Model Process for Implementing Maintainability

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Abstract: Most companies lack a formal method to address maintainability during the project delivery process, yet maintenance can seriously affect project costs. To address the opportunities available to companies through the effective inclusion of maintainability concepts, the Construction Industry Institute formed the Maintainability Research Team. Using a combination of recent literature, a questionnaire survey, personal interviews, and case studies with industry professionals, the research team organized maintainability best practices into a model implementation process. Developed from the owner's perspective, the model process has two levels: corporate and project. Milestones, steps, and activities further define each level. The benefit of the model process is that it provides owners with a starting point for implementing maintainability. This paper outlines the proposed model process and describes the potential roles and benefits of maintainability on various types of projects.

INTRODUCTION

Faced with shrinking maintenance budgets, fewer ''grass roots'' projects, and increasingly competitive global markets, maintainability is becoming a matter of growing importance for many companies. Historically, capital cost, schedule, and functionality have received emphasis during project design and construction. In many instances, less attention has been given to long-term design characteristics such as maintainability, reliability, operability, and human factors such as the ease of performing maintenance functions. However, neglecting to consider maintainability during the planning, design, procurement, construction, and start-up of a facility can result in decreased availability and output, increased life-cycle operation and maintenance (O&M) costs, and costly maintenance retrofits.

Because the true cost-effectiveness of a capital project is its performance and cost throughout its life cycle, maintenance costs are a major part of the total operating costs of all constructed facilities. In the process and manufacturing industries, maintenance costs represent between 15% and 40% of the costs of goods produced (Mobley 1990). Studies indicate that American industry spends >$200 billion each year on maintenance, and production losses due to equipment downtime usually equal or exceed maintenance costs (Fogel and Petersen 1997). Hence, decreasing maintenance represents a significant opportunity for cost improvement in the project delivery process.

For the purposes of this paper, maintainability is the design characteristic that pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions (Blanchard et al. 1995). Throughout this paper maintainability refers to the design characteristic described above while a maintainability process is defined as a formal method to incorporate maintenance knowledge and experience into the project delivery process, including corporate-level and project-level activities. A formal maintainability process provides a method for gathering and assessing maintainability information for appropriate consideration during the project delivery process. As with constructability, a maintainability process is the attempt to have knowledgeable industry professionals identify the right questions at the right time. This paper outlines the proposed model process for maintainability and describes the potential impact it can have on various types of projects. A more nuanced and detailed description of the model process can be found in the ''Maintainability implementation guide'' of the Construction Industry Institute (CII) (1999).

RESEARCH METHODOLOGY

The research methodology and model process is comparable to earlier constructability research (CII 1993). Although the constructability research was intended to help design/construction practitioners incorporate knowledge about construction into the project process, the primary purpose of this research is to develop a model process for incorporating maintenance knowledge and experience into the planning, design, procurement, construction, start-up, and operation of facilities. Data used to create the model process included (1) literature review; (2) a questionnaire survey; (3) 35 interviews with industry professionals; and (4) six in-depth case studies.

To gain a general understanding of the current role of maintainability in industry, a questionnaire survey was circulated to construction practitioners including project managers, O&M managers, and maintenance technicians. Of approximately 75 surveys distributed, 48 (approximately 65%) were returned. Questions were open-ended to encourage descriptive and qualitative feedback. The questionnaire survey provided the research team with insights into the current state of maintainability implementation and led to the next phase of data collection.

Detailed, structured personal interviews, ranging from 2 to 8 h in length, were the primary means of data collection. In total, the research team interviewed 35 organizations on the current implementation of maintainability within each company. The organizations included in this investigation of maintainability within each company. The organizations included in this investigation were limited to medium-to-large sized companies (i.e., annual sales volume >$20,000,000) currently involved in the design/construction industry. Interviews were conducted with plant managers, maintenance managers, project managers, designers, and O&M personnel from a broad cross section of organizations, including owners, contractors, consultants, and suppliers.

The purpose of each interview was to capture and document maintainability processes, procedures, and tools used by each organization. As maintainability most directly affects the owner of constructed projects, this research focused on owner organizations. In addition, the owners interviewed were largely engaged in industrial and manufacturing construction. Industrial and manufacturing companies appear to have a keen interest in increased maintainability, given its direct impact on profitability; however, this research suggests that a variety of owners and design/construction practitioners can benefit from increased use of maintainability. Finally, to further illus-

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Note. Discussion open until May 1, 2001. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 2, 1999. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 126, No. 6, November/December, 2000. ©ASCE, ISSN 0733-9634/00/0006-0440–0450/$8.00 + $.50 per page. Paper No. 21590.

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trate several maintainability best practices, the research team documented six case studies (Russell et al. 1999).

The collected data and research are organized into maintainability attributes, best practices, and a model process. Two intensive reviews by the industry professionals on the CII Maintainability Research Team helped to finalize the definition and validation of the model process for accuracy and utility.

MODEL MAINTAINABILITY IMPLEMENTATION PROCESS

As previously mentioned, the proposed model process is the result of input from the CII Maintainability Research Team and an investigation into current maintainability programs used in industry. As shown in Fig. 1, the model process consists of two levels (corporate and project) and six milestones: (1) Commit to implementing maintainability; (2) establish maintainability program; (3) obtain maintainability capabilities; (4) plan maintainability implementation; (5) implement maintainability; and (6) update maintainability program. Each milestone contains procedures and activities to help organizations effectively implement maintainability. In general terms, Milestones 1, 2, and 6 focus on corporate-level implementation and Milestones 3, 4, and 5 focus on project-level implementation. Formally, Milestone 3 serves as the interface between the corporate and project levels, although ideally there should be constant interaction between the two levels. The remainder of this paper presents details of the model process and its practical applications, beginning with the corporate-level milestones.

CORPORATE-LEVEL MILESTONES

Creation of a maintainability process reflects a fundamental shift from maintenance as a postproject service to maintenance as a value-adding activity included during project development. The earlier maintainability is incorporated into the project process, the more chance there is to positively affect maintenance outcomes. A well-structured corporate-level program helps ensure maintainability issues are addressed appropriately in the planning and design phases of a project. The corporate-level program consists of three milestones: (1) Commit to implementing maintainability; (2) establish maintainability program; and (3) update maintainability program.

Milestone 1: Commit to Implementing Maintainability

As shown in Fig. 2, the first milestone is to commit to the implementation of maintainability. Committed corporate support and resources are critical to sustaining and improving a successful maintainability program.

Step 1. Develop Upper Management Awareness

The first step toward a formal maintainability process is developing maintainability awareness at the corporate level. Management should become familiar with maintainability objectives, methods, and concepts. After gaining a basic understanding of maintainability and its impact on the project, the management team can then establish its relationship to overall business objectives.

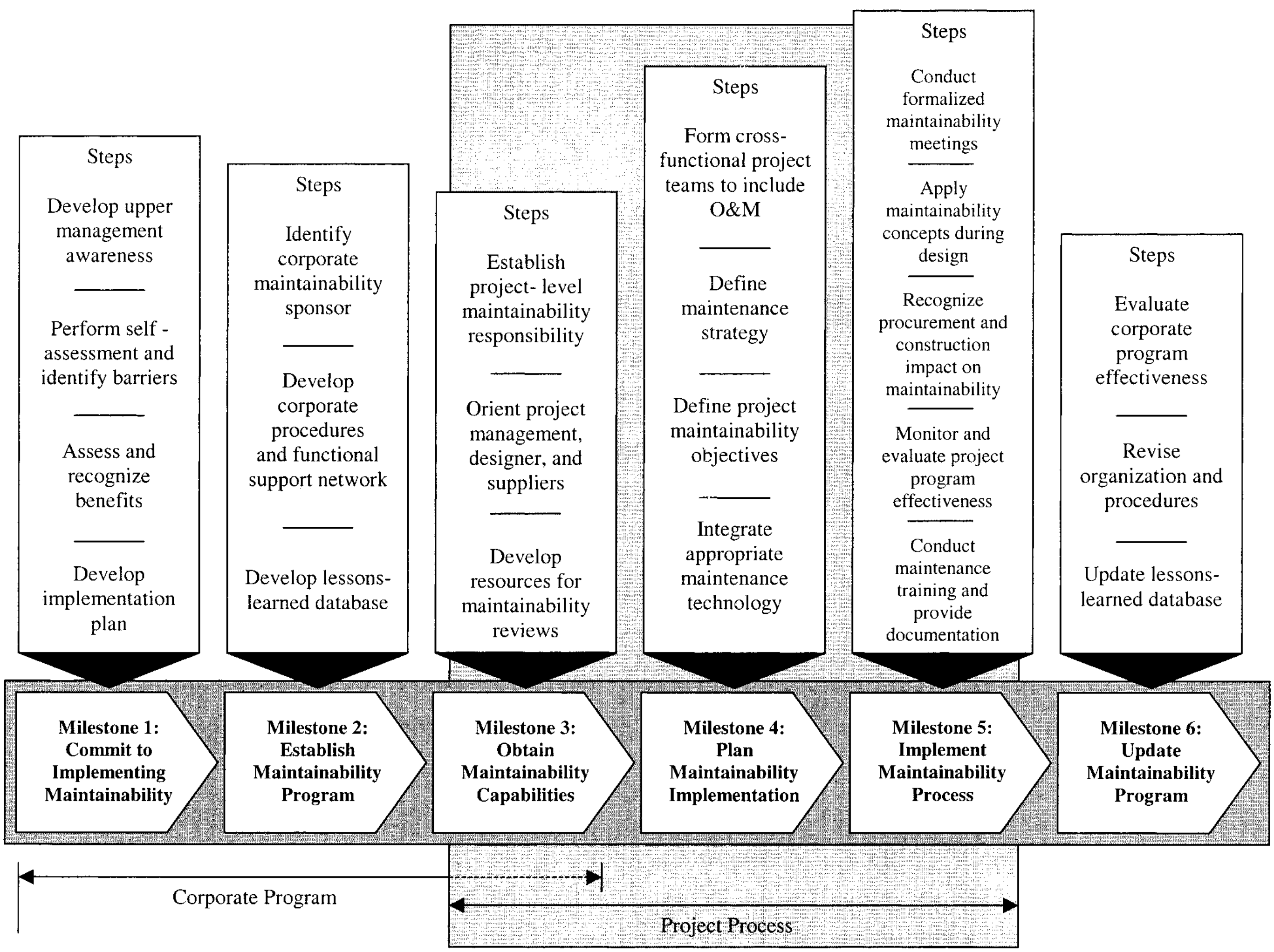

FIG. 1. Milestones and Steps of Model Maintainability Process

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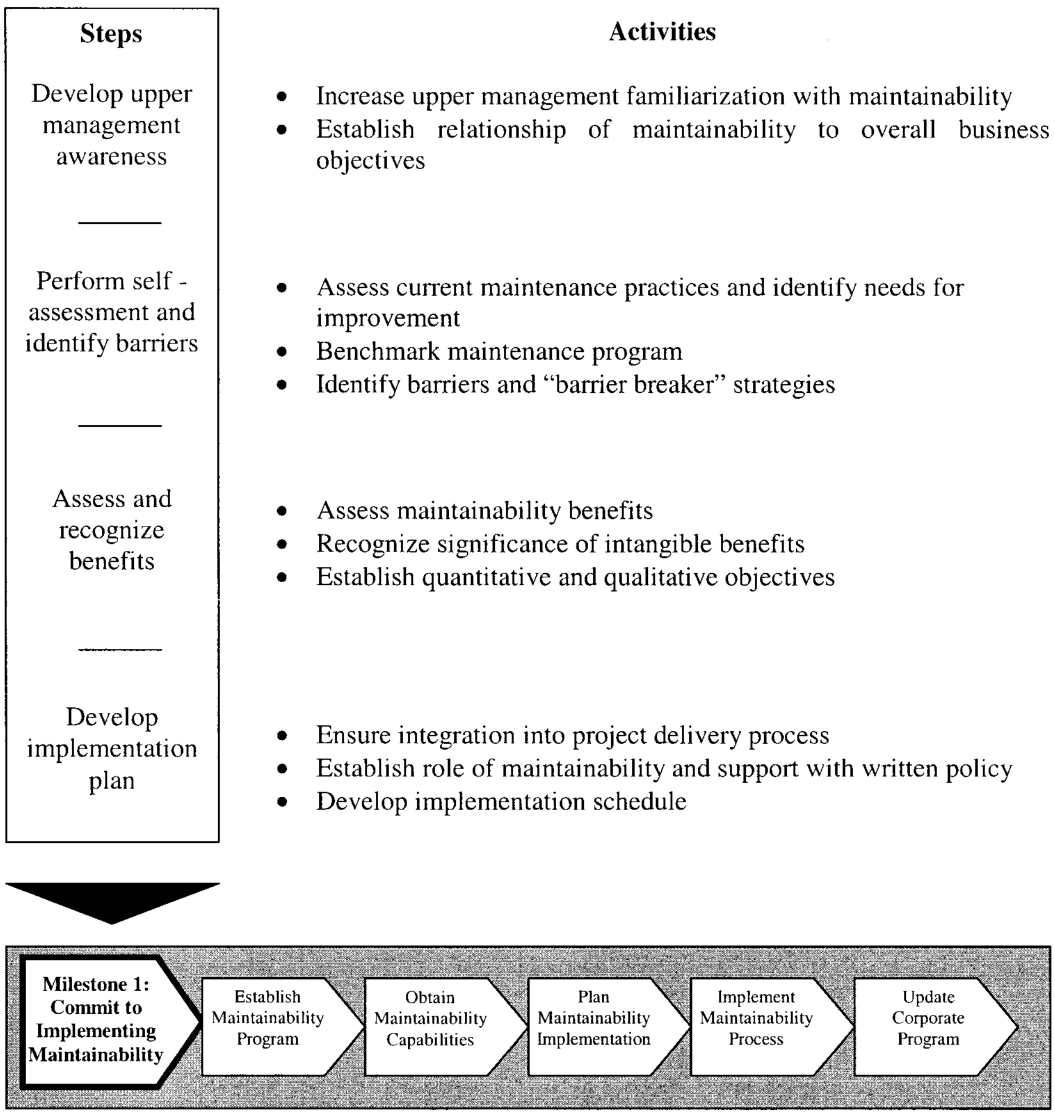

FIG. 2. Commit to Implementing Maintainability

Step 2. Perform Self-Assessment and Identify Barriers

The self-assessment of current in-house maintainability capabilities, practices, and barriers should determine the organization's current maintenance practices and identify opportunities for improvement. Benchmarking against industry standards helps in this assessment of current performance by identifying areas for improvement and providing reference points for measuring future improvement. Additionally, it is important to identify the barriers to maintainability implementation in this self-assessment process. Based upon a questionnaire survey of industry professionals, barriers likely to be encountered in initiating a formal corporate-level maintainability process include added initial cost, quantification of costs/benefits, personnel time investment, and organizational ''functional silos.''

Step 3. Assess and Recognize Benefits

Benefit assessment promotes a unified vision for the maintainability program. Potential benefits of improved maintainability include both tangible, quantitative benefits and less tangible, qualitative benefits. Owner maintainability benefits may be quantified in the short term as start-up savings and in the long term as operating savings. Improved maintainability can result in a more efficient, better-performing constructed facility by reducing downtime for repairs, routine maintenance, adjustments, or changeovers. Other benefits of maintainability are less tangible. Planning for maintainability can minimize changes during design and reduce maintenance-related change orders and rework in construction. Also, early consideration of O&M contributes to a more efficient start-up and commissioning.

Step 4. Develop Implementation Plan

The final step of the commitment milestone is to support maintainability with a formal implementation plan including an implementation policy. An implementation policy should include four key items: (1) Statement of program objectives for the organization; (2) indication of the level of upper management and corporate commitment; (3) identification of the corporate executive sponsor; and (4) ties to project-level implementation (CII 1993). An implementation plan should include (1) the specific means to implement the process; (2) selected projects on which to use the process; and (3) schedule for implementation. It is further recommended that companies form a maintainability implementation committee to develop a maintainability process, implement it on pilot projects, assess the process and results, gather feedback, and update the maintainability process for broader and more successful implementation.

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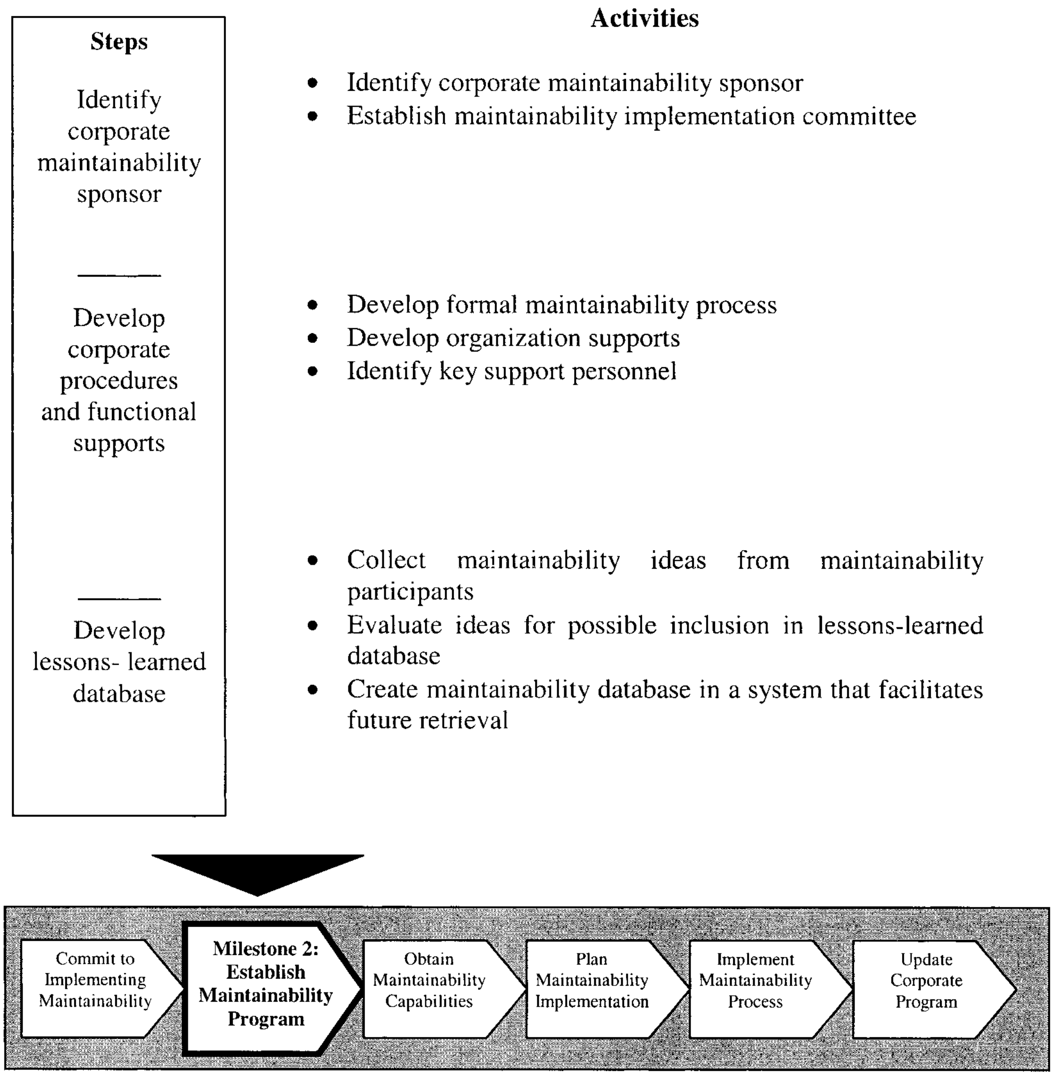

FIG. 3. Establish Maintainability Program

Milestone 2: Establish Maintainability Program

As shown in Fig. 3, the second corporate-level milestone is to establish a formal maintainability program. The corporate program supports implementation of the maintainability process at the project level, providing resources and continuity from project to project.

Step 1. Identify Corporate Maintainability Sponsor

A corporate maintainability sponsor provides influence and authority to commit resources to the program. This corporate-level individual is responsible for overseeing and championing the program and aiding its implementation throughout the company. Once selected, the corporate maintainability sponsor must be empowered with support from the corporate executive management team.

Step 2. Develop Corporate Procedures and Supports

Corporate procedures provide the framework and assure consistent implementation of maintainability activities, and a support system ideally provides a central location for revisions and information dissemination to project-level implementation. Procedures include a formal maintainability work process (e.g., frequency of meetings and design checklists) and recommended steps for implementation within the organization. Organizational supports include the maintainability committee and personnel to manage the program. A program manager is responsible for daily coordination of companywide maintainability efforts such as training, documentation of lessons learned, and information disbursement. Also, depending on the size of the organization and scale of the effort, a database custodian may be beneficial to document project activity and develop an electronic lessons-learned database or website.

Step 3. Develop Lessons-Learned Database

Maintainability programs must be able to effectively capture, store, retrieve, and share the experiences and knowledge contained within lessons learned. A lessons-learned database combines and centralizes maintainability information for dissemination to program participants across an organization. The database should include applicable maintainability design concepts, lessons learned from previous projects, and ideas for future projects. It should be organized and cross-referenced and, ideally, appropriate technology such as electronic databases and company intranet should be used to facilitate ease of retrieval. However, at minimum, standardized paper or electronic forms should be used, as this regularity aids in documenting both best practices and concerns for maintainability consideration.

Milestone 6: Update Corporate Program

As a maintainability program is implemented and experience is gained on each project, it becomes necessary to eval-

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Steps	Activities
Evaluate corporate program effectiveness	• Conduct periodical program evaluation • Recognize, reward, and announce success at both corporate and project-levels
Revise organization and procedures	• Modify program organization and procedures as needed • Ensure maintainability process integration with project execution process
Update lessons- learned database	• Update and expand lessons-learned database • Use standardized procedures for gathering feedback • Evaluate implementation of lessons-learned during project execution

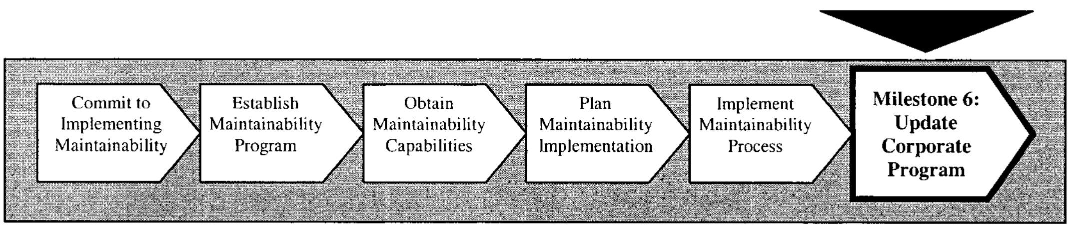

FIG. 4. Update Corporate Program

uate and possibly modify organizational procedures. As shown in Fig. 4, the final corporate-level milestone, updating the corporate program, occurs after project-level Milestones 3, 4, and 5.

Step 1. Evaluate Corporate Program Effectiveness

Periodic evaluations, perhaps annually, should be used to identify areas for improvement. This evaluation should involve personnel at a variety of levels and positions addressing criteria such as (1) What parts of the process worked well?; (2) What parts of the process did not work well or added minimal value?; (3) Are overall corporate maintainability goals and objectives being met?; and (4) Do project-level maintainability programs receive all the necessary support from the corporate program? It is also advisable to increase the awareness and visibility of the maintainability process by recognizing, rewarding, and announcing success at the corporate-program and project-program levels.

Step 2. Revise Organization and Procedures

Based on project evaluations of the corporate program effectiveness, an organization may choose to revise the maintainability program's organization and procedures. It may choose to expand or decrease the amount of documentation (e.g., checklists and procedures). Similarly, some components of the program may need to be significantly overhauled or even removed.

Step 3. Update Lessons-Learned Database

Because projects benefit from the direct integration of maintainability lessons learned, a corporate-level maintainability program improves through effective updates of the lessons-learned database. Lessons-learned databases might start with general maintainability concepts and evolve toward customized activities or project-specific maintenance considerations. Feedback from each project should be culled before inclusion into the lessons-learned database, as an overstuffed repository will prove inefficient and cumbersome.

PROJECT-LEVEL MILESTONES

Project-level maintainability implementation consists of three milestones: (1) Obtain maintainability capabilities; (2) plan maintainability implementation; and (3) implement maintainability. With guidance from formal procedures and the corporate support network, project teams must determine the role of maintainability and the activities to be included on each project. Ideally, the project-level maintainability process should begin shortly after project conception.

Milestone 3: Obtain Maintainability Capabilities

As shown in Fig. 5, Milestone 3 serves as the formal transition from the corporate program to the project-level maintainability process. It consists of three important steps.

Step 1. Establish Project-Level Maintainability Responsibility

The project-level maintainability sponsor should generate awareness at the project level and provide support in implementation. A full-time, dedicated maintainability sponsor may be needed on larger projects, and the project engineer or project manager may be responsible for implementation of the

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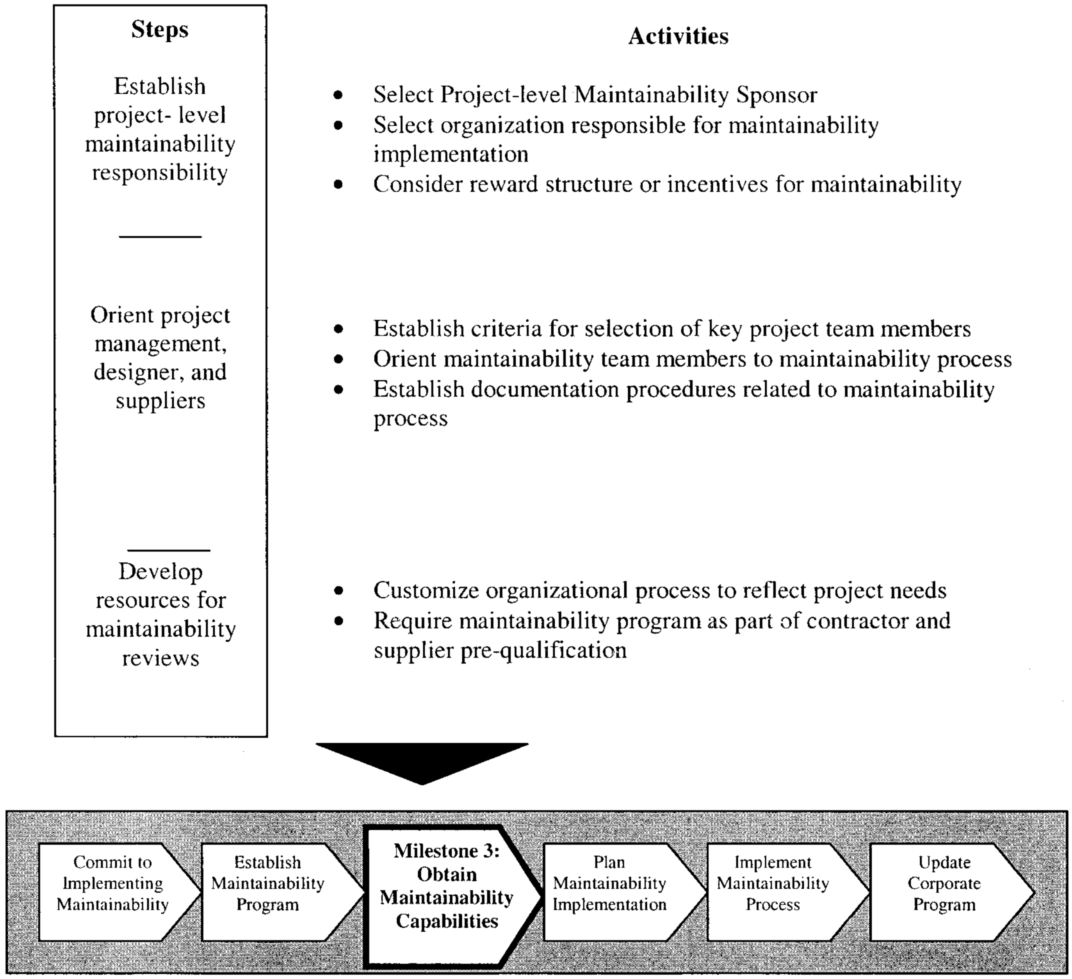

FIG. 5. Obtain Maintainability Capabilities

maintainability process on smaller projects. The corporate-level maintainability sponsor(s) should work regularly with the project-level sponsor(s).

Step 2. Orient Project Management, Designers, and Suppliers

Orientation of project participants facilitates effective execution of the maintainability process. Orientation may include formal training sessions, internal and external networking, progress reviews, and access to company and industry experts. As a minimum, orientation and training should cover the following: (1) Goals for the maintainability program; (2) process of implementation; (3) overview of applicable maintainability concepts; (4) explanation of potential benefits; (5) discussion of general project and company-specific barriers; and (6) distribution of relevant maintainability literature.

Step 3. Develop Resources for Maintainability Reviews

Maintainability objectives will differ among projects; thus, each project may need to customize corporate maintainability procedures according to specific project needs. Critical suppliers, contractors, and consultants should be secured as early as possible in the project to allow their crucial input during the planning phase. When this is not possible, the owner O&M departments must take an active role in representing maintainability issues during project planning.

Milestone 4: Plan Maintainability Implementation

As shown in Fig. 6, planning project implementation of the maintainability process begins at Milestone 4. This milestone consists of four steps describing how to incorporate maintainability into projects.

Step 1. Form Cross-Functional Project Team to Include O&M

Attainment of maintainability objectives requires cooperation of all project participants throughout the entire project delivery process. The maintainability team may be organized as the project team or a subset of the project team, depending on the scope of the maintainability effort. In addition to regular project team members, end-user involvement (O&M, reliability, predictive maintenance, and other project engineering personnel) is essential to the maintainability process, as this contributes to a sense of ownership and responsibility for the project. Additional project participants such as contractors or specialized equipment suppliers should be consulted as needed.

Step 2. Define Maintenance Strategy

A maintenance strategy should preserve and build on current maintenance strengths and be consistent with the maintenance vision. The overall maintenance strategy will likely use a combination of the four maintenance philosophies:

- Reactive maintenance, also known as run-to-failure, waits for machinery or systems to fail before repair actions are taken.
- Preventive maintenance involves time-driven maintenance tasks scheduled at regular intervals to prevent failure of machinery or systems.

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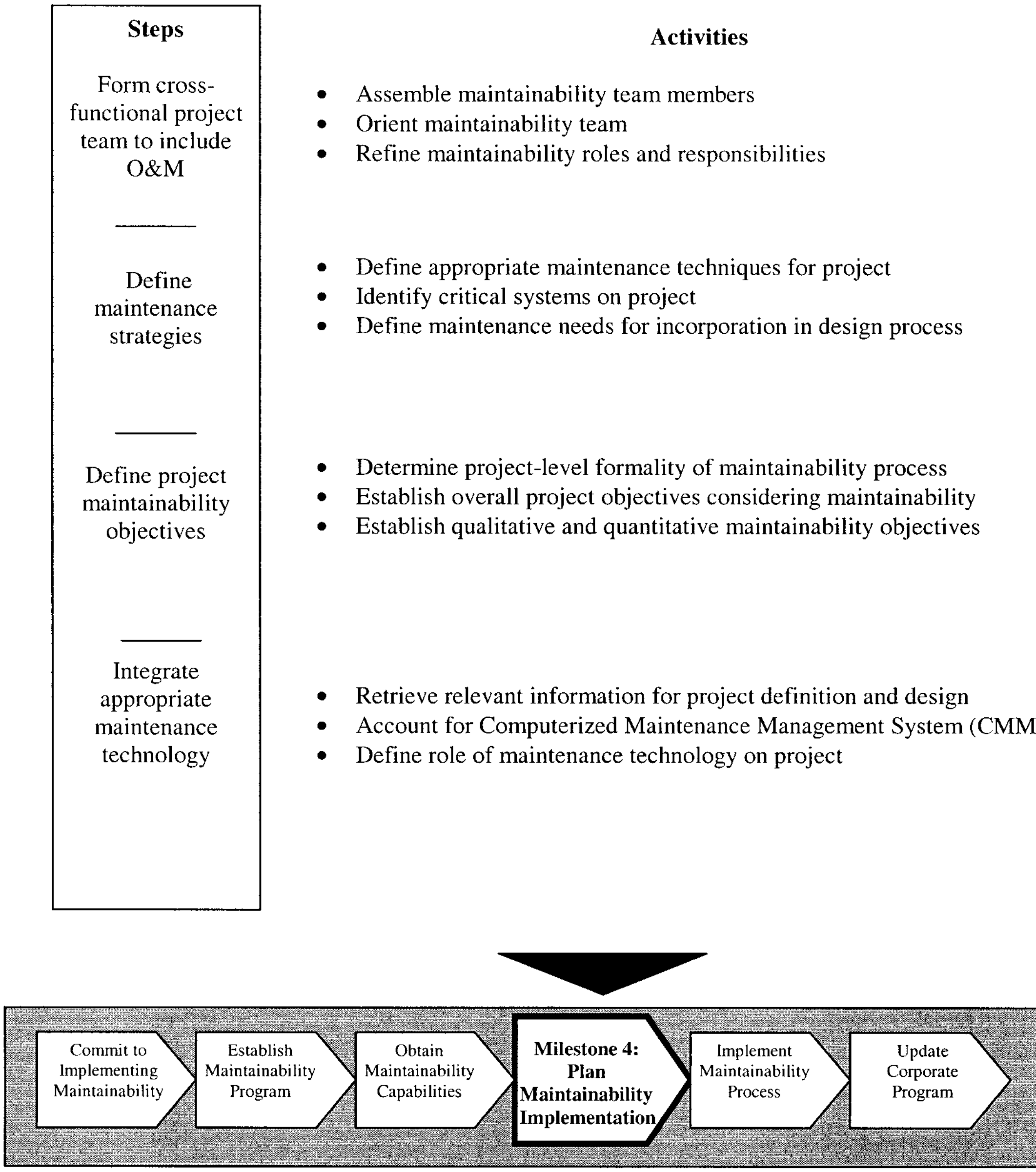

FIG. 6. Plan Maintainability Implementation

- Predictive maintenance, also known as condition monitoring, involves continuous or periodic monitoring and diagnosis of equipment to predict failures and indicate whether preventive or corrective maintenance is needed (*Cost planning* 1996).
- Proactive maintenance uses diagnostics information provided by predictive techniques to isolate, address, and solve the root causes of problems. It applies investigative root-cause failure analysis and corrective technology to eliminate the causes of failures and extend equipment life (Hasselbaum 1993).

While selecting a maintenance strategy, it is advisable to (1) determine business goals and assess the current situation; (2) relate business goals to critical areas and functions; (3) relate equipment to critical areas and prioritize; (4) assess in-house experience and maintainability capabilities; (5) define roles and responsibilities; and (6) apply appropriate maintenance design (White 1997).

Step 3. Define Project Maintainability Objectives

Maintainability objectives must be considered in the context of overall project objectives, such as cost, schedule, and safety. Objectives should be established following five criteria: (1) Written; (2) understandable; (3) measurable; (4) challenging; and (5) achievable (Patton 1980). Maintainability objectives can be qualitative and quantitative.

Qualitative objectives for inclusion on projects include (1) maintainability and reliability designed into project; (2) maintenance activities identified for each equipment piece and system; (3) knowledgeable staff in place through appropriate O&M training; (4) computerized maintenance management system (CMMS) available for maintenance tracking and control; (5) plan for preventive and predictive maintenance established; (6) maintenance best practices in place; (7) make project team members stakeholders in project; and (8) efficient installation of equipment and reduced start-up duration.

Quantitative objectives for inclusion on capital projects include:

- Reduce maintenance cost percent of replacement asset value; design for optimal maintenance conditions should reduce annual maintenance cost.
- Increase mean time between failures; fewer failures translates to higher availability (measure applies to companies combining reliability with maintainability).

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- Reduce mean time to repair; reduced repair time equals less system downtime and higher availability.
- Minimize life-cycle cost (LCC); minimize costs over the entire life of equipment and facilities, rather than the least initial cost.
- Improve availability; the design for maintainability will reduce downtime, especially when combined with reliability improvement efforts.

Step 4. Integrate Appropriate Maintenance Technology

Optimal maintainability requires the appropriate use of technology. The project team should retrieve relevant maintenance technology information for the project's definition and design. New projects and retrofits must be consistent with collecting O&M data. Examples of maintainability data include warranty documentation, spare parts/catalog data, baseline data for maintenance staff (e.g., vibration analysis, thermography, and thickness), O&M manuals and procedures, and as-built drawings. Understanding current as well as future maintenance needs will define the role of maintenance technology on the current project and, through the lessons-learned database, future projects.

A major tool for tracking and documenting maintenance performance is the CMMS, which is a tool to establish and maintain records of all maintenance activities and resource usage. Also, it can generate maintenance work orders. The CMMS contributes significantly to the planning, scheduling, and assessment of maintenance resources and can provide information to measure maintainability results.

Milestone 5: Implement Maintainability Process

Fig. 7 shows the steps and activities for Milestone 5, which comprises six steps that describe how to incorporate maintainability into a specific project.

Step 1. Conduct Formalized Maintainability Meetings

Formalized maintainability meetings facilitate timely communication and discussion of maintainability concepts to be included in a project's development and design. Additional

Steps	Activities
Conduct formalized maintainability meetings	• Select format and timing of meetings • Establish meeting schedule
Apply maintainability concepts during design	• Use formal checklists during design • Conduct formal design reviews • Use electronic lessons learned database
Consider maintainability during procurement	• Standardize equipment, machinery, and materials • Use supplier alliances • Specify and communicate maintainability requirements to supplier
Recognize construction impact on maintainability	• Orient contractors on role of maintainability on project • Begin end-user walk-throughs and training
Monitor and evaluate project program effectiveness	• Maintain records of maintainability ideas • Evaluate and report on implementation progress • Receive feedback and document lessons learned
Conduct maintenance training and provide documentation	• Train end users during project execution • Complete maintenance documentation prior to project completion

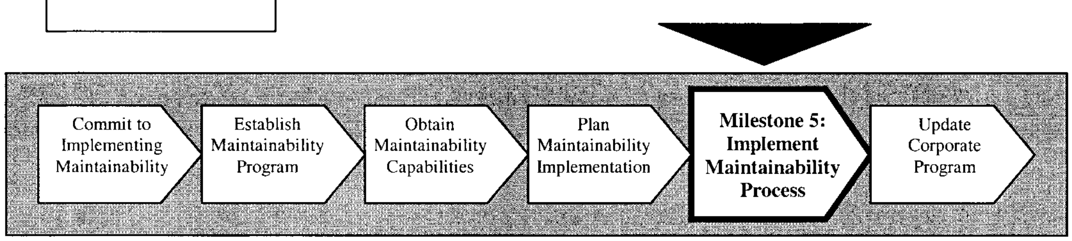

FIG. 7. Implement Maintainability Process

TABLE 1. Sample Formal Maintainability Meetings

Index (1)	Phase of project (2)	Preferred timing (3)	Purpose (4)
1	Preliminary/project scope definition	After concept approval During project scope definition Before funding request	Develop understanding of project among team members Review maintainability concepts Identify resources needed and available personnel
2	Conceptual design	After conceptual design Before detail design of equipment Before funding submittal	Review conceptual design of project Identify opportunities for use of maintainability concepts
3	Detail design and specifications	50% detail design of equipment and facility Before release for procurement and/or fabrication	Review detail design Identify and enhance plans for use of maintainability concepts Identify tools and training requirements for maintenance and operation of equipment
4	Preconstruction	Early construction phase Before equipment and machinery installation May include final design review	Assure implementation of maintainability objectives Arrange training for maintenance and operation of equipment
5	Project closing	After installation and checkout Before final acceptance of project results by plant	Review all aspects of project to assure equipment meets requirements Assure availability of complete and up-to-date documentation

smaller meetings can be conducted to address specific issues in more detail and report the outcome back to the main project team (Dunston and Williamson 1999). Table 1 illustrates five recommended maintainability meetings, with the corresponding timing and purpose of each meeting. Formal questions corresponding to each meeting help ensure that all critical issues are addressed.

Step 2. Apply Maintainability Concepts during Design

Formal checklists and reviews ensure that the project design addresses maintainability objectives. Checklists allow information to be fed forward into the design and serve as a guide during formal design reviews. Design inputs and approvals from the different functional groups should be documented and tracked.

Maintainable design generally consists of two types: (1) Design for maintainability; and (2) design for minimal maintenance cost. Design for maintainability is project implementation of design concepts such as accessibility, standardization, modularity, interchangeability, repairability, and testability. Designing for minimal maintenance cost requires a clear understanding of maintainability strategies and objectives employed on the project, so the designer can evolve a cost-effective maintainable design compatible with the end-users' available resources. An LCC analysis plays an important role in the design for minimal maintenance cost.

Step 3. Consider Maintainability in Procurement Practices

Owners must work with suppliers to understand and assure that machinery and equipment possess the desired level of maintainability. Preferred suppliers standardize equipment and materials, increase purchasing power, and help control the level of installed maintainability through support and product design modification. When compiling a preferred supplier list, the following factors should be considered: (1) Maintenance history; (2) spare parts availability; (3) prior operating experience; (4) supplier service; (5) maintenance requirements; and (6) LCC. Suppliers should be involved throughout the procurement process to aid in the selection of the most cost-effective products to meet project requirements.

Step 4. Recognize Construction Impact on Maintainability

Contractor orientation on project maintainability objectives assures that the desired level of maintainability is built into the project. Project construction issues such as quality of construction and use of acceptance testing criteria can have a major impact upon maintenance and repair requirements after facility acceptance. O&M personnel should walk through to evaluate maintainability of the constructed project and ensure ''as designed'' equals ''as constructed.''

Accordingly, partnering or alliances with design/construction organizations can help facilitate the maintainability process. Past working relationships provide enhanced familiarization and communication, opening opportunities for O&M feedback. Contractors who demonstrate willingness and capability to help owners meet their goals are more likely to obtain future business.

Step 5. Monitor and Evaluate Project Program Effectiveness during O&M Phase

It is important to monitor and evaluate maintainability program effectiveness on the recently completed project. The maintainability team should record maintainability ideas generated and implemented on the project, conduct a maintainability assessment, and document the maintainability program's effectiveness according to formal criteria. Data collection and information generated during this step should be fed back into recently constructed projects, forward into future projects, and directly into Milestone 6.

Step 6. Conduct Maintenance Training and Provide Documentation

An objective of the formal maintainability process is to have end-users of the equipment trained and ready to operate and maintain the facility upon completion. The O&M training conducted during the construction phase can contribute to smoother start-up and optimized O&M. Additionally, by the time of project completion, maintenance documentation should be finalized. Maintenance documentation often includes operating manuals, maintenance manuals, preventive and predictive maintenance procedures, and warranties. Ideally, this information is stored in a CMMS. Documentation is vital to understanding the original design intent as well as to facilitating proper maintenance execution upon turn over of the project.

PRACTICAL APPLICATIONS

For practical applications of the model process, each project team must determine the appropriate role of maintainability during the project planning stages. This task requires experi

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ence and open communication among project participants and knowledge of factors necessitating and affecting the implementation of maintainability.

Need for Maintainability

The major factors affecting the need for a formal maintainability process are described below. Although they will vary in importance from project to project, it is always advisable to consider each factor.

Maintenance strategy—Typically a combination of reactive, preventive, predictive, and proactive maintenance philosophies, the selected maintenance strategy will directed affect project design. For example, systems maintained in a reactive manner require maximum accessibility, ease of maintenance, and readily available spare parts.

Construction type—The type of construction (such as industrial, manufacturing, and general building) affects the role of maintainability. Production-oriented companies have a keen interest in maintainability, as added downtime reduces production, and O&M costs directly affect profitability. General building construction is becoming more involved with maintainability through total building commissioning, which is producing market opportunities for consultants, designers, and contractors while creating value to owners in a more cost-effective building start-up and commissioning.

Owner type—In many cases, a constructed project reflects the owner's involvement, sophistication, and interest and knowledge of maintainability. Owners who maintain a life-cycle project approach are more likely to implement and benefit from a maintainability process.

Past maintenance experience—Historical maintenance experience with similar projects and systems can positively affect the need for maintainability design. Projects containing systems with frequent maintenance or repair requirements necessitate more maintainability attention. Information retrieved from a CMMS, paper files, or workers' knowledge and experience contribute to the knowledge base required to make appropriate maintainability decisions.

Projected cost of maintenance—Projects or systems that are more expensive to maintain present more opportunity for maintainability savings and efficiency improvements, thus increasing the potential benefit of a formal maintainability process.

Criticality—Identified through historical experience or a comprehensive maintenance strategy such as reliability-centered maintenance, critical projects require increased focus of a formal maintainability process. Similarly, projects requiring high availability or operating performance would benefit from an increased maintainability focus.

Complexity—Complex projects, requiring an increased level of technical competence, often have more demanding maintenance requirements. Complex projects also have more interactions between trades, increasing the likelihood of maintainability problems.

Projected life of facility—Projected facility life will affect the need for maintainability consideration in design. Projects with short life cycles generally require less maintenance input than those projects with a longer life cycle.

Location—Location can significantly affect spare parts availability and skilled labor, thus affecting maintainability requirements. For example, plants that are geographically isolated stress maintenance because delivery of parts and spares are expensive and time consuming.

Implementation Issues

Five major factors identified by the research team affect the formality and scope of the maintainability process implemented on a specific project. These are described below.

New versus retrofit—New projects have more latitude in how the maintainability process is organized and implemented. Retrofit projects have existing constraints that must be considered during design and construction. Maintenance strategies and corresponding maintainability design must be compatible with project conditions.

Project size—In general, larger projects offer the potential for a more formal maintainability process. Because larger projects are generally allocated more resources, they are more likely to have full-time personnel involved in the maintainability process. A formal maintainability process would also require a smaller percentage of the project budget, producing more benefit per capital dollar invested. However, smaller and critical projects also benefit from the use of maintainability.

Contracting strategy—The contracting strategy affects the ability to integrate project participants, as well as the assignment of responsibilities and accountabilities, and ultimately affects the benefits accrued. Less tangible effects of contracting strategy include continuity, sense of ownership, and momentum among project participants. Contracts that encourage designers and contractors to view the project from the owner's perspective will facilitate maintainability implementation. An effective contract will explain the role of maintainability, define maintainability objectives, and emphasize long-term value over initial least capital cost.

Maintenance organization—Maintenance organization, whether in-house, out-sourced, or a combination thereof, will affect the collection, storage, and retrieval of maintainability considerations. In-house maintenance personnel generally have more relevant maintenance knowledge and experience, high levels of ownership and commitment, and are more likely to seek creative solutions to maintainability issues. A company that out-sources maintenance to a third party may have a difficult time receiving feedback during the maintainability process.

Related industry practice alignment—Many activities and issues raised during a formal maintainability process are compatible with existing corporate improvement strategies and programs such as total quality management, constructability, preproject planning, and hazards and operability studies. Ideally, maintainability should be used to enhance a current practice of improvement strategies, rather than act as a stand-alone program.

SUMMARY

The preceding model process presents the best practices in maintainability implementation at both corporate and project levels. Corporate-level steps develop and support project maintainability implementation. Project-level maintainability steps and activities build the capabilities necessary to plan and implement maintainability on individual projects. The timing of maintainability input is vital to its inclusion in projects, as maintenance requirements are largely fixed at the time of final project design.

The model maintainability process is not a ''cookbook recipe'' for maintainability success. Each user should assess the appropriateness of each step for implementation within his organization. The steps need not be executed for the process to succeed; rather, it is the sum total of these steps that defines the effectiveness of the process. A formal maintainability process ensures that a cost-effective level of maintainability is built into future projects, providing the link between maintenance needs of tomorrow with constructed projects of today.

ACKNOWLEDGMENTS

The concept and organization of the model process presented here was developed by the Maintainability Implementation Research Team: Frank

M. Bulbeck, Sam Colella, Richard A. Danks, John Holleran, Loren Monty, Robert L. Post, Jon C. VandenBosch, Sean Vannoy, Jim Vinson, Michael E. Walker, Reid R. Weston, and Mike Wittliff. Valuable research support also was provided by Blia Moua. The writers sincerely thank the CII for its support in conducting the research described here. The writers also wish to thank the numerous individuals who provided the data analyzed in this investigation. Without their knowledge, expertise, and willing participation, this investigation would not have been possible.

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