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Reliability Program Standard Implementation Guide

Foreword—This Implementation Guide was developed as a companion, supporting document for SAE Reliability Program Standard JA1000 to provide guidance and assistance for planning and managing reliability programs.

This Guide was developed recognizing the need for customer satisfaction (high reliability, affordability, and speed to market) and increased profitability for suppliers. In addition, its development was influenced by Department of Defense (DoD) Acquisition Reform, and the wide diversity of potential users.

Stressing the importance of the supplier-customer dialogue, the Guide supports the belief that reliability programs are most efficient and effective when developed jointly by the supplier and customer. Rather than following a strictly prescribed approach, the supplier should design (tailor) the reliability program, with customer input to include only value added activities.

Section 1—*Introduction* explains the purpose, scope, and typical uses of the Guide. Section 2—References. Section 3—*Glossary, Terms and Definitions*. Section 4—*The Reliability Program* outlines how to develop a cost effective and value-added reliability program. Benefits and criteria for method selection are also included. Section 5—*Reliability Method Descriptions* includes reliability practices, many of which are recognized as best practices thorughout industry. Also included in this Guide is a glossary of commonly used reliability terms, followed by an acknowledgement of contributors.

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1. *Scope—Introduction*

1.1 Introduction—The importance of reliability in design engineering has significantly grown since the early 1960's. Competition has been a primary driver in this growth. The three realities of competition today are: world class quality and reliability, cost-effectiveness, and fast time-to-market. Formerly, companies could effectively compete if they could achieve at least two of these features in their products and product development processes, often at the expense of the third. However, customers today, whether military, aerospace, or commercial, have been sensitized to a higher level of expectation and demand products that are highly reliable, yet affordable.

Product development practices are shifting in response to this higher level of expectation. Today, there is seldom time, or necessary resources to extensively test, analyze, and fix to achieve high quality and reliability. It is also true that the rapid growth in technology prevents the accumulation of historical data on the field performance of their products. Unfortunately, some reliability methods have depended upon the availability of historical data, other experiential information, or learning through extensive and time consuming tests. The new realities require innovation and creativity in the selection and use of reliability methods, and teamwork and collaboration in the management of product development programs. There must be a shift from seeking to eliminate complaints in products, to eliciting praise for them.

To enable this transition, reliability efforts must be directed toward anticipating problems and designing-in features that assure the achievement of quality and reliability, concurrent with the development process, instead of trying to assess quality and reliability downstream. The gains in time-to-market and cost savings from such an approach can be significant. More recent reliability programs tend not to prescribe reliability tasks or methods to be performed by suppliers. Rather, suppliers are considered equal partners in the effort to produce a reliable product and work with the companies in deciding which reliability methods provide most value in achieving objectives.

Nevertheless, developing reliable products and achieving reliability goals often requires different approaches for various product sectors. For example, in the defense/aerospace sector, the number of customers is relatively small. The product development cycle may span several years, while the product life cycle may last from mere minutes to as long as decades. Furthermore, it is not unusual for several design iterations of technologically different hardware and software to be developed before the final version is incorporated into the production product. Production volumes may range from rates of less than ten to hundreds per year. Also, the reliability discipline in this sector is generally a separate activity from the design discipline.

The commercial sector, in contrast to the defense/aerospace sector, usually has a higher number of different customers. Development cycles could range from months to a few years while life cycles are often measured in years. Production volumes may run up to thousands per day. The reliability discipline is treated usually as an integral part of the up-front design process rather than a separate activity.

Thus, developing a reliability implementation guide to meet the needs of all industry sectors is a formidable challenge. It recognized that this Guide will not strictly apply to all situations or industries. The suggestions made in this Guide must be interpreted in the context of the industry, its accepted practices, and unique company policies. The following statement will be repeated several times in this document to emphasize its importance: "***The selection of methods is a highly individualized process. This point cannot be overemphasized 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.***"

1.2 **What is Reliability?**—ISO 8402: *Quality Vocabulary* defines *Reliability* as: "The *ability* of an item to perform a *stated function* under *stated conditions*, for a *stated period of time*."

Assuming the *item* in the definition is a particular *product*, we see three interesting elements to this definition. First, the product must perform a *stated function*. Second, the product must perform under *stated conditions*, and third, the product must perform for a *stated period of time*. The important question is: "*Who* states the function, conditions, and period of time for the product?"

Considering why a product is purchased, it is obvious that the customer has certain expectations in terms of the product function, environmental conditions it should work in, and how long it should continue to work. If the product satisfies or exceeds these expectations, it is perceived to be reliable. If not, then it is perceived as unreliable. So, the ultimate indicator of product reliability is customer satisfaction! Therefore, it is a supplier's interest to build a product that satisfies (or delights) its customers. In fact, a product is said to have failed when it did not do what was required of it, i.e., it did not satisfy its customer (1).[1]

The definition of reliability also has another interesting aspect - the word "ability." How this "ability" is measured becomes the means for quantifying reliability. Some measure the 'ability' in terms of a probabilistic statement, such as the percentage of products likely to survive (or failure-free life) after the required period of time (e.g., warranty) is over. In this approach, it is recognized that a certain number of failures will occur. Here, the emphasis is to minimize the number of failures to an acceptable level. This would allow a supplier to warrant a product to be "failure-free" for a certain period of time.

Others emphasize methods that help achieve reliability. In this approach, a product that meets all its customer needs, over a lifetime, is deemed reliable. They expect to achieve a failure-free period of time for all products. In other words, there is no such thing as an acceptable level of avoidable failure (2). Such methodologies approach reliability from a more physics-based viewpoint wherein the goal is to determine how the product could fail, understand what would make it fail in that manner, and design it so that the failure cannot happen under the usage conditions for the period of time required.

Both approaches are widely used throughout industry, and each have strong proponents.

1. References are listed in 2.1, Applicable Pulbications.

1.3 **A Framework for Reliable Product Development**—Companies need to face the future with quality and reliability programs that fit the new business era, rather than continue those that may have worked in the past (3). It is clear from our discussion previously that prior to building a product, it must be understood what the customer desires from the product in order to be satisfied. Without proper information about customer needs, quality improvement activities tend to lack both market focus and the proper use of business resources to enhance business results (4). 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 the customer's desires can be built. Therefore, the second objective of reliable product development is *to meet the customer needs.* Once the product is built, however, the customer may not buy it unless assured of its reliability. Therefore, the third objective is *to assure the customer that the needs are met.* These three objectives form the basis for a Framework for Reliable Product Development that underlies the SAE JA1000 *Reliability Program Standard.*

The Framework for Reliable Product Development is based on the concepts of reliability discussed previously and represents today's prevalent thinking of how to develop reliable products (5,6). The standard emphasizes the *supplier-customer* relationship among companies and their suppliers as well as among end-consumers and companies. The three objectives listed previously are set in SAE JA1000 as *Program Requirements* and are worded as follows:

a. *The supplier shall ascertain customer requirements*
b. *The supplier shall meet customer requirements*
c. *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 Reliability Methods. It is essential to understand that reliability transcends several disciplines across many industries. Therefore, it is important not to be prescriptive about the specific reliability methods used in product development. Consequently, SAE JA1000 does not specify the reliability methods to be used. Rather, the customer and supplier(s) must work together to develop a reliability program that completes each activity through the use of mutually acceptable reliability methods (7).

It should be recognized that SAE JA1000 uses the 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.

1.3.1 THE SUPPLIER SHALL ASCERTAIN CUSTOMER REQUIREMENTS—Suppliers must understand customer needs to determine product functions, the conditions it has to perform under, and the expected performance duration. The input from customers may not be in a form that allows direct interpretation in terms of technical design or process parameters. 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 SAE JA1000 Program Requirement include:

a. *Establish Supplier-Customer Dialogue*
b. *Identify Conditions of Use*
c. *Define Maintenance and Service*
d. *Establish Metrics*
e. *Define Product Specification*

1.3.2 THE SUPPLIER SHALL MEET CUSTOMER REQUIREMENTS—Once customer requirements are known, the supplier must look at how to produce a satisfactory product. The resources available to build the product must be considered, including people, materials, tools, manufacturing and assembly processes, equipment, facilities, software, organizational learning, technology, 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 or not the product will fulfill its requirements. This activity is an essential step that provides an assessment of the risk and determines the focus areas for managing it. Having identified risks, the supplier then needs to design the product (and process) by mitigating these risks, through design and process innovation, exploratory development, decision making on serviceability issues, as well as determination of manufacturing and assembly process control windows. Thus, the activities defining this SAE JA1000 program requirement include:

a. *Characterize Resources*
b. *Assess and Manage Risk*
c. *Design to Achieve Reliability*

1.3.3 THE SUPPLIER SHALL ASSURE THAT CUSTOMER REQUIREMENTS HAVE BEEN MET—The supplier needs to demonstrate that given the capabilities of the resources, the product (and process) meets requirements, thus qualifying not just the product design, but also the design, manufacturing, and assembly processes that the supplier uses to build the product. Complete documentation must be maintained to show customers that the product can indeed satisfy their needs. The supplier must identify the specific process parameters that control critical product characteristics, and contain variation within required limits. In addition, suppliers must strive continually to reduce product variability to an acceptable level in their design, manufacturing, and assembly processes. The supplier must 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 SAE JA1000 Program Requirement include:

a. *Qualify the Product and Process*
b. *Establish Process Controls*
c. *Pursue Continuous Improvement*
d. *Establish Data Collection & Reporting*

1.4 Using this Implementation Guide

1.4.1 PURPOSE—The SAE JA1000-1 Reliability Program Standard Implementation Guide (the Guide) is designed to assist suppliers in determining how to satisfy the Program Requirements of SAE JA1000 *Reliability 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 reliability throughout the product or service life cycle.

1.4.2 APPLICATION—This Guide primarily provides assistance for developing reliability programs according to the requirements of SAE Standard JA1000. Suppliers and customers frequently need answers to questions such as:

a. *Who is responsible for reliability goals, planning, etc.?*
b. *What reliability methods are most effective, and how are they applied?*
c. *When are reliability methods used most effectively in the product development cycle?*
d. *Where can we get more detailed information and instructions on how to use the reliability methods?*

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

a. Resource for design and manufacturing engineers to select available reliability methods
b. Provide an understanding of various reliability program activities
c. Provide assistance to suppliers who need knowledge of various reliability methods and techniques, or assistance establishing a formal reliability program. (e.g., A supplier may have an excellent quality program, but lack a formal reliability program).
d. Assistance in planning, scheduling, and structuring their reliability programs
e. Knowledge of available reliability methods, a description of what they accomplish, and when they are best applied
f. Evaluating potential benefits and limitations of reliability methods
g. Practical method selection criteria
h. Provide guidance for subcontractor (second tier) reliability programs, including product assessments (e.g., Commercial Off The Shelf (COTS))

1.5 **Managerial Issues in Reliable Product Development**—Table 1 depicts the Framework for Reliable Product Development. In order for companies to succeed in applying the Framework, certain managerial and organizational issues must be addressed. The most significant among these is the nature of the supplier-customer dialogue, the creation of self-managed, cross-functional product development teams, and the management of supply chains.

TABLE 1—A FRAMEWORK FOR RELIABLE 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. Define Product Specification
The Supplier Shall Meet Customer Requirements
a. Characterize Resources
b. Assess and Manage Risk
c. Design to Achieve Reliability
The Supplier Shall Assure Customer Requirements Have Been Met
a. Qualify the Product and Process
b. Establish Process Controls
c. Pursue Continuous Improvement
d. Establish Data Collection and Reporting

1.5.1 SUPPLIER-CUSTOMER DIALOGUE—The key to successful reliability programs (product development in general), is the quality of the supplier-customer dialogue. Often, weak reliability programs result when customers leave little flexibility for the supplier. Customers often have invoked a standard that included reliability methods (or tasks) the supplier was expected to perform. This was often done with little customizing or "tailoring" to the specific product needs. Consequently, many of the reliability methods added little value to the reliability of the product.

According to SAE JA1000 Reliability Program Standard, the supplier-customer dialogue is the foundation for a reliability program. The Standard shifts the focus from a fixed "document" approach to a performance based, supplier-customer dialogue approach. With rapid technological advances (methods, materials, processes, etc.), documents quickly become obsolete. This Guide supports the belief that the supplier and customer can best determine the most efficient and effective program, and eliminate non-value added activities.

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, 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, product specification, and the customer definition of product failure)
e. Conflict resolution/trade offs procedure
f. Subcontractor requirements/issues

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

1.5.2 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. Unfortunately, such a leisurely approach is 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" are called self-managed teams (8).

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 development, improve product quality, and speed time to market (9). 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.

1.5.3 SUPPLY CHAIN PARTNERING—Over the last decade, US 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 and reliability, reduction of inventory costs, mitigation of defects, and efficiency improvement of their manufacturing and assembly lines (10). 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 and reliability, faster new product development, improved use of technology, reduced time-to-market, minimized investment in resources, and reduction in product development costs (11). The traditional adversarial relationships resulting out of constant demands for price reduction, only served to create a competitive advantage in the short term. Since competitive advantage is increasingly a function of the efficiency and effectiveness of the supply chain, it is apparent that the greater the collaboration between supplier and the customer, the greater the likelihood of realizing a competitive advantage (12,13,14,15).

Suppliers increasingly indicate that they prefer involvement early in the development process, which develops mutual trust. Suppliers get involved in product design, support quality initiatives, are profitable, provide schedule sharing opportunities, respond to cost reduction ideas, maintain consistent communication and feedback, have a well organized crisis management/response system, and are, in general, totally committed to the partnership (16).

The supplier association must not only create an environment of mutual trust between the customer and the supplier, but also among suppliers. In the initial stages of the association, most of time goes into creating a group, exchanging market information, evaluating individual areas of poor performance, and establishing the credentials of other suppliers.

1.6 **Augmenting the Role of Reliability Engineering**—Looking closely at the Framework for Reliable Product Development (see Table 1), it is apparent that everyone in an organization does something that affects the reliability of the product. Thus, in a manner of speaking, everyone is responsible for product reliability! This begs the question, "What, then, is the responsibility of a Reliability Engineer?"

In a very loose manner, it can be said that a typical engineer knows "how things work." However, a Reliability engineer is trained in "how things fail" (17). This is an essential discipline that requires a knowledge of the ways in which products can fail, the effects of failure, and aspects of design, manufacture, maintenance, and use which affect the likelihood of failure. Engineering education, unlike reliability education, is generally deterministic and does not pay sufficient attention to variability in engineering processes, materials, and applications (18). The Reliability engineer, thus, plays a key support role on the product development team in driving attention towards managing and controlling variation.

Concurrent product development teams rely on input from each function being provided by specialist team members, and managed by a team leader. Traditionally, this "specialist support" role has been the hallmark of a Reliability Engineering group. However, many companies are now beginning to consider certain Reliability Engineers equally capable of the leadership role on these teams. Although, many of the activities of the product development team may be quite removed from the traditional Reliability Engineering tasks, there are specific benefits that the team gains by having a Reliability person responsible for coordination of activities. These benefits arise from the very nature of the Reliability Engineering job.

Reliability engineers, in their day-to-day tasks, must interact with Engineering, Manufacturing, Marketing, Suppliers, Planning, Testing, Sales, Customers, and Management, among others, on a fairly regular basis. Therefore, these individuals must be knowledgeable about several disciplines, as well as of how they interface. In addition, a Reliability engineer needs a sound understanding of the product life cycle from "cradle to grave" as well as a top-level understanding of the role played by different disciplines. To be effective in this role, the Reliability engineer must also be an exemplary facilitator and be able to work with a variety of individuals. However, this multidisciplinary knowledge-base, thorough understanding of the product life cycle, and the ability to work with, a get work from, a diverse group of specialists are the very qualities that are desired of the leader of a product development team. With the added background in Reliability, this individual can also help fulfill two roles that organizations find essential for reliable product development: *coordination among the various specialities* and *a strategic understanding of variation as it relates to the potential for failure.*

In light of the previous discussion, it is in the interest of an organization to use the Reliability Engineering function as one of the breeding places for future product team leaders. Individuals demonstrating high potential should be encouraged to spend time in Reliability before moving into product development team leadership assignments. To effectively participate in this role, the Reliability group itself should, perhaps, include a mix of highly experienced and respected individuals in the various Engineering specialties mentoring younger engineers rotating within the Reliability discipline as part of their career path. The Reliability specialists should continue to play the traditional support function of the Reliability Engineering group along with the additional responsibility of coaching younger engineers on Reliability principles and methods, creating in them an awareness of the effects of variation, and training them in the use of Reliability methods to manage variation. This would satisfy the need for good product development team leaders as well as provide a foundation for future Reliability specialists.

In expanding their role, Reliability Engineering groups must also learn to accept a larger set of Engineering Methods than has been traditionally considered a part of a Reliability Engineer's toolkit. It is estimated that 70% of all problems in the automotive industry are design related (10). And by our definition, any problem is a Quality and Reliability problem. However, solutions to these problems lie not in Quality and Reliability, but in other disciplines such as Management, Engineering, and Science (18). Therefore, Reliability engineers must keep abreast of advancements in engineering methods and tools, management techniques, and technological accomplishments that may assist in the product development process. Many projects require the use of engineering tools such as Finite Element Analysis, Design of Experiments, and Statistical Engineering. These and other CAE tools should be part of every Reliability engineer's toolkit or, at the very least, the Reliability engineer should have a good understanding of them and their capabilities and limitations, in addition to traditional Reliability Engineering methods such as *Development Testing, Failure Reporting and Corrective Action, and Reliability Testing.* Management skills that a Reliability Engineer must possess to effectively perform the leadership role on a product development team, include *Project Management Techniques, Conflict Management and Resolution Skills, Presentation Skills, and Leadership Skills.*

Thus, with changes in organizational priorities and the demands for *Faster, Better, Cheaper* products increasing everyday, organizational skillsets must be adapted to the needs of the times, and Reliability Engineering must play a larger role in this effort than has traditionally been the case. The management of risk in product development necessitates that Reliability Engineering develop as a discipline to control these risks through interdisciplinary liaison and control. The challenge is not to let the need to "control" risks, stifle the creative process that drives innovation.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein.

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2. WLR. *"Data Center Management: There is no such thing as an Acceptable Level of Avoidable Failure."* Infosystems, (Aug 1984)
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4. Fredericks, J.O. and Salter II, J.M., *"What Does Your Customer Really Want?"* Quality Progress (Jan 1998)
5. Knowles, I., Malhotra, A., and Stadterman, T.J., *"Framework for an Objective-based Reliability Program Standard.*" Proceedings of the Reliability And Maintainability Symposium (Jan 1995)
6. Malhotra, A., Strange, A., Condra, L.W., Knowles, I., Stadterman, T.J., Boivin, J.I., Walton, A.B., Jackson, M., "*Framework for an Objective and Process-based Reliability Program Standard.*" Communications in RMSL, Vol. 3, No. 1 (Jan 1996)
7. Evans, R.A. "*Easy & Hard.*" IEEE Transactions on Reliability, Vol. 44, No. 2 (Jun 1995)
8. Evans, J.R. and Lindsay, W.M., *"The Management and Control of Quality (3rd. Edition).*" West Publishing Company, St. Paul, MN (1996)
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12. Rich, N. and Hines, P., *"Supply-chain Management and Time-based Competition: The Role of the Supplier Association.*" International Journal of Physical Distribution and Logistics Management, Vol. 27, No. 3 (Mar-Apr 1997)
13. Carlisle, J. and Parker, R., *"Beyond Negotiation: Redeeming Customer-Supplier Relationships.*" Wiley, Chichester, England (1989)
14. Christopher, M., "*Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Services.*" Pitman, London, England (1992)

15. Kanter, R.M., *"When Giants Learn to Dance: Mastering the Challenge of Strategy, Management and Careers in the 1990s."* Simon & Schuster, New York, NY (1989)
16. Moody, P.E., "*Customer Supplier Integration: Why Being an Excellent Customer Counts.*" Business Horizons, Vol. 35, No. 4 (Jul-Aug 1992)
17. Evans, R.A., *"Negative Thinking."* IEEE Transactions on Reliability, Vol. 42, No. 3 (Sep 1993)
18. O'Connor, P.D.T., *"Practical Reliability Engineering 3rd. Edition (Revised)."* John Wiley & Sons, Chichester, England (1994).
19. Evans, R.A., "*Hope Springs Eternal* ...". IEEE Transactions on Reliability, Vol. 42, No. 3 (Sep 1993)

2.2 **Related Publications**—The following publications are provided for information purposes only and are not a required part of this document.

a. SAE J1000, "Reliability Program Standard," 1998-6
b. "Reliability, Availability, and Maintainability (RAM) Dictionary," Edited by Tracy Philip Omdahl, copyright 1988 by ASQC Quality Press
c. ISO 8402, "Quality Vocabulary"
d. "Reliability Toolkit: Commercial Practices Edition," A practical Guide for Commercial Products and Military Systems Under Acquisition Reform," Joint Effort Document of Rom Laboratory and Reliabilty Analysis Center (RAC), P.O. Box 4700, Rome, NY 13442-4700
e. "*Assurance Technologies, Principles and Practices*," Dev. G. Raheja, McGraw-Hill, 1981
f. MIL-STD-785B, "*Reliability Program for Systems and Equipment Development and Production*," 15 Sept 1980
g. "*Reliability Engineering Handbook*," Dimitri Kececioglu, PTR Prentice Hall, 1991
h. SAE AIR 4896, "*Recommended RMS Terms and Parameters*," 1995-12

3. ***Definitions***—The terms and definitions have been included to enhance the understanding of this document. See Appendix B. Many additional reliability terms and definitions can be found in the related publications listed in 2.2.

4. ***The Reliability Program***—This section provides guidance for developing and implementing a reliability program. This implementation guide's intent is not to prescribe any specific reliability methods but rather to provide guidance to assist in structuring a reliability program. A reliability program includes reliability activities and methods selected to assure the reliability of a product in a cost effective manner. A properly planned and executed reliability program benefits both the customer and the supplier as illustrated in Table 2.

TABLE 2—BENEFITS OF A PROPERLY PLANNED RELIABILITY PROGRAM

Customer Benefits	Supplier Benefits
	Increase Probability to meet reliability targets
Reduce customer cost of ownership	Reduce supplier risk
Improve the availability of the product	Reduce warranty costs
Reduce maintenance and logistics burdens	Quantify risk in achieving program requirements
	Help allocate resources to the most value-added activities
	Improves supplier reputation

Section 4 is divided into three functional areas: 4.1 Reliability Program Development, 4.2 Reliability Program Integration and Implementation, and 4.3 Reliability Program Metrics.

4.1 Reliability Program Development

4.1.1 RELIABILITY PROGRAM REQUIREMENTS—In developing a reliability program, the three requirements identified in the parent SAE JA1000 document need to be met. Summarized, the three requirements are:

a. Ascertain Customer Requirements (referred to as R1)
b. Design/Develop to Meet Customer Requirements (referred to as R2)
c. Assure That Customer Requirements Have Been Met (referred to as R3)

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-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:

R1—Ascertaining requirements includes identifying customer requirements for the product and the program
R2—Meeting customer requirements means building the product to meet customer requirements, and executing the required program to meet program requirements.
R3—Assurance means conducting verification activities on the product as well as monitoring and controlling the program (assuring that the program used to develop the product is executed correctly).

Central to all activities throughout the reliability program is the supplier-customer dialogue. This dialogue is essential to fully understand required product characteristics and application and should continue throughout the program to ensure that all customer requirements and changes are known by the supplier.

4.1.2 GENERIC DEVELOPMENT CYCLE PHASES—All products progress through a number of development life cycle phases[2], the definition of which may vary between organizations[3]. 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-cycle phases used are:

a. The Concept Phase which typically involves such actions as determining customer needs, understanding the products 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 and Use Phase which typically involves building, testing and deploying, and supporting operational units to users.

2. Since this document focuses on the development of new products, a complete set of life cycle phase definitions are not warranted.
3. Organizations may include commercial organizations at both the primary supplier and secondary supplier levels or contracting organizations and contractors.

4.1.3 RELIABILITY PROGRAM ACTIVITIES—A reliability program activity is a defined action that uses one or more methods to satisfy a reliability program requirement. The three requirements of SAE JA1000, i.e., R1, R2, and R3 each have their own set of reliability program activities. Table 3 illustrates the three requirements of SAE JA1000 along with the activities associated with each. The paragraph numbers from the standard are also shown. Table 4 provides a mapping of activities to R1, R2, and R3, cross referenced to the three generic product development cycle phases defined in 4.1.2. It should be noted that not all activities of SAE JA1000 may be applicable to every program. Activity selection should be part of the customer-supplier dialogue.

TABLE 3—SAE JA1000 REQUIREMENTS AND ASSOCIATED ACTIVITIES

Requirements		
R1 4.1 The Supplier Shall Ascertain Customer Requirements	R2 4.2 The Supplier Shall Meet Customer Requirements	R3 4.3 The Supplier Shall Assure That Customer Requirements Have Been Met
Activities		
4.1.1 Establish Supplier-Customer Dialogue	4.2.1 Characterize Resources	4.3.1 Qualify the Product and Process
4.1.2 Identify Conditions of Use	4.2.2 Assess and Manage Risk	4.3.2 Establish Process Controls
4.1.3 Define Maintenance and Service	4.2.3 Design to Achieve Reliability	4.3.3 Pursue Continuous Improvement
4.1.4 Establish Metrics		4.3.4 Establish Data Collection and Reporting
4.1.5 Develop Product Specification		

TABLE 4—RELIABILITY PROGRAM ACTIVITIES MAPPED TO REQUIREMENTS AND PHASES

	Concept Phase	Design and Development Phase	Product and Use Phase
R1	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(1) 4.1.2 Identify Conditions of Use(1) 4.1.3 Define Maintenance and Service(1) 4.1.4 Establish Metrics(1) 4.1.5 Develop Product Specification(1)	4.1.1 Establish Supplier-Customer Dialogue(1) 4.1.4 Establish Metrics(1)
R2	4.2.1 Characterize Resources 4.2.2 Assess and Manage Risk	4.2.1 Characterize Resources(1) 4.2.2 Assess and Manage Risk(1) 4.2.3 Design to Achieve Reliability	4.2.2 Assess and Manage Risk(1) 4.2.3 Design to Achieve Reliability
R3	4.3.4 Establish Data Collection and Reporting	4.3.1 Qualify the Product and Process 4.3.2 Establish Process Controls 4.3.3 Pursue Continuous Improvement 4.3.4 Establish Data Collection and Reporting	4.3.1 Qualify the Product and Process(1) 4.3.2 Establish Process Controls(1) 4.3.3 Pursue Continuous Improvement(1) 4.3.4 Establish Data Collection and Reporting(1)

1. Activity also appears in previous phase.

4.1.4 APPLICABLE METHODS (METHODS APPLICABLE TO R1, R2, AND R3)—Section 5 of this guide provides short descriptions for a number of reliability methods. Methods are used to accomplish activities. Tables 5A, 5B, and 5C list the methods in relation to their applicability to the requirements and activities of SAE JA1000 for the concept, design and development, and production phases respectively. The selection of methods is a highly individualized process. This point cannot be overemphasized 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. No priority of importance should be inferred by their relative listing in the tables.

TABLE 5A—MAPPING OF RELIABILITY METHODS TO SAE JA1000 REQUIREMENTS AND ACTIVITIES—CONCEPT PHASE

Requirement	Activities and Methods Concept Phase	Activities and Methods Concept Phase	Activities and Methods Concept Phase	Activities and Methods Concept Phase	Activities and Methods Concept Phase
R1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue a. Focus Groups b. Quality FUnction Deployment c. Reliability Benchmarking d. Risk Assessment e. Surveys/Market Analysis	Activity 4.1.2: Identify Conditions of Use a. Environmental Characterization b. Focus Groups c. Mission Profile Generation d. Quality Function Deployment e. Real World Usage Profiles f. Reliability Benchmarking g. Surveys/Market Analysis	Activity 4.1.3 Define Maintenance and Service a. Focus Groups b. Mission Profile Generation C. Quality Function Deployment d. Rearl World Usage Profiles e. Reliability Benchmarking f. Surveys/Market Analysis g. Reliability Allocation h. Reliability Centered Maintenance	Activity 4.1.4: Establish Metrics a. Environmental Characterization b. Pugh Selection c. Quality Function Deployment	Activity 4.1.5 Develop Product Specfication a. Environmental Characterization b. Mission Profile Generation c. Pugh Selection d. Quality Function Deployment e. Real World Usage Profiles f. Reliability Allocation g. Reliability Centered Maintenance
R2 The supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources a. Regression Analysis/ Correlation b. Production Process Capability Study	Activity 4.2.2 Assess and Manage Risk a. FMEA/FMECA b. Mission Profile Generation c. Probabilistic Design - Stress & Strength Interfer. Method d. Real World Usage Profiles e. Regression Analysis/Correlation f. Reliability Modeling and Prediction g. Risk Assessment h. FRACAS	i. Reliability Allocation j. Reliability Centered Maintenance k. Design Review l. Fault Tree Analysis	Activity 4.2.3: Design to Achieve Reliability a. Activity 4.2.3 is usually not applicable to the Concept Phase. However, the activities listed in the Design & Development Phase may begin in this phase.	
R3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process a. Activity 4.3.1 is usually not applicable to the Concept Phase. However, the activities listed in the Design & Development Phase may begin in this phase.	Activity 4.3.2 Establish Process Controls a. Activity 4.3.2 is usually not applicable to the Concept Phase. However, the activities listed in the Design & Development Phase may begin in this phase.	Activity 4.3.3 Pursue Continuous Improvement a. Activity 4.3.3 is usually not applicable to the Concept Phase. However, the activities listed in the Design & Development Phase may begin in this phase.	Activity 4.3.4: Establish Data Collection and Reporting a. Warranty Tracking/Info Collection b. FRACAS	

TABLE 5B—MAPPING OF RELIABILITY METHODS TO SAE JA1000 REQUIREMENTS AND ACTIVITIES—DESIGN AND DEVELOPMENT PHASE

Requirement	Activities and Methods Design and Development Phase	Activities and Methods Design and Development Phase	Activities and Methods Design and Development Phase	Activities and Methods Design and Development Phase	Activities and Methods Design and Development Phase
R1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue • Focus Groups • Quality FUnction Deployment • Reliability Benchmarking • Risk Assessment • Surveys/Market Analysis	Activity 4.1.2: Identify Conditions of Use • Environmental Characterization • Focus Groups • Mission Profile Generation • Quality Function Deployment • Real World Usage Profiles • Reliability Benchmarking • Surveys/Market Analysis	Activity 4.1.3 Define Maintenance and Service • Focus Groups • Mission Profile Generation • Quality Function Deployment • Real World Usage Profiles • Reliability Benchmarking • Surveys/Market Analysis • Reliability Allocation • Reliability Centered Maintenance	Activity 4.1.4: Establish Metrics • Environmental Characterization • Pugh Selection • Quality Function Deployment	Activity 4.1.5 Develop Product Specfication • Environmental Characterization • Mission Profile Generation • Pugh Selection • Quality Function Deployment • Real World Usage Profiles • Reliability Allocation • Reliability Centered Maintenance
R2 The Supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources • Regression Analysis/ Correlation • Production Process Capability Study	Activity 4.2.2 Assess and Manage Risk • FMEA/FMECA • Mission Profile Generation • Probabilistic Design - Stress & Strength Interfer. Method • Real World Usage Profiles • Regression Analysis/ Correlation • Reliability Modeling and Prediction • Risk Assessment • FRACAS	• Reliability Allocation • Reliability Centered Maintenance •. Design Review • Fault Tree Analysis	Activity 4.2.3: Design to Achieve Reliability • Block Diagram Development • Environmental Characterization • FMEA/FMECA • Fault Tree Analysis • Mission Profile Generation • Probabilistic Design - Stress and Strength Interfer. Method • Pugh Selection • Quality Function Deployment • Real World Usage Profiles • Regression Analysis/ Correlation • Reliability Modeling and Prediction • Accelerated Testing • Design for Mfg/Assembly	• Design of Experiments • Error/Mistake Proofing • Fault Tolerance Analysis • Finite Element Analysis • FRACAS • Pareto Analysis • Part Derating • Reliability Allocation • Reliability Centered Maintenance • Robust Design • Root Cause Analysis • Sneak Circuit/Path Analysis • Variation Simulation Modeling • Wiebull Analysis • Worst Case Analysis • Quality Loss Function • Design Review
R3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process • Risk Assessment • Accelerated Testing • Error/Mistake Proofing • Pareto Analysis • Production Process Capability Study • Reliability Growth Testing • Environmental Stress Screening • Reliability Demo Testing • Sampling Procedures	Activity 4.3.2 Establish Process Controls • Design Review • Risk Assessment • Error/Mistake Proofing • Pareto Analysis • Parts, Materials, Process Review Control • Production Process Capability Study •Environmental Stress Screening • Sampling Procedures • Statistical Process Control	Activity 4.3.3 Pursue Continuous Improvement • Design Review • Warranty Tracking/Info. Collection • Error/Mistake Proofing • Pareto Analysis • Production Process Capability Study •Sneak Circuit/Path Analysis •Statistical Process Control	Activity 4.3.4: Establish Data Collection and Reporting • Warranty Tracking/Info Collection • Accelerated Testing • FRACAS •Pareto Analysis • Reliability Growth Testing	•Environmental Stress Screening •Reliability Demonstration Testing • Sampling Procedures • Statistical Process Control

TABLE 5C—MAPPING OF RELIABILITY METHODS TO SAE JA1000 REQUIREMENTS AND ACTIVITIES—PRODUCTION AND USE PHASE

Requirement	Activities and Methods Production and Use Phase	Activities and Methods Production and Use Phase	Activities and Methods Production and Use Phase	Activities and Methods Production and Use Phase	Activities and Methods Production and Use Phase
R1 The Supplier Shall Ascertain Customer Requirements	Activity 4.1.1: Establish Supplier-Customer Dialogue • Focus Groups • Quality Function Deployment • Reliability Benchmarking • Risk Assessment • Surveys/Market Analysis	Activity 4.1.2: Identify Conditions of Use • Methods from the Design and development Phase may continue into this phase.	Activity 4.1.3 Define Maintenance and Service • Methods from the Design and Development Phase may continue into this phase.	Activity 4.1.4: Establish Metrics • Environmental Characterization • Pugh Selection • Quality Function Deployment	Activity 4.1.5 Develop Product Specfication • Methods from the Design and Development Phase may continue into this phase.
R2 The Supplier Shall Meet Customer Requirements	Activity 4.2.1: Characterize Resources • Methods from the Design and Development Phase may continue into this phase.	Activity 4.2.2 Assess and Manage Risk • FMEA/FMECA • Mission Profile Generation • Probabilistic Design - Stress & Strength Interfer. Method • Real World Usage Profiles • Regression Analysis/ Correlation • *Reliability Modeling and Prediction* • Risk Assessment •Error/Mistake Proofing • Fault Tolerance Analysis • Finite Element Analysis • FRACAS	• Pareto Analysis • Parts Derating • Parts, Materials, Process Review/Control • Reliability Allocation • Reliability Centered Maintenance •Root Cause Analysis • Sneak Circuit/Path Anal • Wiebull Analysis • Worst Case Analysis • Quality Loss Function • Design Review • Reliability Growth Testing • Fault Tree Analysis	Activity 4.2.3: Design to Achieve Reliability • Methods from the Design and Development Phase may continue into this phase.	
R3 The Supplier Shall Assure That Customer Requirements Have Been Met	Activity 4.3.1: Qualify the Product and Process • Design Review • Risk Assessment • Accelerated Testing • Error/Mistake Proofing • Pareto Analysis • Production Process Capability Study • Reliability Growth Testing • Environmental Stress Screening • Reliability Demo Testing • *Sampling Procedures*	Activity 4.3.2 Establish Process Controls • Design Review • Risk Assessment • Error/Mistake Proofing • Pareto Analysis • Parts, Materials, Process Review Control • Production Process Capability Study •Environmental Stress Screening • Sampling Procedures • Statistical Process Control	Activity 4.3.3 Pursue Continuous Improvement • Design Review • Warranty Tracking/Info. Collection • Error/Mistake Proofing • Pareto Analysis • Production Process Capability Study •Sneak Circuit/Path Analysis •Statistical Process Control	Activity 4.3.4: Establish Data Collection and Reporting • Warranty Tracking/Info Collection • Accelerated Testing • FRACAS •Pareto Analysis • Reliability Growth Testing	•Environmental Stress Screening •Reliability Demonstration Testing • Sampling Procedures • Statistical Process Control

4.1.5 METHOD SELECTION CRITERIA—Selecting methods for a given program is a highly individualized process. This point cannot be overemphasized 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 procedures.

However, selecting methods can be made easier by using the criteria listed in 4.1.5.1, Examples 1 and 2 (4.1.5.2 and 4.1.5.3), and Section 5 of this guide (Section 5 provides short descriptions of various methods including their purpose, intended application, benefits, and limitations).

4.1.5.1 *Sample Criteria for Selecting Reliability Methods*

a. Improves the total quality of the product
b. Reduces the time to field the product
c. Is cost effective
d. Reduces safety and environmental risks
e. Has the potential to achieve a "quantum improvement" in the product
f. Can be used within current resource constraints
g. Is proven
h. Is efficient and easily executed
i. Is directly focused on the product under development
j. Has management buy-in for use
k. Is perceived as "best-in-class"
l. Is planned for use based on previous experience
m. Is quantifiable
n. Can be easily introduced to those who must apply
o. Is simple to apply

The following examples illustrate two ways methods could be selected. Example 1 shows a *qualitative* approach, and Example 2 is *quantitative.*

4.1.5.2 *Example 1: Using Decision Matrixes To Tradeoff Between Criteria (Qualitative Approach)*—There are many factors to consider in selecting reliability method(s) for a product development program. It is desirable that a method would possess all or many of the criteria listed in 4.1.5.1. However, it is unlikely that any one method would have many, or all of them. Therefore, it is sometimes necessary to do a tradeoff evaluation. The following example (Figure 1A) shows Time Required to Implement versus Cost. The optimum condition would be a "short" time to implement at a "low" cost. However, in any given situation there may be a need to tradeoff cost to speed the implementation of a method. In another situation, it may be important to lower cost and extend the time necessary to implement.

The same principle is illustrated in the Figure 1B, matrix "Level of Skill" versus "Method Type." In fact, any of the criteria listed in 4.1.5.1 (or other criteria) may be evaluated to help determine the most effective method for a given situation.

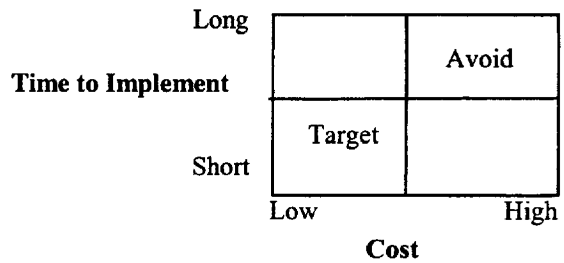

FIGURE 1A—METHOD SELECTION CRITERIA: TIME TO IMPLEMENT VERSUS COST

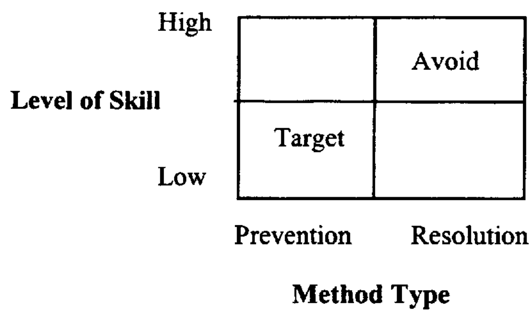

FIGURE 1B—METHOD SELECTION CRITERIA: LEVEL OF SKILL VERSUS METHOD TYPE

4.1.5.3 *Example 2: Selecting Methods Using Group Prioritization and Relative Weighting (Quantitative Approach)*—Company ABC needs to improve a product design. Based on a review of the method descriptions in Section 5, the product development team has determined that either "Method 1" or "Method 2" would be useful in this situation. The team has also determined that implementing both methods would be too costly and must therefore select one. The process used to select the better method is illustrated in Figure 2.

1	2	3	4	5	6
Applicable Criteria	Weighting	Method 1	Method 2	Method 1 Col 2 x Col 3	Method 2 Col 2 x Col 4
a.	3	0	1	0	3
c.	6	1	0	6	0
g.	2	1	0	2	0
h.	5	1	0	5	0
j.	1	0	1	0	1
l.	4	1	0	4	0
			Scores:	17	4

FIGURE 2—SAMPLE CRITERIA USED TO SELECT BETWEEN METHODS

(Refer to Figure 2) Column 1 lists the applicable method criterion, identified a thru o in 4.1.5.1. These were selected through a brainstorming session. Attributes a, c, g, h, j, and l are considered important for the development of this product.

Column 2 ranks the criteria relative to their importance to the product development. The rankings were determined through use of a group prioritization exercise. The highest priority criteria was assigned a weight of 6, second highest a weight of 5, and so on. In this example, c ("Is very cost effective") is most highly weighted (6).

Columns 3 and 4 are either 1 or 0 depending on the group consensus as to which of the two methods best meets the intent of the criterion. In this example, h ("Is efficient and easily executed") is best met by Method 1.

Columns 5 and 6 are the scores for each method (the product of Weighting and Method). The column is then added. Since the Method 1 scored 17 and Method 2 scored only 4, the decision is to use Method 1.

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

4.2.1 RELIABILITY PROGRAM PLAN—A product development program normally has a documented plan. The plan for the reliability program could be a stand-alone reliability program plan or integrated in the broader overall program plan (e.g., product assurance plan). The plan should document the following program details:

a. A description of how the reliability program will be conducted to meet customer requirements.
b. A description of how each reliability activity and method will be performed.
c. Identification of the relevant points of contact responsible for managing the reliability program and those responsible for implementing each activity and method.
d. A description of critical activities.
e. A description of how reliability elements will interface with other engineering disciplines and how reliability tasks and activities are disseminated to designers and other associated personnel.
f. A schedule with estimated start and completion points for all activities and methods.
g. A description of known reliability 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.
h. Statements of sources of reliability guidance documentation.

   1. Identification of inputs required from other disciplines necessary to help implement reliability activities and methods.
   2. Resource allocation information.

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

4.2.2 RELIABILITY PROGRAM IMPLEMENTATION—As each reliability program will be implemented differently according to the particular product development strategy and unique program issues, Tables 4, 5A, 5B, and 5C show how all the elements described in this implementation guide may come together for the implementation of the reliability program. Keep in mind that every organization will have their own phase terminology which will most likely differ from that shown here.

4.3 Reliability Program Metrics—Metrics provide a mechanism for monitoring product and process characteristics to facilitate control over a product's development. In the context of this implementation guide, the metrics of concern are those that measure the reliability characteristics of a product and any process characteristics that may affect the reliability of that product. It is generally recognized that metrics may be applied in either the process or product domains. These two categories provide a mechanism for classifying the plethora of metrics into manageable groupings of either product metrics, which relate to the characteristic of the product (e.g., MTTF, MTBF, Failure Rate, Defect Rate/Defect Density), or process metrics, which relate to the characteristic of the processes used in the development of the product (e.g., Process Capability Level Indices (Cp.)).

4.3.1 KEY ELEMENTS—The measurement process is a control process and as such can be effectively modeled by the four elements of the PDCA closed loop process (Figure 3): [1]

a. Plan - deciding what product or process characteristics to measure, defining the process by which the characteristics will be measured and establishing quantifiable targets or trigger points.
b. Do - monitoring and gathering data on the object of measurement (product or process).
c. Check - evaluating data against defined target values and reporting results.
d. Act - deciding whether to maintain the status quo or make a change to the object being measured.

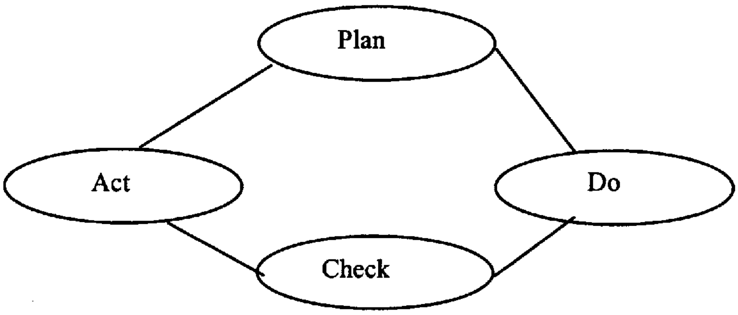

FIGURE 3—THE MEASUREMENT MODEL

4.3.2 PLANNING THE METRICS EFFORT—There are three key elements to planning the metrics effort:

a. Define and Document the Object of Measurement—Define and document the object of measurement (product or process) in a concise and unambiguous manner. This information should be documented in the reliability program plan (or equivalent document).
b. Define and Document Quantifiable Targets—This is essential, as without measurable targets or trigger levels there are no indicators to enable management to make informed decisions. This information should also be documented in the reliability program plan (or equivalent document).
c. Define and Document the Measurement Method—Define the method by which the subject characteristics will be measured[4]. This includes selecting the metric(s) and defining the data collection process. In selecting a metric, care should be taken to ensure that the metric is: [2]

1. Accurate and sufficient
2. Efficient to collect (cost effective)
3. Timely
4. Understandable (simple)
5. Useful (needed and meaningful) and
6. Traceable to the organizations/customers objectives[5]

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4. The only effective way to measure or predict reliability, to date, is through the use of defect data or operational failure data. In the area of project control, the main concern of metrics is related to faults and changes required to correct faults.
5. This last point is an important issue which is normally understated. If a metric is not easily related to the method by which a customer defines needs, or the way an organization defines its objectives in developing a product, then inappropriate metrics may be used to monitor a products development.

One mechanism that may be used to assess the quality of the metric selected is to use the SMART test as described in the Department of Energy PBM handbook [3]:

a. S - Specific; clear and focused to avoid misinterpretation (should include measure assumptions and definitions).
b. M - Measurable; can be quantified and compared to other data. It should allow for meaningful statistical analysis.
c. A - Attainable; achievable, reasonable, and credible under conditions expected.
d. R - Realistic fits into the organizations constraints and is cost-effective.
e. T - Timely; doable within the time frame given.

The selected metrics and the process to be used should be documented in the reliability program plan (or equivalent document). In the case of metrics, the definitions should include not just the name but also description of Purpose, Data Inputs and Collection, and Use.

Data collection procedures should include Organizational Details, i.e., who's responsible for collecting, verifying, and analyzing the data, and should be documented in the reliability program plan (or equivalent document). To enable efficient collection of the data, some consideration should be given to:

a. The means by which this possibly large volume of data is to be stored
b. The degree of overhead to be placed on those responsible for monitoring or collecting the data
c. The appropriateness of the storage mechanism for timely dissemination of information to management

Timely reporting of any results is essential to enable management to make a decision. Agencies responsible for reporting and the reporting chain should be explicitly defined and documented in the reliability program plan (or equivalent document).

4.3.3 GATHERING AND EVALUATING DATA AND REPORTING RESULTS—Throughout the product development, data on the defined metrics concerning the product and process characteristics are monitored and collected, and actions taken as necessay. Data may be collected continuously, at specific intervals, or based on some event. Management can be alerted to the need for possible actions, such as redesign, change in parts, etc., based on trending analysis or a triggering event (when a limit is exceeded). Trending is used to compare achieved results with some predefined goal. Triggering occurs when a predefined limit or trigger point is exceeded. Trending is preferred because it provides an early indication of potential problems, i.e., it is proactive. Depending on where the trigger point is set, when a limit exceeded, the problem has usually already occurred.

Timely reporting of any results, even before an unacceptable condition has occurred (e.g., observing unfavorable trends), is essential to enable management to make a decision. "The quicker the response from the standard, the more uniform the produced quality." [1]

4.3.4 ACTING ON THE RESULTS—Once a condition(s) has been reported, it is up to management to make a decision to maintain the status quo or change product/process. If there are any changes to the metrics or mechanism by which the metrics are collected, these changes should be documented in the reliability program plan (or equivalent document).

5. ***Reliability Methods***—A product team[6] typically uses a number of engineering, mathematical, and managerial techniques to achieve the objectives of reliable 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 reliability methods. The purpose of this section is to provide the reader with concise descriptions of a number of reliability methods in the industrial, military, governmental, and academic world that are available to product teams.

The product team needs two kinds of information to properly apply reliability methods to the reliable 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 reliability methods to use at various points in the making of a reliable 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 situation. This information then enables the team to identify the activities that need to be performed at various points during product development to ensure a reliable product. The team may then compile a reliability program that is in consonance with the overall product development plan.

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

5.1 **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 of each section is similar across descriptions. This is done to ensure uniformity and to assist the product development team in selecting the reliability method that best suits their needs.

5.2 **Criteria for Inclusion of Reliability Methods in this Guide**—Reliability impacts such a large number of activities, that it is sometimes difficult to conclusively say whether or not a particular method is a reliability method. Thus, in order to define the scope of this section, the reliability methods included in this Guide were selected on the basis of the following criteria:

a. Must be a generally recognized practice in at least one industry segment (i.e., not unique to a single company)
b. All methods must have a similar level of heirarchy (i.e., neither too narrow nor too broad)
c. Must be a technique, not a "process" or a "subject"
d. Must be generally considered as a technique that impacts reliability
e. Must not be proprietary to any individual or organization

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6. A product development "team" commonly refers to multi-discipline organizations. However, a product development "team" could be any size, a few or even an individual.

f. Must not be exclusive to software products only

With this brief overview, we now turn to the reliability methods.

Reliability Method Descriptions Page Index

6. ***Acknowledgements***—The individuals from the SAE G-11 Reliability Program Standard Subcommittee, with the support of their sponsoring organizations, have devoted a great amount of time and resources toward the development of the SAE Reliability Program Standard and 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.

Some method descriptions included in Section 5 were contributed by Rome Laboratory, Rome, NY and their contracted agency, Boeing Aircraft. These method descriptions have been formatted or edited with permission. The SAE G-11 RMSL Division Reliability Program Subcommittee gratefully acknowleges this contribution.

PREPARED BY THE SAE G-11 RELIABILITY PROGRAM STANDARD SUBCOMMITTEE

APPENDIX A

A.1 Accelerated Testing

A.1.1 Description—In planning and executing a test, there will often be some need to shorten the test time to obtain information quickly and efficiently with cost, manpower, and facility constraints. This means testing has to be accelerated.

A.1.2 Purpose—Accelerated testing is used to:

a. Remove Dormant Time (or Cycle, Mileage, Revolutions, etc.) and also remove non-damaging and/or less damaging occurrences (Expedited Testing)
b. Determine the critical stressor(s) for acceleration
c. ncrease the level of stress, i.e., higher than normal stressor (or stress factor) magnitude (Single Factor Accelerated Test)
d. Simultaneously increase more than one stressor/factor (Multiple Factors Accelerated Test)

A.1.3 Application—Accelerating test can be used in all product development phases in determining requirements through bench-marking, in robust design study and prototype testing, and in Key Life Tests and/or other Design Verification tests.

A.1.4 Key Elements

a. Identify the objective and scope of the accelerated test. A typical test may have one or more of the following objectives:
   1. Compare the estimated life of two or more designs,
   2. Develop a relationship between stress and life,
   3. Estimate the life of a product at a given stress condition,
   4. Investigate failure modes at elevated stress,
   5. Verify known stress-life model limitation.
b. Collect and understand the failure-related and usage-related information.
c. Identify desired test duration.
d. Determine test duration by removing dormant time/cycle and non/less damaging cycle. This step shortens test time by removing unimportant cycles or time without affecting stress(es). This is the least risky way of shortening time and it is strongly recommended to execute this first.
e. Determine single stressor. After removing dormant time and non/less damaging cycles, test must now be accelerated by selecting a critical stressor. The selected stressor should have a significant impact on accelerating failure modes of interest and should not introduce new failure modes.
f. Identify single factor stress-life model. Once the stress factor is determined, life as a function of this stress factor should be established. This relationship is generally referred to as the S-N curve.

A.1.5 Benefits

a. Shortens product verification time which helps to reduce product design cycle
b. Can reduce product development cost
c. Reveals rapid product performance information for design evaluation
d. Provides an estimation of life in relation to the stress(es) induced for decision making on design
e. Provides a baseline for determination of Environmental Stress Screening parameters
f. Enables early identification of potential failure modes

A.1.6 Limitations

a. Excessive stresses may induce a physical change in the product and/or casue unrealistic damage
b. Cumulative damage to the product may not correlate accurately to actual product usage and determination of the acceleration factor may be difficult
c. Cannot be undertaken until product (or prototype) is available

A.1.7 References

a. Hu, J.M., Barker, D., Dasgupta, A., and Arora, A. "*Role of Failure-Mechanism Identification in Accelerated Testing*," Journal of the IES, July/August, 1993, pp. 39-45
b. Meeker, W. and Hahn, G. "*How To Plan An Accelerated Life Test --- Some Practical Guidelines*," The ASQC Basic Reference in Quality Control, Vol. 10, June 1985, pp. 1-36
c. Nelson, Wayne. "*Accelerated Testing*," John Wiley & Sons, 1990
d. Rabinowicz, E., McEntire, R.H., and Shiralkar, B. "*A Technique for Accelerated Life Testing*," Transactions of ASME, August, 1970, pp.706-710

A.2 Block Diagram Development

A.2.1 Description—There are three commonly used block diagrams:

a. Hierarchy Block Diagram—Breaks a product into natural and logical elements and becomes more detailed at each level down, e.g., vehicle, chunk, system, subsystem, and component.
b. Functional Block Diagram—Breaks the system into its smaller elements and shows the functional and physical relationships among the elements.
c. Reliability Block Diagram—Breaks a system into smaller elements and shows the relationship from a reliability standpoint; that is, the sequence and relationships of elements that define operational failure or success of a system.

A.2.2 Purpose—The purpose of a block diagram is to divide a complex system into more manageable levels and to depict the relationships among various elements in a system.

A.2.3 Application—Block diagrams are among the first tasks completed during product definition. They should be constructed as part of the initial concept development. They should be started as soon as the program definition exists, completed as part of the requirements analysis, and continually expanded to a more detailed level as data become available in order to make decisions and trade-offs.

A.2.4 Key Elements—The following are the key elements of block diagrams

a. Determine both the system boundaries and the levels of detail or complexity to be analyzed.
b. Partition the system into logical subsystems or components
c. Identify the physical and functional relationships of the various elements of a system
(Additional elements specific to reliability block diagrams)

1. Define system reliability
2. Translate to a mission success diagram, which is a Reliability Block Diagram (RBD) constructed using the basic configurations of series, parallel, and complex subsystems
3. Conduct qualitative analysis, such as the success path from input to output
4. Develop reliability model to quantify the reliability of the system at a specific time as depicted by the RBD
5. Assign reliability for each block and calculate system reliability

A.2.5 Benefits

a. Facilitates an understanding of the system by showing the relationships among its elements
b. Can provide a visualization of the flow of information within a system
c. Assists in identification of, or lack of, redundant features and paths
d. Provides inputs to other reliability methods, e.g., Failure Modes and Effects Analysis/Failure Modes, Effects, and Criticality Analysis, Reliability, Prediction, and Fault Tree Analysis
e. Provides input to facilitate design decisions and trade-offs

A.2.6 Limitations

a. May provide an overly simplistic view of a complex system
b. The level of detail of the block diagram may mask the functional interdependencies of its elements
c. The diagram does not show the physical location of elements within the system. This may constitute a problem if the elements are affected by their relative locations.

A.2.7 References

a. Denson, W. and Chandler, G. "*Nonelectronic Parts Reliability Data*," Reliability Analysis Center, Department of Defense Information Analysis Center.

b. Kapur, K.C. and Lamberson, L.R. "*Reliability in Engineering Design*," Wiley, New York, 1977.

c. Lewis, E.E. "*Introduction to Reliability Engineering*," Wiley, 1987.

A.3 Design for Manufacturing (DFM) and Design for Assembly (DFA)

A.3.1 Description—DFM and DFA are methods encompassing core design principles and several related design analysis methods focusing on production manufacturing and assembly. They seek to optimize the activities of product design, manufacturing, and ease of assembly into a single multifunctional, simultaneous engineering activity.

A.3.2 Purpose—The purpose of DFM and DFA is to optimize a product consistent with the intended manufacturing, assembly, and service strategy. Specific objectives include:

a. Assures that manufacturing, assembly, and service of the design is well matched to the intended strategies
b. Assures that every unit is produced correctly without adverse affect on function, appearance, or reliability
c. Promotes concurrent engineering, cross-functional teamwork, and consensus decisions
d. Balances design features to production methods resulting in minimum overall costs and maximum value
e. Assures easy serviceability
f. Enhances ergonomic conditions for production operators and service technicians

A.3.3 Application—DFM and DFA are applicable to any product that must be manufactured and/or assembled. They are especially valuable where the original design requires multiple fasteners, and steps in the manufacturing and assembly processes.

A.3.4 Key Elements—DFM and DFA core principles include teamwork, integration, and minimization of part count, easy error-proof assembly (Poke-Yoke), ergonomic driven operations, avoidance of adjustments and fasteners, obvious part identification, and easy part handling. The main points of DFM and DFA consider the following:

a. Gravity is the assembly's best ally
b. Sufficient room for hands and standard tools
c. Visibility of operation
d. Holding/resistance to insertion
e. Insertion guidance
f. Ease of alignment and positioning
g. Fasteners versus snap together
h. One person assembly
i. One hand retrieval and positioning.

Handling issues include:

a. Size and weight
b. Two-handed insertion and assembly
c. Fragile, flexible or won't hold its own shape
d. Tangles and nesting problems
e. Sticky, sharp, hot, slippery
f. Handling or adjustment.

Examples of qualitative measures that have been marketed to assess effectiveness include the Lucas Design Efficiency (number of essential parts/total parts), Xerox Producibility Index (sum of each part's assembleability rating/total parts), the Boothroyd and Dewhurst Design Efficiency (3 x total essential parts/total assembly time), and the Westinghouse DFA Calculator (assembly time predictor). Numerous company assessment methods have also been developed with their approaches widely published.

A.3.5 Benefits

a. Encourages design teams to consider the impact of design on how the product is manufactured and assembled
b. Leads product development teams towards less complex designs
c. Reduces manufacturing and/or assembly time
d. May result in improved manufacturing and assembly processes
e. Encourages Human Factors' and ergonomic considerations during design

A.3.6 Limitations

a. Projected savings in time and cost may be overly optimistic
b. Improvements may not be applicable to other similar products
c. The method is labor intensive and requires a cross-functional team with a high level of technical and interpersonal skills
d. Needs to be done in coordination with other method, such as FMEA, that ensure failure modes are not introduced
e. Elements that help DFM/A may have an adverse effect upon reliability, maintainability and supportability.

A.3.7 References

a. Ardayfio, D., Carlson, A., and Marcel, R., "*Application of DMFA in Automotive Vehicle Development*," Paper No. 92-DE-7, The American Society of Mechanical Engineers, 1992
b. Adler, R. and Schwager, F., "*Software Makes DFMA Child's Play (Westinghouse DFA Calculator)*," Machine Design, April 9, 1992
c. Boothroyd, G. and Dewhurst, P., "*Product Design for Assembly*," Boothroyd and Dewhurst, Inc., 1987
d. Munro and Associates, Inc., "*Design for Manufacture*," Participant Training Manual (Lucas DFM Technique), 1994

A.4 *Design of Experiments (Classical)*

A.4.1 **Description**—If an experiment is to be performed most efficiently, then a scientific approach to planning must be employed. The Design of Experiments refers to the process of planning the experiment so that appropriate data will be collected, which may be analyzed by statistical methods resulting in valid and objective conclusions. The statistical approach to experimental design is necessary if one wishes to draw meaningful conclusions from the data. When the problem involves data that are subject to experimental errors, the statistical methodology is the only objective approach to analysis. Thus, there are two aspects to any experimental problem: the design of the experiment and the statistical analysis of the data. These two subjects are closely related, since the method of analysis depends directly on the design employed.

A.4.2 **Purpose**—A designed experiment is a plan for data collection and analysis directed at making a decision about whether or not one treatment is better than another.

A.4.3 **Application**—Experiments are carried out by investigators in all fields of study either to discover something about a particular process or to compare the effect of several factors on some phenomenon. In the engineering and scientific research environment, an experiment may either be a *confirmation* (verify knowledge about the system) or *exploration* (study the effect of new conditions on the system). In industrial research, the experiment is almost always an intervention or change in the routine operation of a system, which is made with the objective of measuring the effect of the intervention.

A.4.4 **Key Elements**—The three basic principles of experimental design are *replication* (a repetition of the basic experiment), *randomization* (both the allocation of the experimental material and the order in which the individual runs or trials of the experiment are to be performed are randomly determined), and *blocking* (a technique used to increase the precision of an experiment). The steps involved in the design of experiments are:

a. Recognition of and statement of the problem
b. Choice of factors and levels
c. Selection of a reponse variable
d. Choice of experimental design

    1. Array type (orthogonal or other)
    2. Replication, randomization, and blocking
    3. Sample Size

e. Performance of the experiment
f. Data analysis
g. Conclusions and recommendations

A.4.5 **Benefits**

a. Allows simultaneously studying of effects of various factors, thereby facilitating design optimization
b. Identifies relationship between cause and effect
c. Provides an understanding of interactions among causative factors
d. Minimizes experimental error (noise), i.e., variation from disturbing factors, (known and unknown)
e. Can be used in a simulation environment, i.e., before product (or prototype) is available
f. The method can be used to make designs insensitive to variation (see also Robust Design)

A.4.6 **Limitations**

a. Training is required in order to develop and analyze an experimental design
b. Selection of proper experimental factors is critical to successful experimentation
c. When done on actual prototypes, numerous build configurations may be required

A.4.7 References

a. Montgomery, D.C., "*Design and Analysis of Experiments,*" John Wiley & Sons (1984)
b. Box, G.E.P., Hunter, W.G., and Hunter, J.S. "*Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building,*" John Wiley & Sons (1978)
c. Scheaffer, R.L. and McClave, J.T., "*Probability and Statistics for Engineers,*" Duxbury Press (1995)

A.5 Design of Experiments (Taguchi)

A.5.1 **Description**—Taguchi DOE is a systematic methodology, developed by Dr. G. Taguchi, that leads to most cost effective product that is least sensitive to uncontrolled/uncontrollable noises ("noise" is any uncontrollable variation which affects the performance of the system). It consists of three phases called system design, parameter design, and tolerance design. Most widely used parameter design uses an outer noise array with traditional factorial inner array design. Concept of signal-to-noise ratio which incorporates location and variability measure through loss function is used as performance measure. Initial static concept has been now extended to dynamic cases where response changes over operational range like fluid flow over operating "rpm". In dynamic case, energy based system ideal function is maximized at the expense of error states (failure modes). This powerful concept of maximizing what you want versus traditional failure elimination gives Robust Design a special place in making reliable product (eliminating a specific failure does not guarantee increase in useful work).

A.5.2 **Purpose**—The purpose of Robust Design is to gain a competitive advantage by simultaneously focusing on trio of quality, cost, and speed. Staying on customer target with the least variation despite "noises" yields superior quality, use of cost sensitive parameter during parameter design gives economy and focusing on maximizing "good" versus eliminating failure states gives speed.

A.5.3 **Application**—Robust Design has been successfully used in wide variety of industries and disciplines. It is used during product development, design, verification, and manufacturing stages. When used in early design stages, it best yields its potential of improved quality, cost, and timing. Scope of application is also wide, from personal baking to complex product, service industry, etc.

A.5.4 **Key Elements**—Dynamic parameter design represents general case. Static is a specific single point case of dynamic. In static case, one of the Nominal-The-Best, Smaller-The Better, or Larger-The-Better signal-to-noise ratio is utilized while in dynamic case, system ideal function is used. In either case, two step optimization, (a) shrink and (b) shift, is used to obtain the desired target with the least variability. The system is characterized by control factors, noise factors, input signals (customer intent) and output signals, the system ideal function and associated error states. All these are displayed in what is termed as P-Diagram. Key to the successful implementation is defining ideal function, control factors/noise factors association, measurement strategy, and meaningful execution of test strategy.

A.5.5 Benefits

a. Quality, cost, and timing superiority
b. When used in conjunction with analytical approach, paper to product is feasible
c. Prevention based approach versus detection, i.e., proactive versus reactive
d. Operational/execution superiority due to:

   1. Randomization is not required
   2. Orthogonal Array and linear graphs
   3. Simple two step optimization
   4. Conformational runs to quantify improvement

e. Designed for engineers versus statisticians

A.5.6 Limitations

a. High level of complexity (resources, time, execution cost)
b. Lack of availability of adequate training in the field
c. Lack of management confidence in the tool

A.5.7 References

a. Fowlkes, W.Y., Creveling, C.M., "*Engineering Methods for Robust Design*," Addison-Wesley, 1995
b. Roy, R., "*A Primer on the Taguchi Method*," Van Nostrand Reinhold, 1990
c. Phadke, M.S., "*Quality Engineering Using Robust Design*"

A.6 Design Review

A.6.1 Description—Design review is a formal, structured examination of the work of the design/development team by peer and colleague experts to detect and remedy deficiencies in the design, and assess the status of development of a component, system, or end item. It is intended to review all aspects of the product and process planning, design, analysis, testing, and launch readiness. Realiability should be explicitly included in each design review.

A.6.2 Purpose—Design reviews assure that the design and development of parts and processes are systematically examined by objective experts prior to full scale production to assure the designs meet the customer's requirements. Design reviews provide direction, establish an organized forum for problem prevention discussions, utilize the collective expertise of all affected areas, and provide specific follow-up responsibility.

A.6.3 Application—Design reviews are used for:

a. Clarifying customer requirements
b. Reviewing progress against the development plan for a product or process
c. Assuring corporate design policy is understood and consistently applied across affected organizations
d. Hearing the collective experience and judgements of experts from all areas
e. Assuring follow-up responsibility and timing is identified for specific issues

A.6.4 Key Elements

a. The three key elements to a design review are:

1. Schedule—Design reviews should be scheduled to precede major milestone events in a development program. They should be scheduled far enough in advance to allow all teams to conduct internal design reviews in preparation for the formal design review.
2. Agenda—An agenda should be published indicating the review topics and order of review. The agenda should be designed to assure a clear understanding of the design objectives, progress made against those objectives, and risks and opportunities with recommendations.
3. Operating Rules—To conduct successful design reviews:

    a. The design review should not be viewed as an attack on the design team but as a forum to help resolve issues beyond the control of the team and an opportunity for the team to learn from experts in other disciplines.
    b. Interface issues must be addressed from a positive team standpoint.
    c. Design reviews should be scheduled to allow time to react during the design cycle to issues raised.
    d. The review team should consist of peers and colleagues who have the expertise, depth of knowledge, and experience to assess the adequacy of the design to meet customer and program requirements.
    e. The material to be discussed should be distributed prior to the actual review.
    f. Follow-up and closure or risks and opportunities along with assignments and timing should be provided for all issues.

A.6.5 Benefits

a. Improves the design by integrating knowledge from peer subject matter experts
b. Greater understanding of requirements
c. Focused effort - more unity within the team
d. Minimizes downstream design changes
e. Increases teamwork and communication among the team members

A.6.6 Limitations

a. If not properly conducted, can be come adversarial and counterproductive
b. If held too often, can slow the product development process
c. If held too infrequently, may result in inferior designs

A.6.7 References

a. "*Handbook of Reliability Engineering and Management,*" Ireson, W. Grant; Coombs, Jr., Clyde F., McGraw Hill, 1966
b. "*Practical Reliability Engineering,*" Third Edition, O'Connor,Patrick, D. T., John Wiley & Sons, 1993
c. "*Reliability Engineering Bible,*" Dodson, Bryan; Nolan, Dennis, Quality Publishing, 1995

A.7 Environmental and Product Usage Profile

A.7.1 Description—Environmental and Product Usage Profiles (EPUP) quantify the operational frequency, load, and environmental extremes under which the customer uses a product. EPUP is intended to represent the actual customer usage of the product in terms of frequency, loads, stresses, and environmental conditions. It includes a detailed study of all types and ranges of environmental parameters encountered by a system during it's entire lifecycle. EPUP also identify the ranges of operating conditions that the system must accommodate as well as the frequency of usage of each system or component within the product. Furthermore, EPUP profiles may provide the necessary information for determining percentiles of customer usage and environmental levels.

A.7.2 Purpose—The output from EPUP is used as input to concept selection, material selection, test design, specification development, and process design. It is also used to identify the environmental conditions a system will face in the field and determine the correct design solutions to any potential environmentally induced failures.

A.7.3 Application

a. Generic EPUP need to be collected prior to the product development while the previous version of the product is in customer use.
b. EPUP should be included in product development when there is an opportunity for cost savings or a significant increase in customer satisfaction.
c. Safety issues, customer satisfaction, and high warranty items should be considered when prioritizing which EPUP to acquire.
d. EPUP is needed in those designs where the information on the environmental impact on system performance is limited or the design is new to the environment.

A.7.4 Key Elements

a. Identify the "trigger" event to initiate or prioritize the development of EPUP, e.g., high warranty item, emerging market, customer satisfaction, safety issue, etc.
b. Identify engineering scope, e.g., system on which to obtain the usage profile, item functions, etc.
c. Plan data collection and collect data.
d. Analyze the data and translate customer usage to system/component duty cycle.
e. Document and disseminate results and recommendations
f. Analyze the product's components to determine if they can withstand the usage and environmental types and ranges identified.
g. Evaluate the design, identify of any weaknesses, list the design improvement options, and implement corrective action.

A.7.5 Benefits

a. Help product design engineers have a better understanding of how customers actually use the product.
b. Clarify the operating environment and quantify the stress levels applied to the products.
c. Products that have been designed with information from usage profiles during the product development process will have fewer field surprises and recall campaigns and will yield higher customer satisfaction.
d. Usage profiles help in identifying noise factors for robust design, identifying duty cycles for Key Life Tests, preventing under-design and over-design of products.
e. Provides vital information about the environmental conditions that the product will encounter.
f. Assists in environmental parameter selection for simulation, analysis, and testing.

A.7.6 Limitations

a. May not be possible to characterize all environments or usages.
b. An over estimation of EPUP impact may lead to unnecessary precautions and an over-design of the system to guard against problems that are not seen in the field. The reverse is an under-reporting of the conditions which could lead to weak designs and over stressed, unreliable systems.

A.7.7 References

a. Anderson, Ronald G., "*Requirements for Improved Battery Design and Performance*, "SAE 900842, 1990
b. Atkinson, Ward J., "*Occupant Comfort Requirements for Automotive Air Conditioning Systems*," SAE 860591, 1986
c. Bernard, Christine, "*Vehicle Mission Profile in the Field Usage*," SAE 92A015, April 1992
d. Birchmeier, J.E. and Smith, K.V., "*Optimization of a Light Truck Rough Road Durability Procedure Using Fatigue Analysis Methodology*," SAE 820693, 1982, p. 109
e. Dixon, W.G. and Kuchera, G.J., "*Correlation of Laboratory, Proving Ground and Customer Testing Helps Reduce Lead Time between Design and Production of Equipment*," SAE 670076, 1967
f. Grubisic, V., "*Determination of the Load Spectra for Design and Testing*," Giornale ed Atti della Associazione Technica dell' Automobile, Vol. 46, No. 1 (January 1993), p. 8

A.8 Environmental Stress Screening (ESS)

A.8.1 **Description**—ESS is a process or series of processes in which environmental stimuli are applied to electronic items in order to precipitate latent part and workmanship defects to early failure. Rapid thermal cycling and random vibration are the most commonly used environmental screens and are effective in identifying most types of latent manufacturing defects.

Design and placement of screens depends on the number and type of expected defects, product design characteristics, technology characteristics, thermal and vibration responses, and the maturity of the product design and manufacturing process.

At lower levels of assembly, stronger screens can be used without damaging the entire product. At higher levels of assembly, ESS can be used to identify intermittent failures. These failures are detected best with test equipment or built-in-test (BIT) capabilities. The screening results, such as defects per unit by type of defect, are usually recorded in a data collection system such as a FRACAS.

A.8.2 **Purpose**—To induce failure of defective products before the products are fielded reliability.

A.8.3 **Application**—ESS can be applied to electrical, electro-optical, electromechanical and electrochemical parts, assemblies, and systems. It should be applied at times when defect removal is relatively inexpensive. ESS is intended to screen defects in a manner that is not harmful to properly manufactured material. Screens are designed during development to optimize reliability and cost.

A.8.4 Key Elements—Environmental Stress Screening involves:

a. Preparation of ESS plans
b. Identification of the Nature of Anticipated Defects. This is done by studying the equipment to determine the typical flaws expected to be precipitated through ESS.
c. Development of Random Vibration and Temperature Cycling starting regimens. Recommended baseline regimens are available in guidance documents. Thermal and vibration surveys are often conducted on sample hardware specimens to assist in deriving initial regimens
d. Determination of facility requirements/screening equipment availability
e. Production screening after optimizing/finalizing initial ESS profiles
f. Transition from 100% screening to screening based on selective sampling
g. Integration of the screening process with the data collection, analysis, and continuous improvement processes

A.8.5 Benefits

a. Fewer latent defects are delivered to the field
b. Incipient failures can be identified at convenient production steps resulting in less higher-level assembly rework
c. May lower warranty costs
d. If wide variation exists in the process, ESS can be an acceptable trade-off

A.8.6 Limitations

a. This screening method usually reduces the useful life of products
b. Determination of the proper ESS stress levels and durations for products used in different applications may be difficult.
c. ESS is directed towards weeding out defective products rather than as a means of preventing the building of defective products.
d. ESS may divert attention from controlling process variation

A.8.7 References

a. Institute of Environmental Sciences, "*Environmental Stress Screening Guidelines for Assemblies*"
b. Mil-Hdbk-344A, "*Environmental Stress Screening of Electronic Equipment*"
c. Tri-Service Technical Brief 002-93-08, "*Environmental Stress Screening Guidelines*"
d. Mil-Hdbk-2164, "*Environmental Stress Screening Process for Electronic Equipment*"
e. RL-TR-94-233, "*Environmental Stress Screening Process Improvement Study*"

A.9 Error/Mistake Proofing

A.9.1 Description—Error and mistake proofing are methods to identify potential problems in the design or manufacturing of a product. Although the terms are often used interchangeably, error proofing pertains to the product design, and the focus of mistake proofing is to eliminate potential manufacturing related mistakes.

A.9.2 Purpose—Error and mistake proofing are intended to prevent errors (design) or mistakes (process/manufacturing) from occuring.

A.9.3 Application—Error proofing may be used in any design related activity. Mistake proofing is often used in the following manufacturing operations where:

a. Mispositioning could occur
b. Adjustment is required
c. Statistical Process Control (SPC) is difficult to apply or apparently ineffective
d. Attributes, not measurements are important
e. Training cost and employee turnover are high
f. Mixed model production occurs
g. Customers make mistakes and blame the supplier
h. Special causes could reoccur
i. External failure costs dramatically exceed internal failure costs

A.9.4 Key Elements

a. Humans can make errors/mistakes due to a variety of conditions including:
   1. lack of training
   2. forgetfulness
   3. fatigue (physical and/or mental)
   4. distractions
b. To reduce the chance of errors/mistakes, focus on the process and the behavior rather than on the individual.
c. Error proofing is designing a potential failure or cause of failure out of a product or process so that the defect cannot be made (PROACTIVE).
d. Mistake proofing is any change to an operation that helps the operator reduce or eliminate mistakes and/or provides immediate feedback and corrective action, should a mistake occur (REACTIVE).

A.9.5 Benefits

a. Can be an inexpensive method for reduction of manufacturing and assembly defects
b. Reduces rework
c. Integrates easily with other problem prevention methods
d. Compensates for human error

A.9.6 Limitations

a. Not all processes can be error-proofed
b. May add cost or assembly time

A.9.7 References

a. Shingo, S., "*Zero Quality Control: Source Inspection and The Poka-Yoke System*," Productivity Press, Cambridge, MA, 1986
b. Grout, J.R. "*Towards Achieving Zero-Defect Quality: Mistake-Proofing*," Seventh Annual Texas Quality Expo

A.10 Failure Modes and Effects Analysis (FMEA)/Failure Modes, Effects, and Criticality Analysis (FMECA)

A.10.1 Description—Failure Mode and Effects Analysis is a design evaluation procedure used to identify potential failure modes and their effect on system performance, to identify actions to eliminate or mitigate the risk associated with the identified failure modes, and to document the process. In the FMECA, there is an additional assessment related to the failure mode's severity and probability of occurrence.

Both types of analyses begin with general information concerning design concepts, past history, concept diagrams, and potential risks. Teams are formed from design, manufacturing, quality, supplier, and service. The analyses are performed and follow-up actions are identified. The FMECA procedure tends to be more complex in the risk assessment. This is the primary difference in the two applications. Advocates of the FMEA procedure prefer the simpler, less complex risk assessment.

A.10.2 Purpose—The primary objective of either the FMEA or FMECA is to improve the design of the product or the process that is being analyzed. Higher risk failure modes are identified through the analysis, and their effects are either eliminated or mitigated by recommending design or process improvements or other actions. In order to be effective, the FMEA or FMECA must be done concurrently with the design development and engage the participation of a cross-functional expert team.

A.10.3 Application—FMEAs or FMECAs are generally done where a level of risk is anticipated in a program early in product or process development. Some of the factors that are considered in deciding to do FMEAs or FMECAs are: new technology, new processes, new designs, or changes in the environment, loads, or regulations. FMEAs or FMECAs can be done on components or systems that make up products, processes, or manufacturing equipment. They can also be done on software systems. FMEAs are often used in commercial applications; FMECAs are often used in aerospace or defense applications.

A.10.4 Key Elements—The FMEA or FMECA analysis generally follows these steps:

a. Identification of how the component of system should perform
b. Identification of potential failure modes, effects, and causes
c. Identification of risk related to failure modes and effects
d. Identification of recommended actions to eliminate or reduce the risk
e. Follow-up actions to close out the recommended actions
f. Documentation and archiving
g. The analysis must be completed in time for the recommended actions to be implemented into the final design or process.

A.10.5 Benefits

a. The method is directed towards improving designs and processes by preventing potential failures.
b. Identifies and prioritizes areas of potential risk in the design or process.
c. Can serve as evidence of "due care."
d. Encourages multi-discipline participation i the analysis of designs and processes.
e. Provides input to various related activities, e.g., analysis, test planning, process control planning, etc.

A.10.6 Limitations

a. The method relies on estimations and predictions of the failure modes and their risk, rather than hard field data.
b. The time taken to do the analysis must be balanced with the benefits derived from the activity.
c. FMECA is additionally limited by the complexity of the criticality analysis.

A.10.7 References

a. *"Potential Failure Modes and Effects Analysis (FMEA) Reference Manual,"* 2nd. Edition, Automotive Industries Action Group (AIAG) (1995)
b. SAE ARP5580 *"Failure Mode, Effects, and Criticality Analysis"*
c. O'Connor, P.D.T., *"Practical Reliability Engineering,"* 3rd. Edition Revised, John Wiley & Sons, England (1995)
d. SAE J1739 *"Potential Failure Modes and Effects Analysis (FMEA)"*

A.11 Failure Reporting Analysis and Corrective Action System (FRACAS)

A.11.1 Description—FRACAS is a closed loop method that is used to identify and correct failures in any product or process, and verify that the corrective action prevents recurrence of the failure.

A.11.2 Purpose—The purpose of a FRACAS is to document, track, analyze, and correct reported failures in a closed loop fashion. It is also a management tool for focusing on critical concerns, resolution, and resources dedication for timely program execution.

A.11.3 Application—A Failure Reporting Analysis and Corrective Action System (FRACAS) is normally implemented at the system, hardware, and software level and typically involves more than one physical entity. Ideally, however, the system level FRACAS will coordinate the failures that are recorded between the hardware and software.

The software FRACAS is similar to a hardware FRACAS in many ways. Failures are recorded, corrected and the root causes of the failures analyzed. This is typically done by a Failure Review Board. While hardware failures may be analyzed to find product specific defects, software failures are analyzed more to find deficiencies in the software engineering process.

A hardware FRACAS will track information that is pertinent to correcting the hardware failure. A software FRACAS will track information that is pertinent to reproducing the software failure so that it can be corrected. It will also track the root cause of each failure so that a Pareto analysis can be performed on a group of failures at some later time.

A.11.4 Key Elements—The components of a FRACAS include the following:

a. A mechanism for tracking the failures
b. A system level Failure Review Board (FRB) to analyze the failures and recommend and approve corrective actions
c. A software and/or hardware level FRB to analyze specific failures and recommend and approve corrective actions
d. A feedback loop between the mechanism and the FRB
e. A mechanism for tracking the status of the failure and routing the report to the appropriate personnel

A.11.5 Benefits

a. A single reliability data source that permits quick and efficient access to reliability data
b. Supports root cause investigation to resolve concerns
c. Documents the initial incident to the verification of the corrective action
d. Builds on past experience and provides better future reliability targets and risk assessment

A.11.6 Limitations

a. Does not prevent failure from occurring in the first place (downstream "find and fix")
b. Requires resources that could be used for failure prevention
c. Quality of data depends upon exposure to noises; if not properly selected, may yield false security

A.11.7 References

a. Lakey, P. and Neufelder, A., "*System and Software Reliability Assurance*," Rome Laboratories, Rome, NY, 1996

A.12 Fault Tolerance Analysis (Markov Modeling)

A.12.1 Description—Markov modeling is a probabilistic model that can accurately capture the effects of both order-dependent component failures and changing failure rates resulting from stress or other factors. There are two types of Markov models: discrete and continuous. The most commonly used type for engineering applications is the continuous time Markov chain, which is divided into the following three categories: homogenous, non-homogenous, and semi-Markov. The Markov model is a very flexible tool in modeling dynamic system behaviors. Of the many reliability modeling tools that can represent system behavior extending from the simplest system behavior to the most complex system behavior -- Markov modeling lies in the middle. Typical inputs needed to construct a Markov model are: combinations of failed elements that will fail the system, combinations of degraded modes of operation that are possible before a system will fail, and failure rate. Typical outputs of a Markov model are: probability of failure, reliability, availability, and failure rate.

A.12.2 Purpose—Markov modeling is used to evaluate system reliability as a function of time by mapping out the states of the system -- fully operational, degraded, failed -- and the probability of moving from one state to another.

A.12.3 Application—Typical applications are: reliability/availability/maintainability predictions, waiting line and servicing (queuing) modeling, inventory system analysis, traffic flow modeling, computer system performance evaluation, setting maintenance policies and dispatch requirements, software engineering (Petri net simulations), and modeling complex redundancies.

A.12.4 Key Elements—The following are the key elements of Markov modeling

a. Obtain failure rates
b. Build a Markov model by defining the objective, defining the system, identifying the various states of the system, determining which failures will result in system failure, and computing transition rates from one state to another
c. Run the Markov modeling software package and analyze the results

A.12.5 Benefits

a. Offers greater flexibility than other modeling techniques in modeling dynamic-system behavior
b. Enables the designers to determine the relative impact of alternative designs on system reliability
c. Offers flexibility to accommodate various situations; e.g., time-varying failure rate, sequence-dependent behavior, repairable systems, intermittent faults, standby system with spares, degraded modes of operation, and common-cause failures
d. Identifies and prioritizes areas of potential risk in the design or process
e. Can serve as evidence of "due care" reliability

A.12.6 Limitations

a. The model can be difficult for users to construct and verify.
b. As the number of system components increases, there is exponential growth in the number of states resulting in labor intensive analysis.
c. The method relies on estimations and predictions of the failure modes and their risk, rather than hard field data.
d. The time taken to do the analysis must be balanced with the benefits derived from the activity.

A.12.7 References

a. Bavuso, S.J., Rothmann, E., Dugan, J.B., Trivedi, K. S., Mittal, N., Boyd, M. A., Geist, R. M., and Smotherman, M. D. NASA Technical Paper 3452, Volume 1, 2, 3 & 4, 1994
b. Boyd, M.A., "*What Markov modeling can do for you,*" 7th Annual RMS Workshop, 1995
c. Gebrael, M.G., "*Markov modeling as a reliability tool,*" 8th Annual SAE RMS Workshop, 1996
d. Lewis, E.E., "*Introduction to Reliability Engineering,*" John Wiley & Sons, 1987
e. Kececioglu, D., "*Reliability of Maintained System with Redundancy Using the Markov Chain Approach,*" 34th Annual Reliability Engineering and Management Institute, 1996

A.13 Fault Tree Analysis (FTA)

A.13.1 Description—Fault tree analysis (FTA) is a deductive method used to identify all possible system failures of a product. The method identifies a 'top level' or catastrophic failure event, and deductively analyzes downward to the component level, identifying all possible reasons that could cause failure.

A.13.2 Purpose—The purpose of FTA is to quickly, comprehensively, and logically identify all possible failures of a product or system.

A.13.3 Application—FTA is typically used for the following:

a. Product evaluation and design improvement in the development phase
b. Troubleshooting and repair of products in the field service
c. Estimation of reliability performance
d. Prediction and quantifying risk

A.13.4 Key Elements—FTA consists of a model (fault tree diagram) with symbols and gates. The 'tree' diagrams the functions, failures, and conditions of a product. The symbols and gates are as follows:

a. Symbols:

1. Fault Event
2. Basic Event
3. Undeveloped Event
4. Normal Event
5. Conditional Event
6. Transfer Symbols

b. Gates:

1. AND Gate
2. OR Gate
3. INHIBIT Gate

A.13.5 Benefits

a. Can identify simultaneous multiple failure modes for single failure points.
b. Can serve as evidence of "due care."
c. Provides input to various related activities, e.g., test planning, and trouble shooting and maintenance manuals procedures and testing.
d. Can predict the probability of occurrence of a given event.

A.13.6Limitations

a. The method relies on estimations and predictions of the failure modes and their risk, rather than hard field data.
b. The time taken to do the analysis must be balanced with the benefits derived from the activity.
c. FTA is additionally limited by the complexity of the analysis.
d. The method is labor intensive and requires a high level of technical expertise.

A.13.7 References

a. SAE ARP 926A "Fault/Failure Analysis Procedure"
b. "*Reliability Toolkit: Commercial Practices Edition*," Rome Laboratory, Reliability Analysis Center
c. "*Fault Tree Handbook - Systems and Reliability Research*," Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission, Washington DC 20555

A.14 Finite Element Analysis (FEA)

A.14.1 Description—Finite Element Analysis (FEA) is a numerical procedure for analyzing the effects of stress (thermal, physical, etc.) on parts. Usually the problem addressed is too complicated to be solved satisfactorily by classical analytical methods. The finite element procedure produces many simultaneous algebraic equations, which are generated and solved on a digital computer.

The primary differences between classical methods and finite elements are the way they view the structure and the ensuing solution procedure. Classical methods consider the structure as a continuum whose behavior is governed by partial or ordinary differential equations. Finite Element Analysis considers the structure to be an assembly of small finite-sized particles. The behavior of the particles and the overall structure is obtained by formulating a system of algebraic equations that can be readily solved with a computer. The finite-sized particles are called *finite elements*, defined as hypothetical subdivisions of a structure or system, posessing a regular shape which can be analyzed. The points where the finite elements are interconnected are known as *nodes* or *nodal points*, and the procedure in selecting the nodes is termed *discretization* or *modeling*.

A.14.2 Purpose—To analytically assess the behavior of engineering components, subsystems, and systems under various conditions of use through the knowledge of fundamental physics and advanced numerical techniques.

A.14.3 Application—Finite Element Analysis has become a valuable tool for modeling complicated structural, mechanical, thermal, fluid, and electrical systems. Although, it originated as a method of stress analysis, today finite elements are also used to analyze problems of heat transfer, fluid flow, lubrication, electric and magnetic fields, manufacturing processes and many others.

A.14.4 Key Elements—Finite Element Analysis requires:

a. Development of individual elements, often with classical mechanics concepts
   1. Discretize or model the structure by dividing it into finite elements. This step is the most crucial in determining the solution accuracy of the problem.
   2. Define the element properties and select the types of finite elements that are most suitable to model the physical system.

b. Assembly of elements into a structure or system
   1. Assemble the element stiffness matrices, which relate the nodal displacements to the applied forces at the nodes.
   2. Apply the loads (which include externally applied concentrated or uniform forces, moments, and ground motions).
   3. Define the boundary conditions, i.e., set several nodal displacements to known values

c. Solution of the assembly, involving modern methods of computing
   1. Solve the system of linear algebraic equations (to solve for the nodal displacements)
   2. Calculate stresses (if required)

A.14.5 Benefits

a. Identifies and prioritizes areas of potential risk in the design or process.
b. Can serve as evidence of "due care."
c. FEA can analyze bodies with irregular shapes, multiple boundary conditions and loads, and various materials.
d. FEA can provide an early method of reliability assessment and reliability validation.
e. FEA can be used to assess the impact of design changes or to optimize designs.
f. FEA can be coupled with other tools. For example, FEA and response surface design of experiments have been combined for optimization and trade-off studies.

A.14.6 Limitations

a. The method relies on accurate estimation of boundary conditions and loads.
b. The time taken to do the analysis must be balanced with the benefits derived from the activity.
c. FEA is additionally limited by the complexity of the analysis and the computer resources available.
d. The method requires a high level of specialized technical expertise.
e. Care must be taken to distinguish between variation in the measurement system, and variation in the parameter being measured. For example, tension in belts may drop off after being tightened.

A.14.7 References

a. Cook, R.D., Malkus, D.S., and Plesha, M.E., "*Concepts and Applications of Finite Element Analysis,*" 3rd. Edition, John Wiley & Sons (1989)
b. Anderson, W.J., "*Finite Element Method in Mechanical Design,*" Short course, University of Michigan, Ann Arbor, MI (1990)
c. Spyrakos, C.C., "*Finite Element Modeling in Engineering Practice,*" West Virginia University Press, West Virginia (1994)

A.15 Focus Groups (User Focus Groups)

A.15.1 Description—An organized meeting (brainstorming session) to determine what the customer wants from a product. A focus group session consists of the correct mix of panelists, moderator, and observers. Panelsits include the customers and users of a product who provide inptus. The moderator should be recognized as having no vested interest in the outcome of the session and should be respected by the panel. The observers are the eyes, ears, and recorders for the group. They should remain silent unless specifically queried by the moderator. They should also understand that the sources of information are to remain anonymous.

A.15.2 Purpose—Focus groups are very effective for gathering customer expectations and requirements.

A.15.3 Application—A focus group is a very general method which can be applied to any planned new or modified product development.

A.15.4 Key Elements—Conducting successful focus group sessions requires planning. The following steps are necessary:

a. Select an appropriate topic.
b. Prepare an agenda.
c. Select a team for the session.
d. Set up the facility and provide supplies.
e. Conduct the session, then follow up.

A focus group session is accomplished in six steps:

a. Introduction - sets the tone for the session.
b. Brainstorming - elicits ideas as they flow from the participants.
c. Grouping - gathers the ideas into topic groups.
d. Clarification - smoothes out any inconsistencies, conflicts, or ambiguities.
e. Ranking - lists the ideas in their perceived order of importance.
f. Wrap-up - recaps the meetings objectives.

A.15.5 Benefits

a. Provides requirements definition quickly.
b. Allows direct contact with the customer.
c. Gives insights into unstated requirements and other customer expectations.

A.15.6 Limitations

a. May not provide complete spectrum of customer requirements.
b. Sometimes difficult to conduct logistically.
c. Is usually more expensive than other methods.

A.15.7 References

a. System Reliability and Qualitly Process, Rome Lab draft technical report prepared by McDonnell Douglas Corporation

A.16 Measurement Systems Analysis

A.16.1 Description—Because measurement plays such a significant role in helping a facility accomplish its mission, the quality of the measurement systems that produce those measurements is important. The ideal measurement system would have correct measurements every time it was used. Unfortunately, such measurements systems seldom exist, so decision makers must use measurement systems with less desirable properties. However:

a. The proper measurement systems must be in statistical control, which means that the variation in the measurement system should be due to common causes and not due to special causes.
b. The variability of the measurement system must be small compared with the manufacturing production process variability.
c. The variability of the measurement system must be small compared to the specification limits.
d. The increments of measure must be small relative to the smaller of either the process variability or the specification limits.
e. Although, the statistical properties of the measurement system may change as the items being measured vary, the largest (worst) variation of the measurement system must be small relative to the smaller of either the process variation or the specification limits.

A.16.2 Purpose—To determine whether the measurement system has adequate discrimination, is statistically stable over time, and has a small measurement error.

A.16.3 Application—Measurement Systems Analysis can be done on any gage or instrument that is used for taking measurements.

A.16.4 Key Elements—Measurement system error can be classified into five categories:

a. Accuracy—Gage accuracy is the difference between the observed average of measurements and the master value. The master value can be determined by averaging several measurements with the most accurate measuring equipment available.
b. Repeatability—Gage repeatability is the variation in measurements obtained with one gage when used several times by one operator while measuring the identical characteristics on the same parts.
c. Reproducibility—Gage reproducibility is the variation in the average of the measurements made by different operators using the same gage when measuring identical characteristics on the same parts.
d. Stability—Gage stability (or drift) is the total variation in the measurements obtained with a gage on the same master or master parts when measuring a single characteristic over an extended time period.
e. Linearity—Gage linearity is the difference in the accuracy values through the expected operating range of the gage.

Collectively, these procedures are referred to as *Gage R&R*. However, other techniques have been developed to conduct a measurement systems analysis, including the "Isoplotting" technique developed by Shainin Consultants for use in Statistical Engineering analyses.

A.16.4.1 BENEFITS

a. Provides a criterion to accept new measuring equipment
b. Provides a comparison of one measuring device against another
c. Provides a basis for evaluating a gage suspected of being deficient
d. Provides a comparison for measuring equipment before and after repair
e. Is required for calculating process variation, and the acceptability level for a production process
f. Helps develop gage performance curves to indicate the probability of accepting a part of some true value

A.16.5 Limitations

a. May require specialized resources (facilities, equipment, staff, etc.)

A.16.6 References

a. "*Measurement Systems Analysis Reference Manual*," Automotive Industry Action Group (1990)
b. Shainin Consultants

A.17 Mission Profile

A.17.1 **Description**—A mission profile is a quantitative characterization of how the design will be used in the field. The profile itself is made up of a set of independent possibilities called elements, paired with their probability of occurrence. For example, if operation A occurs 60% of the time, B occurs 30%, and C occurs 10%, the profile is [A, 0.6...B, 0.3...C, 0.1].

A.17.2 **Purpose**—Making a good reliability estimate depends on testing the product as if it were in the field. The mission profile is an essential foundation of any reliability program plan that provides the critical information required in the selection of appropriate reliability tests and determining the test parameters.

A.17.3 **Application**—Mission profiles can be applied to a great variety of systems, but are most useful for systems operating in unique or stressful environments where the profile is needed to identify design weaknesses vulnerable to the environmental conditions. The method is most often used in aerospace and defense products.

A.17.4 Key Elements

a. Customer Profile—A customer profile consists of an array of independent customer types. A customer type is one or more customers in a group that intend to use the system in a relatively similar manner, and in a substantially different manner from other customer types.
b. User Profile—A user is a person, group, or institution that operates, as opposed to acquires, the system. A user type is a set of users that will operate the system similarly. Identification of different user types allows the task of operational profile development to be divided among analysts. The user profile is the set of user types and their associated probabilities of using the system.
c. System Mode Profile—A system mode is a way that a system can operate. The system can include both hardware and software. Most systems have more than one mode of operation. For example, an airplane flight consists of takeoff and ascent mode, level flight mode and descent and land mode. System modes can be thought of as independent segments of a system operation or various different ways of using a system. A system can switch among modes sequentially, or permit several modes to operate concurrently.
d. Functional Profile—After a good system mode profile has been developed, the focus turns to evaluation of each system mode for the functions performed during that mode, and then assigning probabilities to each function. Functions are essentially tasks that an external entity such as a user can perform with the system, e.g., the user of an e-mail system would want the functions: *create message*, *look up address*, *send message*, *open message*, etc. Functions are established during requirements based on what activities the customer wants the system to be able to perform. Developing a functional profile is, therefore, a part of developing requirements.
e. Operational Profile—A function may comprise several operations. In turn, operations are made up of many run types. Grouping run types into operations partitions the input space into domains. A domain can be partitioned into subdomains, or run categories. To use the operational profile to drive testing, first choose the domain that characterizes the operation, then the subdomain that characterizes the run category, and finally the input state that characterizes the run.

A.17.5 Benefits

a. Assists in anticipating and planning for outside variables that affect system performance and reliability.
b. Provides vital information about the environmental conditions that the product will encounter.
c. Assists in environmental parameter selection for simulation, analysis, and testing.

A.17.6 Limitations

a. May not be possible to anticipate all environments.
b. Overestimating the environmental impact may lead to unnecessary over-design of the system to guard against problems not seen in the field. Underestimation could lead to weak, unreliable systems.
c. Costly and time-consuming to make these measurements.

A.17.7 References

a. *System and Software Reliability Assurance Notebook*

A.18 Pareto Analysis

A.18.1 **Description**—Pareto Analysis, based on the Pareto Principle developed by Vilfredo Pareto (an Italian economist), is one of the "basic seven QC tools" - check sheets, Pareto charts, Ishikawa diagrams, flow diagrams, histograms, scatter plots, and control charts. The Pareto Principle states that a small subset of problems (the "vital few") affecting a common outcome tend to occur much more frequently than the remainder (the "useful many"). This analysis has also been referred to as the "80/20 Rule" (i.e., 80% of the problems result from 20% of the causes).

A.18.2 **Purpose**—To help the engineering community in prioritizing and focusing resources where they are most needed. It may allow for the measurement of an impact of a design change upon product performance by comparing the before and after. Effective Pareto analysis can be used to determine which subset of problems should be solved first or which problems deserve the most attention.

A.18.3 **Application**—Pareto analysis can be used in all manufacturing and non-manufacturing applications of quality improvement.

A.18.4 **Key Elements**—To effectively apply Pareto analysis techniques requires:

a. Assemble the data to be analyzed
b. Add up the total of each item under analysis
c. List the items in order of magnitude, starting with the largest
d. Calculate the total of all the items, and the percentage that each item represents of the total
e. Draw, or construct, the bar chart
f. Draw in a cumulative curve
g. Label the diagram with appropriate titles, etc.
h. Interpret the diagram

A.18.5 Benefits

a. Presents to the user a graphic representation of defects/failures that require, generally, the most attention.
b. Very simple technique and does not require much time and effort.
c. Can be used for decision making in technical as well as non-technical areas.

A.18.6 Limitations

a. The user may be tempted to draw improper conclusions based on incomplete or inaccurate comparisons of data analysis. One must use common sense - two key customer complaints may deserve more attention than 100 other complaints, depending on who the customer is and what the complaint is.
b. Inaccurate comparisons, such as time vrsus cost, may yield improper conclusions.

A.18.7 References

a. "*The Memory Jogger - A Pocket Guide for Continuous Improvement*," GOAL/QPC, Methuen, MA (1988)
b. "*The Deming Management Method*," Mary Walton, Dodd, Mead & Company, NY (1986)
c. "*Basic Quality Problem Solving*," Internet web site http://www.sas.com

A.19 Parts Derating

A.19.1 Description—Parts Derating is the practice of limiting stresses, such as electrical, thermal, and mechanical, stresses on parts and assemblies to levels below their specified ratings. If a product is expected to operate reliability, one of the contributing factors must be a conservative design approach, and incorporating realistic derating. In practice, derating can be accomplished by either reducing stresses or by increasing the capability of the part or assembly. Selecting a part or assembly with greater capability is the most common method used to meet derating requirements.

As a general rule, derating should not be conservative to the point where cost and schedule are significantly impacted. Neither should the derating criteria be so loose as to render the process ineffective.

A.19.2 Purpose—To insure that parts and assemblies will not fail prematurely from stresses experienced during normal operation.

A.19.3 Application—This method is applicable to any design process. To be utilized effectively, designers should be provided with Design Guidelines as early as possible. These guidelines may have varying levels of detail, depending on available data. Note that the guidelines should be to the same level of detail as the analysis you want to perform. Some guidelines are available for electrical parts, others will require generation of internal guidelines.

A.19.4 Key Elements—There are 2 key elements in the derating process:

a. Derating guidelines must be provided to those doing the design. These guidelines either define the percent of maximum rating or are curves showing the derating required for a particular part type or assembly. Thus, derating can become one of the design requirements.
b. Theoretically analyze or physically test the design to insure that the derating guidelines have been incorporated into the design.

A.19.5 Benefits

a. Derating is effective since the failure rate of most parts and assemblies tends to decrease when applied stress levels decrease below the specified maximum value.
b. May effect design changes that improve the reliability of the product.

A.19.6 Limitations

a. The analysis effort requires access to design documentation and analysis, Derating Guidelines, and personnel with the technical expertise and tools to perform the required analysis.
b. Can be a time consuming effort at a point in the projects life cycle when resources are limited.
c. Can lead to overdesign of the product and therefore, may not be cost-effective.
d. It may be difficult to ascertain by exactly how much the product should be derated.

A.19.7 References

a. Reliability Analysis Center, "*Reliability Toolkit: Commercial Practices Edition*"
b. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"
c. MIL-STD-975, "*NASA Standard Parts Derating*"
d. RADC-TR-84-254, "*Reliability Derating Procedures,*" Rome Labs, 1984
e. RADC-TR-82-177, "*Reliability Part Derating Guidelines,*" Rome Labs, 1982
f. RL-TR-92-11, "*Advanced Technology Component Derating,*" Rome Labs, 1992

A.20 Parts, Materials, and Process Review/Control

A.20.1 **Description**—Parts, Materials, and Process Control are the efforts to insure that the parts, materials, and processes are compatible with each other, and that the provider of these items has the ability to provide reliable items in the quantity and time frame required. This requires an evaluation of both the item and the item's provider.

A.20.2 **Purpose**—The purpose of this method is to insure that the selected parts, materials, and processes can withstand the manufacturing environment, and reliably perform the needed function for the design life of the product in the use environment. This method is risk reduction effort.

A.20.3 **Application**—This method is applicable to both new and redesign efforts. It is also applicable to initial manufacturing process selection and any manufacturing process changes.

A.20.4 **Key Elements**—Successful implementation of this method requires management participation and support to ensure cooperation among disciplines and resolve any differences based on the ultimate impacts on cost, schedule, and performance. Major factors in implementing this method are the evaluation, selection, and management of vendors and the actual selection of the parts, materials, and processes that will be used.

A.20.5 **Benefits**

a. Provides a means of controlling the quality and reliability of incoming parts and materials.
b. Identifies defective parts or materials before they are assembled or used with your product.
c. Assists in imposing prevention procedures and process controls on supplier reliability.

A.20.6 **Limitations**

a. Requires a significant effort in maintaining a documentation of parts, materials, and processes by suppliers and reviewing of the information by customers.
b. May hinder the use of the latest and greatest parts, materials, or technologies.
c. If not properly managed, such programs may create friction between customers and suppliers.

A.20.7 **References**

a. Reliability Analysis Center, "*Reliability Toolkit: Commercial Practices Edition*"
b. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"
c. MIL-HDBK-965, "*Acquisition Practices for Parts Management*"
d. "*Quality System Requirements*," QS-9000, 3rd Edition, 1998.

A.21 Probabilistic Design—Stress and Strength Interference Method

A.21.1 Description—The stress/strength interference approach evaluates the probability that the stress to which a product is subjected will exceed the inherent strength of the product, leading to product failure. Both stress and strength are subject to variation. There are a number of sources of variation for the stress placed on a product, e.g., customer use, environmental differences, etc. Similarly, manufacturing and/or assembly variation will produce variation in the strength of the product. The variation for both stress and strength can be represented in probability distributions. When the stress and strength distributions overlap, a product whose strength falls in the area of overlap will fail if the stress in that area happens to be greater than the product strength. Clearly, the smaller the area of overlap, the more robust the design and the lower the failure rate.

A.21.2 Purpose—The purpose of the stress/strength interference approach is to determine the probability of product failure, using the area of overlap between the stress and strength distributions. For high failure rate situations, this overlap may then be reduced:

a. By determining manufacturing/assembly conditions that produce high product variability in strength and therefore be able to reduce such excess variability by redesigning these processes to eliminate such conditions and/or by monitoring the processes through quality control methods
b. By determining inherent design weaknesses in the product that lead to failure susceptibility and therefore be able to improve the design to make it more robust to stress
c. By understanding the causes of deterioration of the product with age and usage and therefore be able to increase lifetime strength (e.g., by changing materials) to offset such wear and prevent the resultant failure

A.21.3 Application—The stress/strength approach can be applied at the time when the nominal values of design parameters such as dimensions are determined.

A.21.4 Key Elements

a. Identify key failure modes for the system
b. Identify stress/strength characteristics
c. Identify design parameters for stress and strength
d. Determine means and standard deviations for key parameters
e. Evaluate means and standard deviations for stress and strength
f. Calculate probability of failure

A.21.5 Benefits

a. Identifies and prioritizes areas of potential risk in the design or process.
b. Can serve as evidence of "due care."
c. Can help characterize strength and stress distributions.
d. Is applicable early in the design, before product is available.

A.21.6 Limitations

a. Strength and stress information may not be available.
b. Insufficient data may be available to identify the underlying distributions.
c. There may be multiple characteristics with different stress/strength distributions that influence final reliability.

A.21.7 References

a. Thoft-Christensen, P. and Baker, M.J., "*Structural Reliability Theory and its Applications*," Springer-Verlag, 1982
b. Lin, Y.K., "*Probabilistic Theory of Structural Dynamics*," McGraw-Hill, 1967
c. Ang, A.S. and Tang, W.H., "*Reliability Concept in Engineering Planning and Design*," 1984
d. Zhou, J. and Nowak, A.S., "*Integration Formulas to Evaluate Functions of Random Variables,*" International Journal of Structural Safety, Vol. 5, December 1988, pp. 267-284

A.22 Production Process Capability Analysis

A.22.1 Description—Production process capability study is the analysis of a stable process to determine its output capability. When variable data is analyzed, capability is defined as the total range of output variation or simply six standard deviations (6σ). When the data is attribute (go/no-go or pass/fail), capability is the average proportion of output that is defective. Capability studies primarily involved variable data from the output of a production process. For this case, the study is usually extended to calculate one or more output uniformity measures or capability indices that relate the output specification to the process capability. Greater index values signify higher uniformity of output. The more commonly used indices are listed in the Key Elements section (A.22.4).

A.22.2 Purpose—Capability studies are used to predict process output variation (using capability or 6σ) and/or to determine whether a process has the ability to meet specified requirements (using capability indices). Studies can be divided into two categories: short-term and long-term. Short-term studies are based on measurements collected from one operating run and are used to validate the adequacy of a proposed or new process, quantify capability of new equipment before shipment, and/or evaluate initial machine setup. Long-term studies collect data over a longer period of time on stable processes and therefore, including all expected sources of variation. They are used to quantify on-going process performance, detect the state of in-control, set/adjust control limits, measure improvement/variation reduction, and assess/select alternative processes or operators.

A.22.3 Application—Usage of capability studies and indices is gaining increased application in the industrial community and is beginning to find application in the service and office environments. As a means to control the output quality, as measure by uniformity or defect rate, its application is invaluable. It also provides a direct means to track and quantify variation reduction.

A.22.4 Key Elements—The more commonly used variable data indices that quantify how well a production process can meet specified requirements include:

a. C_p—This is the capability index which is defined as the tolerance width (USL – LSL) divided by the process capability ($6\bar{\sigma}$), irrespective of process centering. Usage requires an output that is stable, normal, or near-normally distributed, and a standard deviation estimated by $\bar{\sigma} = \bar{R}/d_2$, where $\bar{R}$ is the average of the moving ranges on the $\bar{X}$ and $\bar{R}$ chart and d_2 is a constant dependent on the sample size, n, used in grouping the moving ranges. C_p is usually expressed as Equation A1:

$$\frac{(USL - LSL)}{6\bar{\sigma}} \quad \text{(Eq. A1)}$$

b. P_p—This is the performance index which is defined as the tolerance withd (USL – LSL) deivided by the process performance ($\bar{\sigma}_s$), irrespective of process centering. An output that is normal or near-normal is required (but allowing special cause variation) and a standard deviation ($\bar{\sigma}_s$) estimated from the sample standard deviation (s). P_p is usually expressed as Equation A2:

$$\frac{(USL - LSL)}{6\bar{\sigma}_s} \quad \text{(Eq. A2)}$$

where:

$$\bar{\sigma}_s = \sqrt{\sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n-1}}$$

c. C_{pk}—This is the capability which accounts for process centering by measuring the distance to the closest specification limit and scaling it by the process standard deviation. C_{pk} is defined as the minimum calculated value of CPU or CPL, the upper and lower capability indices. The same usage requirements noted for C_p, previously, apply. C_{pk} values of 1.00 and 1.33 predict out-of-specification or defect rates or 2700 and 63 parts per million respectively. See Equations A3 and A4.

$$CPU = \frac{USL - \bar{\bar{X}}}{3\bar{\sigma}} \quad \text{(Eq. A3)}$$

$$CPL = \frac{\bar{\bar{X}} - LSL}{3\bar{\sigma}} \quad \text{(Eq. A4)}$$

d. C_{pm}—Measures a quadratically weighted distance from the target, and is scaled by the specification width. See Equation A5.

$$C_{pm} = \frac{(USL - LSL)}{6\sqrt{[(T - \bar{x})^2 + \overline{\sigma_s^2}]}} \quad \text{(Eq. A5)}$$

where: T is the target.

e. P_{pk}—This is the performance index which accounts for process centering and is defined as the minimum of $\frac{USL - \bar{X}}{3\bar{\sigma}_s}$ or $\frac{\bar{X} - LSL}{3\bar{\sigma}_s}$ with the same usage requirements noted for P_p, previously, applying.

A.22.5 Benefits—The concept of capability and the related capability indices have an enormous extent of application as a standardized, scientific approach to quantify processes. Each of the purposes noted previously provides an obvious, corresponding benefit.

A.22.6 Limitations—Several indices have been developed because no single index can satisfy all needs. Since, all indices have weaknesses and can be misleading, usage of two indices is recommended, i.e., C_p and C_{pk}, as well as a graphical presentation or study. When distributions are not normally shaped, alternative means to measure defective rates must be used, e.g. PPM.

A.22.7 References

a. "*Fundamental Statistical Process Control Reference Manual,*" Automotive Industry Action Group (AIAG), Detroit, MI (1991)
b. "*Juran's Quality Control Handbook,*" 4th. Ed. Edited by J.M. Juran and F.M. Gryna, McGraw_Hill Book Company, New York, (1988)

A.23 Pugh Selection

A.23.1 Description—Pugh Selection is a method to evaluate several alternative concepts, design, processes, etc., and systematically evaluate each against a given datum to select that alternative which best satisfies the assessment criteria. It uses a matrix approach along with an iterative procedure to produce potential hybrids that may be better than any of the original ideas.

A.23.2 Purpose—The purpose of the Pugh Selection method is to select the best alternative when confronted with several alternatives that possess positive and negative qualities.

A.23.3 Application—Pugh Selection is an effective method for:

a. Helping clarify customer requirements
b. Reviewing several alternatives against a "standard"
c. Assuring that the selection criteria is understood by the team
d. Consensing in a team environment on the acceptability of specific attributes of an alternative
e. Assuring that the best alternative is identified

A.23.4 Key Elements—The key steps in the Pugh Selection are as follows:

a. Identify and describe all alternatives for a given concept, design, process, etc.
b. List the criteria that will be used to assess each alternative. These criteria should be based on requirements, specification, constraints, and needs. The "Voice of the Customer" should be an essential parts of the criteria.
c. Select the current design direction as the Datum. This is the concept against which all alternatives will be assessed "equal to, better than, or worse than" based on each criteria.
d. Compare and score each alternative against the Datum for each criteria. Use a "+" to designate the alternative is "better than" the Datum for the criteria indicated. Use a "-" to indicate "worse than," and an "S" to indicate "Same As" the Datum.
e. Total up the "+"s, "-"s, and "S"s for each alternative. If a significant number of "-"s are total for any alternative, eliminate that alternative or modify its description to try to eliminate the "-"s.
f. Create "hybrid" alternatives based on changing the "-"s to "+"s or "S"s wherever possible.
g. Make the alternative with the highest "+" to "-" ratio the Datum and repeat the process. Repeat these steps as necessary. When no alternative has a "+" to "-" ratio greater than 1.0 and no further "hybrid" alternative can be created, the Datum is the optimal alternative.
h. The process can be used to select several alternatives or only the one best alternative.

A.23.5 Benefits—The Pugh Selection method can result in:

a. Greater insight into requirements and solutions
b. Sifting quickly through many alternatives and generating new ones
c. Better understanding of alternative ideas
d. More objective selection process
e. Increased teamwork and communication among the team members

A.23.6 Limitations

a. Evaluation is subjective.
b. Not easy to differentiate between two closely matched design alternatives.

A.23.7 References

a. Chrysler Corporation, "*Product Assurance Planning Manual*," 2nd Edition, 1995

A.24 Quality Function Deployment (QFD)

A.24.1 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.

A.24.2 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.

A.24.3 Application—QFD may be used for the following activities:

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

A.24.4 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—Reliable.
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—Few parts, high quality parts.
d. Determine critical areas for project focus by mapping HOWs to WHATs.
e. Setting design targets to meet the customer needs.
EXAMPLE—Failure rates, failure modes, expected life.
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: *analysis of written requirements, marketing data, surveys, structured interviews*, and *group discussions.*

A.24.5 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

A.24.6 Limitations

a. Usually requires a facilitator to be effective.
b. The scope of the QFD method is overwhelming to many new practicioners.
c. Developing the 'House of Quality' can require a larger effort than some teams can commit to.

A.24.7 References

a. "*Quality Function Deployment, Linking a Company with its Customers*," Ronald G. Day, ASQC Press 1993
b. "*Better Designs In Half The Time*," Bob King, Growth Opportunity Alliance of Greater Lawrence, MA, 2nd Edition, 1988 (GOAL/QPC, 13 Branch Street, Methuen, MA 01844
c. The American Supplier Institute (ASI) provides publications, training and software on QFD. ASI, ,17333 Federal Drive, Suite 220, Allen Park, Michigan 48101
d. "*Quality Function Deployment: How To Make QFD Work For You*," Lou Cohen. Addison-Wesley Publ Co, 1 Jacob Way, Reading, MA 01867. 1995. 368 pp
e. Transactions from the Symposia on QFD, June 1989-1995, are available from the QFD Institute, 1140 Morehead Court., Ann Arbor, MI 48103
f. Software Package QFD/CAPTURE, and QFD Seminar: Principles of Quality Function Deployment, by International TechnoGroup Incorporated (ITI)

A.25 Quality Loss Function

A.25.1 Description—The relationship between the monetary value lost by society because of the deviation of the product from its intended performance. The Quality Loss Function was developed by Dr. G. Taguchi to provide an estimate of the monetary loss incurred by manufacturers and consumers as product performance deviates from its target value. The following quadratic equation approximates the quality loss in a wide variety of situations.

$$L(y) = k(y-m)^2 \quad \text{(Eq. A6)}$$

where:

L(y) is the loss in monetary value as a function of the measured response y of the product; m is the target value of the product's response; and k is an economic constant called the quality loss coefficient.

A.25.2 Purpose—The purpose of the quality loss function is to quantify a design's performance, and to establish manufacturing tolerances, such that, a product or process performs its intended function at the target value with minimum deviation.

A.25.3 Application

a. Evaluate proposed changes in a process.
b. Measure the quality of process and products. It relates quality not only to the customer but also to the society. Many specific applications can be found in robust design/Taguchi method.

A.25.4 Key Elements—Some variations of the quality loss function are needed to cover adequately certain commonly occurring situations. Three such variations are given as follows:

a. Nominal-The-Best—This type is required when a nominal value of a characteristic is preferred. Dimensions, clearance, and viscosity are typical examples of this type of characteristic.
b. Smaller-The-Better—This type involves a non-negative characteristic, whose target value is zero. Typical examples of such a characteristic are impurity, wear, shrinkage, deterioration, and noise level.
c. Larger-The-Better—For cases where the larger the value of the characteristics the better the product performance, there are no predetermined target values. Examples of such are the strength of material and fuel efficiency.

A.25.5 Benefits

a. Expresses performance loss in dollars (or applicable monetary unit)
b. Communicates the cost of poor reliability to management
c. Helps determine what manufacturing (or factory) tolerances should be
d. Provides a method for establishing economically justifiable consumer tolerances based on consumer losses, deviation from the target value, and scrap/rework costs.

A.25.6 Limitations

a. Requires a knowledge of scrap and rework costs
b. Requires knowledge of the functional targets

A.25.7 References

a. Taguchi, G., Elsayed, A.E., and Hsiang, T.C., "*Quality Engineering in Production System*," McGraw-Hill, 1989
b. Fowlkes, W.Y and Creveling, C.M., "*Engineering Methods for Robust Product Design Using Taguchi Methods in Technology and Product Development*," Addison-Wesley, 1995
c. Phadke, M.S., "*Quality Engineering Using Robust Design*," Prentice Hall, 1989
d. Taguchi, G., "*Introduction to Quality Engineering*," Asian Productivity Organization, 1986
e. Roy, R. A., "*Primer on the Taguchi Method*," Van Nostrand Reinhold, 1990

A.26 Regression Analysis/Correlation/Prediction Modeling

A.26.1 Description—Regression analysis is a combination of both statistical methods, tools and analytical techniques. It is part of the body of mathematical science known as "emperical studies" (as oppossed to "theoretical studies") and it uses a *parametric technique* to discover the apparent relationship(s) that may (or may not) exist between variables. The methodology requires a number of sets of observations (usually historical data but could be test data from a D.O.E. etc.) of the measured values of the dependent variable (Y) and the corresponding values of the independent (X) variable(s).

Correlation analysis quantifies the degree of association between the variables. It is expressed as a numeric value and is usually referred to as the correlation coefficient "r". Correlation studies can help evaluate the cause-and-effect relationship between two variables. The correlation coefficient, r, is a value that ranges from –1 to +1. Values close to +1 indicate a strong positive correlation between the variables. Values close to –1 indicate a strong negative correlation. Values close to zero indicate little or no correlation.

The data sets are usually initially plotted as a "scatter diagram." From the scatter diagram, conclusions can often be drawn by a visual examination of the pattern (or lack thereof) that emerges as to whether any relationship actually exists. The data can then be examined by means of a "correlation analysis" study to determine the strength and direction of the relationship. If there appears to be a correlation between the variables, it may then be possible to develop a mathematical model that can be used to predict new values of the output (dependent) variable in response to new values of the input (independent) variable(s).

A correlation analysis can also serve to quantify the degree of association between the variables and the regression equation (i.e., model) that is developed. In this analysis, the measureable is the square of the correlation value r and is called "R square." It can range from 0 to 1 and measures how well the model is able to explain the variation in the data used to create the model. A value of 1 means that the model is able to account for 100% of the observable variation in the data and would be regarded as a perfect model (but only if other conditions are also met). Most statistical software packages report out the R square value as part of their model "quality" indices.

It is always important, however, to use good judgement and "common-sense" when interpreting the results of any model. A regression equation can be calculated with only three data points, but little confidence can be placed in the result. Some textbooks state that no less than 18 lines of data sets should be used. In general, the more data points are used, the higher the confidence level of the result. Most of the better software packages report the confidence level.

It all depends upon the number of "degrees-of-freedom" you have. That is to say the number of "observation data sets" you have less the number of "regression variables" in your model plus one. The more degrees of freedom you have, the higher will be the confidence level.

A.26.2 Purpose—Regression analysis models can be developed from either "time-series" data or from "cross-sectional" data. Time-series models are developed from observations that have been taken *over time* for a particular situation. They can then be used to predict expected behavior at future points in time for that given situation. They are also useful for the performance of "trend analysis" studies of the expected "average" behavior of the phenomenon under study with time.

Cross-sectional models are developed from observations taken from different conditions at the *same point in time.* In this case, cross-sectional models are useful for studying the relationships between the variables at the given point in time. These models prove useful by providing an increased understanding of the relationships between the variables and what the effect is on the output if one changes one or more of the inputs (a "what-if" analysis).

The model becomes extremely useful when all of the significant "cross-sectional" input variables that affect the output have been identified and are included in a time-series analysis. Such models are not easily developed and often require considerable statistical skills and understanding of the input variables. In addition, multiple iterations of the modeling "runs" are often required to achieve an acceptable model.

A.26.3 Application—Recent applications in Reliability include Historical Warranty Trend Analysis/Prediction, Warranty Cost Negotiations, Reliability Growth Tracking, Similar Systems Analysis, Competitive Designs Analysis, and Comparative Design Trade-Off Studies.

A.26.4 Key Elements—The regression analysis/prediction model development procedure requires the following key elements be followed for model "credibility":

a. Determine the phenomenon that you want to study.
b. Choose the independent and dependent variables you believe you want to study (if known, otherwise proceed to the next step).
c. Obtain the appropriate observation sets you believe to best represent the phenomenon under study.
d. Perform a "Descriptive Analysis" of the data: Scatter diagrams, Pearson Correlation Analysis, Outlier Analysis, etc., and "Scrub" your data if required.
e. Choose the "regression variables" to be included in the modeling study based upon the data analysis.
f. Develop the prediction model (time-series and/or cross-sectional) using the selected regression analysis software.
g. Assess the "Quality" of the model using the "Quality-Assessment" tools provided as part of your statistical software package.
h. Test the model's predictive abilities on suitable test data.
i. Study the results for increased understanding of the relationships (i.e., do they "make sense" in light of what is known about the phenomenon).
j. Re-iterate the model development steps until an acceptable model is obtained.
k. Document your results, assumptions and the methodology used.
l. When the model is acceptable, apply the model to the task at hand, analyze, and report out the results in a format appropriate to the customer's requirements
m. Always remember that all models are false (being only approximations to reality) but some models are less false than others. The task is to find those models.

A.26.5 Benefits

a. Provides an *increased understanding* and insight into your products and processes.
b. Quantifies results with a suitable metric based upon current and past realities.
c. Ability to use this information as a predictor of expected future performance.
d. Translates "Engineering-Design-Controllable-Variables" into the language of management (i.e., cost). Management can then use this information for future planning to make products cheaper, better, faster and with reduced design/development cycle time.
e. The information that it provides as its output is *future-focused*. When combined with other engineering inputs during the design/development phases, it allows a proactive approach to improvement.

A.26.6 Limitations

a. Human resource limitations
b. Availability of tools usually means a capital investment in software and computer systems to support the activity.
c. The software support system must be integrated with the other engineering and management systems in use. These should be real-time, on-line, and available to all stakeholders.

A.26.7 References

a. Montgomery, D. C., and Peck, E. A., "*Introduction To Linear Regression Analysis*," 2nd Edition, John Wiley & Sons (1992)

b. Graybill, F. A., and Iyer, H. K., "*Regression Analysis: Concepts and Applications*," Duxbury Press, Belmont, CA. (1994)

c. Shtub, A., Bard, J.F., and Globerson, S., "*Project Management: Engineering*," Technology, and Implementation. Prentice Hall, Englewood Clifs, NJ (1994)

A.27 Reliability Allocation

A.27.1 Description—Design engineers must translate over-all system characteristics, including reliability, into detailed specifications for the numerous units (parts) that make up the system. The reliability of an individual unit varies with the type of function to be performed, the complexity of the unit, and the present engineering method of accomplishing the function. Reliability allocation encompasses the problem of assigning the correct numerical reliability to each sublevel of an item in such a manner that the overall item reliability is equal to its reliability goal. Frequently, reliability requirements are determined at a high level in the system. Reliability allocation techniques help allocate these requirements to the lower levels in an equitable or fair manner. Allocations are often made on the basis of considerations such as complexity, criticality, operational profile, environmental conditions, and past experience.

A.27.2 Purpose—To assign reliability requirements to individual units to attain the desired system reliability.

A.27.3 Application—Since reliability allocation is normally required early in the program when little or no hardware information is available, the allocation must be updated periodically. Points in the project at which allocation should take place are:

a. At the conclusion of the subsystem development-testing phase.
b. At the conclusion of qualification testing for the majority of the functional components of the system.
c. At the initiation of any major design revision to the system.

A.27.4 Key Elements

a. Identify the intended functions of the system
b. Identify the parts within the system
c. Determine the ratings of each part based on the criteria of the given weighting factors
d. Calculate allocated part failure rate and reliability.

A.27.5 Benefits

a. The analysis provides a way for the product development/reliability engineers to understand and develop the reliability target relationships between components, subsystems, and system reliability.
b. The product development/reliability engineers are obliged to consider reliability equally with other parameters such as cost, weight, and performance characteristics
c. The analysis provides specific reliability targets for the suppliers to meet for their particular design. This will lead to improved design, procurement, manufacturing, and testing procedures.
d. The analysis could lead to optimum system reliability because the allocation process would provide for handling such factors as complexity, state of the art, criticality, and effect of operational environment.

A.27.6 Limitations

a. Assumes that the components of a system are independent, i.e., failure of one component does not affect other components. However, since this assumption is usually not valid in most electromechanical systems, this limitation overrides the benefits of this method.
b. Meeting a reliability allocation is interpreted by some to mean that no further improvement is required.

A.27.7 References

a. "*Reliability Engineering*," ARINC Research Corp., Prentice-Hall, Inc., Englewood Cliffs, NJ, p. 593, 1964
b. "*Reliability of Military Electronic Equipment*," Advisory Group of Reliability Electronic Equipment (AGREE), Office of the Assistant Secretary of Defense Research and Engineering, p. 377, June 4, 1957
c. Karmiol E.D., "*Reliability Apportionment*," Preliminary Report EIAM-5 Task II, General Electric, pp. 10-22, April 8, 1965
d. Bracha V.J., "*The Methods of Reliability Engineering*," Machine Design, pp. 70-76, July 30, 1964

A.28 Reliability Benchmarking

A.28.1 Description—Reliability Benchmarking is a process used in identifying gap(s) and improvement opportunities for products compared to Best-In-Class products with respect to Reliability Metrics. Reliability Benchmarking activities may include Benchmarking metric selection, test design and planning, failure criteria definition, sample size determination, data collection and analysis, assessment of design differences that could affect product reliability, and use of this information in a Benchmarking process. In general, Benchmarking is the search for best practices that, when applied, lead to superior performance. The application of Benchmarking study findings should produce increased customer satisfaction, improve competitive advantage, and shorten product development cycle time.

A.28.2 Purpose—Organizations use benchmarking to:

a. Provide data and analysis support to Value Management study
b. Provide data to Product Design Engineers for continuous improvement and value-added engineering
c. Provide performance information to management
d. Set a goal for realistic process improvement and an understanding of any changes necessary to facilitate that improvement

A.28.3 Application—Ideally, Benchmarking should be performed early in the product development phase so that findings can be implemented and reliability can be designed into the product. Reliability Benchmarking can be applied in these circumstances:

a. When there is an unexpected decreasing trend of products' reliability performance and customer satisfaction.
b. When we want to improve the reliability performance of our products so that they become competitive with the best products in the industry
c. When we want to see alternative designs for a specific product or search for best solutions relating to our design concerns
d. When we need Best-In-Class information for setting our targets

A.28.4 Key Elements

a. Identify critical success factors: characteristics, conditions, and variables that have a direct influence on customer satisfaction
b. Define the statement of purpose and formulate a Benchmarking plan
c. Determine metrics used in Benchmark study

A.28.5 Benefits

a. Data and facts to convince management that there is a gap that must be closed to remain competitive
b. Opportunities for identifying specific variances, design leverage, new technology, and quality issue for value-added engineering and continuous improvement
c. Reliability-related information for system design specification, key life test, engineering specification development, DVP&R updating, and target setting

A.28.6 Limitations

a. Difficult to get benchmarking data
b. Leads to a mindset of following what has been done in the past by successful companies, rather than leading new frontiers

A.28.7 References

a. Feingold, H., "*Reliability of Repairable System*," 1984
b. Modarres, M., "*What Every Engineer Should Know About Reliability & Risk Analysis*," Marcel Dekker, 1993
c. Crow, L.H., "*Reliability Analysis for Complex Repairable System*," 1989

A.29 Reliability Centered Maintenance

A.29.1 Description—Reliability Centered Maintenance is a decision tree methodology used to determine the most appropriate preventive maintenance for an item in its particular operating context. It provides an audit trail of why the preventive maintenance tasks and schedules have been selected.

A.29.2 Purpose—RCM's purpose is reduce maintenance/inspection costs while at the same time providing an acceptable level of reliability.

A.29.3 Application—RCM is usually applicable to complex systems where maintenance and inspection is difficult or expensive to perform. It should be started early in the design of the system in order to maximize its impact on supportability.

A.29.4 Key Elements—RCM sets the maintenance/inspection interval of all parts and subsystems based on the time interval that provides and acceptable failure probability given the operational criticality of the part or subsystem. The RCM process is based on the responses to the following seven fundamental questions for the item being analyzed:

a. What are the functions of the item in its operating context?
b. In what ways can the item fail to fulfill its functions?
c. What causes each functional failure?
d. What happens when each functional failure occurs?
e. In what way does the functional failure matter?
f. What can be done to prevent the failure?
g. What should be done if a suitable preventive task cannot be found?

Using a decision tree process, RCM places predictable function failures into specific categories. Each failure consequence is classified as to whether they are hidden or evident to the operator while undertaking his normal duties. Within each of these categories, the consequences are assessed as to safety, operational, and non-operational effects. The following maintenance strategies are then used for each part: On-condition maintenance, scheduled rework, scheduled discard, failure finding. Once the system enters design, decision logic can be used to respond to unanticipated failures and assess the need for additional maintenance tasks. As testing proceeds, structural strength and fatigue failures may result in additional maintenance recommendations. The result of RCM is a matrix of inspection/maintenance intervals by part or subsystem.

A.29.5 Benefits

a. Can result in lower maintenance costs for fielded equipment, especially that equipment where maintenance or inspections are difficult to perform due to location or complexity.
b. Provides an audit trail such that any further review can identify how tasks were justified.

A.29.6 Limitations

a. RCM is very labor intensive. It should not be carried out at too low a level, nor superficially at too high a level where root causes are not identified.
b. RCM uses the Failure Mode and Effects Analysis (FMEA) to perform its work. If the FMEA is not specifically tailored for the RCM, it may require significant revision.
c. RCM provides maintenance tasks for a specific operating context. If that context changes significantly, the tasks may no longer be suitable and the RCM will have to be redone.
d. In order for RCM to be truly effective, precise distributions of failure patterns are required. Oftentimes, this data is not readily available in the precise format required.

A.29.7 References

a. "*SAE RMS Guidebook*," 2nd Edition, SAE International G-11 RMS Committee (1995).
b. MIL-STD-1843, "*RCM for Aircraft, Engines and Equipment*"
c. MIL-STD-2173, "*RCM Requirements for Naval Aircraft, Weapons Systems and Support Equipment*"

A.30 Reliability Demonstration Testing

A.30.1 Description—For an example, let λ be the true failure reat of a design. In a demonstration test, two failure rats, λ0 and λ1, must be specified where (λ0 < λ1). A good test plan will reject, with high probability, designs with a true failure rate that approaches λ1. A gtoo test plan will aceept, with high probability, designs with a true failure rate that approaches λ0.

Basing an accept/reject decision on the results of a demonstration test has two basic risks. First, if a fundamentally good design fails too many times during the test, then it could be rejected. Conversely, if a lower quality design happens to perform well during the test, a poor design could be accepted. These risks must be specified in advance as parameters of the test.

a. The producer's risk is the probability of rejecting product with a true failure rate equal to λ0.
b. The consumer's risk is the probability of accepting product with a true failure rate greater than or equal to λ1.

A.30.2 Purpose—The purpose of reliability demonstration testing is to verify, with a stated degree of statistical confidence, that the product meets the specified reliability requirement.

A.30.3 Application—This test is best applied to designs that have clear and measurable performance requirements that can be used as parameters for the reliability demonstration testing.

A.30.4 Key Elements—Three types of demonstration tests are recommended:

a. A *fixed duration test* is used when the amount of test time and cost must be known in advance. A fixed duration test provides a demonstrated failure rate to a desired confidence level.
b. A sequential test will accept designs that have a failure rate much lower than λ0 and reject designs that have a failure rate much higher than λ1, more quickly than a fixed duration test having similar parameters. However, the total test time may vary significantly according to the true failure rate.
c. A failure-free execution interval test will accept designs that have a failure rate lower than a λ0 value more quickly than a fixed duration test.

A.30.5 Benefits

a. Provides a verification of product life in relation to the stress(es) induced
b. Verifies product design intent
c. Sets clear decision-making criteria for a given level of confidence
d. Completion of reliability demonstration testing provides the evidence of the design meeting requirements

A.30.6 Limitations

a. Effort must be expended to assure that the test correlates to actual product usage
b. Sample size and test duration introduce consumer's and producer's risk
c. Accuracy of results is dependent on how production representative the samples are
d. Calculation of consumer's and producer's risk varies based on statistical assumptions

A.30.7 References

a. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"

A.31 Reliability Growth Testing (Modeling)

A.31.1 Description—In the development and initial production of a system, testing normally reveals some design deficiences. A reliability growth process is an iterative process of design, test, fix, and test again; i.e., as failure modes are discovered through testing, they are corrected by redesign followed by more testing. THere are several approaches to reliability growth measurement. The choice of which to use depends on the design level, on the kind of data available, and on the type of output desired. Two of the most common continuous reliability growth models are the Army Material System Analysis Activity (AMSAA) model and the Duane model. Typical input needed for reliability growth measurement is number of incidents versus mileage, time, or cycles. Typical outputs of a reliability growth curve are: (1) Failure Rate or MMBF versus miles (cycles, hours), (2) Reliability versus program design timing, (3) Improvements from one prototype to the next at a target βq life.

A.31.2 Purpose—The two main purposes of reliability growth measurement are to provide a snapshot of the reliability status at a point in time and to show the gain in reliability due to fixes during the development process.

A.31.3 Application

a. To demonstrate reliability growth
b. To compare demonstrated reliability with planned reliability
c. To track progress toward meeting reliability targets throughout the program design cycle
d. The models are designed for tracking reliability in situations where fixes are introduced within a test phase. It is not appropriate for estimating reliability change between phases.

A.31.4 Key Elements

a. In order to track reliability growth, phase by phase test data (failure versus test time) are collected.
b. Check the test procedure and verify if problems discovered by the test are fixed and retested to verify the fix.
c. Plot reliability growth using reliability growth model (Cumulative number of failures, failure rate, and MTBF).
d. Interpret reliability growth results.

A.31.5 Benefits

a. Takes into account the changing failure rate as fixes are introduced within a development phase.
b. It can address both failure data and time-truncated data, as well as data where exact failure times are known only to some calendar intervals.
c. Provides for confidence intervals to determine whether the planned growth is being met.
d. Evaluates the effectiveness of corrective actions taken within a phase.
e. Provides a guide to management of progress toward the required system reliability, thereby allowing for reallocation of resources if necessary.

A.31.6 Limitations

a. Reliability growth models rely on the Test-Analyze-And-Fix approach. This approach assumes inadequate initial reliability. Numerous cycles of testing, analysis of failures, and product redesign are required to grow reliabilty to the required level, a process that may be time consuming and costly.
b. Cannot be undertaken until product (or prototype) is available.
c. Selecting the proper reliability growth model is subjective.
d. Reliability growth models assume a predictable reliability growth rate.
e. If hardware and software development are not synchronized, growth testing results may be misleading.

A.31.7 References

a. Crow, L.H., "*Evaluating the reliability of repairable systems*", RAMS, 1990

b. Mil-HDBK-189, "*Reliability Growth Management*," National Technical Information Services, Springfield, VA, 1981

c. Kapur, K.C. and Lamberson, L.R., "*Reliability in Engineering Design*," Wiley, New York, 1977

d. Lewis, E.E., "*Introduction to Reliability Engineering*," Wiley, New York, 1987

A.32 Reliability Modeling and Prediction

A.32.1 Description—Reliability Modeling and Prediction techniques use existing performance data to predict the future performance of similar systems that are fielded in similar situations. The process is a mathematical exercise where reliability factors, calculated from performance data and benchmark testing, are substituted into a performance equation to yield a failure rate value representing the reliability level of a design in the field.

A.32.2 Purpose—This technique is used to evaluate which system design to field in a specific set of environmental conditions, estimate the amount and level of maintenance actions required in the field, and determine the logistical needs of the fielded system.

A.32.3 Application—This technique is most effective in the analysis of established technologies where there is a history of performance to draw from.

A.32.4 Key Elements—There are three prediction procedures:

a. *Parts Count Technique*—Uses a gross parts count and calculates the failure rates of individual components to predict the reliability of a larger system.
b. *Parts Stress Technique*—Same procedure as above only stress levels are used in the calculations.
c. *Existing System*—Uses similar system performance to extrapolate reliability. Used when part data is not available or incomplete.

A.32.5 Benefits

a. The ability to extrapolate performance data from historical and benchmark testing sources to a new design can identify weaknesses in a new design.

A.32.6 Limitations

a. The applications for this technique are limited due to it's narrow focus and wide range of variables that can skew results dramatically. In order to be valid, there are a great deal of prerequisites that must be addressed before applying this technique.
b. The part/system performance data used in the reliability factors must be up-to-date, the field environments and test environments must match and the variations between the tested system and the fielded system must be kept to a minimum. Even when these conditions are satisfied, there are other concerns such as the differences between the performance of each individual manufacturers' parts, or even part batch supplies from the same manufacturer, which can vary wildly.
c. This technique has limited applications in new state-of-the-art designs, since there is no performance data to be collected.

A.32.7 References

a. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"
b. "*Reliability Toolkit: Commercial Practices Edition,*" Rome Laboratory, Reliability Analysis Center
c. "*Systems Engineering and Analysis,*" Blanchard, B.S., Fabrycky, W.J., Prentice Hall, Englewood, NJ, 1981

A.33 Risk Assessment

A.33.1 Description—Risk assessment is a method to identify and rank risks associated with schedule, cost, safety, performance, customer relationship, or competitive position in a program. Risk assessment is typically performed by cross-functional teams, and is one part of an overall risk management program.

A.33.2 Purpose—Risk assessment identifies and prioritizes potential program or product risks, and provides a plan to reduce those risks.

A.33.3 Application—Risk assessment may be used for any program or product development process where potential risks exist. Risk assessment should be especially considered for unproven technologies, complex systems with integration or interfacing requirements, or systems/products used in extreme operating environments.

A.33.4 Key Elements—A typical risk assessment model includes the following elements:

a. Identification of negative events that may adversely effect a program or product, and the program or product aspect(s) potentially impacted by the risk.
b. Estimation of the severity of each event and the probability of its occurrence.
c. Calculation or estimation of risk level (based on the combined severity and probability of occurrence). A common tool used is the risk assessment matrix.
d. Risk reduction plan. List ways the probability and impact of risk(s) can be minimized or eliminated.

A.33.5 Benefits—Risk assessment can result in the following benefits:

a. Identifies and prevents problems before they can occur
b. Attacks the root cause of problems
c. Prioritizes risks and potential problems
d. Cost and cycle time reduction
e. Improved quality of product or process

A.33.6 Limitations

a. Can be difficult to quantify
b. Criteria is interpreted differently by different teams resulting is sometimes non-comparable risk assessments between teams

A.33.7 References

a. "*Project Management, Engineering, Technology and Implementation,*" Shtub, A., Bard, J.F., Globerson, S., 1994, Prentice Hall, Englewood Cliffs, NJ 07632

A.34 Root Cause Analysis

A.34.1 Description—Root Cause Analysis is a process used to solve operational, design, or process problems within an organization.

A.34.2 Purpose—Root Cause Analysis is performed to identify the cause of a failure in a system or process with the purpose of segregating the failed population, assessing the cause of the problem, developing and verifying a corrective action, and implementing the corrective action in both the product and the process that caused the error.

A.34.3 Application—Root Cause Analysis can be applied to any situation, product, or process problem where the intent is to not only fix the problem population, but also to identify why the problem occurred and develop a permanent corrective action.

A.34.4 Key Elements—Root Cause Analysis typically consists of four steps:

a. Gathering data about the problem
b. Analyzing the data for root causes and solutions
c. Communicating prevention plans for decision
d. Implementing recommendation

As data is gathered about a particular problem, it is important to determine the start and end points of the problem and segregate any product produced during that time. This product is the suspect lot. It should be inspected to assure that any non-conforming product is removed before the product goes to the next station or to the customer. Analyzing the data should involve a cross-functional team to determine what measurements to make, what data to collect, and what analysis technique to use. Duplicating the problem to verify root cause should be done. Brainstorming or other methods should be used to identify solutions to the problem. Once a solution is developed, it should be verified. An implementation plan should be presented to management to correct the problem. This plan should also address non-conforming product from the suspect lot.

Although the process includes identifying and remedying things that contributed to the problem, the primary focus is upon finding things that can be done within the organization to keep the problem from recurring. Because organizations control their processes with policies and procedures, a proper root cause analysis process should identify where in the organization a policy/procedure can be established, or where an existing policy/procedure can be better implemented to keep the problem from returning.

A.34.5 Benefits

a. Root Cause Analysis is a disciplined system to solve problems using a pre-defined, proven process.

A.34.6 Limitations

a. Sometimes requires considerable resources and engineering expertise.

A.34.7 References

a. Ireson, W. G., Coombs, C. F., Moss, R. Y., "*Handbook of Reliability Engineering and Management*," 2nd Edition", McGraw Hill, 1988, pgs. 13.9-13.17
b. "*A Reliability Guide to Failure Reporting, Analysis, and Corrective Action*", ASQ Reliability Division, ASQ Quality Press, Milwaukee, 1977
c. Mil-Std-721, "*Definition of Terms for Reliability and Maintainability*", Philadelphia Naval Publications and Forms Center

A.35 Sampling Procedures

A.35.1 Description—The major aim of the use of sampling procedures is to ensure that the producer submits lots or batches of a product that are equal to or better than a mutually agreed level. The intent is that the consumer is assured that each lot or batch is of an acceptable quality. The sampling procedures that are defined may be used by the producer to ensure that responsibility for the products' quality rests with the producer. It is necessary to understand that the responsibility for quality is not placed in the inspection process since the inspector has no direct means of inserting quality into the production process unless a closed loop feedback of inspection failure is in place.

A.35.2 Purpose—To ensure that equipment produced is at or better than a mutually agreed level that is acceptable to the consumer.

A.35.3 Application—Sampling procedures have been produced and are outlined in the ISO 2859-0 and Mil-Std-105E.

A.35.4 Key Elements—The method of sampling may comprise of a number of approaches as defined in ISO 2859-1. They may be summarized:

a. Acceptance sampling
b. Statistical sampling
c. Ad hoc sampling
d. 100% inspection
e. Other practices

Guidance on the techniques that can be applied may be found in the references.

A.35.5 Benefits

a. A carefully selected sampling plan will give assurace to both the customer and producer that the sampled lot or batch is likely to be of the mutually agreed upon quality level.
b. A carefully selected sampling plan should not add significantly to the cost of the product.

A.35.6 Limitations

a. With the exception of 100% inspection, there is always a risk of a producer supplying a customer with an inferior product. In fact, even 100% inspection can fail to reveal product defects that later manifest themselves in the use environment.
b. The sampling process selected needs to be cost effective for the type of product and its intended use environment.
c. This method is not intended to improve the design.

A.35.7 References

a. ISO 2859-0, "*Sampling Procedures for Inspection by Attributes - Part 0: Introduction to the ISO 2859 Attribute Sampling System*"
b. ISO 2859-1, "*Sampling Procedures for Inspection by Attributes - Part 1: Specification for Sampling Plans Indexed by Acceptable Quality Level (AQL) for Lot by Lot Inspection*"
c. ISO 2859-2, "*Sampling Procedures for Inspection by Attributes - Part 2: Sampling Plans Indexed by Limiting Quality (LQ) for Isolated Lot Inspection*"
d. ISO 2859-3, "*Sampling Procedures for Inspection by Attributes - Part 3: Skip Lot Sampling Procedures*"
e. ISO 8422, "*Sequential Sampling Plans for Inspection by Attributes*"
f. ISO/TR 8550, "*Guide for the Selection of an Acceptance Sampling System, Scheme or Plan for Inspection of Discrete Items in Lots*"
g. Mil-Std-105E, "*Sampling Procedures and Tables for Inspection by Attributes*"

A.36 Sneak Circuit Analysis (SCA)/Sneak Path Analysis (SPA)

A.36.1 Description—Sneak Circuit Analysis (SCA) is a detailed process that detects flaws within a hardware design that evade common reliability analysis methods.

A.36.2 Purpose—The definition of a sneak circuit is a design flaw that causes the occurrence of an unwanted function or impedes the operation of a desired function while all components are operating properly. Since sneak circuit conditions are flaws designed into a system they can easily slip past conventional reliability methods.

A.36.3 Application—Due to the complexity and cost restrictions of SCA, the analysis had been restricted to only high safety risk or space and launch vehicle applications. The rationale was that if sneak circuit conditions were to appear in other system designs, they would be dealt with in the field with either special operating instructions for the system to prevent the occurrence of a failure or a major recall to fix the design.

The recent development of CAD tools and design analysis software that has been especially geared to perform SCA has made this analysis more affordable and timely for a wider range of applications. The designs that are most susceptible to a SC condition are those that are highly complex, or have multiple interfaces or technologies integrated together. Also, updates to, or the reworking of, existing systems to add new features are excellent candidates for SCA since the interfaces of old and new functions could easily hide sneak circuit conditions.

A.36.4 Key Elements—When performed manually, the cost and schedule of a SCA requires that the latest design schematic be used to perform the analysis since any change to the design after the analysis is complete could add new sneak circuits which would void any previous SCA.

Using an automated approach minimizes this problem since it is a repeatable process and can be completed at a much lower cost.

A.36.5 Benefits

a. The greatest benefit of SCA is the early detection of a major flaw that would be designed into multiple units and spread though an entire line of products. The cost to fix such a problem once it is fielded with a system would at least be restrictions on system operation and could in the worst case require a major recall to fix the design.
b. This is the only method that can detect sneak paths or unintended operations.
c. Can serve as evidence of "due care."

A.36.6 Limitations

a. The time taken to do the analysis must be balanced with the benefits derived from the activity.
b. SCA is additionally limited by the complexity of the analysis.
c. The method is labor intensive and requires a high level of technical expertise.

A.36.7 References

a. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"
b. "*Reliability Toolkit: Commercial Practices Edition*," Rome Laboratory, Reliability Analysis Center
c. "*Assurance Technologies, Principles and Practices*," D. G. Raheja, McGraw-Hill, 1991
d. RADC-TR-82-179, "*Sneak Analysis Application Guidelines*," Rome Laboratory, Rome NY, 1982
e. "*SCAT, Automated Circuit Analysis Technique*," Rome Laboratory, Rome NY, 1990

A.37 Statistical Process Control

A.37.1 Description—Statistical Process Control (SPC) is a group of tools and techniques used to measure, analyze, and control processes. SPC tools include control charts, attribute charts, process log sheets, and other tools. Common SPC techniques include analysis of variance and regression and correlation.

A.37.2 Purpose—SPC is used to analyze and monitor processes, determine process capability, and bring processes under control. After the process is under control, SPC is used to identify and eliminate unique (special) causes of variation not associated with the process itself. The goal of SPC is to minimize process variation and eliminate defects.

A.37.3 Application—SPC may be effectively used for improving any process (manufacturing, management, sales, accounting, information systems, etc.). SPC is often associated with manufacturing processes, where component dimensions must be held to strict tolerances. However, SPC may be equally effective for other processes, such as clerical work, sales order entry, and other service industries.

A.37.4 Key Elements

a. Causes of Process Variation—SPC addresses two principle causes of process variation: common causes and special causes. Processes with common variation only are said to be "stable." Processes are said to be "unstable" if they also have special cause variation.

b. Types of Data. SPC works with two types of data:

   1. Variable data (*quantitative* data obtained by *measuring* the characteristics of a process or product, e.g., duration, pressure, etc.).
   2. Attribute data (*qualitative* data obtained by *counting*, e.g., counting the number of defects or mistakes, good or bad parts).

c. Control Charts (Variables) - Examples include:

   1. Run Chart - displays data over time
   2. X Chart - mean of data collected (x bar)
   3. R Chart - range of data collected
   4. S Chart - sample standard deviation (s)

d. Control Charts (Attributes) - Examples include:

   1. p - percent non-conforming
   2. np - number non-conforming
   3. u - number of units non-conforming
   4. c - number of non-conformities

e. Control Limits. Control limits show the extent of variation expected if only common causes are present. Points beyond indicate the presence of special causes and indicate an unstable process.

f. Techniques:

   1. Analysis of Variance - comparison of variation between different samples
   2. Regression and Correlation - dependent or independent relationship between variables

A.37.5 Benefits

a. Improved quality
b. Prevention of errors
c. Elimination of defects/scrap reduction
d. Reduces common cause variation
e. Cycle Time reduction
f. Cost savings
g. Increased output/production

A.37.6 Limitations

a. Need dedicated resources to measure, plot, and interpret data.
b. Extensive training is required of floor personnel.
c. Must overcome tendency to 'tweak' processes based on 'Kentucky windage.'

A.37.7 References

a. American National Standards Institute, "*Control Chart Method of Controlling Quality During Production*" (ASQC Standard B-3-1958/ANSI Z1.3-1958, revised 1975
b. American Society for Testing and Materials, "*Manual on Presentation of Data and Control Chart Analysis*" (STP-15D), 1976. Available from ASTM, 1916 Race Street, Philadelphia, PA 19103
c. "*Statistical Process Control - SPC Reference Manual,*" Automotive Industry Action Group, copies available from AIAG (810) 358-3570

A.38 Surveys/Market Analysis

A.38.1 Description—An investigation aimed at determining the needs and wants of potential customers. Potential customers are queried to determine their reaction to new product ideas and their degree of satisfaction with existing products. A market analysis may also include uncovering information related to competitor's products and their share of the market place.

A.38.2 Purpose—To identify customer needs and expectations as an input to developing supplier product goals. Customer satisfaction with existing products is determined in order to improve upcoming new or modified products. Surveys can also be applied within an organization to improve internal operations. Market analysis can help to determine the practicality and feasibility of developing a new product.

A.38.3 Application—Surveys can be used to address desired features and attributes that range from basic functionality to general appearance. They can be applied to new products, potential new products, or existing products.

A.38.4 Key Elements—Questionnaires should be designed for ease of use. The appropriate sample size and targeted audience must be carefully determined. For new product developments, proper timing is important to assure a successful survey. They are normally performed in the earl development phases but at times could be conducted when a sample product or prototype is finished. In this event, survey takers can provide feedback based on an actual entity instead of a concept. Feedback must be solicited in time to incorporate product changes prior to development and production.

A.38.5 Benefits

a. Acquires customer feedback for the purpose of continually improving products and processes.

A.38.6 Limitations

a. Can be subject to bias and sampling error.

A.38.7 References

a. "*Juran's Quality Control Handbook*," J.M. Juran, Editor-in-Chief, Frank M. Fryna, Associate Editor, McGraw-Hill, 1988

A.39 Variation Simulation Modeling (VSM)

A.39.1 Description—Given the design tolerances, the geometry of the components, and the assembly methods employed, variation simulation modeling simulates the resulting build variations using the Monte Carlo technique. Monte Carlo simulation applies randomly-generated data to a mathematical description representing the relationship between some design variables.

A.39.2 Purpose—To predict the effect of component and process variation on product quality.

A.39.3 Application—Variation simulation modeling can be used to model any process that can be defined mathematically. Because of variation simulation modeling's applications to product design, fabrication, and assembly, it can be used by all types of engineers in all phases of a product's life cycle. Product designers and engineers, production tooling and manufacturing process engineers, and reliability engineers use variation simulation modeling. It is used early in the planning stages to evaluate concepts in design and tooling. The tool is used throughout product design to continually refine assembly processes and piece-part tolerances. Any problems at prototype and start of production can be analyzed using variation simulation modeling to determine the best course of action. Field reliability and durability problems can be assessed using variation simulation modeling, with corrections to the manufacturing processes implemented as necessary.

A.39.4 Key Elements

a. Inputs to the variation simulation model are the component, or piece-part, dimensions such as the form tolerances of a door or fender.
b. Outputs are the dimensions between assembled parts, such as the gap between a door and a fender.
c. To use variation simulation modeling, the component parts must first be defined geometrically using critical points. Then the assembly process must be defined mathematically. This results in a model of the parts and assembly process which variation simulation modeling uses to simulate many instances of assembling the product. Results of the simulation show the predicted variation of the assembled product.
d. Persons who wish to build variation simulation models need an understanding of product design, manufacturing techniques, and assembly tooling concepts. In addition, they need some background in tolerancing, probability, statistics, and simulation. Some knowledge of computers and a programming language may also be required.

A.39.5 Benefits—Benefits of variation simulation modeling include:

a. Early identification of build problems (therefore, fewer expensive tooling changes)
b. Aids the engineer in focusing on the few critical dimensions which require statistical process control
c. Aids in identifying the many, less critical dimensions which allow the use of simpler manufacturing techniques
d. Allows analysis of production problems to indicate tooling adjustments which are most likely to improve quality, and
e. Promotes creative development of new manufacturing processes and assembly tooling through use of predictive capabilities

A.39.6 Limitations

a. Requires knowledge of process capability
b. Requires extensive computer resources
c. Requires geometrical and mathematical model of all parts

A.39.7 References

a. "*Tolerance Variation Analysis and Ease of Manufacture*" Quality Control Handbook, Juran, J. M., 4th Edition, 1988, pgs. 13.56-13.62

A.40 Warranty Tracking and Information Collection

A.40.1 Description—A warranty tracking and information collection system provides data for both business and reliability engineering needs of a company. It provides the field failure information for a "Failure Reporting, Analysis, and Corrective Action System" (FRACAS). Warranty data indicates if there is an issue *as perceived by the customer or user of the product.* It may or may not indicate what the problem is.

A.40.2 Purpose—Warranty data has the potential to provide:

a. Warnings of emerging reliability issues
b. Data to rank different issues
c. Comparison data to estimate reliability or assist with the problem identification stage of problem solving:

   1. Compare different models or design levels
   2. Compare different batches or production times
   3. Compare different option combinations
   4. Compare different customer types
   5. Compare failure rate over time in service to determine if problems are infant mortality, random, or wear out, etc.

d. Identification of potential shortfalls in the diagnostic procedures
e. Justification for product changes
f. Estimates of the financial reserves that the company should put aside to cover the warranty of the product

A.40.3 Application—Any firm which offers a warranty should track it. The minimal reason is to understand the financial liability that the warranty incurs. The following factors indicate that a more complex warranty tracking system would be useful:

a. Complexity in the product line up
b. Field issues which need engineering design or manufacturing process changes
c. Constant changes in the design or production methods
d. Complex enough products that the items are repaired versus replaced

A.40.4 Key Elements

a. The system needs to contain information for tracking and sorting the warranty data:

   1. Serial number or identification number of unit repaired.
   2. Date of production of unit.
   3. Date of repair.
   4. Key features on unit: make, model, options, etc.
   5. Customer complaint information, including the symptoms that the customer is experiencing.
   6. Service diagnosis.
   7. If the unit has internal computers with diagnostic codes, these should be included.
   8. If the unit has a time in service, usage counter or usage information, then this information should be included. Examples include: copy count on a photocopy machine, mileage on an automobile, flight time and number of flights on an airplane, etc.
   9. Parts replaced or repair procedure. Note that parts replaced could be entire unit if the unit is replaced.
   10. Cost of repair.

b. The system needs a mechanism for retrieving, sorting, selecting, analyzing and reporting the data.

A.40.5 Benefits

a. Warranty data can indicate if there is an issue as perceived by the customer or user of the product. It may or may not indicate what the problem is.
b. A warranty tracking system may provide valuable insight for resolving reliability issues.
c. It provides some of the information necessary for prioritization of engineering and reliability issues.
d. It may provide warnings of emerging reliability issues.

A.40.6 Limitations

a. Warranty tracking provides a lagging indicator of quality and reliability: many months of production may occur between the start of a new problem and the time that the trend or new problem is visible in the warranty data.
b. The data may be biased or corrupted. For example, in the automotive industry, the warranty system is designed to reimburse the dealerships for warranty repair, not provide engineering information. Sometimes the symptom that the customer is complaining about can have multiple root causes and diagnostic procedures are often not available to sort between the potential root causes. In these cases, the dealership is forced to replace multiple parts until the symptoms go away. All of the replaced parts will be listed in the warranty system tallies, and the root cause listed will be the one that provides the maximum payment to the dealership, not necessarily the part or parts that contributed to the problem.
c. Warranty data must be supplemented with data or testing from other sources to confirm engineering root causes.
d. The customer may have trouble describing the problem to whoever writes up the service request, or the person writing up the service request may not have sufficient information to clearly describe the customer symptoms.
e. Depending upon the complexity of the product and of the information stored in the database, warranty databases can require extensive computer resources.

A.40.7 References

a. "*Reliability, Maintainability, and Supportability Guidebook*," 3rd. Edition. SAE International RMS G-11 Division, SAE International, Warrendale, PA (1995)
b. Omdahl, T.P., "*Reliability and Maintainability Dictionary*," ASQC Press (1988)
c. Brennan, J.R., "*Warranties: Planning, Analysis, and Implementation - A Practical Approach*," SAE International, Warrendale, PA (1994)
d. "*Reliability Toolkit: Commercial Practices Edition*," Joint Effort Document of Rome Laboratory and Reliability Analysis Center (RAC), Rome, NY

A.41 Weibull Analysis

A.41.1 Description—Weibull analysis is a statistical procedure commonly used to analyze life or "time-to-failure" data. It results in the computation of the two or three parameters of that particular Weibull distribution that best fits the data. The parameters are:

a. β, the shape parameters that describes whether the failure mode is time-increasing (β >1), constant (β = 1), or time-decreasing (β <1),
b. η, the scale parameter, which indicates the time at which exactly 63.2% of the population will have failed, and t_0, the location parameter, which indicates where the distribution begins.
c. δ, The location parameter, which indicates where the distribution begins (minimum life).

A.41.2 Purpose—Weibull Analysis is used to determine compliance to requirements, predict future failures, determine test requirements, compare designs, or determine spare parts requirements.

A.41.3 Application—Weibull Analysis can be applied to any type of measurement data. It can be used for test data, inspection data, or interval data. Once the parameters of the distribution are identified, confidence limits can be applied to the data to assess compliance to requirements. It is applicable to development or production data. Many software packages are available that analyze data and depict graphically the results. There are two statistical techniques commonly used for estimating the Weibull distribution which best fits the data. One uses the least squares technique and median ranks, commonly called just "median ranks." The other is maximum likelihood estimation. (Maximum likelihood estimation of Weibull requires a computer, therefore earlier references only used the median ranks method.)

A.41.4 Key Elements—If exact failure times are known, the Weibull analysis requires the computation of Median Rank values for each failure time. Several formulas exist to approximate the median rank. The procedure then involves plotting the failure times against the median ranks on log versus log-log paper and fitting a straight line through the resulting points. The slope of the line (on one-to-one paper) is the value of the beta parameter and the x-value at 63.2% on the y-axis is the eta parameter of the Weibull distribution. For different aspect ratio Weibull probability paper, the beta value can be determined by drawing a line that is parallel to the graph line and also passes through a selected point and scale to read the beta value. If interval failure times are known, the cumulative probability of failure is computed instead of the median rank value. The plotting proceeds as previously mentioned.

There are several excellent software packages available that perform the calculations and plotting. Software can also give confidence limits in several forms, make predictions of spares required, provide goodness of fit estimates, and generally, take the drudgery out of the computations.

Care should be exercised when interpreting Weibull graphs and performing Weibull analysis. Usually, only one failure mode at a time should be analyzed. Those failures occurring due to other modes should be treated as suspended data points when analyzing a particular failure mode.

When a graph shows a curve upward, it usually suggests that more than one failure mode is present in the data. A downward pointing curve could indicate that the three parameter Weibull model might be a better fit to the data. The third parameter is an offset parameter that can be interpreted as a "failure-free" period.

A.41.5 Benefits—A Weibull analysis is useful to:

a. Determine compliance to a requirement
b. Predict future failure trends
c. Predict spare parts needs
d. Identify future testing requirements
e. Reduce sample size requirements over traditional success testing methods

A.41.6 Limitations

a. Because there exist many software packages that perform the Weibull calculations and plotting, the tendency is to use Weibull analysis when other distributions may fit the data better.
b. A good understanding of Weibull analysis and its capabilities is a must before blindly using it.
c. It is important to plot a Weibull Probability plot to make sure that the Weibull distribution fits the data, before proceeding any farther with the analysis.

A.41.7 References

a. "*Reliability in Engineering Design*," Kapur, K.C., Lamberson, L.R., John Wiley & Sons, 1977.
b. "*The New Weibull Handbook*," Abernethy, Robert, self-published, 1996.
c. "*Reliability Engineering Bible*," Dodson, Bryan; Nolan, Dennis, Quality Publishing, 1995.
d. "*Reliability & Life Testing Handbook Volume 2*," Kececioglu, Demitri, Prentice Hall, 1994.

A.42 Worst Case Analysis

A.42.1 Description—Worst Case Analysis is a collection of techniques for estimating variation or evaluating the effects of variation in a product or process. Three common methods illustrate the breadth of these techniques:

a. Worst Case Circuit Analysis (WCCA)—An analytical analysis of the effects of component and environmental variation on the performance of an electronic circuit. By analyzing circuit function over the entire range of input and component variation that is expected to occur, performance under the worst case scenario can be determined and/or assessed.
b. Assembly Variation Analysis (AVA)—An analytical simulation technique to estimate build variation in an assembly. AVA first creates a model that includes the geometric definition and variation of components in the assembly, applies a Monte Carlo simulation of variation to the components, and finally estimates the three sigma assembly variation and the significance of each contributing component tolerance.
c. Worst Case Testing—Generally a small number of supplemental laboratory qualification tests performed at or just beyond the extremes of operational environment on samples containing one or more design characteristics at the specification limit.

A.42.2 Purpose—Worst case analysis is used in several phases of development to fulfill the following needs:

a. To aid in making designs or process performance less susceptible to part parameter variation and drift
b. To demonstrate that a product, process, or assembly will meet the design specification and/or customer requirementss under the worst combination of conditions that may occur
c. To assure that the threshold of failure is outside of a specified or possible worst case set of conditions
d. To comply with tasks specified in contractual documents or agreements

A.42.3 Application—Worst case analysis techniques can be effectively applied in the design, verification, prototype build, and qualification test phases of development. Application examples include the creation of more robust electronic circuit designs, assuring component fits or ability to assemble, qualifying safety critical functions at extremes of specification/operation, and improving durability/reliability performance.

A.42.4 Key Elements—Elements that are key to one or more of the worst case analysis techniques include:

a. A Worst Case Parts Database identifying and quantifying the dominant sources of variation on critical circuit parts utilized in a program or product line
b. Knowledge of the specification limits, design/process variation, and extremes of operating environments
c. Analytical simulation techniques such as Monte Carlo Analysis
d. Laboratory environmental chambers and test apparatus for qualification test and evaluations

A.42.5 Benefits—A key benefit from worst case analysis is improved reliability. This is achieved by application of techniques in design and verification that assure specified performance over the entire potential range of variation, i.e., assuring a robust design. In effect, this addresses a root cause of unacceptable reliability, the elimination of failures and performance complaints that are commonly caused by part variation and/or environmental extremes. Benefits that can be expected from the AVA technique include, reduced variation, more effective and focused variation controls, elimination of costly downstream assembly problems, and improved fits and appearance quality.

A.42.6 Limitations—In general, all the techniques presented do not directly reduce a design's sensitivity to variation, only assure performance at extremes. Designed Experiments and Taguchi Methods can be more effective when robustness must be maximized. It should also be recognized that the effectiveness of the WCCA technique is contingent on a quantified Worst Case Parts List. If variation knowledge on critical parts is missing or inaccurate, results will be compromised.

A.42.7 References

a. "*Product Assurance Planning Manual, 2nd. Ed.*," Chrysler Corporation, Detroit, MI (1995)
b. "*Reliability Toolkit: Commercial Practices Edition*," Reliabilty Analysis Center, Rome, NY
c. MIL-HDBK-338, "*Electronic Reliability Design Handbook*"

APPENDIX B

GLOSSARY TERMS AND DEFINITIONS

B.1 ***Accelerated Test***—A test in which the applied stress level is chosen to exceed that stated in the reference conditions in order to shorten the time required to observe the stress response of the item, or magnify the response in a given time.

B.2 ***Acceptance Test***—A test conducted under specified conditions by, or on behalf of, the customer, using delivered or deliverable items, in order to determine the item's compliance with specified requirements.

B.3 ***Activity***—An element of the reliability program that uses one or more methods to achieve its intended result.

B.4 ***Burn-in***—A reliability conditioning procedure which is a method of aging an item by operating it under specified environmental and test conditions in accordance with an established procedure in order to eliminate early failures and age or stabilize the item prior to final test and shipment.

B.5 ***Component***—A discrete, functional part of a system or equipment that is essential to operational completeness of the subsystem or equipment.

B.6 ***Customer***—The recipient of a product (e.g., the customer may be the purchaser, beneficiary, ultimate consumer, or user).

B.7 ***Environment***—The aggregate of all external conditions, circumstances, stresses and their combinations that influence, surround, and affect the development and life of a produce or service, its performance, and survival.

B.8 ***Failure***—An event that makes equipment deviate from specified limits of acceptable performance, or that terminates the ability of a unit to perform its required function.

B.9 ***Failure Mechanism***—The process of degradation, or chain of events, leading to and resulting in a particular failure mode.

B.10 ***Failure Mode***—The manner by which a failure mechanism is observed.

B.11 ***Failure Rate***—The ratio of the probability that failure occurs in the interval between two times, given that the failure has not occurred prior to the beginning time, divided by the interval length.

B.12 ***Hardware***—Physical equipment as opposed to programs, procedures, rules, and associated documentation, which are forms of software.

B.13 ***Implied Customer Requirements***

a. Self-imposed and measurable requirements, not explicitly demanded by customers, that a manufacturer specifies for a product.
b. The difference between the specified requirements and the requirements that should have been specified in order to be successful, in the event that there is a customer perceived failure or failure to penetrate a market, even when specified requirements are met.

B.14 ***Inherent Reliability***—The potential reliability of an item's design under realistic and/or stated conditions of use and operation.

B.15 ***Life Cycle***—A series of stages a product or process passes through during its lifetime.

B.16 ***Maintenance***—Actions necessary for retaining an item or in restoring it to a specified condition.

B.17 ***Mean-Time-Between-Failure (MTBF)***—For a repairable item, unit, or system, the total test or operating time of all items, units, or systems on test divided by the number of relevant failures of all modes.

B.18 ***Mean-Time-To-Failure (MTTF)***—For a non-repairable item, unit, or system, the total test or operating time of all items, units, or systems on test divided by the number of items, units, or systems removed from test due to failure.

B.19 ***Method***—A standardized procedure to accomplish a particular activity.

B.20 ***Metric***—Quantified figure-of-merit to assess conformance to a requirement or goal.

B.21 ***Mission Profile***—A time-phased description of the events and environments an item experiences from initiation to completion of a specified mission, to include the criteria of mission success or critical failures.

B.22 ***Performance Requirements***—A statement that specifies a characteristic which a system or system component must possess.

B.23 ***Process***—A series of activities leading to a desired result.

B.24 ***Product***—Hardware, software, or any combination thereof.

B.25 ***Qualification***—Action(s) that constitutes formal evidence that a product or process has met its requirements.

B.26 ***Qualification Test***—A formal test to obtain approval to produce an item, which determines compliance with its specified or implied design requirements. It is conducted by, or on behalf of, the customer, but usually by the developer for the customer under specified conditions and using representative production items.

B.27 ***Reliability***—The ability of an item to perform a required function, under stated conditions, for a stated period of time.

B.28 ***Reliability Analysis***—A set of activities using specified methods to determine product or process reliability risks.

B.29 ***Reliability Assessment***

a. The process of determining the achieved level of reliability of an existing system or system component.
b. An estimate of the achieved reliability calculated using data gathered during tests and performance measurement.

B.30 ***Reliability Assurance***

a. The management and technical integration of the reliability activities essential in maintaining reliability achievements including design, production, and product assurance.
b. Deliberate positive measures to provide confidence that a specified reliability will be achieved.

B.31 ***Reliability Engineering***

a. The science of including those factors in the basic design which will assure the required degree of reliability, availability, and maintainability.
b. The set of design, development, and manufacturing activities by which reliability is achieved.

B.32 ***Reliability Goal***—The idealistic target level of reliability desired for the product.

B.33 ***Reliability Program***—A set of reliability activities and methods which are organized in a logical progression, tailored to a specific product, scheduled according to the product's program milestones, assigned to responsible individuals and/or organizations for execution, and monitored and controlled for effectiveness.

B.34 ***Reliability Requirement***—Minimum acceptable reliability stated in an equipment specification. This is a binding level of reliability. Contrast with reliability goal, which is an idealistic target. If demonstration of achievement of the reliability requirement is made a part of the contract requirements by the customer, with associated rewards and penalties, there may also be included a minimum acceptable value for confidence level to which the proof of achievement must be demonstrated.

B.35 ***Reliability Tests***

a. Tests and analyses which are used to measure both the level of reliability of an item and also the dependability or stability of this level with time and use under various environmental conditions.
b. A test to statistically prove that the specified reliability is achieved with specified confidence.

B.36 ***Requirement(s)***

a. Customer Requirements—The expressed or inferred needs and wants that a customer desires from a product.
b. Product Requirements—Acceptable levels of specific performance parameters for a given set of conditions.
c. Program Requirements—The three requirements identified in SAE JA1000 para. 1.1.

B.37 ***Resources***—The means available to an organization for developing a product including materials, facilities, people, capital, time, equipment, hardware, and software.

B.38 ***Risk***—A possible future which has a substantial likelihood and which, if realized, would have an undesirable effect on a product system effectiveness.

B.39 ***Service***—Actions necessary for retaining an item in a specified condition.

B.40 ***Specification***

a. Statement of a desired or required goal often within upper and/or lower limits.
b. A document describing a product's physical, environmental, and performance requirements along with specific tests and/or analytical procedures to validate those requirements.

B.41 ***Supplier***—An organization that provides a product to a customer.

B.42 ***System***—An organized, interconnected, and united collection that is self-sufficient in its intended customer operational environment and capable of either performing or supporting an operational function, or both.

B.43 ***Systems Engineering***—Applying scientific and engineering knowledge to study, plan, design, construct, and evaluate a man-machine system so that the various parts of the system and the uses of various subsystems are planned and comprehended before hardware designs are committed.

B.44 ***Test***—To establish or increase confidence that an item performs as specified by exercising it and comparing the results to the required results.

B.45 ***User***—The entity to whom a product or the services from a product, are provided.

B.46 ***Validation***—Establishing through analysis, test, or both, that an item's performance is acceptable for customer use based on its performance on specific tests when compared against established performance criteria.

B.47 ***Verification***—The process of determining whether the products of a given phase of the development cycle fulfill the requirements established during the previous phase.

B.48 ***Warranty***—Express or implied guarantee to the purchaser by the seller that an item will perform as specified or represented for a minimum specified period of time or usage.

Rationale—Not applicable.

Relationship of SAE Standard to ISO Standard—Not applicable.

Application—The SAE JA1000-1 Reliabilty Program Standard Implementaiton Guide (the Guide) is designed to assist suppliers in determining how to satisfy the Program Requirements of SAE JA1000 Reliability Program Standard (the Standard). Although this Guide has bene 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 reliability thoughout the product or service life cycle.

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