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(R) Maintainability Program Standard Implementation Guide

RATIONALE

This document was updated to complete a revision that was initiated in 2005. Changes include technical clarifications, major editing of the text, figures and tables. Additions and deletions as deemed necessary by the Maintainability Committee members were incorporated in this revision. The objectives and the intent of the document remain unchanged in this revision.

FOREWORD

This Implementation Guide was developed as a companion supporting document for SAE Maintainability Program Standard, JA1010. This Guide has been designed to provide guidance and assistance for planning and managing maintainability programs.

Its development was influenced by a number of factors, including current market trends (optimized maintainability, affordability and speed to market), Department of Defense (DoD) Acquisition Reform, and the wide diversity of industries and applications for this Implementation Guide.

This Guide, as well as its related standard, stresses the importance of the supplier-customer dialogue. It supports the belief that maintainability programs are most efficient and effective when developed jointly by the supplier and customer. Rather than following a single prescribed approach, the supplier should design (tailor) the maintainability program, with customer input, and include only value-added activities. Throughout the program, the supplier provides the customer with evidence that the program objectives are being met. Since the primary goal of the maintainability program is to provide products that satisfy the customer, prescribed activities and methods that do not add value should not be performed.

Section 1 (Scope) outlines the background, purpose and scope of this Guide and the supplier-customer dialogue. Section 2 provides (References) to applicable publications. Section 3 (Glossary) includes terms and definitions to enhance the understanding of this document. Section 4 (Maintainability Program) defines the maintainability program. The section also outlines how to develop a maintainability program, its benefits and criteria for method selection and the principles for establishing a cost effective and value-added maintainability program. Section 5 (Maintainability Case) outlines the strategy to ensure the maintainability requirements are satisfied. Section 6 (Maintainability Methods) includes maintainability practices recognized as best practices throughout industry.

This is a living document and should be treated as such, therefore technology changes, this document may also change. Comments (recommendations, additions and deletions) and any pertinent data, which may be useful in improving this document, should be addressed to: Chair SAE G11 RMS&PM Division.

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http://www.sae.org/technical/standards/JA1010/1_201105

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1. SCOPE

This document provides information to help the reader view maintainability in the context of an overall systems engineering effort. The guide defines maintainability, describes its relationship to other disciplines, addresses the basic elements common to sound maintainability programs, and describes the tasks and activities associated with those elements.

1.1 Purpose

SAE JA1010-1 Maintainability Program Standard Implementation Guide (the Guide) is designed to assist suppliers in determining how to satisfy the program requirements developed per SAE JA1010 *Maintainability Program Standard* (the Standard). Although this Guide has been designed for use with the Standard, it is not required by the Standard. The Guide may be used for programs in any Government or commercial application. It applies to all activities for achieving desired levels of maintainability throughout the product or service life cycle. The guide's main purposes are:

a. To provide insight into the need for specifying maintainability in an item/system or production development program and to describe the structural elements of a sound maintainability program.

b. To describe the design, analysis, test, and management tasks and activities that may be conducted to meet the objectives, the required levels of maintainability and incorporation of these tasks in a tailored program.

c. To provide guidance for structuring solicitations and proposals to ensure that these tasks and activities are addressed.

d. To provide guidance for evaluating how well maintainability is addressed in proposals submitted in response to a solicitation.

e. Provide guidance to contractors and subcontractors on the application of the Maintainability Case (MC) procedure (see Section 5 of this guide).

1.2 Application

This Guide primarily provides assistance for developing maintainability programs according to the requirements of SAE Standard JA1010. Implementation of the guide will help to answer questions frequently asked by suppliers and customers such as:

a. Who is responsible for maintainability goals, planning, etc.?

b. What maintainability methods are most effective, and how are they applied?

c. When are maintainability methods used most effectively in the product development cycle?

d. Where can we get more detailed information and instructions on how to use the maintainability methods?

This Guide may also be used as a general reference for maintainability methods and maintainability program management. Suppliers and customers may also find the Guide useful for other purposes such as those listed below:

a. Resource for design and manufacturing engineers to select available maintainability methods.

b. Provide an understanding of various maintainability program activities.

c. Provide assistance to suppliers who need knowledge of various maintainability methods and techniques, or assistance establishing a formal maintainability program.

d. Assistance in planning, scheduling and structuring their maintainability programs.

e. Knowledge of available maintainability methods, a description of what they accomplish, and when they are best applied.

f. Evaluating potential benefits and limitations of maintainability methods.

g. Practical method selection criteria.

1.2.1 Background

Maintainability is a discipline that has increased in importance as systems have become more complex, support costs have increased, and resources have decreased. Maintainability is important in all product sectors, where high levels of maintainability are increasingly becoming an important factor in production and customer cost of ownership.

Maintainability has been a recognized discipline for many years. Achieving the high levels of maintainability needed in military and complex industrial and commercial systems is often difficult to accomplish. System complexity, competing performance requirements, the rush to incorporate promising/immature technologies, the pressures on acquisition budget, and schedule compression contribute to the degree of difficulty.

The information in this guide reflects both the move to incorporate commercial "best practices" and the lessons learned over many years of former acquisition practices. When appropriate, commercial and military standards are cited herein for reference. Whereas many of these documents emphasize what to do and how to do it, this guide focuses on the objectives of a sound maintainability program and the engineering tools and techniques available to meet these objectives.

SAE JA1010 uses only the terms “customer” and “supplier”. It is important to understand that this can represent the relationship between the “end consumer” (customer) and “the company that produces the end product” (supplier) and equally that between “the company that produces the end product” (customer) and “the company that produces a sub-system” (supplier). For continuity therefore only “customer” and “supplier” are used throughout. When interpreting the Program Requirements and the activities therein, it is necessary to keep in mind the applicable context and the parties being discussed.

1.2.2 What Is Maintainability

The definition of Maintainability is defined slightly different in various standards, guides and text books. The definition used in this document is taken from MIL-HDBK-470A, Designing and Developing Maintainable Products and Systems. This definition can be modified by a customer or supplier and agreed to by them to reflect the specific product or system.

Definition of Maintainability - The relative ease and economy of time and resources with which an item can be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. In this context, it is a function of design.

Maintainability, in some industries referred to as serviceability, is a design parameter. Although other factors, such as properly trained personnel and a responsive supply system, can help keep downtime to a minimum, it is the inherent maintainability that determines this minimum. Improving training or support cannot effectively compensate for the effect on availability of a poorly designed (in terms of maintainability) product. Minimizing the cost to support a product, and maximizing the availability of that product are more efficiently done by designing the product to be reliable and maintainable.

Testability, an important subset of maintainability, is a design characteristic that allows the status (operable, inoperable or degraded) of an item to be determined, and faults within the item to be isolated, in a timely and efficient manner. The ability to detect and isolate faults within a system, and to do so efficiently and cost effectively, is important not only in the field, but also during the testing phases of manufacturing. The expected percentage of faults that can be detected and isolated to a specified or desired level of ambiguity must be determined. The consequences of poor testability include higher manufacturing product test costs, higher support costs, and lower customer confidence and satisfaction.

1.2.3 Framework For a Maintainable Product Development

Suppliers should construct maintainability development programs that fit the customer needs. It is clear that, prior to building a product, customer needs must be understood. Without proper information about customer needs, development activities tend to lack focus and are likely to generate a poor design solution. Therefore, *to ascertain the needs of the customer* becomes an important objective towards the goal of customer satisfaction. Once the needs have been ascertained, a product that satisfies those needs can be produced. Therefore, the second objective of maintainable product development is *to meet the customer needs*. Integral with the maintainability development program is the need to verify and validate the requirements throughout the design process. Therefore, the third objective is *to assure the customer that the needs are met*. These three objectives form the basis for a framework that underlies the SAE JA1010, *Maintainability Program Standard*. This standard represents today's prevalent thinking of how to develop maintainable products and emphasizes the *supplier-customer* relationship among companies and their suppliers as well as among end-consumers and companies. Table 1 provides the framework for the development of a maintainable product. The three objectives listed above are set in SAE JA1010 as *Program Requirements* and are worded as follows:

- The supplier shall ascertain customer requirements
- The supplier shall meet customer requirements
- The supplier shall assure that customer requirements have been met

Each program requirement further consists of a number of activities. These activities are accomplished by a number of possible maintainability methods. It is essential to understand that maintainability transcends several disciplines across many industries. Therefore, it is important not to be prescriptive about the specific maintainability methods used in product development. Consequently, SAE JA1010 does not specify the maintainability methods to be used. Rather, the customer and supplier(s) must work together to develop a maintainability program that completes each activity through the use of mutually acceptable maintainability methods.

It should be recognized that SAE JA1010 uses the term "customer" to mean the *end-user* or a *company*. For example, the user of a lawn tractor is a customer of the dealer and manufacturer. A *company* may also be a customer. For example, an auto manufacturer is the "customer" of its instrument panel supplier. Also, there could be multiple or intermediate customers to a supplier. Therefore, when interpreting the program requirements and the activities therein, one needs to keep in mind the applicable context and the parties being discussed.

TABLE 1 - A FRAMEWORK FOR MAINTAINABLE PRODUCT DEVELOPMENT

The Supplier Shall Ascertain Customer Requirements a. Establish Supplier-Customer Dialogue b. Identify Conditions of Use c. Define Maintenance and Service d. Establish Metrics e. Develop Product Specification f. Operating Environment
The Supplier Shall Meet Customer Requirements a. Characterise Resources b. Assess and Manage Risk b. Design to Achieve Maintainability
The Supplier Shall Assure Customer Requirements Have Been Met a. Qualify the Product and Process b. Establish Process Control c. Pursue Continuous Process Improvement d. Establish Data Collection and Reporting

1.2.3.1 The Supplier Shall Ascertain Customer Requirements

Understanding the customer's maintainability needs is the first and most obvious step in meeting the objective of a maintainable product. It is important that the level of maintainability addressed here is that which is measured by the customer, not necessarily that measured during design and development. An important part of understanding customer needs is to collect and study lessons learned on prior products, preferably products similar to the one being acquired or manufactured. By learning which problems have plagued products or processes in the past, the maintainability engineer can adopt design approaches that reduce, if not eliminate, those problems in the new product or processes.

Dialogue between customer and supplier should take place to gain a clear understanding of the product life cycle, operating profile and environmental conditions. This discourse should cover the wider aspects of the maintenance policy, future maintenance resources, integration with related functions and identification of possible trade-offs and risks. A mutually agreed set of requirements that accurately reflects the intended performance and use of the product should be the aim at this stage in the project. Supplier/customer information interchange should identify all the appropriate activities needed for inclusion into a maintainability program that ensure the customers' requirements will be met. The maintainability program is discussed in detail in Section 4.

Suppliers must understand customer needs to determine product functions, the conditions it has to perform within the expected performance duration and the in-service support policy. The input from customers may not always be in a form that allows direct interpretation in terms of technical design. Furthermore, inputs may come from multiple customers. Therefore, supplier engineers need to translate the input into the desired technical parameters to be able to achieve the required product functionality. Thus, the activities defining this JA1010 Program Requirement include:

a. Establish Supplier-Customer Dialogue

b. Identify Conditions of Use

c. Define Maintenance and Service

d. Establish Metrics

e. Develop Product Specification

f. Operating Environment

1.2.3.2 The Supplier Shall Meet Customer Requirements

Once customer requirements are known, the supplier must determine how to produce a satisfactory product. The resources available to build the product must be considered, including personnel, materials, tools, manufacturing and assembly processes, equipment, facilities, software, organizational processes, technology, in-service support, money, and time. These resources must be characterized for their capabilities and limitations. With the knowledge of the product requirements, conditions of use, and resource capabilities and limitations, it must be determined whether the product will fulfill its requirements. This activity is an essential step that provides a risk assessment and determines the focus areas for managing it. Having identified risks, the supplier then must design the product (and process) by mitigating these risks through design and process innovation, exploratory development, decision making on serviceability and support issues, as well as determination of manufacturing and assembly process control issues. Thus, the activities defining this JA1010 program requirement include:

a. Characterize Resources

b. Assess and Manage Risk

c. Design to Achieve Maintainability

1.2.3.3 The Supplier Shall Assure That Customer Requirements Have Been Met

The supplier needs to demonstrate to the customer's satisfaction that the product meets requirements, thus qualifying the product design. Effort should be expended from the system concept through the hardware development phase to: (1) determine the accuracy of and update the analytical (predicted) data obtained from maintainability engineering analysis; (2) identify maintainability design deficiencies for resolution; and (3) gain progressive assurance that the maintainability of the product can be achieved and demonstrated. Complete documentation must be maintained to show customers that the product can indeed satisfy their needs. The generation of information from the Maintainability Program can be accumulated in the Maintainability Case (MC) described in Section 5, which will provide the customer with progressive assurance that the product will meet the customer requirements.

The supplier should also develop a closed-loop feedback system that channels information about the product during the development process, as well as after it has been sold to various groups within the supplier's organization. Thus, the activities defining this JA1010 Program Requirement include:

a. Qualify the Product and Process

b. Establish Process Control

c. Pursue Continuous Process Improvement

d. Establish Data Collection and Reporting

1.2.4 Managerial Issues in Maintainable Product Development

Table 1 depicts the framework for the development of a maintainable product. In order for companies to succeed in applying the framework, certain managerial and organizational issues should be addressed. The most significant among these are, the nature of the supplier-customer dialogue, which is essential for a successful program. The creation of self managed, cross-functional product development teams, and the management of supply chains should also be considered.

1.2.4.1 Supplier-Customer Dialogue

The key to successful maintainability programs (product development in general) is the quality of the supplier-customer dialogue. To be successful, an ideal supplier-customer dialogue should be initiated by the supplier as early as possible in the product development cycle and continue throughout the entire product life cycle. The output from the dialogue will vary in complexity based on product and organizational requirements. As applicable, typical outputs would include the following:

a. Details of the supplier-customer dialogue itself (roles, responsibilities, participants, authorization, frequency, duration and modes of communication).

b. Documentation of requirements.

c. Contractual issues (program costs, repair costs, support costs, metrics, liability, warranty, delivery, approved sources, applicable standards).

d. Full and adequate definition of all product requirements (conditions of use, operating environment, maintenance and service, in-service support, product specification, and the customer/supplier definition of product failure).

e. Conflict Resolution

f. Trade-off Procedure

The details and complexity of the dialogue and requirements will of course vary. The supplier-customer dialogue is the first step in developing the maintainability program. However, it continues throughout the length of the product development and life cycle.

1.2.4.2 Product Development Teams

Up until the mid-1980s, a sequential product development model was standard practice throughout industry. Each step in the new product development process was handled by a single functional specialty. Such an approach became less and less viable in the emerging faster-paced high-tech arena. The new approach is to establish a product development team with representatives from all the relevant functions working together from the start. Some industries carry this concept even further by giving these cross-functional teams much higher responsibility and authority in making decisions. Such "highly trained group of employees, fully responsible for turning out a well defined segment of finished work" is called self-managed teams.

The product development team is entrusted to guide new products through development. By placing decision making in the hands of the team, companies better coordinate product developments, improve product quality and time to market. The combination of several disciplines into one group expands the overall skill set of the team. Not only do the group members actively take advantage of group dynamics and collective thinking, but the diversity of skills present makes it possible to view issues from different perspectives, evaluate them, and assign and follow up on tasks within the team. The long association builds camaraderie between team members, gives each person a better appreciation for the others' jobs, and helps members clearly see the value of their work to the project.

1.2.4.3 Supply Chain Partnering

Over the last decade, manufacturers have cut their production and component costs dramatically by overhauling their supplier bases. Suppliers now take responsibility for just-in-time (JIT) delivery of parts, part quality, reliability and maintainability, reduction of inventory costs, mitigation of defects, and efficiency improvement of their manufacturing and assembly lines. However, many companies are now taking "supplier partnering" and "supplier alliances" into an even more advanced form of supply chain management called "supplier integration." These companies focus on aligning with all the critical suppliers in their supply chain to achieve higher quality, reliability and maintainability, faster new product development, improved use of technology, reduced time to market, minimized investment in resources, and reduction in product development costs.

Suppliers increasingly indicate that they prefer involvement early in the development process. Suppliers get involved in product design, support quality initiatives, increase profitability, provide schedule sharing opportunities, respond to cost reduction ideas, maintain consistent communications and feedback, have a well organized crisis management/response system, and are, in general, totally committed to the partnership.

1.2.5 Objectives of a Maintainability Engineering Program

The objectives of a Maintainability Program are accomplished by implementing the six steps outlined in the following paragraphs. Each objective should be analyzed and tailored to the level applicable for the product or system being developed for a customer. The supplier shall implement and conduct a Maintainability Program reflecting the agreed upon tailoring of the objectives.

1.2.5.1 Integrate Maintainability with the Systems Engineering Process

Systems engineering is a top down iterative process involving definition of requirements, flow down of requirements, functional analysis, allocation, design, test and evaluation. By integrating the maintainability activities into the design of both the product and the manufacturing processes for creating the product, maintainability requirements will be addressed concurrently with other requirements. The up-front integration of maintainability issues/activities/requirements with engineering and manufacturing design activities will help to reduce program costs and schedules by minimizing duplicate efforts and re-designs. An integrated systems approach is essential because maintainability is a major product characteristic.

1.2.5.2 Product Life-Cycle Cost

The in-service/field support cost factors can far outweigh the development and acquisition costs with most military and many commercial products. Maintainability and other design and logistics disciplines are now well developed for ensuring that supportability and operating cost factors are identified and considered from concept and throughout the life cycle of the equipment, so that they influence the design with the aim of optimizing the life cycle costs. Proper Maintainability influence on product designs includes support considerations which influence the equipment concept and design, identifies the necessary support needed to field the equipment and provides an integrated process for delivering supportable equipment and support infrastructure.

1.2.5.3 Thoroughly Understand the Design

Thoroughly understanding the design is essential to making the final product maintainable. Accessibility, human factors, diagnostic capability, and repair times must be known or determined with as much certainty as time, budget, and technical knowledge allow. Understanding the maintenance required to support the product during use will aid in identifying the potential shortcomings in design relative to maintainability, supportability and logistics. These shortcomings should be addressed during the initial design phase to ensure all aspects of the product life cycle will be successfully handled, including the spares (replacement parts), special tools (if any are required), maintenance technician training and product disposal.

1.2.5.4 Design for Desired Level of Maintainability

A maintainable product is the result of a conscious and dedicated effort to incorporate design features that make preventive and corrective maintenance easy, safe, and economical in terms of time and resources. It is the responsibility of the product development team to design the product so that it can be maintained within the constraints of time and resources.

One aspect of maintainability is pro-active failure detection, which allows identification of a deteriorating product performance prior to an actual malfunction. The hardware, software, or other means, used to detect that a malfunction is about to occur are collectively called *prognostics*. This leads to a reduction in malfunctions occurring at indeterminate times. The replacement of items can be scheduled, with all the necessary resources, to a time and place convenient to both the user and maintainer, thus reducing down time. The pre-emptive nature of the actions effectively moves corrective maintenance to preventive maintenance, thereby minimizing secondary consequences.

Another aspect is determining when a product has malfunctioned and why. The hardware, software, or other documented means used to determine that a malfunction has occurred and to isolate the cause of the malfunction are collectively called *diagnostics*. As products become more complex, diagnostics capability becomes an essential and critical part of design. For such products, diagnostics is a driver of maintainability because identifying and isolating a problem to its root cause often accounts for the majority of repair time. The most effective diagnostic capability encompasses built-in test (BIT), which includes any automatic and/or semi-automatic testing. Also included in this capability are manual testing, maintenance aids, and technical information. The necessary level of training and experience of personnel should be identified at the earliest phase of the program along with maintenance aids.

1.2.5.5 Validate Maintainability

Throughout the design process, continual assessment of maintainability should take place through qualitative and quantitative analysis. Computer simulation of maintenance can be a useful tool, which allows the maintainability characteristics of a design to be “evaluated” before any model, or prototype is even constructed. Maintainability and testability demonstrations can be conducted to show whether or not a product possesses the requisite characteristics. The specific approach used for demonstrations should be agreed upon between the customer and supplier and be identified in the program plan.

1.2.5.6 Monitor Maintainability

It is important for the customer, the supplier, or both to monitor the maintainability of the product in actual use. This monitoring may be done through tracking warranty data, field experience, collecting specialized information, customer complaints, and surveys. Monitoring and subsequent analysis of the data is done to identify maintainability issues/problems, identify needed changes in policies, procedures, processes or design and to identify and document lessons learned.

2. REFERENCES

The following applicable publication forms a part of this guide to the extent specified herein and is the primary reference for this guide.

2.1 SAE Publication

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE JA1010 Maintainability Program Standard

2.2 Related Publications

The following publications are provided as additional sources of information related to the topics in this guide and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE AIR5121 Software Supportability

SAE ARP5580 Recommended Failure Modes and Effects Analysis (FMEA) Practices for Non-Automobile Applications

SAE JA1000 Reliability Program Standard

SAE JA1000-1 Reliability Program Standard Implementation Guide

SAE JA1002 Software Reliability Program Standard

SAE JA1003 Software Reliability Program Implementation Guide

SAE JA1004 Software Supportability Program Standard

SAE JA1005 Software Supportability Implementation Guide

SAE JA1006 Software Support Concept

SAE JA1011 Evaluation Criteria for Reliability Centered Maintenance (RCM) Processes

SAE JA1012 Guide to Reliability Centered Maintenance Standards

2.2.2 Military Publications

Available from U.S. Government, DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094 and ASSIST website at http://assist.daps.dla.mil/online/start/.

MIL-HDBK-470A Designing and Developing Maintainable Products and Systems

MIL-HDBK-502 Acquisition Logistics

MIL-HDBK-759 Human Engineering Design for Military Materiel

MIL-STD-1472F Human Engineering Design Criteria for Military Systems, Equipment and Facilities

MIL-STD-1629 Procedures for Performing Failure Mode, Effects and Criticality Analysis (Cancelled, reference only)

MIL-HDBK-2155 Failure Reporting, Analysis and Corrective Action System

MIL-HDBK-2165 Testability Program for System and Equipment

MIL-PRF-49506 Logistics Management Information Performance Specification

2.2.3 Ministry of Defence Publications

Available from British Ministry of Defence, UK Defence Standardization, Room 1138, Kentigern House, 65 Brown Street, Glasgow G2 8EX, http://www.dstan.mod.uk.

Defence Standard 00-25 Human Factors for Designers of Equipment

Defence Standard 00-40 (Part 1) Reliability and Maintainability

Defence Standard 00-42 (Part 3) Reliability and Maintainability (R&M) Assurance Guide—R&M Case

Defence Standard 00-45 (Part 1) Requirements for Application of Reliability Centred Maintenance

Defence Standard 00-60 Integrated Logistics Support

2.2.4 Other Publications

ATA MSG-3—Operator/Manufacturer Scheduled Maintenance Development, Air Transport Association of America, 1301 Pennsylvania Avenue NW, Suite 1100, Washington, DC 20004-1707.

Maintainability Toolkit, System Reliability Center, 201 Mill Street, Rome, NY 13440, Website: http://src.alionscience.com.

RTCA/DO 178—Software Considerations in Airborne Systems and Equipment Certification, RTCA, Inc, 1828 L Street NW, Suite 805, Washington, DC 20036, E-mail: info@rtca.org.

3. GLOSSARY OF TERMS AND DEFINTIONS

A glossary has been included to enhance the understanding of this document. Appendix D contains various terms and definitions associated with maintainability and the product life cycle. Many additional maintainability terms and definitions can be found in the related publications listed in 2.2.

4. THE MAINTAINABILITY PROGRAM

4.1 Maintainability Program Development

No single set of specific tasks and activities defines the “best” maintainability program. Specific tasks and activities should be selected based on the type of product, the technology being used, product development budget and schedule constraints, customer needs, and so forth. Certain elements are necessary for a sound maintainability program and provide guidance to the process of selecting specific tasks and activities. These elements include program requirements, development cycle phases and program activities.

A maintainability program should be documented in a Maintainability Program Plan. Such a plan should address the management approach, required resources, interface with related disciplines, the activities constituting the program and a schedule showing when activities should occur. No single model or standard plan is cited in this guide because the plan should reflect the unique requirements of the program, the technology being used in the product, the amount of new development versus commercial off-the-shelf (COTS) or a non-developmental item and other factors. The elements described in the following sections, however, should be addressed in all maintainability plans.

A sound maintainability program begins with the proper integration of maintainability with all elements of a program. It is management that assigns and allocates resources, directs and controls processes, ensures the interaction of the functions and evaluates progress. A maintainable product begins with a deliberate decision by management to make the product maintainable to the level desired by the customer. Maintainability considerations/requirements are integral to the design process. As such, it must be considered in the same way as loads, temperature, weight, etc., that is, a design requirement leading to certain design approaches and features. To achieve a maintainable design, certain engineering techniques like simulations, tests and analyses should be conducted. Some of these analyses may be unique to maintainability while others are also performed for other purposes. Finally, data are needed to support maintainability design and analysis, and data from the maintainability effort are needed in other functional areas, especially logistics planning.

This section provides guidance for developing and implementing a maintainability program. The content of the implementation guide is not to prescribe any specific maintainability methods, but rather to provide guidance to assist in structuring a maintainability program. A maintainability program includes activities and methods selected to assure achievement of a maintainable product in a cost-effective manner. A properly planned and executed maintainability program benefits both the customer and the supplier as illustrated in Table 2.

TABLE 2 - BENEFITS OF A PROPERLY PLANNED MAINTAINABILITY PROGRAM

Customer Benefits	Supplier Benefits
—Reduce customer cost of ownership —Improve the availability of the product —Receive a maintainable product —Reduce logistics burdens	—Increase the probability of meeting maintainability targets —Reduce supplier risk —Quantify risk in achieving program requirements —Help allocate resources to the most value-added activities —Enhances capabilities in future programs

4.1.1 Maintainability Program Requirements

The three requirements identified in the Maintainability Program Standard (SAE JA1010, Section 4, Program Requirements) need to be met in developing a maintainability program. The three requirements are:

Ascertain Customer Requirements (referred to herein as M1)
Meet Customer Requirements (referred to herein as M2)
Assure That Customer Requirements Have Been Met (referred to herein as M3)

The term “customer” may refer either to the end user, an intermediate contracting agency such as in the case of a DoD program office, or a primary supplier obtaining products from a secondary supplier (e.g., major product developer obtaining parts from a third party supplier). In a similar vein, a supplier may be the customer for sub-tier suppliers.

Considering these different perspectives, the guide was written for a broad audience. It treats the activities within each phase at a conceptual level of abstraction and identifies typical methods used by industry to satisfy each of the three generic requirements.

When viewing the three requirements, the user needs to take a holistic perspective by considering both the product and process for a particular product development program. For example:

M1—Ascertaining requirements includes identifying customer requirements for the product and the program

M2—Meeting customer requirements means building the product to meet customer requirements, and executing the required program to meet program requirements.

M3—Assurance means conducting verification activities on the product as well as monitoring and controlling the program. The Maintainability Case (MC) is a recommended method for drawing all the assurance evidence together into a logical compilation and audit trail to show the progress towards compliance with the customer requirements.

Central to all activities throughout the maintainability program is the supplier-customer dialog. This dialog is essential to fully understand required product characteristics and application and should continue throughout the program to ensure that the supplier knows all customer requirements and changes.

4.1.2 Generic Development Cycle Phases

All products progress through a number of development life cycle phases, the definition of which may vary between organizations. While it is recognized that industry employs a variety of different defined development phases, this Guide will use three broad generic development phases to illustrate program implementation. These phases provide a basis for the topics discussed in this implementation guide and should be modified by each user of the guide to suit their specific practices and particular product development strategies. There may be more or fewer than three phases, and the nomenclature may be different than that shown here.

There are three generic development phases used in this Implementation Guide. To assist the reader of this implementation guide in understanding the boundary lines for these phases, a number of actions have been identified for each phase. The three development phases used are:

a. The Concept Phase which typically involves such actions as determining customer, needs, understanding the product's intended operating environment, studying product feasibility, and considering alternate design solutions to meet customer needs.

b. The Design and Development Phase which typically involves such actions as developing a detailed approach and solution for producing a product, and then designing the solution using the detailed approach.

c. The Production & Use Phase which typically involves producing, testing, deploying, and supporting operational units.

4.1.3 Maintainability Program Activities

A maintainability program activity is a defined action that uses one or more methods to satisfy a maintainability program requirement. The three requirements of SAE JA1010 (Section 4, Program Requirements), i.e., M1, M2, and M3 each have their own set of maintainability program activities. Table 3 illustrates the three requirements of SAE JA1010 along with the activities associated with each. The paragraph numbers from SAE JA1010 are provided for cross reference purposes. Table 4 provides a mapping of activities to M1, M2 and M3 and cross referenced to the three generic product development cycle phases defined in paragraph 4.1.2. It should be noted that not all activities of SAE JA1010 may be applicable to every program. Activity selection should be part of the customer/supplier dialogue.

4.1.4 Applicable Methods (Methods Applicable to M1, M2, and M3)

Section 6 of this guide provides short descriptions for a number of maintainability methods. Methods are used to accomplish design, test and support activities. Tables 5A, 5B, and 5C list the methods in relation to their applicability to the requirements and activities of SAE JA1010 for the concept, design and development, and production phases, respectively. The selection of methods is a highly individualized process. This document does not attempt to prescribe any given methodology for selection of methods, or set of methods. There is no right answer that will apply across the board to every organization or every product development. Suppliers and customers need to determine which methods are most applicable to their specific product developments. No priority of importance should be inferred by their relative listing in the tables.

TABLE 3 - SAE JA1010 MAINTAINABILITY PROGRAM
STANDARD REQUIREMENTS AND ASSOCIATED ACTIVITIES

(The following referenced paragraph numbers and titles are from JA1010)

	Requirements	Activities
M1	4.1 The Supplier Shall Ascertain Customer Requirements	4.1.1 Establish Supplier-Customer Dialogue 4.1.2 Identify Conditions of Use 4.1.3 Define Maintenance and Service 4.1.4 Establish Metrics 4.1.5 Develop Product Specification 4.1.6 Operating Environment
M2	4.2 The Supplier Shall Meet Customer Requirements	4.2.1 Characterize Resources 4.2.2 Assess and Manage Risk 4.2.3 Design to Achieve Maintainability
M3	4.3 The Supplier Shall Assure That Customer Requirements Have Been Met	4.3.1 Qualify the Product and Process 4.3.2 Establish Process Control 4.3.3 Pursue Continuous Process Improvement 4.3.4 Establish Data Collection and Reporting

TABLE 4 - MAINTAINABILITY PROGRAM ACTIVITIES MAPPED TO REQUIREMENTS AND PHASES

(The following referenced paragraph numbers and titles are from JA1010)

	Concept Phase	Design & Development Phase	Production & Use Phase
M1	4.1.1 Establish Supplier-Customer Dialogue 4.1.2 Identify Conditions of Use 4.1.3 Define Maintenance and Service 4.1.4 Establish Metrics 4.1.5 Develop Product Specification 4.1.6 Operating Environment	4.1.1 Establish Supplier-Customer Dialogue* 4.1.2 Identify Conditions of Use* 4.1.3 Define Maintenance and Service* 4.1.4 Establish Metrics* 4.1.5 Develop Product Specification*	4.1.1 Establish Supplier-Customer Dialogue* 4.1.4 Establish Metrics*
M2	4.2.1 Characterize Resources 4.2.2 Assess and Manage Risk	4.2.1 Characterize Resources* 4.2.2 Assess and Manage Risk* 4.2.3 Design to Achieve Maintainability	4.2.2 Assess and Manage Risk* 4.2.3 Design to Achieve Maintainability*
M3	4.3.4 Establish Data Collection and Reporting	4.3.1 Qualify the Product and Process 4.3.2 Establish Process Control 4.3.3 Pursue Continuous Process Improvement 4.3.4 Establish Data Collection and Reporting*	4.3.1 Qualify the Product and Process* 4.3.2 Establish Process Control* 4.3.3 Pursue Continuous Process Improvement* 4.3.4 Establish Data Collection and Reporting*

*Activity also appears in previous phase

TABLE 5A - MAPPING OF MAINTAINABILITY METHODS TO SAE JA1010 REQUIREMENTS AND ACTIVITIES-CONCEPT PHASE

Requirement	Activities and Methods: Concept Phase					
M1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue C.1-Benchmarking C.11-Lessons Learned Data Base C.20-Program Plan C.30-Supplier Monitoring C.33-Trade Studies	Activity 4.1.2: Identify Conditions of Use C.1-Benchmarking C.6-Environmental Characterization C.11-Lessons Learned Data Base C.17-Goals and Requirements C.20-Program Plan C.27-Repair Strategies C.34-Testability/ Diagnostics C.36-Hardware/ Software Maintainability Integration	Activity 4.1.3: Define Maintenance and Service C.6-Environmental Characterization C.9-Human Factors Analysis C.17-Goals and Requirements C.21-Maintenance Cost Analysis C.27-Repair Strategies C.34-Testability/ Diagnostics C.36-Hardware/ Software Maintainability Integration	Activity 4.1.4: Establish Metrics C.1-Benchmarking C.11-Lessons Learned Data Base C.17-Goals and Requirements C.21-Maintenance Cost Analysis C.27-Repair Strategies	Activity 4.1.5: Develop Product Specification C.6-Environmental Characterization C.13-Allocations C.17-Goals and Requirements C.33-Trade Studies	Activity 4.1.6: Operating Environment C.6-Environmental Characterization C.11-Lessons Learned Data Base C.17-Goals and Requirements C.27-Repair Strategies
M2 The Supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources C.12-Logistics Support Analysis C.20- Program Plan C.22-Physical and Digital Mock-ups C.32-System Integration	Activity 4.2.2: Assess and Manage Risk C.3-Design for Manufacturing and Assembly C.13-Allocation C.16-Design Evaluation Analysis C.18-Modelling C.19-Predictions C.25-Quality Function Deployment C.33-Trade Studies C.37-Maintenance Task Analysis	Activity 4.2.3: Design to Achieve Maintainability C.3-Design for Manufacturing and Assembly C.4-Design Reviews C.5-Design Tools C.9-Human Factors Analysis C.16-Design Evaluation Analysis C.18-Modelling C.19-Predictions C.31-Support Equipment Analysis C.34-Testability/ Diagnostics			
M3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process C.16-Design Evaluation Analysis C.18-Modelling C.19-Predictions C 36-Hardware/ Software Maintainability Integration	Activity 4.3.2: Establish Process Controls C.4-Design Reviews C.5-Design Tools C.14-Assessment C.16-Design Evaluation Analysis C.37-Maintenance Task Analysis	Activity 4.3.3: Pursue Continuous Process Improvement C.4-Design Reviews C.5-Design Tools C.14-Assessment C.33-Trade Studies C.37-Maintennce Task Analysis	Activity 4.3.4: Establish Data Collection and Reporting C.2-Data Collection/Analysis		

TABLE 5B - MAPPING OF MAINTAINABILITY METHODS TO SAE JA1010 REQUIREMENTS AND ACTIVITIES-DESIGN AND DEVELOPMENT PHASE

Requirement	Activities and Methods: Design and Development Phase					
M1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue C.1-Benchmarking C.20-Program Plan C.30-Supplier Monitoring	Activity 4.1.2: Identify Conditions of Use C.1-Benchmarking C.6-Environmental Characterization C.11-Lesson Learned Data Base C.27-Repair Strategies C.31-Support Equipment Analysis	Activity 4.1.3: Define Maintenance and Service C.6-Environmental Characterization C.7-Error and Mistake Proofing C.9-Human Factors Analysis C.12-Logistics Support Analysis C.21-Maintenance Cost Analysis C.22-Physical and Digital Mock-ups C.23-Obsolescence Plans C.24-Parts Management C.26-Reliability Centered Maintenance C.27-Repair Strategies C.37-Maintenance Task Analysis	Activity 4.1.4: Establish Metrics C.1-Benchmarking C.11-Lesson Learned Data Base C.13-Maint. Allocations C.17-Goals and Requirements C.18-Modeling C.19-Predictions C.27-Repair Strategies	Activity 4.1.5: Develop Product Specification C.6-Environmental Characterization C.11-Lessons Learned Data Base C.13-Allocations C.17-Goals and Requirements C.18-Modeling C.33-Trade Studies	Activity 4.1.6 Operating Environment C.1-Benchmarking C.6-Environmental Characterization C.11-Lesson Learned Data Base C.17-Goals and Requirements C.26-Reliability Centered Maintenance C.27-Repair Strategies
M2 The Supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources C.4-Design Reviews C.11-Lessons Learned Data Base C.12-Logistics Support Analysis C.16-Design Evaluation Analysis C.20-Program Plan C.31-Support Equipment Analysis C.32-System Integration C.33-Trade Studies C 36-Hardware/ Software Maintainability Integration	Activity 4.2.2: Assess and Manage Risk C.4-Design Reviews C.5-Design Tools C.7-Error and Mistake Proofing C.8-Failure Modes and Effects Analysis C.9- Human Factors Analysis C.15-Demonstration C.16-Design Evaluation Analysis C.18-Modeling C.19-Predictions C.22-Physical and Digital Mock-ups C.23-Obsolescence Plan C.28-Maintenance Safety Analysis C.33-Trade Studies C.37-Maintenance Task Analysis	Activity 4.2.3: Design to Achieve Maintainability C.3-Design for Manufacturing and Assembly C.4-Design Reviews C.5-Design Tools C.7-Error and Mistake Proofing C.8-Failure Modes and Effects Analysis C.9-Human Factors Analysis C.10-Interchangeability C.16-Design Evaluation Analysis C.19-Predictions C.22-Physical and Digital Mock-ups C.28-Maintenance Safety Analysis C.29-Software Maintainability C.31-Support Equipment Analysis C.34-Testability/ Diagnostics C.36-Hardware/ Software Maintainability Integration C.37-Maintenance Task Analysis			
M3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process C.14-Assessment C.15-Demonstration C.16-Design Evaluation Analysis C.19-Predictions	Activity 4.3.2: Establish Process Controls C.4-Design Reviews C.5-Design Tools C.14-Assessment C.15-Demonstration C.16-Design Evaluation Analysis	Activity 4.3.3: Pursue Continuous Process Improvement C.4-Design Reviews C.11-Lessons Learned Data Base C.14-Assessment C.26-Reliability Centered Maintenance C.33-Trade Studies C.37-Maintenance Task Analysis	Activity 4.3.4: Establish Data Collection and Reporting C.2-Data Collection/Analysis C.12-Logistics Support Analysis C.26-Reliability Centered Maintenance		

TABLE 5C - MAPPING OF MAINTAINABILITY METHODS TO SAE JA1010 REQUIREMENTS AND ACTIVITIES-PRODUCTION AND USE PHASE

Requirement	Activities and Methods: Production and Use Phase					
M1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue C.1-Benchmarking C.30-Supplier Monitoring	Activity 4.1.2: Identify Conditions of Use C.1-Benchmarking C.11-Lessons Learned Data Base C.27-Repair Strategies C.31-Support Equipment Analysis C.37-Maintenance Task Analysis	Activity 4.1.3: Define Maintenance and Service C.7-Error and Mistake Proofing C.22-Physical and Digital Mock-ups C.26-Reliability Centered Maintenance C.27-Repair Strategies C.37-Maintenance Task Analysis	Activity 4.1.4: Establish Metrics C.1-Benchmarking C.11-Lessons Learned Data Base C.27-Repair Strategies C.37-Maintenance Task Analysis	Activity 4.1.5: Develop Product Specification C.11-Lessons Learned Data Base C.33-Trade Studies	Activity 4.1.6: Operating Environment C.1-Benchmarking C.2-Data Collection/ Analysis
M2 The Supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources C.12-Logistics Support Analysis C.31-Support Equipment Analysis C.32-System Integration C.33-Trade Studies C.35-Training	Activity 4.2.2: Assess and Manage Risk C.2-Data Collection/Analysis C.7-Error and Mistake Proofing C.9-Human Factor Analysis C.11-Lessons Learned Data Base C.12-Logistics Support Analysis C.14-Assessment C.15-Demonstation C.26-Reliability Centered Maintenance C.28-Maintenance Safety Analysis C.33-Trade Studies C.37-Maintenance Task Analysis	Activity 4.2.3: Design to Achieve Maintainability C.7-Error and Mistake Proofing C.9-Human Factors Analysis C.16-Design Evaluation Analysis C.22-Physical and Digital Mock-ups C.28-Maintenance Safety Analysis C.31-Support Equipment Analysis C.33-Trade Studies C.35-Training C.37-Maintenance Task Analysis			
M3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process C.2-Data Collection/ Analysis C.14-Assessment C.15-Demonstration C.19-Predictions C.31-Support Equipment Analysis	Activity 4.3.2: Establish Process Controls C.3–Design for Manufacturing and Assembly C.23-Obsolescence Plan C.24-Parts Management C.26-Reliability Centered Maintenance C.33-System Integration C.36-Hardware/ Software Maintainability Integration C.37-Maintenance Task Analysis	Activity 4.3.3: Pursue Continuous Process Improvement C.2-Data Collection/Analysis C.7-Error and Mistake Proofing C.12-Logistics Support Analysis C.26-Reliability Centered Maintenance C.27-Repair Strategies C.33-Trade Studies C.36-Hardware/ Software Maintainability Integration C.37-Maintenance Task Analysis	Activity 4.3.4: Establish Data Collection and Reporting C.2-Data Collection/ Analysis C.14-Assessment C.15-Demonstation C.26-Reliability Centered Maintenance		

4.1.5 Maintainability Method Selection Criteria

Selecting Maintainability methods for a given program is a highly individualized process. This point cannot be over emphasized and this document does not attempt to prescribe any given method or set of methods. There is no right answer that will apply across the board to every organization or every product development. Suppliers and customers need to determine which methods are most applicable to their specific product developments. Selecting methods should be based on product development strategies and individual needs and procedures for the user's operating environments.

However, selecting maintainability methods can be made easier by using Tables 5A, 5B and 5C as guidance for the program phase. These tables provide a correlation between the Maintainability Program Standard (JA1010) requirements, activities and the methods described in this document. Section 6 provides short descriptions of maintainability methods including their purpose, intended application, benefits, and limitations.

4.1.5.1 Concept Phase Methods

The suggested methods for the Concept Phase are outlined in Table 5A. The JA1010 requirements (M1, M2, and M3) and the related activities associated with the requirements are outlined in Table 5A. Selection of any Maintainability methods for the requirement and activity depends on the type of product, complexity and the intended operating and maintenance environments. The selection of methods should be coordinated with the customer and the product users as well with the product supplier. The suggested Maintainability methods represent typical activities related to the early phase of a program. The Concept Phase methods are basically associated with early planning, requirement definitions, minimizing cost of operations and design analysis. The degree of implementation for any method depends on the product operational criticality and the expected user cost burden in the operational environment. Trade off should be made in the method selection process to assure complete maintainability coverage during the product definition in the Concept Phase.

The goal for the selection of Maintainability methods and the implementation of the methods is to perform an effective design influencing effort at a minimum cost. The effectiveness of a Maintainability Program depends on the personnel and the team supporting the execution of the Concept Phase methods. The product and the operations of the product influence the degree and level that maintainability method are considered and implemented during this phase. Each method can be implemented on a scale of minimum to maximum cost for the supplier technical engineering effort during this phase. It is imperative that the Maintainability methods implemented during this phase produce effective requirements, a maintainable product concept and support resources identification.

4.1.5.2 Design and Development Phase Methods

Many of the methods initiated in the Concept Phase continue into the Design and Development Phase as shown in Table 5B. The level of effort or the type of activities may change due to the transition from a concept to an actual supplier design phase. As the design details and information becomes available, in depth analysis and predictions of the product characteristics can be observed and documented. Maintainability methods transitioning from the concept phase and new method implemented during this phase become supportive of design decisions and identifying the product requirements for support resources in the operating environment.

The Maintainability method selection process should be focused on the impact and influence the method can make or contribute to the design process. The complexity of the product, operational criticality and development cost should be used as a guide in selecting Maintainability methods. The degree of implementation and the supplier engineering level of effort to perform the method should be dependent on the product. The level of effort to perform each method should be based on the expected contribution to the design and the final product performance. Judgment in the method selection is generally based on engineering experience, customer needs, performance expectations and cost.

4.1.5.3 Production and Use Phase Methods

The Maintainability methods used in this phase are primarily verification, data collection and assessment of the product characteristics. Often many of these methods will have been initiated in earlier program phases and transition to activities associated with actual hardware and software through later phases. The recommended Maintainability methods for this phase are listed in Table 5C. All the methods are shown as continuing efforts from the Design and Development Phase. The degree of implementation is dependent on the complexity of the product, cost and customer expectations.

The selection process for the Maintainability methods should be directed at verifying requirements, establishing operational/maintenance history for the product and corrective action for the discrepancies identified in the Production and Use Phase. The selected methods should provide benefits or improvements to the product usability, provide user confidence in the product and provide operational and maintenance feedback to the supplier engineering and management teams. The methods should be tailored to the complexity of the product and the potential product improvements for performance enhancement.

4.1.5.4 Maintainability Methods Summary by Program Phase

Table 6 provides an overview of the recommended Maintainability methods and applications as they relate to the three program phases outlined in Table 5A, 5B and 5C. This summary is provided to show the application of the method by program phase. Some of the Maintainability methods are recommended for all program phases while others are recommended for selective program phases. Appendix C contains descriptions of the Maintainability methods with additional information on the purpose, application, key elements, benefits, limitations and references.

TABLE 6 - MAINTAINABILITY METHOD USAGE BY PHASE

Appendix C - Page Index/Method Title	Table 5A Concept	Table 5B Design and Development	Table 5C Production and Use
C.1 Benchmarking	#	#	#
C.2 Data Collection/Analysis	#	#	#
C.3 Design for Manufacturing and Assembly	#	#	
C.4 Design Reviews	#	#	
C.5 Design Tools	#	#	
C.6 Environmental Characterization	#	#	
C.7 Error and Mistake Proofing		#	#
C.8 Failure Modes and Effects Analysis		#	
C.9 Human Factors Analysis	#	#	#
C.10 Interchangeability		#	
C.11 Lessons Learned Data Base	#	#	#
C.12 Logistics Support Analysis	#	#	#
C.13 Maintainability Allocations	#	#	
C.14 Maintainability Assessment	#	#	#
C.15 Maintainability Demonstration		#	#
C.16 Maintainability Design Evaluation Analysis	#	#	#
C.17 Maintainability Goals and Requirements	#	#	
C.18 Maintainability Modeling	#	#	
C.19 Maintainability Predictions	#	#	
C.20 Maintainability Program Plan	#	#	
C.21 Maintenance Cost Analysis	#	#	
C.22 Digital and Physical Mock-ups	#	#	#
C.23 Obsolescence Plans		#	
C.24 Parts Management		#	
C.25 Quality Function Deployment	#		
C.26 Reliability Centered Maintenance		#	#
C.27 Repair Strategies	#	#	#
C.28 Maintenance Safety Analysis		#	#
C.29 Software Maintainability		#	
C.30 Supplier Monitoring	#	#	#
C.31 Support Equipment Analysis	#	#	#
C.32 System Maintainability Integration	#	#	#
C.33 Trade Studies	#	#	#
C.34 Testability/Diagnostics		#	
C.35 Training	#	#	
C.36 Hardware/Software Maintainability Integration	#	#	#
C.37 Maintenance Task Analysis	#	#	#

Denote a task that may apply to this phase.

4.2 Maintainability Program Integration and Implementation

Historically, product Maintainability efforts were sometimes integrated without sufficient planning and integration into the overall product development program. Consequently, the Maintainability program was disjointed from the rest of the program and was therefore less beneficial to the product. Ideally, Maintainability methods and activities should be carefully chosen and integrated into the overall program.

4.2.1 Maintainability Program Plan

The product maintainability development plan would ideally be a stand alone document for the maintainability program, or may be integrated in the broader overall program plan. The plan should document the following program details:

a. A description of how the maintainability program will be conducted to meet customer requirements.

b. Provide the maintainability methods and activities to be utilized.

c. A description of how each maintainability activity and method will be performed.

d. Identification of the relevant points of contact responsible for managing the maintainability program and those responsible for implementing each activity and method.

e. A description of critical activities.

f. A description of how maintainability elements will interface with other engineering disciplines and how maintainability tasks and activities are disseminated to designers and other associated personnel.

g. A schedule with estimated start and completion points for all activities and methods.

h. A description of known maintainability problems to be solved and an assessment on the impact of these problems on meeting customer requirements. Plans on how to solve these problems could also be included.

i. Statements of sources of maintainability guidance documentation.

    1. Identification of inputs required from other disciplines necessary to help implement maintainability activities and methods.

    2. Resource allocation information.

    3. Identification of maintainability analysis results to other disciplines.

j. Establish success criteria.

A formal plan may not always be required, but when required, the extent of the plan should be mutually agreed upon between the supplier and customer.

4.2.2 Maintainability Program Implementation

Implementation of each maintainability program will vary according to the particular product development strategy and unique program issues. Tables 4, 5A, 5B, and 5C show how all the methods described in this implementation guide may come together for the implementation of the maintainability program. Each organization may have their own phase terminology which could differ from that shown here.

4.3 Performance Based Maintainability Requirements

4.3.1 Quantitative Performance Based Requirements

Quantitative performance based maintainability requirements are analytical parameters that are capable of being expressed as a quantity and are susceptible to measurement. These requirements are typically determined using time based factors, the most common of which are; (1) the mean time or maintenance man-hours required to return a product to a serviceable condition; and (2) the frequency with which these repairs must be conducted over time. Typically, these performance requirements are based on average values (mean time to repair, for example), however, they can also be tailored to include other statistically significant maintainability characteristics (such as maximum time to repair), as the requirements of the program dictate. Table 7 provides a listing of the most common quantitative requirements used by customers and suppliers.

4.3.1.1 Corrective Maintenance versus Preventive Maintenance

When establishing quantitative performance based maintainability requirements, further consideration needs to be given to the types of maintenance which can be performed. There are two types; (1) corrective maintenance, which includes those maintenance actions required to restore a failed item to a specified condition after a failure has occurred; and (2) preventive maintenance, which includes those maintenance actions performed with the desire to retain an item in a specified condition by providing systematic (usually scheduled) inspection, detection, and prevention of incipient failures. Chargeable corrective maintenance times are related to activities associated with troubleshooting, disassembly, repair, replacement, reassembly, alignment, adjustment and checkout. Preventive maintenance actions include periodic inspections, calibration, condition monitoring, and/or replacement of critical items at designated time intervals. A single maintainability based performance requirement can be developed which includes both corrective and preventive maintenance (e.g., maintenance man-hour/operating hour), however, more detailed maintenance requirements can also be developed which specifically addresses one maintenance type or another.

4.3.1.2 Levels of Maintenance

Levels of maintenance relate to the division of functions and tasks for each area where maintenance is performed. They are determined based on the location and the capabilities (both in terms of manpower and equipment) of the activity at that site. Maintenance levels are typically broken down into the following categories: (1) on-system/on-equipment maintenance typically accomplished at the customer's operational site (*Organizational level maintenance*), which is best characterized as including tasks which are performed by the user organization on its own equipment by personnel usually involved with the operation and use of that equipment, having minimum time available for detailed and lengthy system maintenance; (2) off-line maintenance performed at a nearby location for those components removed from the operational site for maintenance (*Intermediate level maintenance*), using facilities typically including maintenance personnel which are usually more skilled and better equipped, allowing them to perform more detailed troubleshooting and repair tasks; or (3) maintenance conducted at a remotely located overhaul facility or the supplier's facility (*Supplier/manufacturer/depot level maintenance*), which typically contains complex and relatively bulky capital equipment, large quantities of spares, environmental control provisions, and has the capabilities of performing the most highly complex maintenance operations including the complete overhauling, rebuilding and calibration of equipment. Quantitative maintenance requirements are typically established separately for each level of maintenance since their mission, operating environment, and capabilities are distinctly independent of one another.

4.3.1.3 Examples of Quantitative Maintainability Performance Requirements

Examples of Quantitative Maintainability Performance Requirements are provided in Table 7.

TABLE 7 - QUANTITATIVE MAINTAINABILITY REQUIREMENTS EXAMPLES

Requirement	Description	Maintenance Type/Level of Maintenance
Mean Time to Repair (MTTR)	The average repair time for a system or component during a given evaluation period. $\text{MTTR} = \frac{\text{Total Elapsed Maintenance Times for All Maintenance Actions Considered}}{\text{Total Number of Repairs Completed During Evaluation Period}}$	**Type-** Typically associated with corrective maintenance performed as a result of chargeable failures experienced. **Level-** Can be determined for any level of maintenance.
Maximum Time to Repair (M_{Max})	The time below which a specified percentage of maintenance tasks must be completed to restore the system to an operation state.	**Type-** Typically associated with corrective maintenance performed as a result of chargeable failures experienced. **Level-** Can be associated with any level of maintenance.
Mean Time Between Maintenance Action (MTBMA)	$\text{MTBMA} = \frac{\text{Total Operating Hours Accumulated During Evaluation Period}}{\text{Total Number of Maintenance Actions Experienced}}$	**Type-** Typically associated with corrective maintenance performed as a result of chargeable failures experienced. **Level-** Associated with on-equipment maintenance conducted at the organizational level.
Mean Time Between Removal (MTBR)	$\text{MTBR} = \frac{\text{Total Number of Operating Hours Accumulated During Evaluation Period}}{\text{Total Number of Removals Experienced}}$	**Type-** Typically associated with corrective maintenance performed as a result of chargeable failures experienced. **Level-** Associated with on-equipment maintenance conducted at the organizational level
Maintenance Man-hours per Operating Hour (MMH/OH)	$\text{MMH/OH} = \frac{\text{Total Maintenance Man-Hours for All Maintenance Actions}}{\text{Total Operating Hours Accumulated During Evaluation Period}}$	**Type-** Can be determined for either corrective or preventive maintenance or a combination of both. **Level-** Associated with on-equipment maintenance conducted at the organizational level.
Maintenance Man-hours per Maintenance Action (MMH/MA)	$\text{MMH/MA} = \frac{\text{Total Maintenance Man-Hours for All Maintenance Actions}}{\text{Total Number of Maintenance Actions Completed During Evaluation Period}}$	**Type-** Can be determined for either corrective or preventive maintenance or a combination of both. **Level-** Associated with on-equipment maintenance conducted at the organizational level.
Maintenance Down Time (MDT)	A measure of the time a system is down for repair of critical hardware and software faults, including time associated with logistic delays.	**Type-** Can be determined for either corrective or preventive maintenance or a combination of both. **Level-** Associated with on-equipment maintenance conducted at the organizational level.

NOTES – Refer to the following documents for a complete discussion on quantitative values.

1. MIL-STD-470A, Designing and Development Maintainable Products and Systems, Para 4.4.1, Appendix B and Appendix D.
2. Maintainability Toolkit - Topic 2.3, Topic 6.3, Topic 6.4, Section 7, Appendix E and Appendix G.

4.3.2 Qualitative Performance Based Requirements

Qualitative performance based maintainability requirements are associated with physical design characteristics such as accessibility, commonality, error proofing and standardization and are imposed to ensure that certain specific maintainability enhancing features are included in the system design from its inception.

Areas of consideration for qualitative performance based maintainability requirements include:

—Component Placement and Accessibility
—Reliability in Terms of Making Less Reliable Components More Accessible
—Standardization and Interchangeability
—Error proofing
—Complexity with the Focus on Minimum Parts
—Human Factors Considerations (Lifting and Handling Requirements, Shipping Requirements)
—Damage Susceptibility
—Labeling
—Packaging (Modularity)
—Transportability
—Maximum Use of Common Tools

—Support Equipment Requirements
—Fault Localization and Isolation
—Testability
—Safety

In practice, one generalized approach for implementing qualitative maintenance requirements would be to establish a set of maintainability design guidelines based on system requirements, common design practices, and lessons learned from previous programs. These requirements can then be further translated into a series of checklists for distribution to system and equipment designers as aids to be followed in the day-to-day design process.

4.3.3 Implementation of Performance Based Maintainability Requirements

Performance based maintainability requirements are first used to allow the customer to establish expectations or needs in the beginning of a program as a series of design parameters pertaining to the inherent maintainability characteristics of the system in question. As the program progresses into the development and production stages, these initial requirements are then used as a basis for monitoring product and process characteristics in order to chart the progress of, and to facilitate control over, a product's development.

4.3.3.1 Establishment of Overall Operational Performance Based Maintainability Requirements

It is important that clearly defined, quantifiable operational design requirements are established at the beginning of a program in order to ensure that the product meets the customer needs from both maintainability and an overall program perspective. In the initial phases of the requirements selection process, careful attention must be placed on selecting maintainability performance based requirements which are realistic, not only in terms of being achievable through design, but which also take into consideration overall program cost, schedule, and performance. At the same time, consideration should be given to the maintenance concept, the field maintenance environment, human factors, and safety. Once a final set of maintainability requirements has been arrived at based on these considerations, they should be formally documented for distribution to the applicable engineering/contracting activities.

4.3.3.2 The Performance Monitoring and Control Process

The maintainability management plan is the standard tool used to outline the approach and processes by which maintainability performance is monitored and controlled through all phases of a product's life cycle, taking into account the previously established performance based maintainability requirements. One goal of the plan is to establish appropriate formal maintainability engineering involvement at the earliest stages possible in the program's progression from concept through full-scale development. Plans and schedules are established for maintainability engineering activities such as system design and analysis, demonstration and test, and data collection and monitoring. A second goal is to establish effective maintainability management control of the design and development process through the review and validation of timely and accurate feedback from these activities, and from a program management perspective, through the supervision of program tasks. In terms of schedule, maintainability decision points must be identified and established in the program plan supporting overall program milestones. Several key engineering activities associated with the maintainability performance monitoring and control process are outlined below.

4.3.3.2.1 System Design Development and Analysis

As the design of the product progresses, the maintainability characteristics must be analyzed to verify that the design approach is on track to meet maintainability needs and to identify critical areas which may require further design improvement. Maintainability allocations and predictions should be conducted as part of this process for comparison purposes to the originally established maintainability requirements. Design reviews should also be conducted to specifically assess the maintainability achieved in preliminary and final design iterations and to identify specific problem areas and paths for resolution.

4.3.3.2.2 Maintainability Verification, Demonstration, and Evaluation

Informal maintainability demonstrations can be conducted throughout the design development phase, when they are used to aid product development and identify potential problem areas with the physical design. A very useful technology for this is computer digital visualization, for which commercially available software already exist. After the design process has been completed, more formal demonstrations are conducted with higher fidelity hardware, which more closely resembles the final product in terms of form, fit, and weight. The focus of these later demonstrations then shifts to verifying conformance to a specified quantitative maintainability requirement as a condition for acceptance of that product by the customer.

4.3.3.2.3 Continuous Maintainability Monitoring

Finally, product maintainability should be monitored on a regular basis by analyzing the data generated by users of the product, preferably as part of an automated maintenance management reporting system. On a case-by-case basis, failure analyses and other problem reports can be used to identify specific maintainability problem areas as they arise. The overall goal of this effort would be to investigate the underlying cause of the reported problems and identify corrective actions for initiation as part of a closed loop process.

5. MAINTAINABILITY CASE (MC)

The description of the Maintainability Case described in this section follows the British Ministry of Defence Standard 00-42 (Part 3), Reliability and Maintainability Case. The authors of this section were key contributors to the Defence Standard 00-42 and tailored the following to represent the Maintainability Case requirements presented in the following paragraphs.

5.1 Introduction

As stated earlier, the maintainability program must be an integral part of the overall project program. This part of the Implementation Guide describes the principles of the MC and provides guidance on the content and its use for the life of the product. Figure 1 shows the relationship among the overall project program, reliability program, and the MC.

5.2 Definition

The Maintainability Case is a reasoned, auditable and documented argument created to support the contention that a defined product satisfies the maintainability requirements. It provides an audit trail of the engineering considerations from requirements through to evidence of compliance and is intended to be used throughout the program chain from prime supplier down to individual sub-suppliers. It forms an integral part of all the engineering activities that take place during the program, and provides traceability as to why certain activities were undertaken and how they were be judged to be successful. In essence it represents a framework comprising the proposed maintainability program plan and activities, the ‘success criteria’ for each activity, and the evidence that supports that the ‘success criteria’ was met. The MC should be continually updated as the program progresses.

5.3 Success Criterion

A success criterion is a clear and unambiguous statement for each stage of the program, which will enable management to determine whether or not the result of each activity (the evidence) has attained the expected performance. For example a success criterion may be the achievement of a prescribed Mean Time to Repair (MTTR) for a specific part of the complete system. The achievement of these criteria will give both customer and supplier confidence that the program is proceeding according to expectations. If the results indicate that the product maintainability performance is not at the expected level for the specific stage of the program or that the evidence does not satisfy its ‘success criteria’, then the product development program should be reviewed. This may include measures such as a re-design or a change to the original requirements.

5.4 Status Report

At predetermined intervals during the maintainability program the MC will typically be summarized in a MC Status Report which includes a summary of the evidence developed by the maintainability activities. This status report is reviewed to assure that the maintainability program is meeting the agreed-upon requirements. The MC and the MC Status reports also assure that the dialogue between customer and supplier is developed and maintained. The frequency of the MC Status report needs to be agreed upon before the program starts and should be sufficient to keep the customer informed of progress without being too frequent as to be an unnecessary burden.

5.5 Application

MC is most beneficial in complex or long time-frame programs characterized by lengthy intervals between milestones, and multiple locations and contractors. However, it can benefit programs of virtually any length or complexity. The level of tiers of the MC and number of suppliers can be tailored and should be mutually agreed upon by the customer and prime supplier.

5.6 Maintainability Case Process

Figure 1 shows the maintainability program as an integral part of the general project process. It is a representation of how the maintainability program links to the project process and builds the evidence framework for the maintainability case. Analysis of the maintainability requirements provides the targets for the proposed design and identifies maintainability risks. The activities within the maintainability program should both mitigate the risks and provide evidence that the requirements have been met. This evidence in turn feeds into the MC to provide progressive assurance that milestones and requirements are being met.

5.6.1 Content

The MC should include as appropriate:

a. The maintainability requirements and supporting rationale.

b. A description of the strategy for achieving the maintainability requirements in design and production and an assessment of its feasibility, strengths, and limitations.

c. The feasibility of collecting relevant, meaningful, and sufficient data for maintainability evaluation.

d. The feasibility of testing the product in accordance with its identified operational profiles, given the uncertainties of product deployment.

e. The resources needed for testing and data collection.

f. Testing results.

g. Performance in previous usage.

h. Simulation results.

i. Results of analyses including relevant calculations.

j. Expert assessment of product Maintainability based on a. through i. and engineering judgment.

Appendix A contains a more detailed description of the content of the MC Status Report.

5.6.2 Assumptions

Figure 2 illustrates that the reasoned arguments in the MC can combine different types of evidence within the bounds of the assumptions. It is important that these assumptions should be declared openly. During the Maintainability Program, the key assumptions should be validated where possible. The reasoned arguments enable claims to be made about the expected maintainability performance, and these claims, together with their backing evidence, make up the MC. General guidance in the presentation of evidence in the MC and the assessment of that evidence is included in Appendix A.

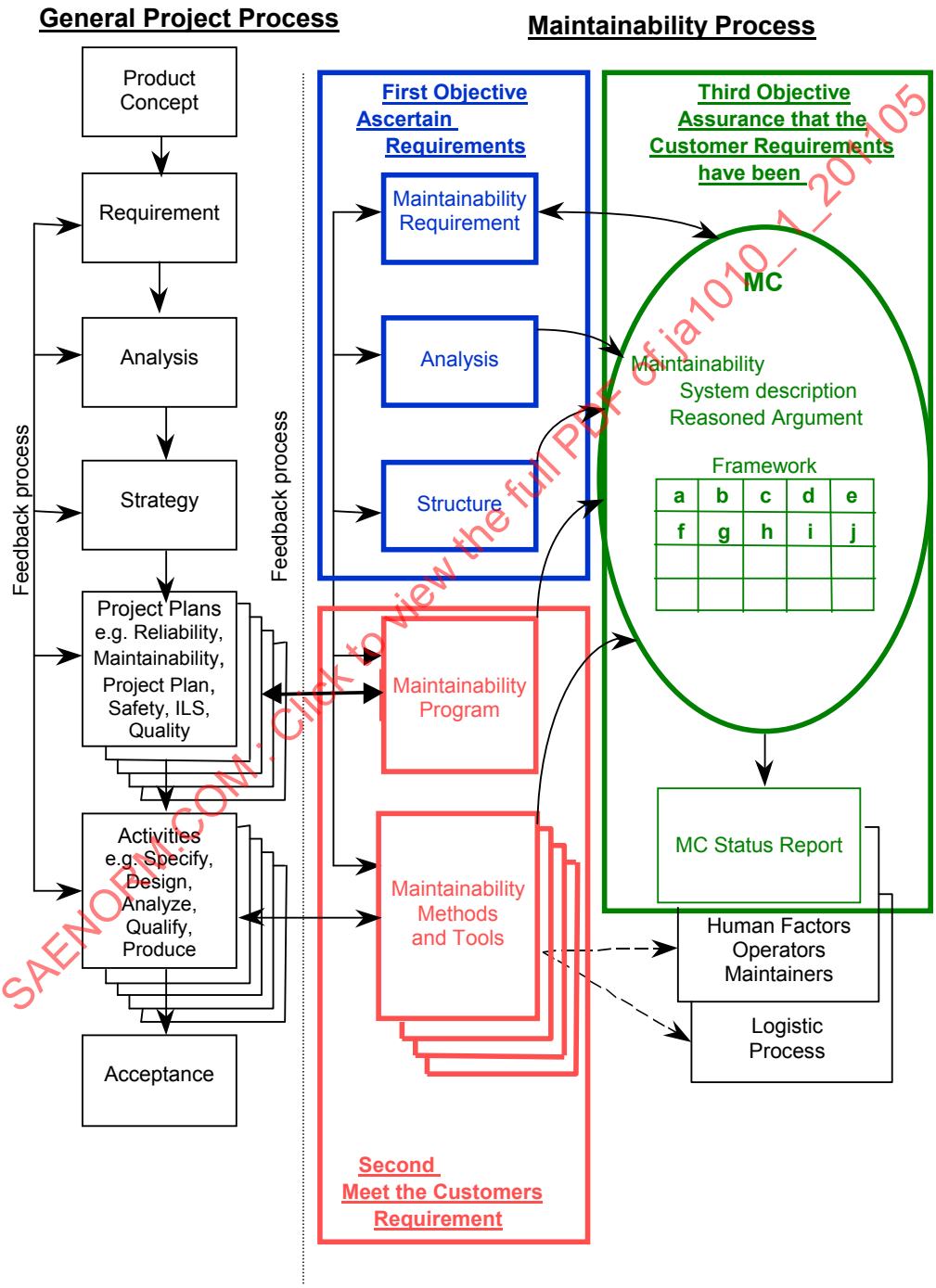

FIGURE 1 - RELATIONSHIP BETWEEN THE MAINTAINABILITY PROCESS, THE OVERALL PROJECT PROGRAM AND EVIDENCE PRODUCED

5.6.3 Program Maturity

A particular development stage within a product life cycle phase may be undertaken by more than one supplier, each having a different starting point and associated risks. For example, one supplier may propose a new concept, whereas another may propose a solution based on an existing product. The new concept may require more analytical and development test activities, whereas the maintainability evidence for the existing product would be based largely on data from past performance. Therefore, the proposed activities in the maintainability program and type of evidence presented by the supplier in the MC will vary depending on the nature and maturity of the material being designed, developed or produced, and the usage and environment when in service.

5.6.4 Combined Status Report

Figure 1 shows the relationship between the maintainability program and the overall project program. It also shows the MC Status Report as a potential input to the operator/maintainer information and the logistics support process. Appendix B describes the expected content of the MC Status Report. The MC Status report may be combined with other assurance validation evidence (Logistics, Maintainability, etc.) into a single Status Report at the discretion of the customer.

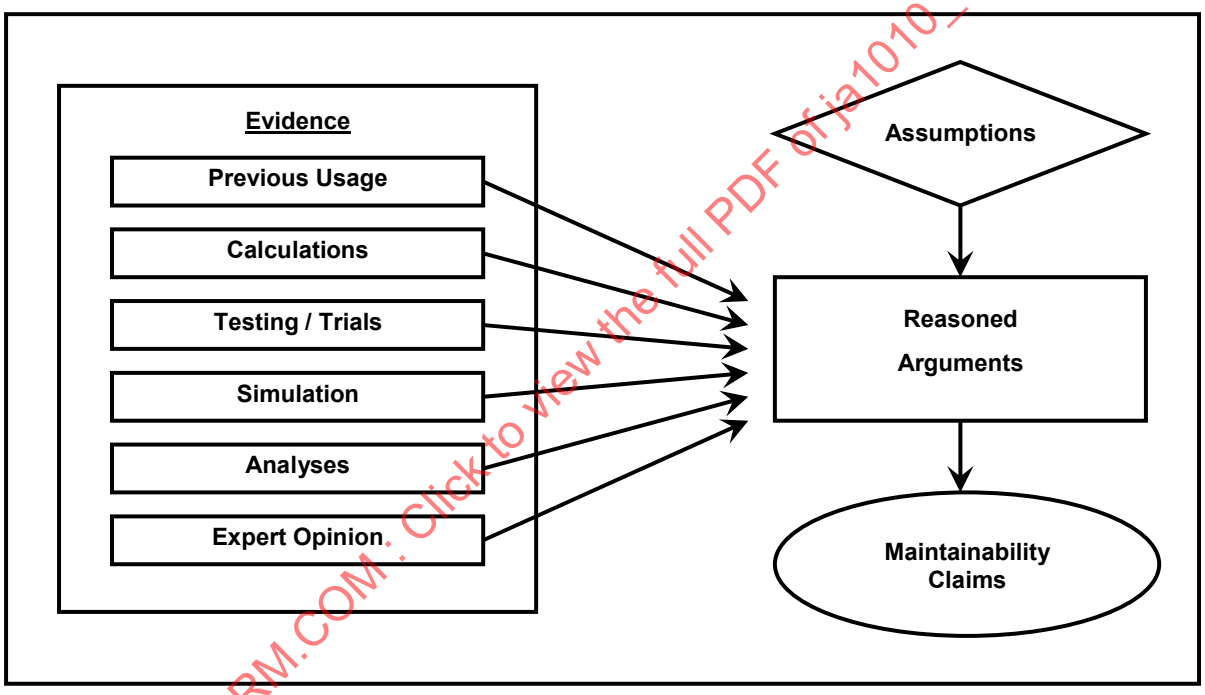

FIGURE 2 - CLAIMS BASED ON ASSUMPTIONS AND EVIDENCE

5.6.5 Review and Update

The MC is a working document and must be continually reviewed and updated, especially when:

a. There are changes in the maintainability requirements.

b. There are changes in how or where the product is used.

c. The product is modified.

d. There is an accepted deviation between actual performance and design target(s).

5.7 Maintainability Case and Product Life

5.7.1 Documentation Flow

Figure 3 illustrates the flow of documentation between the customer and the supplier(s) during MC development and production. At the concept stage of a product's life, the customer will determine the maintainability requirements so that his operational and support needs are satisfied. The rationale for the maintainability requirements should be recorded, preferably in an initial MC Status Report to potential suppliers, thereby ensuring that the requirements are directly traceable thereafter to the original customer requirements. This MC should be provided to the supplier(s) as part of the request to him to participate in the program, with due consideration of security and commercially sensitive issues. This will provide the supplier with visibility of the maintainability requirements and how they have been determined.

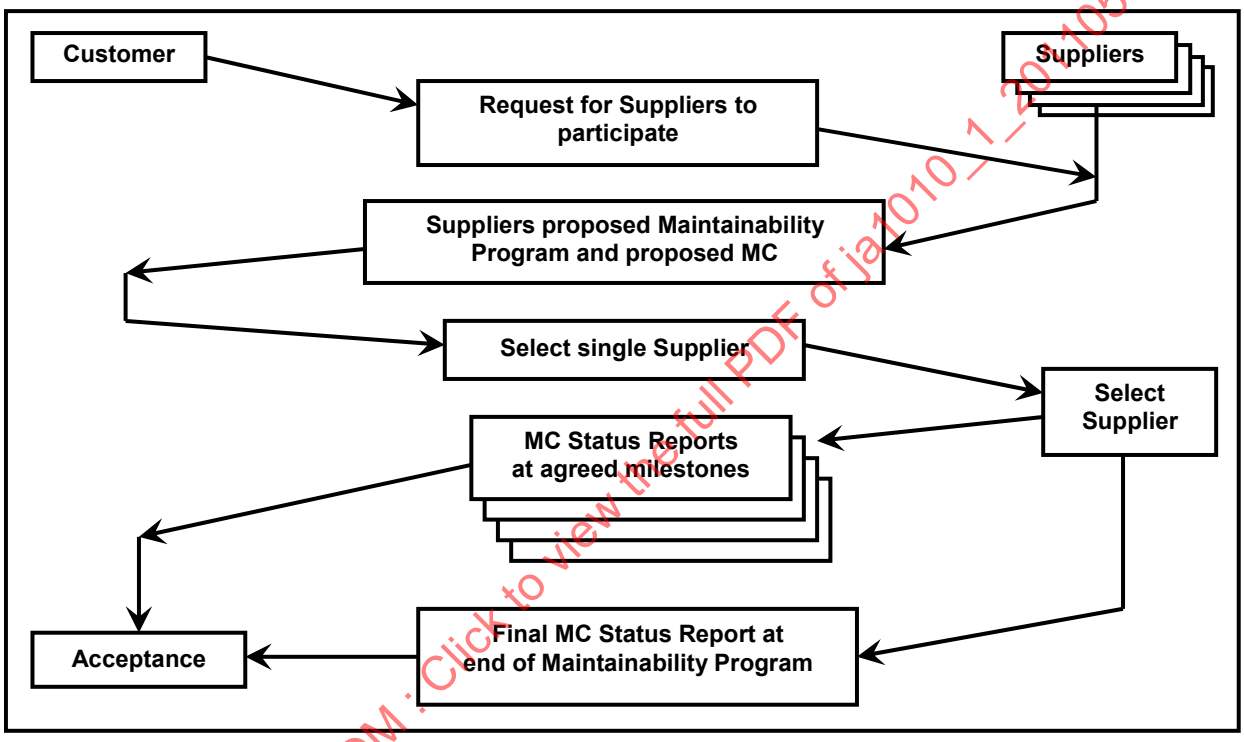

FIGURE 3 - MC DOCUMENTATION FLOW FOR INITIAL DEVELOPMENT AND/OR PRODUCTION

5.7.2 Responsibility

When there is an agreement to undertake a maintainability program, the responsibility for the MC will move to the supplier. The responsibility for the MC will remain with the supplier until that part of the program is complete and the customer has accepted the MC, at which time the ownership shall return to the customer.

5.7.3 Ownership

The ownership may change between the customer and supplier several times during the life of the product, and possibly between the customer and different suppliers, if different suppliers undertake programs at different times. Figure 4 shows the flow of documentation where improvements are to be incorporated into an existing design. These may take place as a mid-life update, or where progressive improvement is carried out by several separate stages during the life of a product.

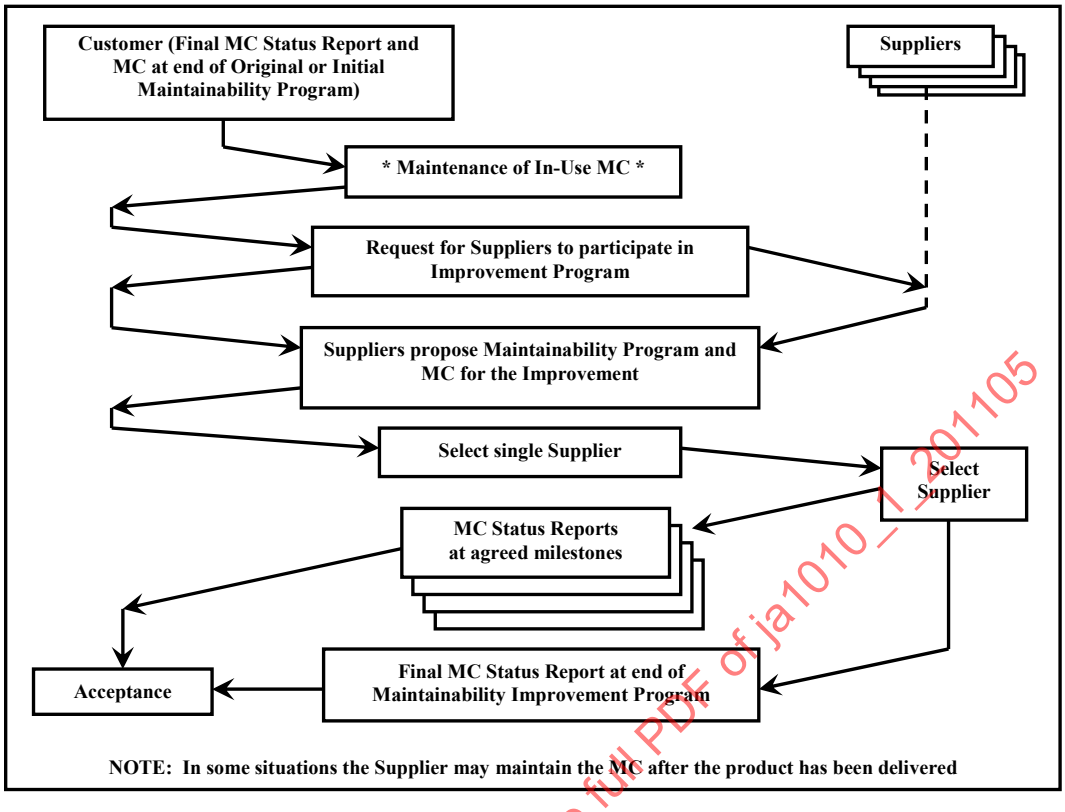

FIGURE 4 - MC DOCUMENTATION FLOW FOR AN IMPROVEMENT PROGRAM

5.7.4 Product Improvement Programs

When improvements are to be incorporated into an existing design, the final MC and MC Status Report from the existing design can be used as a starting point. These improvements may take place as a mid-life update, or where progressive improvements are carried out by several separate stages during the life of a product.

5.7.5 Uncertainty

During a program, the MC shall provide the supplier and customer with progressive maintainability assurance. At the start of a program, the assurance may simply be an estimate based on evidence of the current maintainability measure for the product, usually with an associated high level of uncertainty. The maintainability activities undertaken during the program, will aim to drive the maintainability measures toward the supplier's target maintainability and increase the confidence that the estimate is representative of the product's actual maintainability.

5.7.6 Final Maintainability Case Status Report

The final MC Status Report supplied by the supplier will be reviewed by the customer as part of the program completion process.

6. MAINTAINABILITY METHODS

A product team typically uses a number of engineering, maintenance, logistics and managerial techniques to achieve the objectives of maintainable product development i.e. *define customer needs*, *meet those needs through the design and manufacture of a product*, and *assure the customer that the needs have been met*. Collectively, these techniques are referred to as maintainability methods. The purpose of this chapter is to provide the reader with concise descriptions of a number of maintainability methods in the industrial, military, governmental, and academic world that are available to product teams.

6.1 Maintainability Methods Applications

The product team needs two kinds of information to properly apply maintainability methods to the maintainable product development. First, it needs to select the proper method from a number of available techniques, i.e. *do the right things*. Having selected a particular method, the team then needs to determine the right way to perform it, i.e. *do things right*. The descriptions in this Implementation Guide are designed to assist product teams with the former, i.e. *selection of proper maintainability methods to use at various points in the making of a maintainable product*. Rather than providing detailed descriptions of each method, an attempt has been made to focus only on the key aspects that determine the relevance of a method to a particular product. This information then enables the team to identify the activities that need to be performed at various points during product development to ensure a maintainable product. The team may then compile a maintainability program that is in consonance with the overall product development plan.

Having decided on a particular set of maintainability methods for the maintainability program, the team then needs information on how to use and apply them. Since, this information is available in the literature, as well as through various courses, seminars, and lectures, the descriptions in Appendix C do not describe how to perform the maintainability methods. However, a bibliography of references is provided with each description and the reader is encouraged refer to these sources for detailed information on the selected maintainability methods.

6.2 Format of the Method Descriptions

The information in each method description is divided into eight sections. These are:

a, Description. (The main features of the method)

b. Purpose. (What the method helps in achieving)

c. Application. (The types of situations where the method is usually used)

d. Key Elements. (A very brief summary of how the method is used, i.e., the main steps involved, typical inputs, and typical outputs)

e. Benefits. (The value that the method adds to the product development process)

f. Limitations. (Cautionary statements about the method, its cost or skill levels required)

g. References. (Bibliography of sources for more information on the method)

The content and format is similar for each task description. This is done to ensure uniformity and to assist the product development team in selecting the maintainability method that best suits their needs.

6.3 Criteria for Inclusion of Maintainability Methods in this Guide

Maintainability impacts such a large number of activities, it is sometimes difficult to conclusively say whether or not a particular method is a maintainability method. Thus, in order to define the scope of this chapter, the maintainability methods included in this Guide were selected on the basis of the following criteria:

a. Should be a generally recognized practice in at least one industry segment i.e. not unique to a single company.

b. All methods should have a similar level of hierarchy i.e. neither too narrow nor too broad.

c. Should be generally considered as a technique that impacts maintainability.

d. Must not be proprietary to any individual or organization.

With this brief overview, you can now turn to the maintainability methods in Appendix C.

7. ACKNOWLEDGEMENTS

The individuals from the SAE G-11M Maintainability, Supportability, & Logistics Committee, with the support of their sponsoring organizations, have devoted a great amount of time and resources toward the development of this Implementation Guide. Under the auspices of the SAE, a series of intensive meetings and reviews were held among core members to develop and refine the content of the Standard and the Implementation Guide. The resulting document drafts of each meeting were in turn forwarded to extended team members for wider review and commentary. Major drafts were then made available to SAE member reviewers for their comments and ballot approval.

8. NOTES

8.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE G-11M - MAINTAINABILITY, SUPPORTABILITY, & LOGISTICS COMMITTEE

APPENDIX A - GENERAL REQUIREMENTS FOR THE MAINTAINABILITY CASE (MC) STATUS REPORT

A.1 INTRODUCTION

1. This appendix provides general guidance of the content of a MC Status Report. The detailed layout and depth of contents must be decided between the Customer and Supplier before the program commences. The MC Status Report is an executive summary of the MC, and it presents an argued claim, based on evidence and assumptions, that the product will satisfy the maintainability requirements. The report will not actually contain all the evidence produced, but will summarize and act as a 'signpost', indicating where the detailed evidence is documented.

2. The following paragraphs suggest some possible headings and describe the content for sections within the MC Status Report. It is recognized that this structure may not be suitable for every program, but it is intended to provide guidance on the type of information that should be contained within the report.

3. For complex products, the MC Status Report may draw on and reference a hierarchy of lower-level MC Status Reports for the sub-products of which the whole product is comprised.

Section 1: Product Description

A succinct description which accurately reflects the product being reported on such as:

a. Part number/Manufacturing drawing number/part name.

b. Serial Number.

c. Revision level/Modification level.

d. Physical characteristics.

e. Interface boundaries, if applicable.

Section 2: Maintainability Requirements

This should describe the rationale for the requirements and the suppliers progress towards meeting the customer's requirements. It should show the latest estimate of the products maintainability. Changes from previous Status Reports should be highlighted.

Section 3: Maintainability Risk Areas

The supplier should identify the risk areas associated with the product satisfying the maintainability requirements, and how these risks have been managed since the last status report.

Section 4: Maintainability Program Changes

Based on the risks identified, the maturity of the design and the progress the supplier is making, the supplier shall identify the changes made to the maintainability program since the last Status Report and any intended changes in the remaining period prior to delivery of the product.

Section 5: Maintainability Evidence

This section should summarize the evidence gathered during the program from the various maintainability activities undertaken and included in the framework. This section should discuss the activities to be undertaken and the evidence that will be produced and how this will be used to support the claim.

Section 6: Maintainability Claims

Typically, the claims will be that the product will satisfy each of the maintainability requirements. This section should provide a reasoned argument why each of the requirements will be met in service, based on the evidence and any assumptions. All assumptions should be listed explicitly.

Section 7: Limitations of Use

This section should define the boundaries on the product use, which if exceeded will mean the maintainability claim may no longer be valid.

Section 8: Conclusions and Recommendations

This section should contain a summary of the conclusions developed from the Maintainability evidence accumulated to date, including an assessment of compliance with the Maintainability requirements. In interim issues, it should recommend whether the project should proceed to its next milestone or what work is required to enable the project to progress. It should recommend what activities need to be conducted in the future to generate the necessary assurance that the Maintainability requirements will be satisfied.

APPENDIX B - GENERAL GUIDANCE IN PRESENTATION AND ASSESSMENT OF THE EVIDENCE IN THE MAINTAINABILITY CASE (MC)

How to Present the Evidence

1. This section provides guidance on how to present the evidence in the MC. The evidence required to demonstrate progressive assurance and final compliance of the maintainability requirement will depend on the nature and development state of the equipment, and are likely to vary significantly from one program to another.

2. Before producing the initial MC it is essential that the objectives of all the tasks in the Maintainability Program are fully understood, and the success criteria defined for each activity that will contribute to providing progressive assurance or final compliance demonstration. The success criteria should be those by which the activity can be judged to have been completed satisfactorily in order to progressively move towards the final maintainability requirement. It should be noted that not all activities lend themselves to a quantified success criteria, and may require qualitative criteria based on the objectives of the activity.

3. The evidence of maintainability assurance does not result from the generation of the activity results only, but also from the implementation of actions to address the risk identified by the activity. Undertaking the activity at the appropriate time such that it is most effective in achieving the required level of assurance is very important. Therefore the evidence from the analysis consists of the documentation showing that actions have been implemented in a timely manner.

4. The input to the MC from an activity in the Maintainability Program can be considered to include the following parts:

   a. Objective and Success Criteria (What the activity intends to achieve, and defining how the activity will be judged to be successful);

   b. Outputs (The outputs from the activity);

   c. Assumptions (The ground rules, limitations and guidance);

   d. Evidence (How the outputs substantiate claims in the MC);

   e. Development and Maintenance of Evidence
   (How will the results of the activity be maintained to reflect the latest design).

How to Assess the Adequacy of Evidence

5. The checklist in this section should be considered a prompt and does not imply a 'Yes' and 'No' answer. Professional judgment is required to evaluate the evidence presented. The checklist must not be considered as being prescriptive or exhaustive, it is generic and provides guidance.

   a. Are the objectives for the activity clearly defined?

   b. Has the activity been undertaken in a systematic manner and is it complete?

   c. Has the activity been undertaken at the appropriate time?

   d. Is the usage and environment of the activity that has been undertaken appropriate for the activity been documented?

   e. Has the physical and functional boundary of the activity been clearly defined?

   f. Are any assumptions defined (e.g. inputs from other products or services), and are they realistic and reasonable?

   g. Is justification given for the activity method/technique used, and is it reasonable?

h. Who was consulted during the activity, (e.g. customer, operator, maintainer, designer etc.)? Was this level of consultation reasonable?

i. Are the activity recommendations clearly defined, and are they reasonable?

j. Does documentary evidence indicate that the recommendations have been implemented?

k. Have the activity results been progressively updated to reflect the latest design, and is this being used as an input to design reviews.

APPENDIX C - MAINTAINABILITY METHODS

C.1 BENCHMARKING

C.1.1 Description

The process of analyzing and assessing contractor and competitor's performance relative to maintainability in order to establish a required minimum level of performance for products and services.

C.1.2 Purpose

The purpose is to establish the expected standards of performance for the products and services produced in a competitive environment. The performance standards should be directed at life cycle cost, product safety and efficient maintenance task performance.

C.1.3 Application

Benchmarking should be a continuous activity throughout the design, development and operational phase of a product. It should be a key activity that a contractor performs and maintains for current products and future product developments.

C.1.4 Key Elements

a. Data collection plan

b. Analysis and evaluation capabilities to properly assess both contractor and competitor performance

C.1.5 Benefits

a. Provides a means to identify products shortcomings

b. Provides the opportunity to develop superior products

C.1.6 Limitations

a. Cost of developing, collecting and maintaining data base and reports

b. Limited capabilities or inexperience personnel in performing objective assessment

c. Trade-offs among product attributes may hinder achieving established benchmark standard

C.1.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.5, Data Collection and Analysis)
Maintainability Toolkit, Topic 2.2: Market Competition

C.2 DATA COLLECTION/ANALYSIS

C.2.1 Description

The process of collecting and cataloguing maintenance and operational data forms a historical data base for analysis and assessment purposes.

C.2.2 Purpose

Maintenance and operational data is collected and summarized in an organized reporting format. Analyses and reports provide feedback for verification of compliance with design requirements, demonstrates performance characteristics and identifies problem areas.

C.2.3 Application

Data collection can be used in all phases of a program with the major benefit in the testing and operational phases. The data collected should be maintenance and operational information for the product that includes hardware and software. Maintenance data should include scheduled and unscheduled information as well as information on modifications, hardware/software configurations and upgrades and special engineering events. Analysis of the data and reporting should be directed at establishing system performance characteristics and identifying major failure trends, events requiring excessive resources, and time consuming maintenance tasks.

C.2.4 Key Elements

a. Data collection plan

b. Hardware and software identifications/configurations

c. Data base and computer software

d. Summary report plan

e. Technical expertise for reviewing and analyzing data

f. Data collection forms

g. Data reviews and scoring of data

h. Trained technicians for data reporting

i. Maintenance task times, maintenance man-hours, etc.

C.2.5 Benefits

a. Provides a means to identify hardware and software problems

b. Historical data base and summaries to improve product performance

c. Method to demonstrate compliance with the requirements.

d. Justify the cost of upgrading hardware and software

e. Provides the customer with accurate and up to date performance data

f. Justify the cost of system maintainability improvements

C.2.6 Limitations

a. Cost of developing, collecting and maintaining data base and reports

b. Limited by the quality of the data in the data bases

c. Lack of management support to maintain data collection process

C.2.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.5, Data Collection and Analysis)
MIL-HDBK-2155—Failure Reporting, Analysis and Corrective Action System
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
Maintainability Toolkit, Topic 8.0, Maintainability Data Collection and Analysis
Maintainability Toolkit, Appendix F, Data Analysis Techniques

C.3 DESIGN FOR MANUFACTURING AND ASSEMBLY

C.3.1 Description

A process of planning and organizing the logical and efficient steps for the preparation of hardware and software to be assembled, tested and delivered to the user.

C.3.2 Purpose

The purpose is to assure that the manufacturing process and requirements do not significantly effect the maintainability of the product in the operational environment. The manufacturing process can impact maintainability due to process quality/consistency and the subassembly packaging techniques required during the assembly steps in the production of the product.

C.3.3 Application

This process should be initiated during the concept phase and continued through the production phase. A balance between an efficient manufacturing assembly process and cost should be made with the resultant achievement of product maintainability. Application of digital mockups and simulations should be used to satisfy the requirements of the manufacturing process and product maintainability.

C.3.4 Key Elements

a. Maintainability design analysis

b. Personnel familiar with Manufacturing process

c. Product elements and interfaces

C.3.5 Benefits

a. Maintainable product, which meets design intent in the operating environment

b. Cost savings during testing and corrective action

c. Reduce downtime to correct problems during the manufacturing process

C.3.6 Limitations

a. Lack of software tools for design analysis and manufacturing process

b. Correct mixture of technical experts

c. Product cost goals

C.3.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 1.2.7, Manufacturing

C.4 DESIGN REVIEWS

C.4.1 Description

Design reviews are a formal and planned review of the design during the development phases of a program. Design reviews by technical experts are an examination of the product capabilities to meet design requirements.

C.4.2 Purpose

The design review examines all aspects of the design during established milestone of the system development. This activity includes the systematic evaluation of the proposed hardware and software design, status of the compliance with the requirements, review of analyses, review of the proposed verification methods and status of support resources elements.

C.4.3 Application

a. Verify design compliance with requirements and goals

b. Progressive review of the design evolution during the development phases

c. Feedback by technical experts on problems and shortcomings of the design and support elements

d. Identify areas requiring additional technical support and follow-up

C.4.4 Key Elements

The key elements of the design review are:

a. Schedule – A schedule for the design and development phases of a program should identify the various design reviews. The design review schedule is integrated with the overall master schedule for the program and the key phases. The schedule should allow for preparation, conducting the review and follow-up after the review.

b. Agenda – An agenda should be developed and agreed upon with the customer for each design reviews. Each design review should show progress in the design development and provide for the review and evaluation of supporting data. Each review has specific purposes and these need to be identified and addressed during the review.

c. Operating Rules – Rules for the preparation, conduct and reporting should be established in advance of each design review. The rules should identify the key personnel, the technical experts and the customer personnel involved with the hardware and software. In addition, the type of documentation, formats, presentation materials, feedback/comments approach and action item plan should be established and understood by all the participants.

d. Detail Review/Assessments – A complete review and assessment of the design related to the Maintainability requirements and goals should be conducted and results presented at the design review.

e. Action Items/Follow-up – At the conclusion of each design review, a clear set of action items should be identified and documented for corrective action. Each action item should be assigned to a responsible person for developing corrective action and with at an established closure date.

f. Documentation – A complete set of supporting documentation should be identified, collected and stored for reference purposes and demonstrating design review closure.

C.4.5 Benefits

a. Establishes the level of design maturity at each review phase

b. Verify compliance with design requirements

c. Identifies design changes and modifications to comply with requirements

d. Provides an understanding of the design for the customer and users

e. Provides for the integration of the end product design and functions

C.4.6 Limitations

a. The number of design reviews may be limited due to impact on schedule and cost

b. The correct mix of technical experts is sometimes difficult to obtain

c. Recommended action items may not be completed, due to budget/schedule constraints

C.4.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.2.6, Reviews)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.5, Validate the Maintainability through Analysis and Test

C.5 DESIGN TOOLS

C.5.1 Description

Design tools include software, mock-ups, hardware and other means used to evaluate, analyze and assist in product design, development and operational performance. (See C.22 for more detail on physical and digital mock-ups).

C.5.2 Purpose

The purpose of the design tools is to provide a quick and economical method to identify design limitation and assist in developing recommendations for design improvements and efficient maintenance task performance.

C.5.3 Application

Maintainability design tools should be an integral part of the overall design tool set for engineering. The tools should interface with the development activities during all phases of product development. These tools should have the capability to simulate maintenance tasks and interact with the design using the human anthropometric/ergonomic capabilities and limitations. A number of independent commercially available software tools or embedded tools in major computer aided design tools can be used for this activity.

C.5.4 Key Elements

a. Maintenance tasks simulations planned for product

b. Anthropometric requirements for the planned operating and maintenance environment

c. Operation and maintenance requirements

d. Maintenance concept and/or plan

e. Software analysis and simulation tools

f. Complete list of support resources like tools, support equipment, facilities and software models of those items pertinent to performing maintenance task analysis under review.

C.5.5 Benefits

a. Establishes the level of design maturity at each review phase

b. Minimizes interface problems between product and supporting resources

c. Reduces design changes during development testing and initial operations

d. Reduces delays in product development and schedule delays

e. Efficient operations and maintenance for the customer

f. Provides customer confidence in maintainability of product/system design prior to qualification

C.5.6 Limitations

a. Lack of availability of required software design analysis tools

b. Correct mix of technical maintenance experts is sometimes difficult to obtain

c. Lack of qualified personnel to use software

d. Lack of sufficient design concept definition.

C.5.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Para 4.2.6, Reviews)
MIL-STD-1472—Human Engineering Design Criteria for Military System, Equipment and Facilities
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
Maintainability Toolkit, Topic 5.9, Design Tools

C.6 ENVIRONMENTAL CHARACTERIZATION

C.6.1 Description

Environmental characterization of a system defines the ground-rules, objectives and requirements in which the system operates. This provides an environmental baseline for the design engineers and support personnel during the development of the design and support elements.

C.6.2 Purpose

The characterization maybe documented as requirements in a specification or as goals and objectives in design criteria guidelines. The primary purpose is to provide to the design engineer with a complete and concise list of information impacting operations and maintenance during the design phase.

C.6.3 Application

The set of environmental characteristics reflecting the operational and maintenance environments should be used by the designers and design support personnel during design development. It provides guidance and identifies specific requirements and goals for the product to meet in order to operate in the intended environments.

C.6.4 Key Elements

a. The environmental characteristics should be documented

b. Operational and maintenance environments should be clearly identified

C.6.5 Benefits

a. Provides a listing of the operational and maintenance environments that the product will encounter during the life cycle

b. Provides a consolidated and concise list of the environments

c. Provides guidance in the development of support resources

d. Provides product design which is compatible with the intended operational environment

C.6.6 Limitations

a. The technical information is limited by the personnel experience and customer information provided

b. Needs to be maintained and updated as required and distributed to engineering, management and the customer

C.6.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.2, Operational and Support Environments)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military System, Equipment and Facilities
Maintainability Toolkit, Topic 5.1, Specific Considerations

C.7 ERROR AND MISTAKE PROOFING

C.7.1 Description

A process of reviewing and analyzing the design, operating environments and the operators/maintainers capabilities to identify potential areas requiring error/mistake proofing relative to assembly and maintenance.

C.7.2 Purpose

The purpose is to identify potential problem areas requiring design to eliminate errors and mistakes during product maintenance and operations.

C.7.3 Application

This activity should be integrated with the maintainability analysis methodology during the design and development phase for the early identification and correction of potential problems. Continuous review, identification and corrective action for problem areas should progress through the production phase and follow up in the user environment.

C.7.4 Key Elements

a. Maintainability design analysis

b. Maintenance plan and operations plan

c. Personnel with maintenance and operations experience

d. Digital mockups and simulations

C.7.5 Benefits

a. Fewer product maintenance induced errors

b. Provides for product life cycle cost savings and minimizing maintenance

c. Reduce downtime and maintenance resources

C.7.6 Limitations

a. Cost of error proofing the design and product minimized if incorporated early in the design process

b. Limited capabilities and experience of personnel performing analysis

C.7.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.9, Safety and Induced Failures)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix C, Design Guidelines)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 5.7, Safety and Induced Failures

C.8 FAILURE MODES AND EFFECTS ANALYSIS

C.8.1 Description

The Failure Modes and Effects Analysis (FMEA) is an assessment used to identify potential failure modes and the effect on the system performance. The analysis should identify actions to eliminate or mitigate the risks associated with the identified failure mode.

C.8.2 Purpose

The FMEA identifies potential failures that require the customer maintenance team to repair and return the system to operation. The cataloguing of the failures is a systematic approach to provide assurance that a failure can be detected, isolated and tested after maintenance.

C.8.3 Application

This activity is conducted during the design phase and the analysis is provided to the design team for consideration of fault detection and isolation capabilities. The analysis provides the documentation and status of the fault coverage at the design reviews and during design verification activities.

C.8.4 Key Elements

a. System description, design details and drawings

b. Definition of the hardware and software elements

c. Feedback to the software engineers and design engineers

d. Software program to automate the analysis task

e. Key maintenance related inputs are required

C.8.5 Benefits

a. Provides a listing of the possible failure and probability of occurrence

b. Provides information for developing a fault detection and isolation plan

c. Problems can be addressed during the design phase

d. Can be down to piece parts or developed as functional analysis

C.8.6 Limitations

a. Time consuming analysis

b. Generally is performed late in the design development process and has little impact on the design

c. Dependent on correct identification of failure modes

C.8.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.3.3, Failure Modes and Effects Analysis)
MIL-STD-1629—Procedures for Performing a Failure Mode, Effects and Criticality Analysis
Maintainability Toolkit, Topic 5.5, Testability and Diagnostics
Maintainability Toolkit, Topic 6.2, Commonly Used Maintainability Analyses
SAE ARP 5580—Recommended Failure Modes and Effects (FMEA) Practices for Non-Automobile Applications

C.9 HUMAN FACTORS ANALYSIS

C.9.1 Description

The Human Factor analysis is an evaluation and review of a design to assure consideration for the human operator and maintainer in various environments and operating conditions.

C.9.2 Purpose

The human factor analysis is a systematic review, evaluation and analysis of the design during the development phase. It identifies deficient designs that impact human performance and safety during the operation and maintenance of the product. Inputs and recommendations from technical experts are considered and incorporated to improve design for the end user.

C.9.3 Application

Human factor analysis should be conducted from the conceptual phase to the initial induction of the hardware and software into service. This analysis has a major impact on design improvements during the early stages of a design.

C.9.4 Key Elements

a. Technical experts with human factors operating and maintenance experience

b. Software tools and physical mockups, i.e., tools, support equipment, etc., to interact with design engineering and computer aided design tools

c. Operational and maintenance plans

d. Operating environments

e. Personnel skill levels and training

f. Anthropometrics requirements

C.9.5 Benefits

a. Improves operating efficiencies and safety for the customer

b. Improves the maintenance and reduces the downtime of the hardware and software

c. Reduce customer operating and life cycle cost

d. Minimize impact on design changes

C.9.6 Limitations

a. Limited by the level of expertise of the reviewers

b. Limited use in design development due to the lack of sufficient resources

C.9.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.3.5, Human Factors Analysis)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix C, Design Guidelines)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-HDBK-759—Human Engineering Design for Military Materiel
DEF STAN 00-25 – Human Factors for Designers of Equipment
Maintainability Toolkit, Topic 3.4, Design for the Desired Level of Maintainability
Maintainability Toolkit, Topic 6.2, Commonly Used Maintainability Analysis

C.10 INTERCHANGEABILITY

C.10.1 Description

The ability of the product to be replaced with similar items and not affecting the performance of the end product.

C.10.2 Purpose

The purpose is to provide for the replacements, modifications and upgrades during the product life cycle.

C.10.3 Application

This capability is applied to products or components in systems that have a long life expectancy and known replacements, upgrades and modification are planned at intervals during the life cycle.

C.10.4 Key Elements

a. Performance characteristics

b. Form and fit requirements

c. Future growth requirements

d. Commercial products enhancements

e. Obsolesce plan/parts management plan

f. Supplier replacement products development plans

C.10.5 Benefits

a. Minimizes impact on design changes

b. Reduced logistics costs

c. Facilitates improvements to product/system performance

C.10.6 Limitations

a. Special/unique designed products

b. Lack of awareness of commercial supplier's product design plans, i.e., parts management plan, etc.

c. Inherent design limitations

C.10.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.10, Standardization and Interchangeability)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)

C.11 LESSONS LEARNED DATA BASE

C.11.1 Description

A database containing operations and maintenance lessons learned about products under development and currently in use by customers and those learned from similar products throughout their life cycle.

C.11.2 Purpose

Provides a historical database of information to be used for the development of preferred designs and recommendations for the improvement of product designs and support resources. Lessons learned are important references to ensure problems are not repeated and enhancements for design improvements are incorporated in the current product design and development effort.

C.11.3 Application

This activity should be a continuous product development activity and integrated with a feedback system from the users and operators of the products. The database should be accessible and easily interrogated for information and lessons learned (e.g., searchable by type of product, type of problem and solution, etc.). Periodic reviews should be made of the database to verify the information is correct, up-to-date and applicable for the contractor products. A system to identify benefits and cost savings should be an integral part of the system to demonstrate it usefulness in product development.

C.11.4 Key Elements

a. Data base plan

b. Participant awareness and training on the importance of this activity

c. Feedback process for benefits and cost savings

d. Reliable data sources

C.11.5 Benefits

a. Eliminates problems that have been encountered in previous designs

b. Product enhancements and better product acceptance by customers

c. Can be used to develop design review checklists

d. Excellent tool for developing maintainability design requirements

C.11.6 Limitations

a. Time consuming to maintain database

b. Only as good as data in database

c. Sometimes difficult to get engineering and support personnel to review and use data

C.11.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.5, Data Collection and Analysis)
Maintainability Toolkit, Topic 8.1, Types and Sources of Data

C.12 LOGISTICS SUPPORT ANALYSIS

C.12.1 Description

The Logistics Support Analysis is an evaluation and review of a design to assure consideration for the logistical elements in the various operational environments and operating conditions.

C.12.2 Purpose

The Logistics Support Analysis is a systematic review, evaluation and analysis of the design during the development phase. It identifies deficient designs that impact logistics performance during the operation and maintenance of the product. Inputs and recommendations from technical experts are considered and incorporated to improve product design for the end user.

C.12.3 Application

Logistics support analysis should be conducted from the conceptual phase to the initial introduction of the hardware and software into service. This analysis has a major impact on design improvements during the early stages of a design. A systematic analysis, documentation and recommendation effort should be used for this activity. The logistics support analysis applies to the integration of support resources like support equipment, tools and facilities with the primary objective directed at improving operational and maintenance efficiencies. Industry and government practice is to tailor the analysis to the specific needs of the project.

C.12.4 Key Elements

a. Technical experts with logistics experience

b. Software tools and physical mock-ups, i.e., tools, support equipment, etc., to interact with design engineering and computer aided design tools

c. Operational and maintenance plans

d. Operating environments

e. Personnel skill levels and training

f. Product performance requirements

C.12.5 Benefits

a. Improves operating efficiencies and safety for the customer

b. Improves the maintenance and reduces the downtime of the product

c. Reduce customer operating and life cycle cost

d. Minimize impact on design changes

C.12.6 Limitations

a. Limited by the level of expertise of the reviewers

b. Limited use in design development due to the lack of sufficient resources

c. Logistics support analysis cost may limit the depth of the effort

d. Timely execution of the analysis task is required to have an impact on the design

C.12.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4, Maintainability Analyses and Test)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-HDBK-502—Acquisition Logistics
MIL-PRF-49506—Logistics Management Information Performance Specification
Maintainability Toolkit, Topic 1.2.5, Logistics and Support
DEF STAN 00-60—Integrated Logistics Support (Part 0 through Part 3)

C.13 MAINTAINABILITY ALLOCATIONS

C.13.1 Description

The maintainability allocation process is the systematic apportionment of the system level quantitative maintainability requirements to lower level components of the system.

C.13.2 Purpose

The maintainability allocations consist of quantitative requirements that are intended for use during the design process. These requirements form the basis for the design and provide guidance and objectives to meet the system level requirements.

C.13.3 Application

Maintainability allocations are identified and documented during the conceptual and early design phases of a program. The allocated requirements and goals are documented in specifications, design requirements documents and reports. Design and support personnel use this information as guidance during design development. Status of requirements compliance is reported during design reviews, evaluations, predictions and analyses.

C.13.4 Key Elements

a. Quantitative requirements and goals

b. Conceptual design

c. Operational and maintenance concepts

C.13.5 Benefits

a. Provides for a systematic flow down of requirements

b. Provides design requirements and goals

c. Provides organized approach and plan for the design

d. Provides elements used in design trade off studies

C.13.6 Limitations

a. Accomplished when little design detail are available, therefore frequent updates are required as design progresses

b. Limited by the design details available during the conceptual and early design phase

c. Cost may limit the benefit derived

C.13.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.6.2, Maintainability Allocations)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix D, Predictions)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.1, Understand the Customer's Maintainability Needs
Maintainability Toolkit, Topic 6.5, Predictions, Allocations and Assessments

C.14 MAINTAINABILITY ASSESSMENT

C.14.1 Description

Maintainability assessments provide the periodic status of the design adequacy during the various stages of a system development process.

C.14.2 Purpose

The primary purpose of assessments is to evaluate the design against requirements and goals, identify deficiencies and define enhancements to improve the design for supportability and life cycle considerations.

C.14.3 Application

Assessments are accomplished at intervals during design development to assure the design meets the intended operating and maintenance requirements and goals. This effort is usually conducted within the design product team group with key contractor and customer technical personnel.

C.14.4 Key Elements

a. Current design and supporting information

b. Design and technical support personnel

c. Planned approach and corrective action feedback

d. Design requirements and goals

e. Mock up, prototype and models

C.14.5 Benefits

a. Identifies deficient designs early in the development phase

b. Reduces costly redesigns

c. Provides the design team with recommended solutions to problems

C.14.6 Limitations

a. Limited by the technical expertise of the evaluators

b. Program time phase constraints may limit review

C.14.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.6.3, Maintainability Assessments)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Para 4.5, Data Collection and Analysis)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix D, Predictions)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.5, Validate the Maintainability through Analysis and Test
Maintainability Toolkit, Topic 6.5, Predictions, Allocations and Assessments

C.15 MAINTAINABILITY DEMONSTRATION

C.15.1 Description

Maintainability demonstration is a formal method to assess the maintainability of a product prior to the acceptance by the customer and user of the product.

C.15.2 Purpose

Maintainability demonstration is the activity used to verify compliance with the maintainability design requirements through a planned and structured test using personnel and resources in the operation environment.

C.15.3 Application

This is a formal test activity that is conducted with a documented plan, procedures and final report. The demonstration test reflects the operational environment, uses the maintenance resource planned for the system and is formally conducted using customer maintenance personnel. The demonstration test is used to demonstrate compliance with the design requirements, maintenance plan and maintenance resources.

C.15.4 Key Elements

a. A demonstration plan describing the approach should be included in the Maintainability Program Plan

b. A formal demonstration plan should be developed, coordinated and approved prior to conducting the demonstration test

c. The demonstration test procedures should be completed and fault symptoms verified before the formal demonstration test

d. Needs to be supported by the customer with personnel and resources

e. Appropriate system hardware or mock-up simulation

f. A formal demonstration report should be prepared with the results of the demonstration test

C.15.5 Benefits

a. Provides the status on maintainability design requirements compliance and compatibility with the operating resources and environments

b. Demonstrates the ability of the maintenance resources to support the system

c. Identifies problem areas requiring corrective action

C.15.6 Limitations

a. Generally does not reflect the true operating environment and resources

b. Demonstration test activities require a lot of preparation time and resources

c. Requires dedicated system hardware for specified time period or use of realistic mockup

C.15.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.2, Test)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix B, Test and Demonstration Methods)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.5, Validate the Maintainability through Analysis and Test
Maintainability Toolkit, Appendix G, Maintainability Demonstration and Test

C.16 MAINTAINABILITY DESIGN EVALUATION ANALYSIS

C.16.1 Description

Design evaluation analysis evaluates the integration of maintainability design requirements and criteria into the system and support equipment design.

C.16.2 Purpose

The purpose is to identify deficiencies in the design that impact operations and maintenance in the operating environment.

C.16.3 Application

The design evaluation should be a continuous activity throughout the design, testing and initial operational periods. The analysis should document design deficiencies based on the operational and maintenance requirements, personnel interfaces and operating environments. The analysis should address the scheduled and unscheduled maintenance tasks to be performed on the system during the life cycle and provide design recommendations to achieve requirements/goals.

C.16.4 Key Elements

a. Operations and maintenance environments

b. Maintenance tasks identified

c. Maintenance resources

d. Training and skill levels identified

e. Technician experience

f. Maintenance concept defined

C.16.5 Benefits

a. Provides the designers with information and suggestions on needed improvements to the system supportability

b. Establishes the support resources for the system

c. Identify issues to improve the system design

d. Product integration to benefit the maintainer

C.16.6 Limitations

a. Lack of experience of the evaluators with the actual operations and maintenance activities

b. Inadequacy of analysis tools to perform proper evaluations

c. Program priorities may limit incorporation of recommended design changes

C.16.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.3.2, Maintainability Design Evaluations)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 6.2, Commonly Used Maintainability Analyses

C.17 MAINTAINABILITY GOALS AND REQUIREMENTS

C.17.1 Description

Goals and requirements define the maintainability objectives to be met by the design during operations and maintenance in the stated environments and with the proposed support resources.

C.17.2 Purpose

Goals and requirements provide the design team and the supporting specialty engineering elements with the design characteristics to meet the operational and maintenance objectives and environmental conditions.

C.17.3 Application

Documentation should be prepared containing the goals and requirements and made available to all the members of the design team, customers and management. The specific goals and requirements should be kept up to date and referred to during design reviews and assessments.

C.17.4 Key Elements

a. Operational and maintenance concepts

b. Environmental considerations

c. Operator and maintainer skill level and training

d. Quantitative requirements

e. Qualitative requirements

f. Tool standardization and commonality

g. Built-in test concept and plan

C.17.5 Benefits

a. Provides the designers and design team with design goals that enhance the operations and maintenance

b. Provides the customer with the confidence that the system design meets their operational requirements

c. Provides information and data for design personnel and support personnel

C.17.6 Limitations

a. Developing and maintaining data base

b. Lack of experience personnel to develop goals and requirements

c. Inadequate customer/supplier dialogue

C.17.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3, Design for Maintainability)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix C, Design Guidelines)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.1, Understand the Customer's Maintainability Needs

C.18 MAINTAINABILITY MODELING

C.18.1 Description

A maintainability model defines the hierarchy of the designs for allocation and prediction tasks during the early design phase. The model should be maintained and updated during the design and testing phases and can be used to monitor/trend product maintainability in the field.

C.18.2 Purpose

The models establish the equipment levels and the indenture levels for the mathematical relationship required for the allocation and prediction processes. A maintainability model is generally required for prediction processes.

C.18.3 Application

Maintainability modeling is performed as a preliminary task for the allocation and prediction tasks. The maintainability model is required for the requirements allocation task, prediction task and demonstration test task.

C.18.4 Key Elements

a. System indenture levels

b. Product hierarchy outline

c. Quantitative requirements

d. Verification of data used in models

C.18.5 Benefits

a. Provides a systematic breakdown of the system

b. Provides an overview of the maintenance concept and plan

c. Provides an illustrated grouping of the equipment

C.18.6 Limitations

a. Model updates are required

b. Resources for continual updates

c. Model output only as good as data input

C.18.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.4, Quantitative Measures of Maintainability)
MIL-HDBK—470A-Designing and Developing Maintainable Products and Systems (Appendix D, Predictions)
MIL-HDBK—470A-Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
Maintainability Toolkit, Topic 3.1, Understand the Customer's Maintainability Needs
Maintainability Toolkit, Topic 6.3, Quantitative Measures of Maintainability

C.19 MAINTAINABILITY PREDICTIONS

C.19.1 Description

Maintainability predictions are estimates of the design performance from the quantitative and qualitative maintainability perspective.

C.19.2 Purpose

Maintainability predictions provide an estimate of the maintainability characteristics during the design phase. The predictions are used to assure compliance with design requirements and identify shortcomings in the design. The predictions are key in developing a design that meets the requirements in a cost-effective manner.

C.19.3 Application

Maintainability predictions are updated on a continuous basis during the design phase in order to provide the quantitative requirements status to the design team. The early phase of a design may not permit accurate predictions and accuracy of the results depends on task time data and the experience of the maintainability engineer. As the design matures, the accuracy improves as the details of each maintenance task is defined and analyzed. The predictions should be reported and discussed at each design review. Formal predictions, in many cases, are used to demonstrate compliance with the quantitative design requirements.

C.19.4 Key Elements

a. Maintenance concept and plan

b. Specification tree defining system elements and assembly process

c. Definition of system design and installation

d. Experienced personnel with a maintenance background

e. Maintenance resources and environmental information

f. Prediction sources data, i.e., Maintainability, cost, task time measurements/data, etc.

C.19.5 Benefits

a. Provides up to date status on quantitative requirements compliance

b. Useful in any required reallocation process as design progresses

c. Provides foundations for the training requirements and publication content

d. Identifies the skill levels, personnel requirement and maintenance resources required

C.19.6 Limitations

a. Accuracy maybe limited in the early design phases

b. Accuracy limited by the experience of personnel and task time accuracy

c. Needs to be updated continuously to be an effective tool for the design team

C.19.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.4.1.6.1.1, Maintainability Predictions)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix D, Predictions)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 6.5, Predictions, Allocations and Assessments
SAE JA1000-1- Reliability Program Standard Implementation Guide

C.20 MAINTAINABILITY PROGRAM PLAN

C.20.1 Description

A management plan describing the maintainability tasks, providing the scope of the tasks, documenting the results of customer/supplier dialogue and agreements, identifying the functional interfaces and responsibilities for maintenance resources and defining the schedules. The plan interfaces with other program management plans.

C.20.2 Purpose

The program plan tailors planned activities to customer needs and provides an organized approach for the implementation of the Maintainability Program and how it relates to other program functions. The plan provides the program personnel, suppliers and customers with an overview of the implementation of the maintainability activities. It has a description of supporting tasks, schedules, management organization and deliverable documents.

C.20.3 Application

The program plan should be a part of the proposed management plan for the program and should be available at the start of a design program.

C.20.4 Key Elements

a. Provides a list of maintainability program tasks and responsibilities

b. Describes tailoring of the program tasks as they apply to a program

c. Management structure, key personnel and technical interfaces

d. Provides schedules for task performance and documentation preparation

e. Provides a description of the quantitative and qualitative requirements and goals

f. Provides means to verify level of maintainability achieved

C.20.5 Benefits

a. Demonstrates a understanding and approach for developing maintainable products/systems

b. Provides a planned approach for the execution of the program

c. Demonstrates to the customer a commitment to provide maintainable products

C.20.6 Limitations

a. The plan generally reflects the understanding of the planned program and is sometimes not required to be updated during the course of a program

C.20.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.2, Management Approach)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix E, Phasing of Maintainability Elements)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
DEF STAN 00-40 – Reliability and Maintainability (Part 1)
Maintainability Toolkit, Topic 3.0, Structuring a Maintainability Program
Maintainability Toolkit, Appendix D, Section B, Program Requirements
SAE JA1000 – Reliability Program Standard
SAE JA1010—Maintainability Program Standard

C.21 MAINTENANCE COST ANALYSIS

C.21.1 Description

The process of collecting, analyzing and summarizing cost data for trade studies and establishing economical maintenance plans for products and customers.

C.21.2 Purpose

A systematic analysis to identify and select a maintenance concept and plan that reflects the minimum life cycle cost and satisfies the performance requirements for the products and customers.

C.21.3 Application

Maintenance costs are identified and documented during the conceptual and early design phases of a program. A database of cost factors like labor cost per hour, facilities cost, support resources cost as well as operation cost related to fuel, power and other cost elements should be maintained with the latest information available for various maintenance concepts. Maintenance cost analysis is primarily used during the development and design phases.

C.21.4 Key Elements

a. Maintenance cost requirements and goals

b. Cost models and software tools including maintainability math model

c. Conceptual design definition

d. Maintenance resources identified

e. Operational and maintenance concepts and plans

C.21.5 Benefits

a. Provides for a systematic cost profile development

b. Provides allocated cost requirements and goals as well as predictions versus requirements

c. Provides organized cost approach and plan for the design

d. Provides cost elements used in design trade studies

C.21.6 Limitations

a. Limited by availability and accuracy of cost details and historical backup data

b. Limited by the design details available during the conceptual and early design phase

C.21.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 2.2, Effects of Maintainability on Operations and Cost)
Maintainability Toolkit, Topic 2.4, Life Cycle Cost and Affordability

C.22 PHYSICAL AND DIGITAL MOCK-UPS

C.22.1 Description

Physical and digital mock-ups are design evaluation tools used to assure the incorporation of maintainability design requirements and criteria into the system and support equipment designs.

C.22.2 Purpose

The purpose is to validate achievement of maintainability design requirements/goals and identify deficiencies in the design that impact operations and maintenance in the operating environment and provide recommended corrective action.

C.22.3 Application

Digital and physical mock-ups should be a continuous activity throughout the design, testing and initial operational periods. The mock-up reviews should document design deficiencies based on the operational and maintenance requirements, personnel interfaces and operating environments. The analysis should address the scheduled and unscheduled maintenance tasks to be performed on the system during the life cycle. Maintenance task simulations are used to detect design deficiencies and provide recommendation for corrective action. Mock-up reviews are beneficial in a design team environment so that various proposals and recommendations can be evaluated and solutions developed quickly and which have concurrence of the design team.

C.22.4 Key Elements

a. Operations and maintenance environments

b. Operations and maintenance concepts/plans

c. Maintenance tasks

d. Maintenance resources

e. Training and skill levels

f. Technician expertise

g. Human factors design criteria and digital human models for use with digital mock-ups

C.22.5 Benefits

a. Provides information and suggestion on the improvements of the product design and supportability factors

b. Establishes the support resources for the system

c. Digital media allows for concurrent engineering and early influence on design

d. Product maintenance enhancement to benefit the maintainer

e. Early verification that maintainability requirements/goals are being met

C.22.6 Limitations

a. Lack of expertise of the evaluators with the actual operations and maintenance activities

b. Inadequate analysis tools to perform proper evaluations

c. Program priorities may limit incorporation of recommended design changes

d. For physical mockups, degree of completeness can limit the usefulness of this activity

e. Degree of completeness and timeliness of update can limit the usefulness of this activity

C.22.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.2.2, Mock-ups)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix F, Maintainability References)
MIL-STD-1472—Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Maintainability Toolkit, Topic 3.5, Validate the Maintainability through Analysis and Test
Maintainability Toolkit, Topic 5.9, Design Tools

C.23 OBSOLESCENCE PLANS

C.23.1 Description

Obsolescence plans provide a planned approach to address the systems upgrades and sustainability due the unavailability of parts and equipment during a products life cycle.

C.23.2 Purpose

Goals and requirements provide the design team and the support elements with the design characteristics and interfaces to ensure sustainability of the product during the life cycle with product upgrades. The plan defines the design objectives to be met by the product during operations and maintenance in the stated environments and with the proposed support resources. The purpose is to plan for product upgrades and parts obsolescence in a manner that maintains and enhances performance without incurring an unreasonable cost.

C.23.3 Application

Documentation should be prepared containing the goals and requirements and made available to all the members of the design team, customers and management. The specific elements should be kept up to date and referred to during design reviews and assessments. It is important to have suppliers involved in this process since they have the knowledge of their product obsolescence, upgrades and future manufacturing plans. Examples of planned/expected obsolescence include high-tech hardware, which have increasingly short life cycles and computing hardware and associated software. This type of software is usually continuously updated to adapt to ever-changing missions.

C.23.4 Key Elements

a. Operational and maintenance concepts/plans

b. Supplier product support plans

c. Operational life cycle plan for the product

d. Supplier maintenance and repair support plan

e. Spare parts plan and parts availability

f. Customer acquisition and sustainability plans for products

C.23.5 Benefits

a. Provides the designers and design team with design goals that enhance product sustainability and availability

b. Provides the customer with the confidence that the system design meets their life cycle plans

c. Provides information and data for design personnel and support personnel

C.23.6 Limitations

a. Capability to develop realistic plan and adequately forecasting events

b. Lack of personnel experience to develop goals and requirements

c. Inadequate customer/supplier dialogue

C.23.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.10, Standardization and Interchangeability)
Maintainability Toolkit, Topic 1.2.5, Logistics and Support

C.24 PARTS MANAGEMENT

C.24.1 Description

Establish program guidelines for the selection, approval and procurement of component parts, and the management of parts suppliers.

C.24.2 Purpose

To promote the use of known quality and readily procurable component parts that meet performance and durability requirements in a cost-effective manner.

C.24.3 Application

Parts management should be a continuous activity throughout the design, development, and operational usage phases of a product's life. It is critical that parts management principles be applied, not only during the initial parts selection process, but whenever an alternative part is considered at any stage of the product's life, reasons for which could include replacement due to parts obsolescence and second source.

C.24.4 Key Elements

a. Part standardization plan

b. Parts management plan for development and procurement milestones

c. Effective communications between parts management and other engineering disciplines

d. Part selection criteria

e. Part approval process

f. Part usage policies

g. Part qualification requirements

h. Part supplier management plan and evaluation criteria

C.24.5 Benefits

a. Decreased maintenance requirements due to increased product reliability

b. Increased life cycle affordability, availability and sustainability

c. Promotes utilization of common parts for similar application resulting in an overall reduction in parts inventories

C.24.6 Limitations

a. Frequently, parts management principles are overlooked (usually in favor of cost and ease of procurement) when replacement parts are selected for components already found out in the field or market place

b. Failure to flow down parts management requirements to suppliers can result in components of questionable quality and durability

c. Lack of awareness of some parts management program elements on the part of the design engineering and procurement communities may result in failure to implement best design practices

C.24.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.10, Standardization and Interchangeability)
Maintainability Toolkit, Topic 1.2.5, Logistics and Support

C.25 QUALITY FUNCTION DEPLOYMENT

C.25.1 Description

Quality Function Deployment (QFD) is a structured, comprehensive planning process that incorporates the voice of the customer (VOC) into product design and development. QFD is based on a series of matrices that are used to document, correlate, communicate, and track the customer requirements throughout the organization. The QFD planning matrix is called the “House of Quality” because of its shape.

C.25.2 Purpose

QFD is intended to assure that customer requirements and expectations are met by incorporating the voice of the customer (VOC) into product design and development.

C.25.3 Application

a. As a part of business and market analysis to determine which products to develop

b. To help clarify customer requirements

c. For incremental design improvement on next generation designs

d. To get the team to focus on the critical few; the key priorities of the customer

C.25.4 Key Elements

In traditional QFD, there are four phases in which the voice of the customer is deployed: (1), Product Planning (translating customer requirements into products characteristics); (2), Part Deployment (translating product characteristics into parts characteristics); (3), Process Planning; and (4), Process Control. The steps for a product planning QFD (frequently considered the most important ones) include:

a. Identify customer wants and needs (WHATs).
EXAMPLE – Maintainable design.

b. Rank the importance of the customer needs (often relative to the importance of a competitive product).

c. Define satisfaction measures (HOWs) for each need.
EXAMPLE—Reduce parts, high quality parts.
Determine critical areas for project focus by mapping HOWs to WHATs.

d. Setting design targets to meet the customer needs.
EXAMPLE—Maintenance times, ease of maintenance, expected durability of life-limited items. The priority of meeting the quality characteristics is related to the highest priority of the customers and, therefore, will deliver the highest value to the customers.

There are many techniques that may be used to gather input for the QFD like analysis of written requirements, marketing data, surveys, structured interviews, and group discussions.

C.25.5 Benefits

When used by a cross functional team, QFD can result in the following benefits:

a. Greater understanding of the customer needs

b. Focused effort - products or service priorities are known by all

c. Fewer and earlier changes in design

d. Increased teamwork and better communication between departments

e. Lower start-up cost

C.25.6 Limitations

a. Usually requires a facilitator to be effective.

b. The scope of the QFD method is overwhelming to many new practitioners.

c. Developing the 'House of Quality' can require a larger effort than some teams can commit to.

C.25.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 3.1, Understand the Customer's Needs)
Maintainability Toolkit, Topic 2.1. Customer Expectations
Maintainability Toolkit, Appendix B: Quality Function Deployment

C.26 RELIABILITY CENTERED MAINTENANCE

C.26.1 Description

Reliability Centered Maintenance (RCM) is a systematic analysis of the corrective and preventive maintenance activities for a product and establishes a preventive maintenance plan that meets operating cost goal and product availability.

C.26.2 Purpose

A preventive maintenance plan is developed providing an economical and efficient repair and replacement approach for a product based on an analysis of the product reliability, failures, operating environments and product usage.

C.26.3 Application

This activity should begin during the later design phases and should continue through the development, testing and operations of the product. It should be updated on a continuous basis with the latest data and changes implemented in the operations of the product. The objective is to maintain a cost effective maintenance program through the life cycle of a product. Continuous improvement of the reliability centered maintenance plan, based on reliability and maintenance history, provides an economical maintenance program as well as high product availability.

C.26.4 Key Elements

a. Maintenance concept and plan

b. System design drawings and installation drawings

c. Experienced personnel with a maintenance background

d. Maintenance resources and environmental information

e. Prediction source data, i.e., reliability, cost, FMEA, etc.

C.26.5 Benefits

a. Provides a cost effective preventive maintenance program

b. Provides efficient use of the product as well as support resources

c. Provides foundations for the training requirements and publication content

d. Identifies the skill levels, personnel requirement and maintenance resources required

C.26.6 Limitations

a. Accuracy may be limited in the early design phases

b. Quality of data and analysis technique limits accuracy

c. Needs to be updated continuously to be an effective tool

C.26.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3.1.3, Preventive Versus Corrective Maintenance Requirements)
Maintainability Toolkit, Topic 1.2.2, Reliability Centered Maintenance
Maintainability Toolkit, Topic 3.6, Monitor and Analyze Operational Performance
SAE JA1011—Evaluation Criteria for Reliability Centered Maintenance (RCM) Processes
SAE JA1012—Guide to Reliability Centered Maintenance Standards
DEF STAN 00-45 – Requirements for Application of Reliability Centred Maintenance (Part 1)
ATA MSG-3—Operator/Manufacturer Scheduled Maintenance Development

C.27 REPAIR STRATEGIES

C.27.1 Description

Identify various customer, contractor and vendor repair strategies to be used by the system operators and maintainer during the life cycle of the product.

C.27.2 Purpose

The strategies are used in cost model evaluations and for the development of various product maintenance concepts and plans. The final results may be used to establish a maintenance plan that best fits the customer operations with a minimum life cycle cost.

C.27.3 Application

The identification of repair strategies is accomplished early in the design and evaluated by the customer and contractor. The selection of the best repair strategy for the customer is based on the cost, availability of maintenance resources, and customer operating plans. Source data used in the development of strategies should be accurate and updated with current information and maintenance technologies. Product design should reflect repair strategy and anticipated repairs to be performed in service.

C.27.4 Key Elements

a. Requires a list of maintenance tasks and responsibilities

b. Customer maintenance repair plan and resources

c. Management structure, key personnel and technical interfaces

d. Plans for maintenance and repair task performance and documentation preparation

e. Requires a description of the resources and environments

f. Ground rules for determining repair economics versus parts scrapping

C.27.5 Benefits

a. Demonstrates a understanding and approach for developing maintainable products/systems

b. Provides a planned maintenance approach for the life cycle of the product

c. Demonstrates to the customer a commitment to provide maintainable products

C.27.6 Limitations

a. Strategies are limited by availability and accuracy of source data

b. Strategies are dependent on personnel expertise

C.27.7 References

MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 2.2.2, Life Cycle Cost)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Par 4.3, Design for Maintainability)
MIL-HDBK-470A—Designing and Developing Maintainable Products and Systems (Appendix C, Design Guidelines)
Maintainability Toolkit, Topic 5.1, Specific Considerations

C.28 MAINTENANCE SAFETY ANALYSIS

C.28.1 Description

Maintenance safety analysis is a formal method to assess safety issues associated with the maintenance task performance for a product prior to the acceptance by the customers and users of the product.

C.28.2 Purpose

Equipment and personnel safety analysis is the activity used to verify compliance with the safety design requirements through a planned and structured analysis and evaluation using the planned personnel and resources in the operational environment.

C.28.3 Application

This analysis activity is conducted during the design, development, testing and initial operational phases. The safety analysis reflects the operational environment, uses the maintenance resource planned for the product and is conducted using customer maintenance personnel inputs and recommendations. The safety analysis is performed to show compliance with the design requirements and government regulations and demonstrate the ability to use and maintain the product in the proposed environment and operating conditions. The goal should be to provide a safe product, thus reducing personnel and product accidents which impact operator costs and schedules.

C.28.4 Key Elements

a. A complete understanding of the customer approach to the product usage and maintenance

b. List of maintenance resources, like support equipment, facilities and personnel

c. A plan should be developed, coordinated and approved prior to conducting the safety analysis

d. Analysis reviews supported by the customer with personnel and resources

C.28.5 Benefits

a. Provides the status on maintainability design requirements compliance and compatibility with the operating resources and environments in a safe manner

b. Demonstrates the ability of the maintenance resources to support the system in a safe manner

c. Identifies problem areas requiring corrective action