



STATE-OF-PRACTICE IN MAINTAINABILITY: SEVEN CASE STUDIES

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A Report to
The Construction Industry Institute
The University of Texas at Austin

Under the Guidance of the
Maintainability Research Team
Number 142

from
University of Wisconsin-Madison
Madison, WI

December 1999

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Printed in the United States of America.

EXECUTIVE SUMMARY

Research conducted by the Construction Industry Institute (CII) revealed an increasing awareness and development of maintainability in industry. In fact, some companies have invested considerable time and resources in developing maintainability programs to facilitate a timely integration of maintainability into the project delivery process. This report captures the essence of maintainability programs and provides readers with practical insights into current maintainability implementation.

Research Purpose and Objectives - The primary purpose of this research is to document the current state-of-practice in maintainability. Specific research objectives include: (1) conduct in-depth case studies; (2) capture implemented maintainability best practices; and (3) perform a comparative analysis between maintainability programs.

Research Scope – The CII Maintainability Research Team interviewed industry professionals from a broad cross-section of companies. Case study participants were involved in many different types of industry: general building, manufacturing, chemicals, and pharmaceuticals. Additionally, the case studies document a wide variety of maintainability programs, ranging from formalized corporate-wide maintainability programs to pilot programs implemented at one plant location. The maintainability programs were applied to projects ranging from retrofit projects (less than \$500,000) to capital projects (greater than \$2 million). Capital and retrofit projects for equipment, systems, and facilities were included in this research.

Furthermore, the case studies present different project participants leading maintainability implementation: owner-led, contractor-led, and designer-led. Additionally, different perspectives of maintainability implementation were sought from project roles of owner, contractor, architect,

design engineering, and supplier. But as maintainability most directly impacts owners of constructed projects, the majority of this case study research focused on owner organizations.

Research Methodology - The research methodology adopted is formatted similar to constructability and identical to “A Model Process for Maintainability Implementation” Russell et al. 1999. The research methodology included: (1) a questionnaire survey; (2) 35 data collection interviews; and (3) seven in-depth case studies with industry professionals. The seven case studies are grouped into two categories: (1) major case studies and (2) minor case studies. The major case studies describe elements of a maintainability program and include a project implementation, if available. The minor case studies describe maintainability best practices implemented on specific projects.

Maintainability Approaches – This report presents seven maintainability approaches: (1) standard design practice; (2) contract specifications; (3) cross-functional project involvement; (4) pilot maintainability program; (5) integration into existing programs; (6) formalized maintainability program; and (7) comprehensive tracking. Description and application of each approach is presented.

Maintainability Program Attributes – This report presents an organized collection of attributes that positively contribute to an effective maintainability program. The attributes are grouped into five areas: (1) corporate commitment; (2) program resources; (3) maintainability planning; (4) maintainability implementation; and (5) program updating. A comparative analysis compares and contrasts attributes for two maintainability programs (owner-led and contractor-led).

Conclusions – Research findings reveal the emergence of maintainability programs. Varying degrees of formality in maintainability programs exist among several industries and

project participants. The comparative analysis highlights important program attributes that positively impact maintainability implementation. For example, a structured framework for the maintainability work process enhances consistent and effective implementation. Also, collecting feedback and tracking program progress is paramount for continuous improvement. This research observed maintainability implementation evolving in its infancy stages. Active owner involvement continued corporate commitment and support, and increased project implementations are essential for ensuring successful implementation and improved maintainability in the future.

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CHAPTER ONE

INTRODUCTION

Typically, maintenance is given inadequate consideration in project planning and design. As a result, uncertainty in maintenance expenses can contribute to high life cycle costs; thus increasing importance of considering maintainability in the design process. Research conducted by the Construction Industry Institute (CII) reveals an increasing level of awareness and development for maintainability.

For purposes of this research, maintainability is defined as the “inherent characteristic of system design pertaining to the ease, accuracy, safety and economy in the performance of maintenance actions (Blanchard 1995).” Simply stated, maintainability is a design parameter for the ease of maintenance. This definition reinforces the concept that maintenance capability for a project is largely determined during the design process. Therefore, a proactive approach requires early planning and design for maintainability.

This report is an extension of the research conducted in “A Model Process of Maintainability Implementation,” (Russell et al. 1999) in which the CII Maintainability Research Team investigated means by which companies incorporate maintenance knowledge and experience into the project delivery process. This research documents the varying levels of maintainability programs being implemented in industry. Informal programs incorporate maintainability simply through designer experience or engineering standards. At this level, maintainability lacks a structured process to facilitate consistent implementation and maintainability benefits have not been formally recognized. In comparison, formalized maintainability programs have corporate commitment to support integration of

maintainability into the project delivery process. Corporate procedures and resources have been developed to assist effective maintainability implementation. The varying degrees of formality in maintainability programs reflect different approaches taken by companies to design for maintenance.

The CII Maintainability Research Team documented seven in-depth case studies of maintainability implementation in industry. Appendices A through G present all seven case studies in detail. With the data collected from the case studies, the research team identified seven approaches used to implement maintainability. Additionally, this report presents a comparative analysis that compares and contrasts two maintainability programs. The first is an owner-led maintainability program implemented by the engineering division within the owner organization. The owner-led program is applied to equipment/facilities in the manufacturing industry. The second is a contractor-led maintainability program implemented by a full-services organization contracted out by the owner. The contractor-led program is applied to equipment/facilities at a government owned aerospace industry site. Program attributes are used as evaluation criteria for the comparative analysis.

This report provides readers with many practical benefits. The comparative analysis presents an organized collection of attributes positively contributing to an effective maintainability program. The case studies present benchmark examples of actual maintainability programs implemented in industry. Readers will be more informed on the state-of-practice in maintainability; thus readers are in better understanding of the elements involved in development and implementation of a maintainability program.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 PROBLEM STATEMENT

Historically, maintenance has been perceived as a “necessary evil” and an inevitable burden of cost for all projects. This view of maintenance is changing. The impact of maintainability on availability and ultimately, profitability has affected the approach taken towards maintenance. For some, maintenance is a profession requiring the skills of planning, scheduling, and measuring for effectiveness. The increased importance of project planning and design for maintenance has sparked the awareness and growth of maintainability. In fact, some companies have invested considerable time and resources in developing maintainability programs to facilitate a timely integration of maintenance consideration into the project delivery process.

The emergence of maintainability programs appears in varying levels, approaches, and applications. With a wide range of differences in implementing maintainability, standard criteria are needed to evaluate maintainability programs. Thus, this report identifies attributes to be used as evaluation criteria for maintainability programs.

2.2 RESEARCH SCOPE AND OBJECTIVES

The CII Maintainability Research Team adopted a format similar to constructability as its research methodology. This report is an extension of “A Model Process for Maintainability Implementation” (Russell et al. 1999) and thus, the research scope and

methodology are identical. Readers can refer to the previous report (Russell et al. 1999) for further detail.

The purpose of this report is twofold. First, the report provides readers with benchmark examples of maintainability programs implemented through various approaches by different players (owner, designer, and contractor) in different market sectors (manufacturing, general building, pharmaceuticals and chemicals). Second, the report provides evaluation criteria for maintainability programs. Specific research objectives include:

1. Conduct case studies to illustrate the state-of-practice in maintainability;
2. Capture implemented best practices that improved maintainability; and
3. Perform a comparative analysis to identify evaluation criteria for maintainability programs.

2.3 CASE STUDY INVESTIGATION

The CII Maintainability Research Team documented seven in-depth case studies. The research approach leading up to the case studies consist of three phases: (1) questionnaire survey; (2) data collection interviews; and (3) case studies. Phase I began in October 1997 when a three-page questionnaire survey was distributed to industry professionals (i.e., project managers, operations and maintenance managers, and maintenance technicians) from companies represented within and outside of the CII Maintainability Research Team. Of approximately 75 questionnaire surveys distributed, 48 surveys were returned; thus, the response rate was approximately 65%. Further details pertaining to the questionnaire survey are documented in a previous report (Russell et al. 1999).

Phase II, data collection interviews, began in February 1998 and overlapped with case studies. In total, approximately 90 industry professionals were interviewed in 35 different organizations. Industry professionals participating in the interviews ranged from corporate engineering to maintenance technicians, all of who had experience and/or knowledge working with design for maintainability. Phase II was used to identify case study participants. Case study preference was for formalized maintainability programs with an example of project implementation.

Phase III, case studies, was completed from September 1998 to August 1999. The purpose of the case studies was to collect detail information on actual maintainability programs. The research team documented seven case studies that are grouped into two categories: (1) major case studies and (2) minor case studies. Major case studies describe corporate maintainability programs with example project implementations (if available). Minor case studies describe maintainability best practices implemented on specific projects. Data for the case studies was collected through a series of interviews that ranged from half a day to two days. Case studies from several industries provide an array of different programs and approaches to maintainability.

2.3.1 Format of Case Studies

Five major case studies focus on elements of a corporate maintainability program. Each case study was compared to the model process for maintainability implementation (Russell et al. 1999). Thus, each major case study outlines six milestone phases: (1) commit to implementing maintainability; (2) establish maintainability program; (3) obtain maintainability capabilities; (4) plan maintainability implementation; (5) implement

maintainability process; and (6) update corporate program. Actions taken to develop and implement a maintainability program are described within these six milestones. This format for the major case studies allows readers to match case study information with the model process for maintainability implementation.

Two minor case studies focus on specific projects that illustrate implementation of best practices that improved maintainability. The minor case studies are shorter in length and are less detailed than the major case studies. Although a formal maintainability program may not have been in-place, the minor case studies demonstrate that design for maintainability can still be achieved through implementation of best practices.

2.3.2 Brief Summary of Case Studies

Providing an overview of the state-of-practice in maintainability, the case studies were documented from several industries: general building, manufacturing, chemicals, and pharmaceuticals. A specific case study does not necessarily represent the collective state-of-practice for its industry; rather the case study represents only the individual company itself. As shown in Table 2.1, the case studies have differences in: (1) formality of maintainability program; (2) project applications; and (3) implementation lead. Appendices A through G present all seven case studies in-detail.

The formality of a maintainability program varies with each case study. The maintainability programs range from formalized corporate-wide maintainability programs

TABLE 2.1 Summary of Case Studies

Case Study Index (1)	Formality of Maintainability Program (2)	Project Applications				Implementation Lead (5)	Project Example (6)	
		Type (3)			Size (4)			
		Capital	Retrofit	Equip. Facilities				
(a) Major Case Studies								
1	Formal corporate program (highly suggested work process)	X	X	X		> \$2 million	Owner	Medium-sized clean room project
2	Formal corporate program (highly suggested work process)		X	X	X	< \$500,000	Contractor	Small retrofit projects on-site location
3	Pilot program (initial trial at plant site)	X	X	X		Not Available	Owner	Small air-handling unit retrofit
4	Informal corporate program (defined project activities)	X	X	X	X	Not Available	Owner	Large wastewater treatment facility
5	Formal corporate program (elevated to mandatory compliance)	X	X	X		Not Available	Owner	Not Available
(b) Minor Case Studies								
6	Maintainability best practices: 1. contract specifications 2. design concepts		X		X	Not Available	Architect / Engineer	Large airport terminal expansion
7	Maintainability best practices: 1. front-end loading of maintenance 2. life cycle costing 3. maintainability design tool		X	X		Not Available	Engineer	Small hospital chiller retrofit

to pilot programs implemented at one plant location. In addition, each maintainability program differs in the selection and level of participation of project team members. The varying degrees of formality illustrate the evolution and development of maintainability programs.

Maintainability programs should be developed and implemented appropriately to organizational and project needs. The case studies present maintainability programs applied across a variation of project types and sizes. Project applications vary from small retrofit projects (less than \$500,000) to larger capital projects (greater than \$2 million). Both capital and retrofit projects for equipment, systems, and facilities were included in the maintainability programs.

While maintainability programs are primarily owner-driven, the case studies document different project participants leading maintainability implementation: owner-led, contractor-led, and designer-led. Also, different perspectives on maintainability implementation were sought from project roles of owner, contractor, architect, design engineer, and supplier. But as maintainability most directly impacts owners of constructed projects, the majority of case study research focused on owner organizations.

2.4 SUMMARY

Maintainability is a topic growing in awareness. Recognizing the importance of maintenance, companies are developing and implementing maintainability initiatives. While varying levels of formality do exist, all efforts are aimed to achieve the same goal: design for maintainability to increase return on project investment. This report presents case studies describing different programs and project implementations of

maintainability. The assortment of case studies provides an insightful look into the state-of-practice in maintainability across several industries.

The next chapters present the research findings and results. Chapter 3 presents approaches for implementing maintainability. Chapter 4 introduces a comparative analysis and describes the organizational characteristics of the two maintainability programs. Chapter 5 presents the comparative analysis and identifies program attributes as the evaluation criteria. Chapter 6 concludes with practical applications and future research.

CHAPTER THREE

SEVEN MAINTAINABILITY APPROACHES

3.1 INTRODUCTION

The wide range of industries and project participants involved in the case studies contributes to a broad collection of data. The case studies document the state-of-practice in maintainability, illustrating many facets of a maintainability effort and differences in approaches to implementing maintainability. This chapter overviews the five levels of maintainability implementation and describes seven maintainability approaches.

3.2 LEVELS OF MAINTAINABILITY IMPLEMENTATION

The synthesis of data collection interviews and case studies presents five levels of maintainability implementation: (1) designer experience; (2) effective organizational standards; (3) developing maintainability process; (4) formal maintainability process; and (5) comprehensive maintainability program. Details of the five levels of maintainability implementation are presented in a previous research report (Russell et al. 1999). For purposes of illustrating the state-of-practice in maintainability, a brief overview of the five levels will be described.

The five levels of maintainability implementation illustrate the increasing formality and standardization of a maintainability program. Level 1, designer experience, is the minimal level of maintainability implementation. Level 1 depends upon the initiative, awareness, skill, and knowledge of the designer to incorporate maintainability

into the design process. With each succeeding level, increased personnel involvement and maintainability activities enhance effective maintainability implementation; thereby, increasing the opportunity for projects to capture additional benefits from improved maintainability.

Level 5, comprehensive maintainability program, is the highest level of maintainability implementation. Level 5 consists of a formalized corporate maintainability program containing a structured work process with written program procedures. The maintainability work process includes a method for tracking benefits/costs, lessons-learned, and best practices to continually improve and update the program. Level 5 is considered the ultimate best practice process.

3.3 APPROACHES TO IMPLEMENTING MAINTAINABILITY

While the five levels have been previously defined by a prior research report, this report identifies seven approaches used to attain the certain level of maintainability implementation. A combination of the literature review and case study findings reveal seven approaches: (1) standard design practice; (2) contract specifications; (3) cross-functional project team involvement; (4) pilot maintainability program; (5) integration into existing program; (6) formalized maintainability program; and (7) comprehensive tracking. The approaches are not mutually exclusive. Most often, several approaches are used in combination to implement maintainability. As shown in Figure 3.1, the approaches are presented in relative order of increasing maturity and increasing resource requirements.

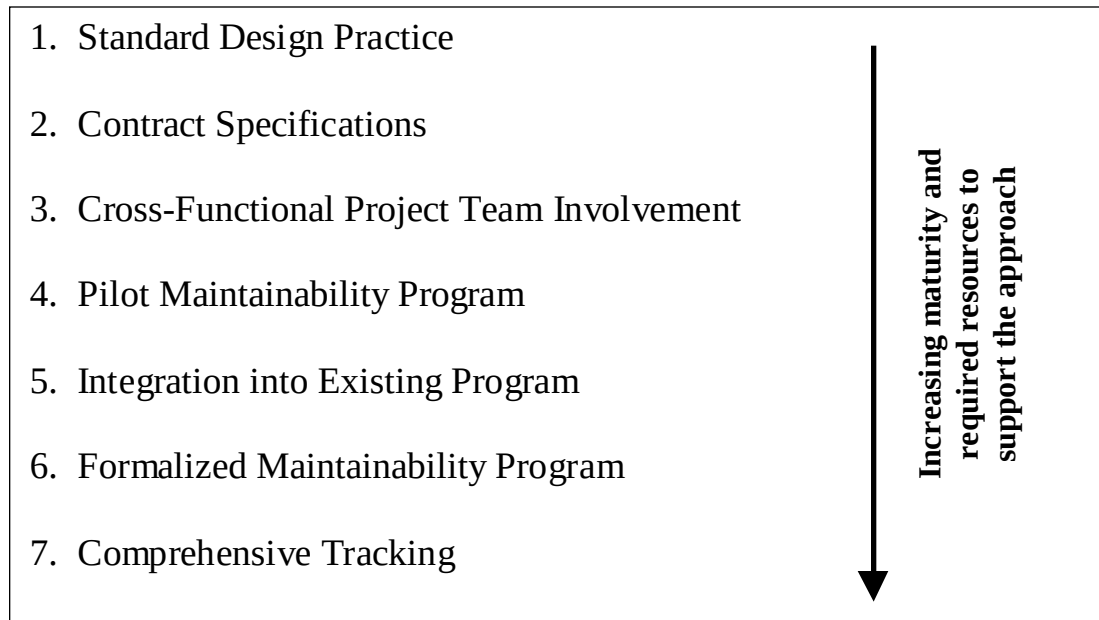


FIGURE 3.1 Approaches to Implementing Maintainability

3.3.1 Standard Design Practice

Standard design practice relies on the designer or company standards to include maintainability as a design objective. Maintainability should be considered in the parts/equipment selection, facility layout, information technology, and overall design of the final product. Examples of maintainability design concepts include accessibility, standardization, modularization, color coding and labeling, preventive and predictive maintenance capability, visual management techniques, and preferred suppliers. A further explanation of maintainability design concepts are presented in a previous research report (Russell et al. 1999). The standard design practice approach assists in providing maintainability concepts to be directly incorporated into the design process.

3.3.2 Contract Specifications

Contract specifications define project expectations and requirements for maintainability. Effective contract specifications outline: (1) definition of maintainability; (2) maintainability objectives; (3) maintainability activities; and (4) maintainability personnel. Specific requirements identified in contract specifications include: (1) operations and maintenance documentation, such as maintenance procedures; (2) operations and maintenance training; (3) maintenance management information systems; (4) maintainability personnel, such as a coordinator; (5) collaboration of project participants in a work process; and (6) preferred suppliers for parts and equipment. The contract specifications approach assists in clear identification of maintainability goals early in the project delivery process.

3.3.3 Cross-functional Project Team Involvement

Cross-functional project team involvement seeks the knowledge, expertise, and participation of personnel experienced in maintenance or personnel affected by the maintainability of the designed project. Cross-functional project team involvement may include the following participants: maintenance technicians, skilled craftsmen, end users, and suppliers/manufacturers. The commitment for cross-functional project team involvement needs to be established early in the project delivery process; thereby allowing cross-functional project team input to be incorporated into the design process. The cross-functional project team involvement approach assists in obtaining the necessary maintainability expertise by involving the appropriate people in the project delivery process.

3.3.4 Pilot Maintainability Program

The pilot program approach identifies key maintainability activities for selected project implementation and experimentation before a formal program is administered. The results from pilot projects are used for refining the maintainability implementation process. Also, benefits and costs may be documented to justify the maintainability program. This approach can assist in determining the appropriateness of a stand-alone formalized program or integration into an existing program. The pilot program approach assists in focusing on selected projects to determine the most efficient implementation process and validate justification for the maintainability program.

3.3.5 Integration into Existing Program

The integration approach identifies maintainability best practices to be integrated into existing programs. Maintainability can be integrated into existing programs, such as reliability, process hazard analysis, and front-end loading. The integration approach is advantageous by linking maintainability to well-established work processes to share personnel and support resources. With the integration approach, maintainability is an objective used to achieve bigger over-arching goals. Additionally, maintainability is more likely to be implemented when integrated into an existing program.

3.3.6 Formalized Maintainability Program

A formalized maintainability program approach has high corporate commitment and support. The corporate-developed formal maintainability program consists of a structured work process that defines procedures, tools, personnel, and resources for

maintainability implementation. Maintainability activities and project roles are clearly identified. The structured work process standardizes, streamlines, and supports implementation process. The formal maintainability program provides a structured work process to facilitate implementation and enhance maintainability.

3.3.7 Comprehensive Tracking

Comprehensive tracking elevates the formalized maintainability program a step further. Comprehensive tracking is a means or methods to capture, document, and share lessons-learned, benefits, and costs for the formal maintainability program. The capability to capture lessons-learned assists in determining standards that will become best practices. Documentation of benefits and costs establish data to provide economic justification and retain management support for the maintainability program. Comprehensive tracking initially begins in the form of a paper database. With experience and maturity, the paper database is converted to an electronic format. The electronic database aids better management, wider accessibility, and effective updates for the maintainability program. The comprehensive tracking approach assists to continuously improve, update, and refine the maintainability program.

3.4 OBSERVATIONS OF APPROACHES IN CASE STUDIES

Each organization needs to select a maintainability approach or a combination thereof that is most suitable for project needs. This section describes the maintainability approaches observed in the seven case studies. The case study observations are presented

in the order of increasing approaches. A summary of the maintainability approaches used by each case study is presented in Table 3.1.

3.4.1 Case Study 7

The primary approach observed in case study 7 is standard design practice. The project engineer was knowledgeable on the importance and significance of long-term considerations such as maintainability. The project engineer took the initiative and extra effort to integrate maintenance into the design process using front-end loading of maintenance, life cycle costing, and maintainability design tool. The standard design practice approach requires the least amount of program resource supports and requirements, because the approach was highly dependent upon the maintainability experience and knowledge of the project engineer.

3.4.2 Case Study 6

The primary approach observed in case study 6, contract specifications, obtained maintainability input from the owner and architect/engineer. Contract specifications clearly defined project requirements for: (1) operations and maintenance data documentation including maintenance procedures; (2) operations and maintenance training; (3) operations and maintenance coordinator/scheduler; and (4) maintenance management information systems. Clear identification of maintainability requirements facilitated the communication of maintainability expectations and assisted in organizing and planning implementation supports, resources, and funds. Additionally, contract

TABLE 3.1 Approaches Observed in Case Studies

Case Study Index (1)	Industry (2)	Individuals Interviewed		Description of Maintainability Approach (5)	Maintainability Approach (6)
		Organization Represented (3)	Representative’s Role (4)		
(a) Major Case Studies					
1	Manufacturing	Owner	Corporate Engineering Project Engineer	Owner-implemented by project engineering division.	Formalized Maintainability Program
2	Aerospace	Contractor	Engineering & Construction Supervisor	Owner undertakes a new business methodology by having contractor-implemented maintainability.	Integration into Existing Program
3	Pharmaceutical	Owner	Corporate Engineering Project Engineer	Owner-implemented pilot program inserts key maintainability activities into the project delivery process.	Pilot Maintainability Program
4	Chemicals	Owner	Corporate Engineering	Owner-implemented by integration of maintenance into the corporate Front-end Loading process.	Integration into Existing Program
5	Manufacturing	Owner	Division Engineers	Owner-implemented by high involvement of suppliers and users.	Formalized Maintainability Program
(b) Minor Case Studies					
6	General Building	Design	Architect/Engineer	Architect/engineer-implemented on an airport expansion through maintainability contract specifications.	Contract Specifications
7	General Building	Design	Project Engineer	Engineer-implemented on a hospital chiller retrofit through front-end loading of maintenance, life cycle costing, and maintainability design tool.	Standard Design Practice

specifications allow contractors to include maintainability as a significant cost added to project bids, without reducing their chances for project award.

3.4.3 Case Study 3

The primary approach observed in case study 3 is a pilot maintainability program implemented on small projects by a pharmaceutical company. The key maintainability activities and resources identified and incorporated into the project delivery process for case study 3 included: (1) project-level maintainability representative; (2) maintenance contact matrix; and (3) maintainability design considerations. The pilot program required less resource requirements up-front to develop and refine a maintainability process before a corporate-wide maintainability program is administered.

3.4.4 Case Studies 2 and 4

Observed in both case studies 2 and 4, the primary approach is maintainability integrated into existing programs. Case study 2 chose to integrate maintainability input and activities into the facility activation phase of its project delivery process. For case study 2, maintainability was a means to achieve smooth facility activation by delivering projects timely and cost-effectively. Case study 2 did recognize the integration of maintainability into facility activation as a formalized maintainability program. Case study 4 chose to integrate maintainability input and activities into an established front-end loading corporate process. For case study 4, maintainability was a means to achieve long-term business goals and project objectives by front-end loading maintenance.

3.4.5 Case Study 1

The primary approach observed in case study 1, formalized maintainability program, treated maintainability as high priority input for achieving long-term optimal production availability for manufacturing equipment/facilities. Corporate plant engineering, the author of the formal maintainability program, provided visible corporate commitment and supports for implementation. Corporate commitment, maintenance philosophy, and program procedures were clearly documented within an implementation manual. Furthermore, the implementation manual contained implementation tools, such as design checklists and maintainability reviews. Providing the necessary supports, the implementation manual defined a maintainability work process. Resource requirements that facilitated maintainability implementation included: (1) corporate-level maintainability personnel (i.e., champion and coordinator) to provide program training and support to individual plants; (2) corporate administration, commitment, and recognition of annual awards program for maintainability; and (3) written program procedures.

In case study 1, maintainability is owner-implemented by the project engineering organization. In-house maintenance personnel assisted the project engineer in establishing maintainability objectives, expected maintainability measurements, and maintenance procedures. Maintainability activities were integrated continuously throughout the entire project delivery process, from project scope to project closing, for thorough consideration and evaluation of maintainability. In summary, case study 1 had a corporate-supported, formalized maintainability program that design for maintainability continuously throughout the entire project delivery process.

3.4.6 Case Study 5

The primary approach observed in case study 5 is a combination of integration with existing program and a formalized maintainability program. In case study 5, maintainability was combined with reliability. Reliability and maintainability are interdependently linked; therefore, it was logical to combine the two into one formal program. Combined, reliability and maintainability had a stand-alone formalized program. Maintainability input was provided from many sources: (1) in-house maintenance personnel; (2) end users; (3) experienced design engineers; and (4) equipment suppliers. The formalized program had written procedures that were easily tailored to individual projects.

Although both case studies 5 and 1 had formalized programs, there were two elements that distinguished the two programs. Case study 5 actively involved suppliers in the maintainability implementation process. Suppliers had active project roles, provided lessons-learned and were involved in re-design of failed or updated parts/equipment. Supplier involvement contributed to a proactive design process, because the design process involved all participants impacting maintainability. The second distinguishing element in case study 5 was that the owner organization was increasing its maintainability commitment by requiring all suppliers to comply with maintainability requirements and specifications. Case study 5 displayed the closest approach to comprehensive tracking.

3.5 SUMMARY

Each case study presents a different perspective on maintainability implementation; thus providing a wide spectrum for the state-of-practice in maintainability. This chapter described seven maintainability approaches: (1) standard design practice; (2) contract specifications; (3) cross-functional project team involvement; (4) pilot maintainability program; (5) integration into existing programs; (6) formalized maintainability program; and (7) comprehensive tracking. The approaches increase in maturity and resource requirements moving from standard design practice to comprehensive tracking. Table 3.2 presents a summary of the approaches used to implement maintainability in each of the case studies.

The next chapter will present a comparative analysis of two maintainability programs, highlighting attributes that positively contribute to effective implementation. Similarities and differences in the two programs will be described.

TABLE 3.2 Summary of Approaches Observed in Case Studies

Approaches (1)	Case Study (2)						
	1. Manuf.	2. Gen. Building	3. Pharm.	4. Chemicals	5. Manuf.	6. Gen. Building	7. Gen. Building
Standard Design Practice		X			X		★
Contract Specifications						★	
Cross-Project Team Involvement	X	X	X	X	X	X	X
Pilot Maintainability Program			★				
Integration into Existing Program		★		★	X		
Formalized Maintainability Program	★	X			★		
Comprehensive Tracking							

★ = Primary Approach

X = Secondary Approach

CHAPTER FOUR

COMPARATIVE ANALYSIS: ORGANIZATIONAL CHARACTERISTICS

4.1 INTRODUCTION

Maintainability programs vary among different segments of the construction industry. To compare and contrast attributes, a comparative analysis is performed on two maintainability programs, derived from the major case studies. The main distinction between the two programs is the organization leading the implementation process. One maintainability program is owner-led, while the other program is contractor-led. The dissimilarity will provide different perspectives on maintainability. This chapter introduces the comparative analysis by describing organizational characteristics for the two maintainability programs.

4.2 OWNER-LED MAINTAINABILITY PROGRAM

A large manufacturing company having annual sales of \$15 billion in 1998 developed the owner-led maintainability program. The company manufactures and sells over 50,000 products in 40 merchandise divisions ranging from automotive to healthcare. For this owner, design for maintainability is a means to achieve long-term optimal production availability. Therefore, maintainability is acknowledged to be an important component of improving profitability and retaining global competitiveness.

Corporate plant engineering developed the formal maintainability program that is a highly suggested work process for delivering equipment and facility projects over \$1.5 million. In brief overview, the formal maintainability program defines a work process

containing tools that enhance consistent and effective implementation. Responsibility for actual project implementation is given to the project engineering organization, which oversees planning, detailed design, and construction activities. Maintenance input is obtained collectively from various in-house departments: engineering, operations and maintenance, safety, and ergonomics. As such, this owner company possesses sufficient in-house capabilities to provide necessary resources to support a formal maintainability program.

4.3 CONTRACTOR-LED MAINTAINABILITY PROGRAM

The contractor-led maintainability program involves an owner in the aerospace industry. Embracing a fully integrated project delivery process and engaging in a new business methodology, the owner has contracted with a full-services organization to lead, facilitate, and perform maintainability services for one site location. Working together, both the owner organization and the full-services third-party contractor provide maintenance input and resources for the maintainability program.

A fully integrated project delivery process is a growing trend. Historically, the typical project delivery process was disconnected with little information fed forward or backward among the stovepiped project delivery phases. Usually, design engineers are not directly held accountable for serviceability impacts (including maintainability) of their work. Often times, design engineers do not have a sense of ownership for the project, thereby eliminating the consideration of long term factors, such as maintainability, in design. This practice may produce projects with low initial cost but result in high life cycle costs such as excessive maintenance expenses. To remedy this

situation, a fully integrated project delivery process attempts to combine separate project delivery phases with smooth transitions to encourage all project participants to work cooperatively in delivering an end product that meets both short and long term objectives.

To effect the fundamental change in the project delivery process, the owner has embraced a new business methodology by contracting with a third-party full-services organization to provide long-term results through a design, construct, operate, and maintain contract. The single point responsibility enables a project to be designed and constructed as planned for efficient maintenance. Additionally, the contract provides flexibility for the full-services organization to coordinate work among all involved parties, thereby creating greater efficiencies within the project delivery process.

The contractor-led maintainability program is facilitated through owner guidelines established in a performance-based contract. The contract term is for five years, one base year plus four one-year renewals. The firm fixed-price of the five-year contract is \$128.2 million. The contract covers small capital projects, less than \$200,000 in construction value, with a cap limit of 400 projects per year. The long-term, performance-based characteristics of this contract is a new business methodology for placing a third-party contractor responsible for maintainability of small capital projects on an owner site.

The long-term, performance-based contract strongly encourages the full-services organization contractor to assure a planned design for maintainability will be constructed accordingly, resulting in a facility that can be operated and maintained efficiently. Projects that have a lack of maintainability consideration may require subsequent re-designs or change orders to adequately accommodate for maintenance. Re-designs or change orders can be costly and will negatively impact the quality of work performance

on this contract. Therefore, the full-services third-party contractor places importance on considering maintainability in design.

4.4 SUMMARY OF MAINTAINABILITY PROGRAM CHARACTERISTICS

Table 4.1 presents salient characteristics for the owner-led and contractor-led maintainability programs. The two programs deal with different focus areas for maintainability. As mentioned earlier, the major distinction between the two programs is the organization responsible for leading maintainability implementation (owner versus contractor). The summary of program characteristics outlines the background for the comparative analysis presented in the next chapter.

TABLE 4.1 Maintainability Program Characteristics

Characteristic (1)	Maintainability Program	
	Owner-led (2)	Contractor-led (3)
Industry	Manufacturing	Aerospace
Focus of maintainability program	Manufacturing equipment	Equipment/Facilities
Project type	Capital projects, new and retrofit	Small capital projects on same owner site
Threshold for maintainability to be used on a project	More than \$1.5 million	Less than \$200,000
Responsible for implementation of Maintainability Program	Project Engineering Division within the owner organization	Third-party ~ full-services organization

4.5 SUMMARY

The comparative analysis is valuable to both owners and contractors by providing insights into program attributes and effective implementation for maintainability. This

chapter provided background information on the organizations involved in the two maintainability programs. Each program is distinctly different in salient characteristics, such as industry type, project application, and implementation lead. Next, chapter 5 will present a comparative analysis highlighting program attributes that positively contribute to successful implementation.

CHAPTER FIVE

COMPARATIVE ANALYSIS:

ATTRIBUTES OF MAINTAINABILITY PROGRAM

5.1 INTRODUCTION

Through literature reviews and data collection interviews, the CII Maintainability Research Team identified specific attributes contributing to effective maintainability programs. Table 5.1 presents an organized collection of the fundamental attributes existing within the owner-led and contractor-led maintainability programs. The program attributes are separated into five main groups:

1. Corporate Commitment;
2. Program Resources;
3. Maintainability Planning;
4. Maintainability Implementation; and
5. Program Updating.

This chapter presents each program attribute along with a description of elements and examples, if applicable. In addition, the approach used to address each attribute will be described for the owner-led and contractor-led programs. The information presented in this chapter will allow readers to compare and contrast similarities and differences in two maintainability programs.

TABLE 5.1 Attributes of Maintainability Program

Program Attributes (1)	Owner-led (2)	Contractor-led (3)
<i>(a) Corporate Commitment</i>		
Policy statement	Y	Y
Executive sponsor	Y	N
<i>(b) Program Resources</i>		
Designated maintainability personnel		
Corporate-level	Y	N
Project-level	Y	Y
Written program procedures		
Maintainability design characteristics	Y	Y
Metrics or performance measurement criteria	Y	Y
Maintainability roles and responsibilities	Y	Y
Maintainability activity scheduling	Y	Y
Maintainability design approval procedure	N	N
Sample tools	Y	Y
Program progress tracking		
Costs/Benefits	N	N
Best practices	Y	N
Information database		
Lesson-learned / Best practices	Y	N
Life cycle cost model	N	N
Maintenance information management system	Y	Y
Orientation program	Y	N
<i>(c) Maintainability Planning</i>		
Review lessons-learned	Y	Y
Establish maintainability objectives	Y	N
Maintainability activity and resources planning	Y	Y
<i>(d) Maintainability Implementation</i>		
Cross-functional teams	Y	Y
Maintainability meetings	Y	Y
Design reviews	Y	Y
<i>(e) Program Updating</i>		
Evaluate program	Y	Y
Update lessons-learned/best practices	N	N
Integration of innovative technology	Y	Y

5.2 CORPORATE COMMITMENT

Critical for success, corporate commitment establishes the support and resources needed to develop, implement, and refine a maintainability program. Corporate

commitment for maintainability consists of two program attributes: (1) policy statement and (2) executive sponsor.

5.2.1 Policy Statement

A policy statement recognizes and emphasizes the importance of maintainability in achieving company goals. In addition to increasing corporate-wide awareness, the policy statement reinforces corporate commitment to maintainability. Effective policy statements include: (1) company commitment to maintainability; (2) definition of maintainability; (3) role of maintainability in business and maintenance goals; and (4) an implementation plan for maintainability. As shown in Table 5.2, an implementation plan facilitates the integration of maintainability into company culture. The implementation plan is a sample taken from a large manufacturing company.

TABLE 5.2 Sample Implementation Plan for Maintainability

Year (1)	Phase (2)	Goal (3)
1	Informal process	Awareness and appreciation
2	Highly recommended process	Detailed focus
3	Mandatory process	Fully integrated maintainability process

Both owner-led and contractor-led programs have policy statements expressing corporate commitment to maintainability. The owner-led program has an informal policy statement embedded within its maintainability program manual. Endorsed by corporate

plant engineering services, the policy statement stresses the purpose, importance, features, and benefits of maintainability. Similarly, the contractor-led program has a maintainability policy statement distributed from the owner to be enforced by the contractor. The policy statement stresses the desired results of designed-in maintenance. Both owner-led and contractor-led programs are highly suggested for project use. Inconsistent use of the maintainability program does not reach its full potential for benefits and implementation. Thus ultimately, a mandatory policy statement is a necessity for corporate wide compliance. In summary, Figure 5.1 presents features constituting an effective policy statement.

Maintainability Policy Statement
Express commitment to maintainability
Define maintainability
Describe role of maintainability to business and maintenance goals
Provide implementation plan

FIGURE 5.1 Features of Maintainability Policy Statement

5.2.2 Executive Sponsor

An executive sponsor oversees the entire corporate maintainability program, evaluating and refining it for continuous improvement. The owner-led program has an executive sponsor in corporate plant engineering services. The executive sponsor has influence to affect executive decisions made in regards to the maintainability program, such as assignment of resources. In contrast, the contractor-led program uses a different approach. Instead of an executive sponsor, the maintainability effort is lead from middle management. The maintainability sponsor at middle management helps champion

implementation at the project-level. While having a maintainability sponsor at middle management has advantages, an executive sponsor at the corporate-level can help allocate corporate resources to improve and expand the maintainability program.

5.3 PROGRAM RESOURCES

Program resources provide direct support for a maintainability program. Program resources consist of five attributes: (1) designated maintainability personnel; (2) written program procedures; (3) program progress tracking; (4) information database; and (5) orientation session.

5.3.1 Designated Maintainability Personnel

Designated maintainability personnel at corporate and project-levels are responsible for directing implementation of the maintainability program. The owner-led program has designated five corporate-level maintainability personnel. Serving as information sources, the designated corporate-level personnel provide individual plants with training and support in implementing the maintainability program. The names and contact numbers for each designated corporate-level person are printed on the front page of the maintainability program manual.

In contrast, the contractor-led program has designated project-level maintainability personnel. A middle manager (i.e., engineering and construction supervisor) provides guidance in direct implementation of the maintainability program. The middle manager also is involved in improving maintainability efforts on the project. In addition to the middle manager, a project-level coordinator is responsible for

organizing, scheduling, and executing maintainability activities. Combined, the middle manager and coordinator are directly responsible for maintainability implementation at the project-level.

Both programs have designated maintainability personnel such that it is suitable for their specific program needs. The owner-led program is implemented on a much larger scale than the contractor-led program; thus the heightened assistance from corporate-level personnel provides the broad company-wide direction needed. The contractor-led program implemented on one site location of a large owner works more effectively when on-site project-level personnel are designated for direct assistance. For a smaller scale or in the case of the contractor-led program, corporate-level personnel may not be as necessary or as economically justified.

An ideal comprehensive maintainability program would have designated corporate and project-level personnel for thorough support and advocacy, from top to bottom. Corporate-level personnel provide over-arching guidance and resources for direct implementation, while project-level personnel execute program activities to achieve improved maintainability.

5.3.2 Written Program Procedures

Written program procedures enhance consistent, effective implementation by clearly describing, defining, and structuring a work process. A work process consists of involving the appropriate people, equipped with the necessary resources, to execute project activities that enhance design for maintainability. Thus as presented in Figure 5.2, written program procedures should outline the following: (1) maintainability design

characteristics; (2) metrics or performance measurement criteria related to maintenance; (3) maintainability-related roles and responsibilities; (4) maintainability idea approval procedure; (5) maintainability activity scheduling; (6) program progress reporting; and (7) sample tools.

The owner-led program has written program procedures compiled in a maintainability program manual. The manual is well written, because it provides a simplistic, but thorough explanation of maintainability. Conceptually and process-oriented, the manual describes a work process that directly integrates maintainability activities into the project delivery process. As outlined in Table 5.3, the manual has four main sections and includes an appendix. Condensed into ten easy-to-read pages, the four sections cover the purpose, justification, features, and work process for maintainability. The appendix contains sample tools to assist project implementation. Specific examples of written program procedures (maintainability design characteristics, metrics or performance measurement criteria related to maintenance, and maintainability-related roles and responsibilities) are presented in Table 5.4. Thus, the program manual has practical applications that can be immediately used by readers to improve maintainability on projects.

Similarly, the contractor-led program has general written program procedures outlining a work process that is used simultaneously for total quality management and maintainability. The work process serves to assist and ensure coordination of maintainability activities into the project delivery process. The work process consists of