect; the need for working together
- Computer uses
- FM's proactive role rather than an administrative one.


- A 17th division to be added to the standard format of construction specifications:
  - Maintenance of the building and its systems
- The need for being owner-directed rather than the contractor
- Long term performance consideration
- The need for convenient checklist preparation
- Providing a maintenance manual
- The need for understanding the life-cycle-costing concept.


The application of a pocket sized infrared scanner that locates and identifies potential electrical problems to improve regular maintenance in the Harvard University facilities is described. General benefits are summarized for short and long term maintenance.


Five performance measures-direct activity, planned work, emergency work, schedule compliance, and planned material- are presented, and are claimed to achieve aggressive
program objectives, provided that they are combined with the necessary tools for efficient planning and quality planner training.


The importance of preventive maintenance is emphasized, and a suggested list of electrical preventive maintenance for a motor control center is given. It is also claimed that the time and effort to implement and and complete scheduled maintenance will be repaid with higher plant efficiency, less chance of unscheduled downtime, and fewer instances of lost production.


- The difference between 'computer furniture' and 'CAD furniture'
- Requirements for a furniture system
- Questions to determine CAD furniture needs.


A means for modeling the maintenance aspect of a project and its contribution to life cycle costing is described. The system encompasses the whole range of mean time between failures and mean time to repair that may be experienced, and the influences of external events.


- A review of different systems that make up a facility, and their integration
- The way that facilities respond to changes, and the tools for flexibility.


An approach to planning manufacturing facilities in two parts:
(1) Location / allocation analysis
(2) Phases of manufacturing (including designing a product, choosing manufacturing processes, production systems, plant layout, material handling and storage systems
(Has good summary of organizational structures, but no information on organizational changes.)


- Existing approach: Short term instead of long term
  Individual instead of enterprise level
- Office-environment relationships
- Reasons for a new concept and how to find it
- How FM is related to the new concept:
  • Defining the limits of the technology involved
  • Defining the role of the facilities managers


- Application of a computer-based FM information system (FMIS) to maintenance and construction programs at Fort Irwin, California: The needs and the apparent benefits of the system
- The purpose and a listing of the phases of the package used for the above mentioned system.


Appendix B:

GLOSSARY OF TERMS

Alternatives and Implications: Plans developed for solving an operations-related problem and its implications such as impact on business, work schedule disruptions, etc., fully understood by the selecting mechanism.

Alternatives: Plans developed for solving an operations-related problem.

Available Resources: Resources available to the project, such as personnel, computer technology, time, space, equipment, materials, energy, etc.

Codes and Regulations: Statutory requirements imposed by various governmental bodies. These requirements can cover safety, environmental, operating systems, and other building codes as imposed by local authorities.

Consumable Resources: A subset of 'Resources' - materials and energy that is directly consumed during the operations of a facility.

Distributed Resources: Resources given to the mechanisms which implement the selected plans.

Evaluated Performance Information: Performance information after it is reviewed and evaluated for possible use in planning the operations.

Execution Plan: Information obtained from the planning and monitoring of the operations and maintenance, including maintenance schedules and instructions, periodic performance reports, etc.

External Constraints: Parameters and variables in the environment that impact the facility and are beyond the control of all project participants. This includes weather, codes, economy, technology, etc.

Facility: The completed building and site, including all installed equipment.
**Facility Champion:** The individual who initiates the idea, commits and mobilizes the funds and resources required to get the facility developed, and leads in establishing a project team.

**Facility Operations Documents:** The documents handed over to the facility managers to enable them to operate and maintain the facility.

**Implications:** The non-technical aspects of a plan which must be considered during the implementation, such as impact on business, work schedule disruptions, availability issues, etc.

**Monitoring Areas:** Areas which are selected to best represent different sections of the facility for monitoring purposes.

**Monitoring Information:** Performance information which is monitored and put into right format for evaluation.

**Monitoring Mechanism:** The mechanism/system which is selected to carry out/assist in the monitoring process. This can be an automated system, an inspection team, the user, etc.

**Operability Information:** The information used to integrate the facilities management expertise on the operations into the earlier construction phases to optimize the provision of the facility.

**Operate Facility (O):** All the activities which, when combined with the facility, are required to provide the user with an operational facility.

**Operating Systems:** All the systems in the facility (environmental, architectural, transportation, communication, etc.)

**Operation Data:** Performance information after it is collected by a monitoring mechanism.
Operational Facility: A facility that satisfies the needs of the user; i.e. meets its intended purpose.

Operations Documents: The formal documents, drawings, specifications, instructions, limitations, procedures and criteria for managing, operating, and maintaining the facility. These include as built drawings, final test reports, system operating guides, equipment operating and maintenance guides, etc.

Operations Experience: The improved ability of the participants that manage the facility to manage similar or related facilities in the future.

Operations Information: Information about how the facility is being operated.

Operations Knowledge (OK): The information and knowledge that results from operating the facility that is not included as formally communicated documents, but is resident in other media, e.g. project files, project files, project participants memories.

Operations Planning Knowledge: The information and knowledge that results from planning the operations of the facility, and the related experience that can be used in the future.

Operations Resource Needs: Information about the manpower, materials, equipment, space, etc. which are necessary for the operations plan to be carried out.

Operations Team: All personnel who are assigned responsibilities, and all tools and equipment which are used by them, for the operating a facility.

Optimization Information: The information used to integrate expertise of participants in providing the facility. This includes designability, constructibility, and operability information.

Physical Performance Information: Information about the progress of activities which, when compared to the plan, is interpreted to assess the status of the project and the appropriateness of the plan.
**Problem Area:** Complete information about the location and the type of problem that is detected during the monitoring (O.2) and the evaluation (O.3) phases.

**Problem Data:** Information which is used for locating and identifying a problem once its existence is detected.

**Problem Feedback:** Information stating that none of the alternative plans are suitable to be selected.

**Problem Identification:** Complete information about the location and the type of problem that is detected during the monitoring (O.2) and the evaluation (O.3) phases before it is communicated to a problem solving mechanism.

**Problem Information:** The problem area as it is understood by the problem solving mechanism.

**Problem Solving Plan:** Selected alternative(s) and mechanism(s) which are developed to solve the operations-related problem.

**Project Execution Plan (PEP):** Owner's plan for procuring all resources and services that are required to provide and manage the facility. A PEP includes schedules, contracting strategy, milestones and budgets.

**Resources:** Include all resources provided for the facility by all participants (building materials; time and man-hours; energy; money, furnishings, supplies, utilities, etc).

**Selected Alternative:** A subset of 'Problem Solving Plan' - the plan which is developed and selected to solve the operations-related problem.

**Selected Mechanism:** The people, equipment, contractors, etc. that will implement the plan.
Skills and Information: The required knowledge, people, devices that can help develop a solution.

Skills and Information Needs: Information on the required knowledge, people, devices that can help develop a solution.

Technical Solutions: The part of a designed alternative which considers only the technical aspect of a problem. These technical solutions, together with its other implications (business aspects, availability, work disruptions, etc., become the alternative plans for solving the problem.

User Requirements: The needs and standards (usually governed by codes, sets of physical and psychological values) which define the desired environment and the effectiveness of a facility.
Appendix C:

SAMPLE DATA COLLECTION FORMS
### JOHN Hopkins U. SCHOOL OF MEDICINE

<table>
<thead>
<tr>
<th>0.1</th>
<th>INPUTS</th>
<th>OUTPUTS</th>
<th>CONTROLS</th>
<th>MECHANISMS</th>
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<td>0.1.1</td>
<td>REVIEW DATA</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>0.1.2</td>
<td>PLAN OPERATIONS</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>0.1.3</td>
<td>ACQUIRE OPERATIONS SERVICES &amp; RESOURCES</td>
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</table>

0.1.1 → important for L+T planning

* Ext. constraints & environmental regs much more critical than other facilities

** Awareness → typical to medical schools

Private inst. vs Public → Constraints: the same

Funds (sources), different

Space covered: 1,000,000 sq ft. → Public

Research → Teaching

Support direct research → day-to-day maint. issues

Staff: 16
<table>
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<tr>
<th>0.2</th>
<th>INPUTS</th>
<th>OUTPUTS</th>
<th>CONTROLS</th>
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<tbody>
<tr>
<td>0.2.1</td>
<td>SELECT CRITICAL PTS./AREAS TO MONITOR</td>
<td>Regs. from researchers</td>
<td>Info on usage</td>
<td>Regs. (codes, etc.)</td>
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<tr>
<td>0.2.2</td>
<td>SELECT MONITORING MECHANISM</td>
<td>Thermostat, Measuring mechanisms, inspectors, etc.</td>
<td>Type of system/Space</td>
<td>User regs.</td>
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<td>0.2.3</td>
<td>COLLECT DATA</td>
<td>Operation info</td>
<td>Observation</td>
<td>User reports</td>
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<td></td>
<td></td>
<td>Temp., cleanliness, etc.</td>
<td>Output</td>
<td>Output of 0.2.2</td>
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<td>0.2.4</td>
<td>REDUCE TO INFORMATION IN CORRECT FORMAT</td>
<td>Info through obv.</td>
<td>Problem Statement</td>
<td>Reports</td>
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<tr>
<td>0.3.1</td>
<td>EVALUATE INFORMATION AGAINST STANDARDS</td>
<td>Monitored information</td>
<td>Indication of problem</td>
<td>Codes (x)</td>
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<td></td>
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<td></td>
<td>presence of non-</td>
<td>Regs.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>existence</td>
<td>General condition (past vs present)</td>
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<tr>
<td>0.3.2</td>
<td>LOCATE &amp; IDENTIFY PROBLEMS</td>
<td>Outputs of 0.2.2 after processed by 0.3.1</td>
<td>Problem statement **</td>
<td>Complexity of the problem or of the facility</td>
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<td>0.3.3</td>
<td>NOTIFY PROBLEM SOLVING MECHANISM</td>
<td>Problem statement</td>
<td>Availability of experts in the field</td>
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-> Mechanisms: the same as 0.2

* Special attention is paid to: changes of codes

** includes type, place, complexity, code adaptations, code adaptations, magnitude, etc.
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<td>UNDERSTAND THE PROBLEM</td>
<td>Problem Info&lt;br&gt;Other info (technical)</td>
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<td>0.4.2</td>
<td>DETERMINE NECESSARY INFORMATION &amp; SKILLS</td>
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<td>Skills &amp; Info&lt;br&gt;Expertise</td>
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<td>ASSEMBLE NECESSARY INFORMATION &amp; SKILLS</td>
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<td>0.4.4</td>
<td>DEVELOP / DESIGN SOLUTIONS</td>
<td>Technical solutions&lt;br&gt;Technical constraints</td>
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<td>0.4.5</td>
<td>ANALYZE IMPLICATIONS</td>
<td>Revised solution&lt;br&gt;Not technical constraints</td>
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<td>0.4.6</td>
<td>PRESENT ALTERNATIVES</td>
<td>Alternatives</td>
<td>Formats&lt;br&gt;Complexity of solutions</td>
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</tr>
</tbody>
</table>

0.4.1 → A necessity for good solutions.
Mechanisms → Same as 0.2.0.3.
* Usually part of it is missed at this stage.
COMPANY/FACILITY: J.H.U. School of Medicine

<table>
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<td>UNDERSTAND ALTERNATIVES AND THEIR IMPLICATIONS</td>
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<td>Suitability</td>
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<td>COMMIT SERVICES AND RESOURCES</td>
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<td>Assignments</td>
<td>Procedures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td>Availability</td>
</tr>
</tbody>
</table>

0.5.1 → "Being aware" is more suitable than "understand".

- Person presenting the alternative (if different from the selector) will have preference over you. This may affect the presentation of the alternatives.

* Possible code changes, adaptations, tech. change