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Integrated Reliability—Roadmap, Framework, and Implementation

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Final Report

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16. Abstract

This report provides the background, motivation, and results of a multiyear effort to understand and develop a framework to address the gaps within the reliability prediction methodologies used for commercial-off-the-shelf (COTS) electronic systems.

The integration of COTS electronics into avionics systems provides advantages of greater computational power, which allows superior flight navigation, tracking, guidance, and communication processing abilities with far superior electronic displays, maps, and sophisticated processing algorithms. Use of COTS electronics provides the advantages of better quality due to high manufacturing volumes. COTS scaling, however, has introduced the problem of life-limited semiconductors due to the increasing susceptibility to different types of failure mechanisms as feature sizes shrink to deep sub-micron levels.

Outdated reliability prediction methodologies are unable to model these new technologies or adequately support reliable aerospace system design. The most widely used component reliability prediction handbook, MIL-HDBK-217, had its last published update in 1995. In 2009, a working group consisting of government and industry organizations was formed to revise the handbook. MIL-HDBK-217 Revision G was completed in May of 2010 and was due for the coordinated Government Industry Review. The publication of Revision G was put on hold by the Defense Standardization Program Office and has been on hold since its 2010 completion. More generalized cutbacks in government spending on research and development make the prospect of a renewed effort to revise MIL-HDBK-217 remote.

In 2011, the Aerospace Vehicle Systems Institute's (AVSI) reliability roadmap project (Authority for Expenditure [AFE] 74) identified the existing gaps in the current reliability prediction methodologies and established an approach for improving reliability prediction capabilities. The roadmap was prioritized by industry consensus using quality function deployment to organize the inputs of a wide variety of industry viewpoints to address the need for high reliability electronic systems. Once the needs were identified and prioritized in the roadmap, AVSI launched the AFE 80 project in 2012 to provide the framework for addressing these needs.

One of the critical elements of this framework is a standard approach to verification, calibration, and validation of new reliability models and methodologies. The broad acceptance of a new reliability methodology depends not only on a technically credible approach for defining it but also a rigorous and standard approach to validating it. The AFE 80 project found a lack of consistency in how these steps were being handled by industry, academia, and government. It enlisted the help of key points of contact in the aerospace community to create a consensus approach for how verification, calibration, and validation should be defined and accomplished.

Because currently available reliability models have not been updated with newer and validated versions, developers will not have accurate methods to design and manage the reliability of future electronics systems. Rapidly changing electronics technologies continue to introduce new failure mechanisms and require new reliability models to be accurately assessed for all types of electronic parts. The complexities of integrated systems make it difficult to maintain systems containing life-limited components. The challenge includes finding suitable replacements for life-limited components. Component obsolescence drives the design to replace complex components with newer technologies that may not always be backwards compatible. This presents new problems in integration and timing and may drive a cascading upgrade of other components, subsystems, and systems.

While AFE 83 was launched to answer the need for practical physics of failure reliability prediction models for semiconductor devices, the In-Service Reliability program (AFE 84) was launched, in part, to examine the validation of models developed by AFE 83 by applying the validation framework developed by AFE 80.

17. Key Words

Aerospace Vehicle Systems Institute, Airborne electronic hardware, Commercial-off-the-shelf, COTS assemblies, Design assurance, Electrolytic capacitor reliability, Electronic-based reliability support, Environmental impacts on reliability, Failure rate, Integrated circuits, Integrated reliability, Physics of failure, Quality function deployment, Reliability analysis, Reliability models, Reliability model calibration, Reliability model spreadsheet, Reliability model verification & validation, Reliability prediction, Reliability roadmap, Reliability standards, Semiconductors, Semiconductor wearout

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LIST OF ACRONYMS

AFE	Authority for Expenditure
AVSI	Aerospace Vehicle Systems Institute
CALCE	Center for Advanced Life Cycle Engineering
CNSE	College of Nanoscale Science and Engineering
COTS	Commercial-off-the-shelf
DoD	Department of Defense
DSPO	Defense Standardization Program Office
EMI	Electromagnetic interference
IP	Intellectual property
LRU	Line replaceable unit
NDA	Non-disclosure agreement
NAVSEA	Naval Sea Systems Command
NSWC	Naval Surface Warfare Center
OEM	Original equipment manufacturer
PMC	Project management committee
QFD	Quality function deployment
R&D	Research and development
RIAC	Reliability Information Analysis Center
RSC	Reliability Simulation Council
TAMUS	Texas A&M University System
TEES	Texas A&M Engineering Experiment Station
WARP	Web-Accessible Repository of Physics-based Models

EXECUTIVE SUMMARY

Electronics device technology has revolutionized our lives. The exponential growth of device processing capability has resulted in a universal connectivity and new social norms that were unimaginable even 10 years ago. New creative commercial applications have driven advances in processing speed and device density—following Moore's Law, roughly doubling processing speed and device density every 18 months. This trend is also transforming the expectations and requirements for high-reliability, life-critical airborne avionics systems.

The integration of commercial-off-the-shelf (COTS) electronics into avionics systems provides advantages of greater computational power, allowing superior flight navigation, tracking, guidance, and communication processing abilities with far superior electronic displays, maps, and sophisticated processing algorithms than available before. Use of COTS electronics provides the advantages of better quality due to high manufacturing volumes. COTS scaling, however, has introduced the problem of life-limited semiconductors due to increasing susceptibility to different types of failure mechanisms as feature sizes shrink to deep submicron levels.

Outdated reliability prediction methods are unable to model these new technologies or adequately support reliable aerospace system design. The most widely used component reliability prediction handbook, MIL-HDBK-217, had its last published update, Revision F, in 1995. In 2009, a working group consisting of government and industry organizations was formed to revise the handbook. MIL-HDBK-217 Revision G was completed by the working group in May of 2010 and was due for the coordinated government/industry review. The publication of Revision G was put on hold by the Defense Standardization Program Office and has languished there since May 2010. More generalized cutbacks in government spending on research and development (R&D) make the prospect of a renewed effort to revise MIL-HDBK-217 remote.

The Aerospace Vehicle Systems Institute (AVSI) invested over a decade of research into electronics reliability, including deep submicron (less than 130 nm) semiconductor wearout mechanisms, atmospheric radiation effects, and the integration of physics of failure methods into reliability predictions. The members of AVSI include military and aerospace contractors with a long-term need for investment in reliability methods.

In 2011, the U.S. Department of Defense encouraged the formation of an AVSI reliability roadmap project (Authority for Expenditure [AFE] 74) to identify the existing gaps in the current reliability prediction methodologies and establish an approach to improving reliability prediction capability. Low R&D funding levels means that every dollar spent must be put to good use. The resulting industry consensus roadmap was prioritized by industry consensus using quality function deployment to organize the inputs of a wide variety of industry viewpoints to address the need for high-reliability electronic systems. Once the needs were identified and prioritized in the roadmap, AVSI launched the AFE 80 project in 2012 to provide the framework for addressing these needs.

One of the critical elements of this framework is a standard approach to verification, calibration, and validation of new reliability models and methodologies. Broad acceptance of a new reliability methodology depends not only on a technically credible approach to defining it, but

also a rigorous and standard approach to validating it. The AFE 80 project found a lack of consistency in how these steps were being handled in industry, academia, and government. It enlisted the help of key points of contact in the aerospace community to create a consensus approach for how verification, calibration, and validation should be defined and accomplished.

Because currently available reliability models have not been updated with newer and validated versions, developers will not have accurate methods to design and manage the reliability of future electronics systems. Rapidly changing electronics technologies continue to introduce new failure mechanisms and require new reliability models to be accurately assessed for all types of electronic parts. The complexities of integrated systems make it difficult to maintain systems containing limited life components. The challenge includes finding suitable replacements for limited life components. Component obsolescence drives the design to replace complex components with newer technologies that may not be backwards compatible. This presents new problems in integration and timing and may drive a cascading upgrade of other components, systems, and subsystems.

Increased susceptibility to radiation effects and random failure mechanisms will present greater integration challenges. The full costs of aircraft unreliability resulting from numerous new technology components in avionics systems requiring replacement and reintegration include much more than direct cash cost. There is time and opportunity loss; loss of data; loss of public trust; and potentially a loss of human life (e.g., the 2005 Malaysian Airlines incident, in which faulty flight control information led to a hazardous flight situation on a commercial airliner).

Funding for R&D remains sparse, and this project recognizes that funds are lacking for even the most highly compelling research requirements. The authors' hope is that R&D funding will return before significant aircraft/system failures force the issue. As R&D funding becomes available, the project findings in this report and the plans for future reliability research will help speed the engagement of funding and resources to effectively address the needs with respect to electronics reliability.

1. INTRODUCTION

Electronics device technology has revolutionized our world. The exponential growth of device processing capability has resulted in a universal connectivity and new social norms that were unimaginable even 10 years ago. New creative commercial applications have driven advances in processing speed and device density—following Moore's Law, roughly doubling processing speed and device density every 18 months [1]. This trend is also transforming the expectations and requirements for high-reliability, life-critical airborne avionics systems.

The integration of commercial-off-the-shelf (COTS) electronics into avionics systems provides advantages of greater computational power, allowing superior flight navigation, tracking, guidance, and communication processing abilities with far superior electronic displays, maps, and sophisticated processing algorithms than ever before. Use of COTS electronics provides the advantages of having better quality due to high manufacturing volumes. However, the integration of modern COTS devices has introduced new issues that may affect overall system reliability. For example, the dramatic shrinkage of gate-level feature dimensions in semiconductor devices has introduced the problem of life-limited semiconductors due to their increasing susceptibility to different types of failure mechanisms as feature sizes shrink to deep submicron levels.

The effect of the device scaling trend on reliability is seen in figure 1. This chart was extrapolated from the 2005 International Technology Roadmap for Semiconductors [2] and projects the mean service life—based on known trends in electromigration—of time-dependent dielectric breakdown and hot carrier injection degradation effects on microcircuits. As device feature sizes shrink, so does the projected mean service life based on these failure mechanisms.

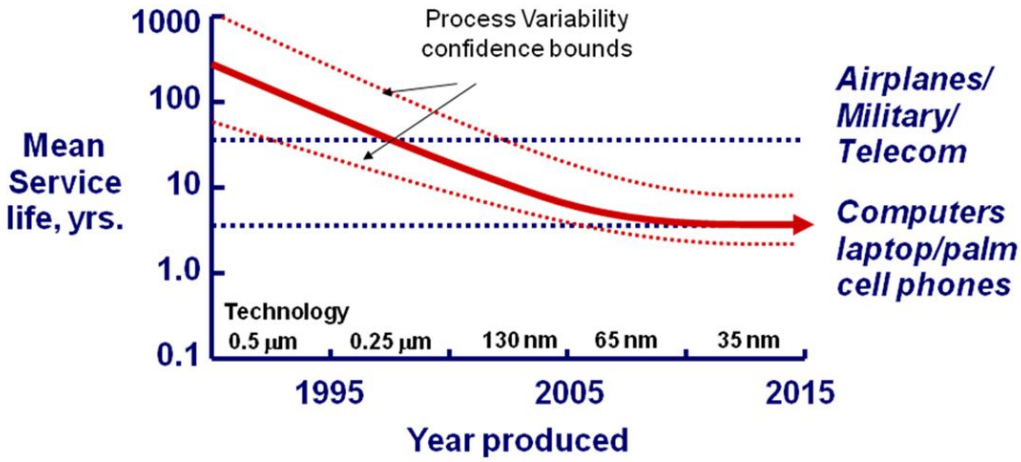

Figure 1. Microcircuit technology trends [2]

Outdated reliability prediction methods are not able to model these new technologies or adequately support reliable aerospace system design (see appendix B). The most widely used component reliability prediction handbook, MIL-HDBK-217, had its last published update, Revision F, in 1995 [3]. In 2009, a working group consisting of government and industry experts was formed to revise the handbook [4]. MIL-HDBK-217 Revision G was completed by the working group in May of 2010 and was due for coordinated government/industry review. The

publication of Revision G was put on hold by the Defense Standardization Program Office (DSPO) and has been on hold since its completion [5]. General cutbacks in government spending on research and development (R&D) make the prospect of a renewed effort to revise MIL-HDBK-217 remote. There is a need for an ongoing industry effort to develop, validate, and maintain good reliability models.

1.1 AEROSPACE VEHICLE SYSTEMS INSTITUTE BACKGROUND

The Aerospace Vehicle Systems Institute (AVSI) has invested more than a decade of research into electronics reliability, including deep submicron (less than 130 nm) semiconductor wearout mechanisms, atmospheric radiation effects, and the integration of physics of failure methods into reliability predictions.

AVSI is a research cooperative that addresses issues impacting the aerospace community through international collaborative research conducted by industry, government, and academia. Members combine their resources and talents to organize and conduct research projects that directly benefit the member organizations and often the aerospace industry as a whole. AVSI provides a voice for their membership to jointly influence tools, standards, processes, and technologies related to the aerospace industry.

AVSI is a division of the Texas A&M Engineering Experiment Station (TEES), which is an agency of the state of Texas and a member of the Texas A&M University System (TAMUS), which in turn is governed by the TAMUS Board of Regents. TAMUS is comprised of 11 universities (Texas A&M University: College Station is the flagship campus), seven state agencies, and one health sciences center. AVSI membership includes large system original equipment manufacturers (OEMs), major subsystems suppliers, government organizations, and academic institutions from the United States, Europe, and South America.

Figure 2 shows AVSI's organization, whose administration is comprised of a full-time director and administrative coordinator, a part-time assistant director, and a chief engineer. The administrative staff provides support to the executive board and AVSI projects to facilitate the operation of the cooperative.

The AVSI executive board is comprised of one representative from each full member (not liaisons and associates) organization plus the director of TEES and the AVSI director. The executive board meets quarterly to endorse new projects and provide project oversight.

When a new AVSI project is initiated under an Authority for Expenditure (AFE), a Project Management Committee (PMC) comprised of representatives from the sponsoring member companies and agencies is formed. The PMC is responsible for executing the project and managing the intellectual property (IP) that is created during the project. Although project members may represent competing companies, AVSI projects necessarily address precompetitive research and technology topics. Members of AVSI projects work together using well-defined mechanisms contained in the AVSI cooperative agreement for sharing information.

The disclosure of any AFE project technology requires PMC approval prior to sharing with another project.

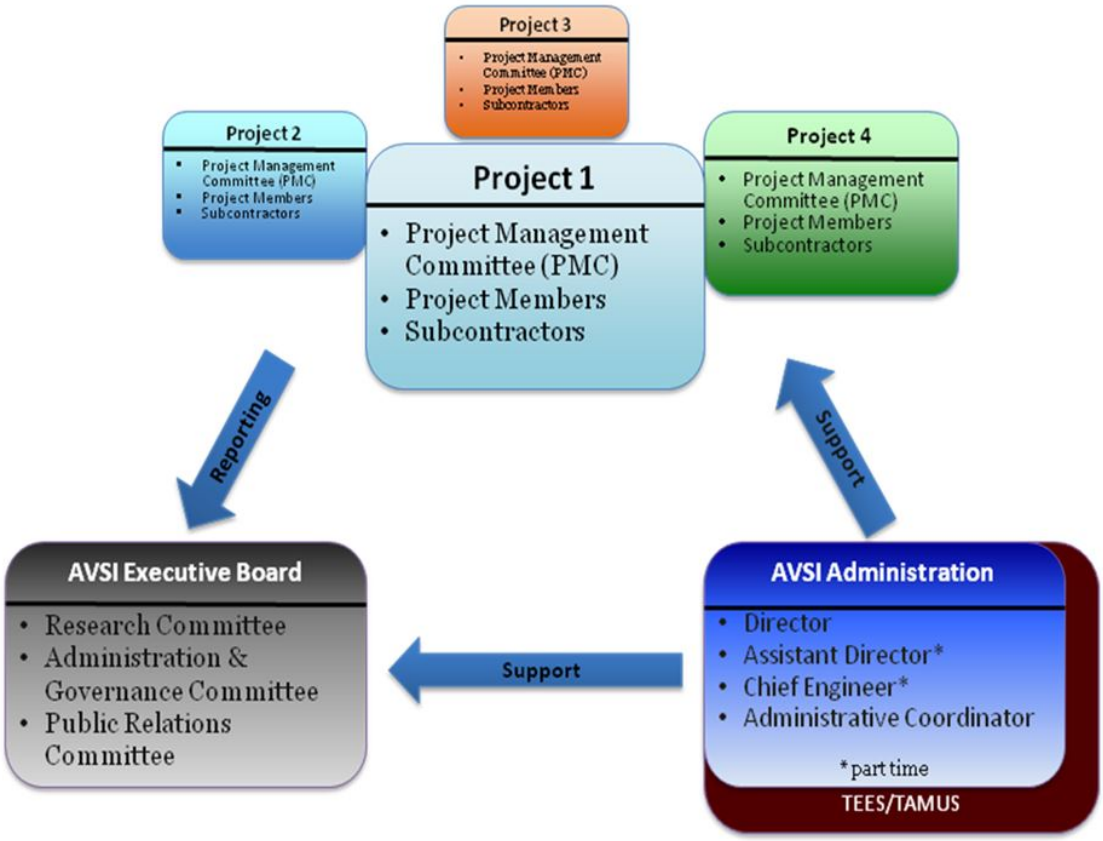

Figure 2. AVSI organization structure

Over its 14-year history, AVSI research has supported projects not only in electronics reliability, but also issues related to certification of safety-critical systems and technical development and support of aerospace industry standards. AVSI projects are suggested by the members and vetted through the AVSI Research Committee; therefore, they cover a broad range of precompetitive technology issues. In addition to the projects pertaining to reliability related technologies—such as atmospheric radiation effects, semiconductor wearout, and reliability prediction—current AVSI projects also include enabling research for wireless avionics intra-communications and system architecture-based virtual integration.

1.2 SCOPE

In 2011, the AVSI reliability roadmap project (AFE 74) identified the existing gaps in the current reliability prediction methodologies and established an approach for improving reliability-prediction capability. Low R&D funding levels mean that every dollar spent must be put to good use. The roadmap was prioritized by industry consensus using quality function deployment (QFD) to organize the inputs of a wide variety of stakeholder viewpoints to address the need for high-reliability electronic systems. Once the needs were identified and prioritized in the

roadmap, AVSI launched the AFE 80 in 2012 project to provide the framework for addressing these needs.

One of the critical elements of this framework is a standard approach to the verification, calibration, and validation of new reliability models and methodologies. Broad acceptance of a new reliability methodology depends not only on a technically credible approach for defining it but also a rigorous and standard approach for validating it. The AFE 80 project found a lack of consistency in how these steps are handled in industry, academia, and government (see appendix C). It enlisted the help of key points of contact in the aerospace community to create a consensus approach for how verification, calibration, and validation should be defined and accomplished.

Figure 3 shows the AVSI reliability roadmap and the reliability-related projects that have, over time, grown the reliability capability. Appendix B provides detailed information on the AVSI reliability roadmap. Future project plans are discussed in section 3.

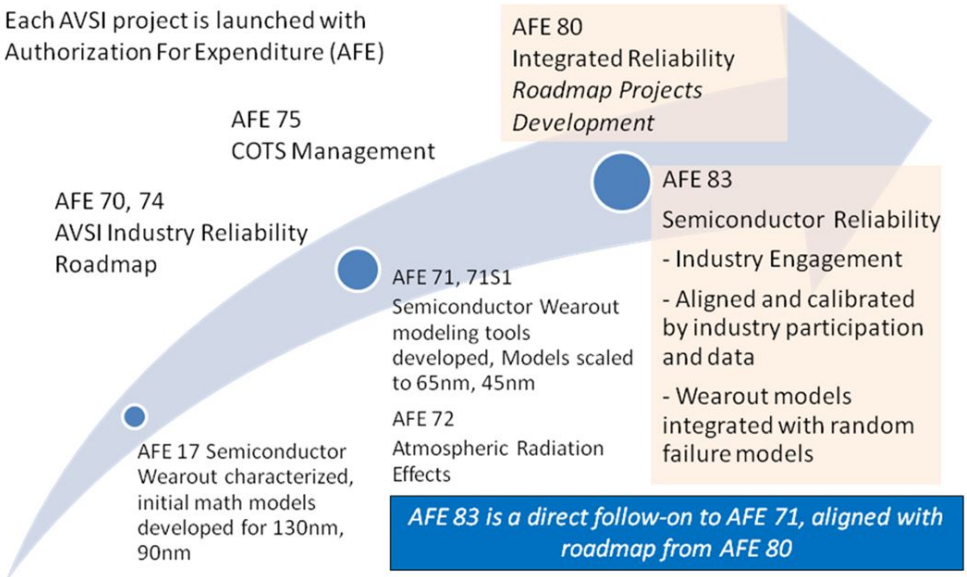

Figure 3. The AVSI reliability roadmap projects

1.3 FUTURE CHALLENGES

Because currently available reliability models have not been updated with newer and validated versions, developers will not have accurate methods to design and manage the reliability of future electronics systems. Rapidly changing electronics technologies continue to introduce new failure mechanisms and require new reliability models to be accurately assessed for many types of electronic parts. The complexities of integrated systems make it difficult to maintain systems containing limited life components. The challenge includes finding suitable replacements for limited life components. Component obsolescence drives the design to replace complex components with newer technologies that may not be backward compatible. This presents new problems in integration and timing and may drive a cascading upgrade of other systems.

Funding for R&D remains sparse, and this project recognizes that funds are lacking across the board for even the most highly compelling research needs. The authors' hope is that R&D funding will return before significant aircraft/system failures force the issue. When R&D funding becomes available, the project findings in this report and plans for future reliability research (see section 3) will help speed the engagement of funding and resources to effectively address electronics reliability needs.

2. FRAMEWORK FOR INTEGRATED RELIABILITY MODELING

The goal of a widely accepted integrated suite of reliability analysis methodologies, as captured in the AVSI reliability roadmap (see appendix B), can only be realized if a standard framework is established that enables consistent application of these methodologies by a variety of stakeholders. The role of MIL-HDBK-217 was not only to provide acceptable methods to assess the reliability of electronics, but it also served as a normative reference that promoted a common understanding of the results of those assessments. The obsolescence of MIL-HDBK-217 is driven in part by the speed of change of the technologies it describes. Therefore, the means to promulgate acceptable methodologies and promote consistent application must also change to keep pace with technology. The AFE 80 project established a framework for integrated reliability modeling and began the development of capabilities identified by the AVSI reliability roadmap. The tasks selected for AFE 80 were identified in the AVSI reliability roadmap as necessary enablers for the effective development of new reliability prediction models.

AFE 80 developed features of the roadmap that are common to all reliability modeling approaches, such as common standards for establishing models (section 2.1.1); application of models (section 2.2); and testing, data collection, and validation (section 2.3). Project members also explored ways to ensure periodic maintenance and updating of the models (section 2.4). Finally, the members investigated the feasibility and established ground rules for implementing a reliability prediction methodology electronically rather than as a static, published document (section 2.5).

2.1 ESTABLISHING NEW RELIABILITY MODELS

As new electronics technologies are introduced, new reliability models must be continuously proposed, developed, verified, calibrated, and validated to establish acceptable reliability modeling methodologies to support the integration requirements of high reliability systems. Rapidly changing electronics technologies continue to introduce new failure mechanisms that require reliability models that accurately assess both random failure rate and wearout. The project identified the need for methods of establishing new reliability models in a standardized manner to provide the structured development and disciplined approach that will lead to wide industry acceptance of the results.

2.1.1 Standards for the Progress of Subprojects

A subproject is defined, for the purposes of this report, as a reliability model development project that supports the AVSI reliability roadmap. It will be proposed and supported by a reliability integration project such as AFE 80. AVSI projects are funded by the pooled resources

of member companies that have agreed to collaborate on the development of common benefit technologies. Because their funding depends on collaboration, it is important that subprojects are carefully planned and justified by clearly addressing the needs of the AVSI project participants (i.e., the PMC members). In this context, the AFE 80 project team established the following guidelines for the progress of subprojects:

1. Be able to answer Heilmeier-type questions to justify the need for the project.
2. Support the implementation of the AVSI reliability roadmap.
3. Produce a reliability prediction model that is:

    a. Integrated with other modeling methods
    b. Clearly and completely defined
    c. Calibrated to field experience
    d. Validated

The Heilmeier questions (also known as the Heilmeier Catechism) were established by George H. Heilmeier, director of the Defense Advanced Research Projects Agency, in the 1970s.

In accordance with the Heilmeier Catechism, researchers proposing a project are required to answer the following questions [6]:

- What are you trying to do? Articulate your objectives using absolutely no jargon.
- How is it done today, and what are the limits of current practice?
- What's new in your approach and why do you think it will be successful?
- Who cares? If you're successful, what difference will it make?
- What are the risks and the payoffs?
- How much will it cost? How long will it take?
- What are the midterm and final "exams" to check for success?

Answering the Heilmeier questions helps those who are proposing a subproject determine whether it's worth pursuing and helps organize the justification for project funding.

The AVSI reliability roadmap (appendix B) was based on a broad industry collaboration to identify existing gaps in the current reliability prediction methodologies, prioritize needs, and establish an approach for improving reliability prediction capabilities. The roadmap used QFD to organize the inputs of a wide variety of stakeholder viewpoints to address the need for high-reliability electronic systems. When a subproject supports the AVSI reliability roadmap, the technologies being proposed in that subproject have already demonstrated an alignment with industry and government stakeholder needs. Furthermore, AVSI contracts with technology providers that are best suited to develop the specific technology being addressed in a given subproject, as determined by the participating members. This broadens the set of stakeholders to include best-in-class technology providers.

Subprojects will support the AVSI reliability roadmap by developing a technology, model, or capability that supports the overall goal of improved reliability predictions.

2.1.2 Typical Progression of Tasks

AVSI reliability subprojects will follow the standards established by AVSI and use AVSI templates and standard outlines for the definition of the project plan. Although each subproject will have unique needs and features, the following are guidelines for the typical progression of tasks:

1. Gather existing research in the area of the technology and engage community of suppliers and users.
2. Propose new models.
3. Develop rules for the application of reliability models.
4. Conduct an independent validation.
5. Establish a mechanism for review and update of models.

The first phase of a subproject will focus on assessing the state-of-the-art reliability modeling of the subject technologies. It may start with a broad literature search and then focus attention on the centers of excellence for research in the subject areas. As more is learned, subject matter experts will be contacted for advice and help with the subproject, and possible participation as a member or subcontractor.

A user community will also emerge as part of the outreach activity associated with the initial assessment phase. It will be valuable to keep the user community engaged with the progress of the work—from the earliest stages of methodology development; through development and validation of the models; and eventually for establishing the new methodology as a new standard with wide industry acceptance.

When a good understanding of a specific technology of interest is accomplished, new models can be proposed based on the physical failure mechanisms. The new models should be detailed enough to provide the information necessary for application design decisions while keeping them simple enough in implementation to be practical for use in a system reliability program. There may be excellent new ideas available from academia and research centers, but the theoretical models may be in a form that is not useful to the average reliability engineer and will need to be adapted for practical use.

The next phase of model development will focus on applications of the new reliability models to verify that the models meet the needs of the practitioner and to calibrate the models by finding good default values for the model parameters.

When the new models are established and calibrated, the next phase is to validate them. When verification and calibration are conducted carefully, with good data and rigorous methods, validation can often be overlooked or underfunded. Rigorously developed models have a certain measure of credibility, which may be viewed as sufficient by the sponsors.

No matter how carefully a new model is developed, reliability models are, by nature, prognostic. The only way to know whether a method is valid or not is to use it to predict something, and see

if the prediction is reasonably accurate. Reliability models must be validated before their use in critical applications. A good validation study will maintain as much independence of the analysis as possible by using new data that are not the original data used to derive or calibrate the models.

If funding is an issue, an interim study based on a literature search or supplier data requests may serve as a bridge to a real validation effort.

The final step is to set up mechanisms for the review and updating of the models. Technologies continually change, as do their dominant failure mechanisms. A subproject that develops a new methodology should establish guidelines for maintenance of the methodology. Maintenance in this sense may include such things as periodic updates of parametric values based on experimental data or predetermined thresholds for changes in key characteristics of the models. One possible mechanism for maintaining models is the collection of Internet-based feedback from an established user community. Whatever the mechanism, it is essential to identify an appropriate custodian with sufficient resources committed for the anticipated list of the methodology.

2.1.3 Common Rules for Engaging and Proposing a Subproject

Subprojects will provide new reliability models to fulfill industry needs identified in the AVSI reliability roadmap. Expertise from outside the AVSI membership (e.g., University of Maryland's Center for Life Cycle Engineering [CALCE], Quanterion Solutions Inc., DfR Solutions) may be engaged for technical guidance, help in developing the subproject proposal, and possible participation as associate members. Potential project participants will be engaged early to ensure their support of the subproject.

Subprojects will be proposed and supported by a reliability integration project, such as AFE 80. AVSI projects are funded by the pooled resources of member companies that have agreed to collaborate on the development of common benefit technologies. Because their funding depends on collaboration, it is important that subprojects are carefully planned and justified by clearly addressing the needs of the sponsors.

AVSI subprojects are governed by the terms of the AVSI cooperative agreement, which includes rules for the ownership and protection of IP. Collaboration with companies outside of AVSI may require an additional non-disclosure agreement to ensure proper handling of sensitive information.

The main issues that were addressed and determined by the PMC to be acceptable for a subproject are the following:

1. Idea proposed from the roadmap.

    a. Ratings from roadmap to determine priorities
    b. Sponsor interest influences choice of next project
    c. Consider dependencies within roadmap to see if combining tasks is a good idea

2. Fit within context of AVSI projects.

    a. Sponsor interest in project
    b. Budget scoped to be approximately the same as other AVSI projects (i.e., approximately $100–200K project)
    c. Able to accomplish goals in one year or split into multiyear structure
    d. Expertise readily available, especially within the AVSI member companies
    e. Alternatively, be proposed in another organization

3. Coordinate with AFE 80 core team.
4. Address IP issues.

2.1.4 Checklist for Subproject Launch

The following is a checklist to use for determining if a subproject is ready to launch:

1. Are sponsors available and interested in funding the project?

    a. Contingencies (in case budgets are short)

        i. Rescope projects, if needed.
        ii. Spread project over longer timeframe, if possible.
        iii. AVSI to pursue other sponsors.

    b. Funding cycles—look at how early a new project needs to be proposed for future government funding cycles

2. What are the benefits for participants?

    a. Highlighting of prior work, platform for wider audience—may provide benefit to other research organizations and encourage their participation

b. Answering Heilmeier questions (especially “Who cares? If you’re successful, what difference will it make?”)

3. Are there enough existing data to complete the task? Is validation data phase secured or agreed on?
4. Are expertise identified and engaged to help with the project?
   a. Other organizations/consortia may be source (e.g., Reliability Simulation Council [RSC])
   b. Engage expertise from prior related AFE projects

5. Is there a plan in place (e.g., schedule and budget)?
6. Is the subproject tied to roadmap?

2.2 APPLICATION OF RELIABILITY MODELS

Aerospace applications often require a 20–30 year service life, whereas COTS electronics usually are designed for shorter market cycles. Commercial applications, such as mobile communications and computing, have requirements for high performance and low cost; consequently, long-term reliability is less of a concern. This leaves less incentive for COTS suppliers to address the need for extended life by applying mitigation measures for these failure mechanisms.

Avionics systems are designed to rigorous high standards of safety and reliability, with growing processing demands of advanced navigation, guidance, and communication systems. High functional density and high-speed processing to support the growing avionics systems requirements are enabled through the use of COTS electronics with deep submicron (less than 90 nm) integrated circuit technologies.

Airborne environments are generally harsher than ground-based applications. For many electronics, each flight cycle induces vibration combined with a thermal cycle, even for those in partially protected areas, such as the electronics bay. Flight environments are harsh on electronics and electronics packaging due to extremes of temperature, frequent thermal cycling, moisture, vibration, pressure, and atmospheric radiation.

An important consideration during reliability model development is the application of the equipment and resulting needs of the reliability practitioners. The development of common rules for using the models helps provide stability and repeatability of the results. Common rules may also establish industry standards to support the new methodology and standards needed for certification. Application considerations are used to calibrate the models by finding good default values for the model parameters that are accurate within the ranges of typical application environments. Plotting results of the models over multiple environmental stresses will help to address the complexities of natural environments. The results will provide a basis for using the new models in the design of high-reliability applications.

2.2.1 Common Rules for Using Models

Different aerospace industry segments (e.g., commercial, space, and military) may have different requirements for similar applications. Some of the common standards for using reliability models in aerospace and other high-reliability applications include:

1. Commonality, repeatability of model results

    a. Accreditation of model and modeling practices
    b. Use of common tools

2. How well model matches reality

    a. Explain extrapolation of model beyond its limits
    b. Model adjustments based on field experience
    c. Use of engineering judgment should capture a rationale

3. Model limitations
4. Library of components/materials

The accreditation of a model and its associated modeling practices provides the ability to independently verify the results of a reliability analysis and therefore allows a customer to have more confidence in the results. When a supplier, integrator, and customer have common tools for the analysis, this helps provide a repeatable and, therefore, well-understood process.

Common rules for the limitations of a model provide a standard scope of applicability and may help when a model is, for some reason, used beyond its limits. For example, a model may have been developed using high-energy neutron testing for characterizing a component's susceptibility to radiation. If this model is then used for energetic particles of a different spectrum, there is a need to understand limitations of this approach. The range of applications of a model may need to be maintained and revised as new applicability is identified.

Establishing a library of the common components, materials, and failure mechanisms will provide a common basis for multiple users and for using a model multiple times. This will also enhance the stability of the methodology and encourage consistency of the results.

2.2.2 Levels of Detail Needed for Different Applications

While a proposed reliability modeling methodology may provide more accurate results, it also may be more involved than other more traditional reliability estimation methods. It may not be necessary to analyze every device in a given unit at the same level of detail. For many, conservative estimates will be adequate to meet random failure rate targets, and a combination of older technologies and limited stress will suggest that reliability and wearout life are adequate. Cost/benefit analysis of proposed reliability methods versus traditional reliability approaches for various applications could prove to be useful. This will require cooperation among suppliers, integrators, and their customers to characterize the costs and benefits at the systems level.

Figure 4, developed under AFE 83, shows a decision process for determining the level of detail needed for modeling semiconductor microcircuit failures. AFE 83 developed a spreadsheet tool that provided a simplified approach to modeling the physical failure mechanisms at the device level. This was an additional level of detail that may not be practical for all applications.

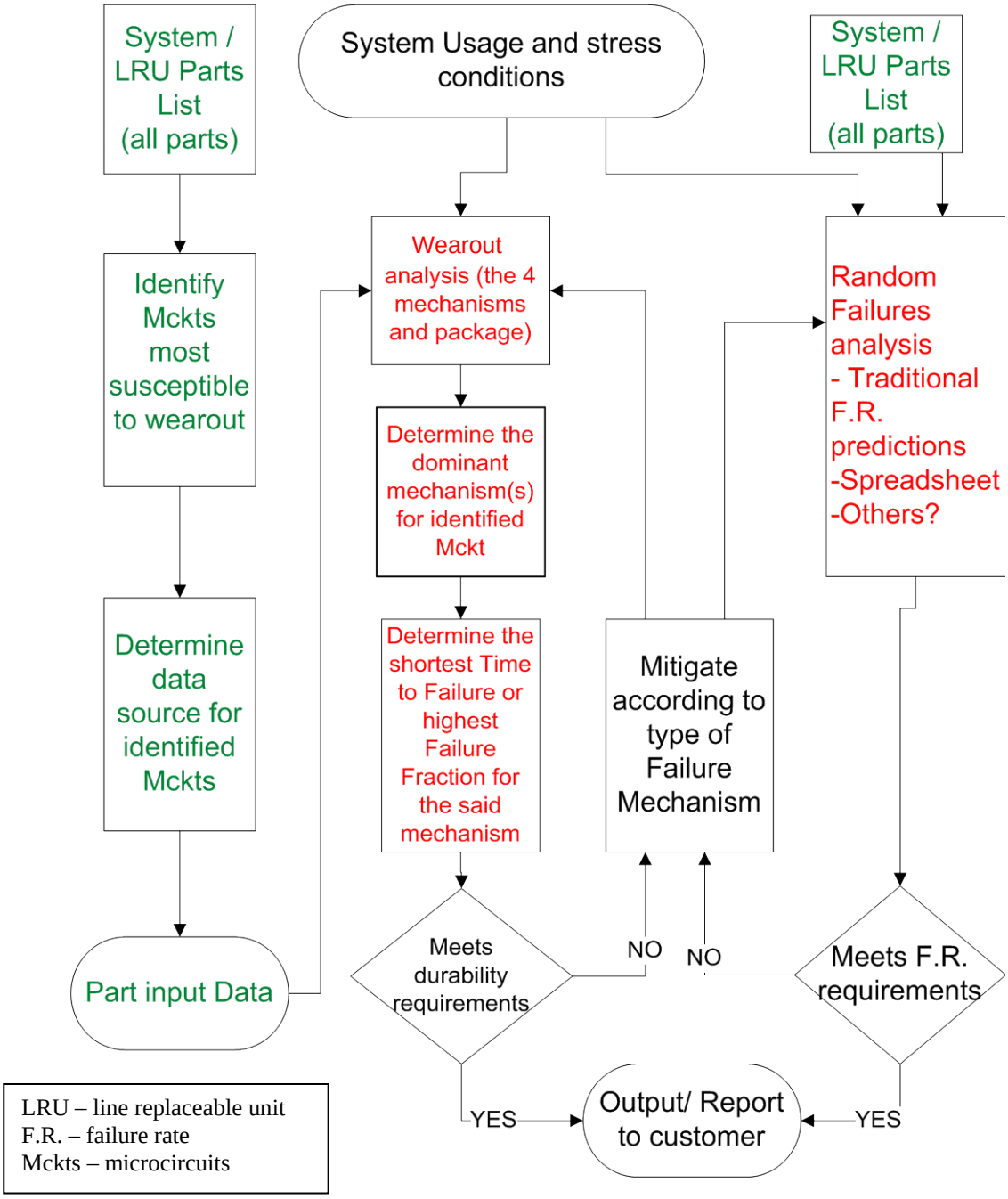

Figure 4. The AFE 83 semiconductor reliability decision flow diagram

2.2.3 Criteria for Modeling Environmental Effects

Airborne environments are generally harsher than ground-based applications. Each flight cycle induces vibration combined with a thermal cycle in many electronics, especially those in partially protected areas, such as the electronics bay. Flight environments are harsh on electronics and electronic packaging because of extremes of temperature, frequent thermal cycling, moisture, vibration, pressure, and atmospheric radiation. In aviation applications, reliability needs can be higher as application conditions become worse.

2.2.4 Address Complexities in the Natural Application Environment

The natural environment in the context of application usage environments may include vibration, temperature, humidity, pressure, radiation, etc.

To adequately address these in a reliability prediction, we need to model the effects of typical use profiles based on patterned cycles and average missions versus specific fatigue mechanisms. We need to focus on those parameters that can be controlled and scaled from reference points to usage environments. Scaling provides a means to work with devices in which the user does not have detailed knowledge of the material properties or design.

Test environments may be very controlled compared with the natural environments. This means that some of the interactions within the natural environment may not be represented by reliability models.

2.3 MODEL DEVELOPMENT LIFE CYCLE

When a new reliability model is developed, the successful implementation of the model depends on the acceptance, within the user community, that the new approach has merit. The process involves verifying the model, providing the required information, calibrating it with known quantities, and then subjecting it to a rigorous validation. The model can be tested and compared with test or field failure data to check its accuracy and gain an understanding of its limitations.

The use of commonly accepted implementation processes for new models is important for credibility and acceptance of the results. During the AFE 80 project, the project team discovered that different industry segments and different government agencies have established different standards for the verification, calibration, and validation of new models. This generally contributes to the lack of acceptance of new reliability models across industry. Different industry segments also have different definitions for verification, calibration, and validation, leading to further confusion and lack of commonality.

Appendix C provides the industry review the project team conducted on verification, calibration, and validation, and the different definitions found across industry. After conducting the industry review, the AFE 80 project team reviewed the results in a series of meetings with industry subject matter experts (i.e., the “Points of Contact”). A consensus was developed to standardize definitions for the purpose of conducting the AVSI reliability subprojects.

The following definitions were established within the Points of Contact meetings after consideration of the industry standards studied by the core team. These are intended to serve the need of establishing the credibility of new reliability prediction models. These definitions differ from those established by the Federal Aviation Administration but are aligned with the Department of Defense's (DoD's) definitions and industry consensus. The core team hoped that aligning with the DoD would encourage the latter to adopt advanced reliability methods developed by AVSI as part of their military standards:

- Model Verification—The process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification.
- Model Calibration—Adjustment of the parameters of a model to better align it with standards, published data, or controlled test data.
- Model Validation—The process of determining the degree to which a model or simulation is an accurate representation of the real-world from the perspective of the intended uses of the model or simulation.
- Model Accreditation—Acceptance by industry, regulatory agencies, or standards organizations based on the technical quality proved by the validation.
- Model—A mathematical representation of the failure rate due to a single failure mechanism (see section 5 for definition).
- Methodology–An integrated collection of models.
- Tool—A realization of the methodology. This is typically a software implementation (e.g., spreadsheet, special purpose software, or iPhone application).

The implementation process based on these definitions follows a timeline, with the flow of information shown in figure 5.

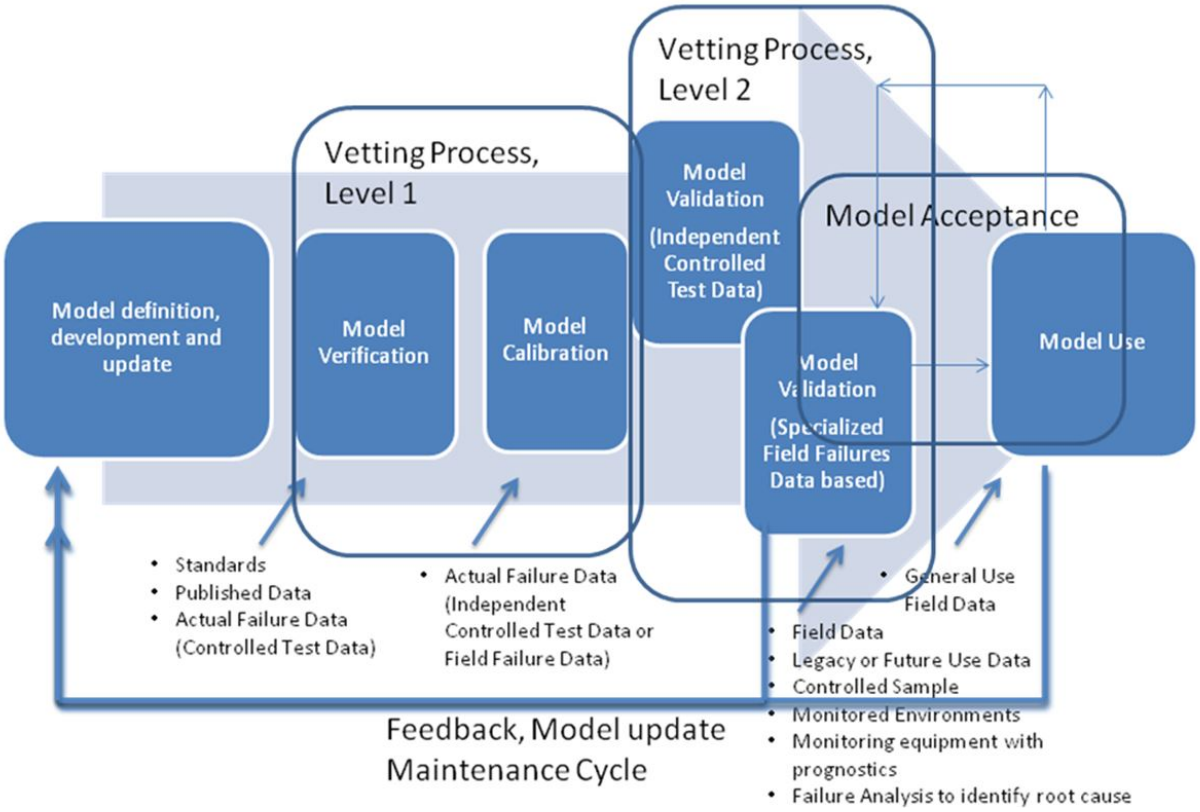

Figure 5. Implementation flow diagram

2.3.1 Verification

Verification is defined, for the purposes of an AVSI subproject, as the process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification. There are several purposes to the verification process, including:

- Provides an early process check for the reliability model
- Improves communication between a sponsor and the developer of a model
- Provides more documentation to clarify the characteristics of a model
- Helps correct problems

The verification process needs to be credible and comprehensive enough to provide the needed assurance.

The verification process also has some potential drawbacks, such as:

- Complexity of the model may make verification difficult, especially for physics-of-failure reliability models.
- Over simplification can cause key concepts to be missed.
- Lack of independence can cause bias in the process.

2.3.1.1 Steps in Verification

Proper verification is performed in 6 steps, as follows:

1. Develop and document a verification plan.

    a. Identify specification(s) or document the developer's concepts (e.g., range of temperatures or other environments; "random" or "wearout" mechanisms; storage; handling; and features needed)
    b. Identify the acceptance criteria, including the approval process, if applicable
    c. Establish standards for meeting the specification
    d. Roles/responsibilities (e.g., independent contractor to conduct study)
    e. Schedule/budget

2. Plan approval or customer review and concurrence.
3. Secure funds and resources (e.g., third party reviewers).
4. Execute verification.
5. Approve or peer review the results.
6. Publish report.

2.3.2 Calibration

Calibration is defined, for the purposes of an AVSI subproject, as the adjustment of the parameters of a model to better align it with standards, published data, or controlled test data. The purpose of calibration of a model is to provide consistency and portability.

A calibration should be conducted using a systematic, ordered process to establish the parameters. Calibration should be best fit to the data based on metric of choice (e.g., correlation coefficient).

Some of the potential drawbacks of calibration include:

- Combining different distributions may create problems unless parametric sensitivity is considered.
- Adjustments that seem to fit a mathematical optimum may not have a physical basis in the real world (i.e., meaning of parameters within a physical context).
- The meaning of each variable and sub-calculation should be understood to understand which variables are calibration parameters.
- If calibration is not possible, the models will have limited usefulness. In this case, it is recommended that the model be redefined.

Calibration is a two-step process: 1) establish standard for how good the calibration must be (i.e., correlation level), and 2) establish an order to the adjustments for multiple parameters.

The resources for calibration include the model whose parameters needed adjustments, contextual data (e.g., environmental stress, component dimensions), physical constants (e.g., coefficient of thermal expansion), and the calibration steps or procedure.

2.3.3 Validation

Validation is defined, for the purposes of an AVSI subproject, as the process of determining the degree to which a model or simulation is an accurate representation of the real-world entities from the perspective of the intended uses of the model or simulation. It serves two purposes: 1) to gain industry acceptance, and 2) to check the accuracy and provide opportunity for any corrections.

The validation process is a rigorous and well-documented procedure, yet it is practical—it can be accomplished in a reasonable amount of time or budget. Validation is also a reproducible and repeatable process. Validation's independence provides an objective assessment and minimizes conflict of interest by having the validation agent being someone independent of and not affiliated with the developer.

Despite this, the validation process has its potential drawbacks as well, including:

- The complexity of the model may make validation difficult, especially for physics-of-failure reliability models.
- Over-simplification can cause key pieces to be missed.
- Lack of independence can cause bias in the process.
- There are difficulties in obtaining data—test data are costly; field data take too long to gather.
- Circular validation may result from reuse of the calibration data set.

2.3.3.1 Validation Steps

The two types of Validation methods are validation by test and validation by field data.

2.3.3.1.1 Steps in Validation by Test

Validation by test is performed in nine steps, as follows:

1. Develop and document a validation plan.

    a. Acceptance criteria (i.e., approval process, if applicable)
    b. Standard for how accurate the industry needs the prediction to be (i.e., how much risk can be tolerated)—that is, a metric for validation accuracy
    c. Roles/responsibilities (e.g., independent contractor to conduct study)
    d. Schedule/budget
    e. Testing plan:

        i. Identify test articles.
        ii. Identify all model parameters and their relationship to the physical aspects of the component and use environment.
        iii. Identify the failure mechanism being modeled. Note that most components will require multiple models to fully characterize their reliability.
        iv. Embedded sensors may be useful to characterize environmental profile (conditions and cycles)—(for semiconductors) should at least measure frequency, voltage, and temperature.
        v. A full description of the component/technology type to which the model applies—to include function and process, as appropriate.
        vi. A full description of the model characteristics (e.g., the logic behind the model and parameter choices).
        vii. A full listing of all assumptions being made to either simplify the model or to extrapolate accelerated test data to normal operating conditions.
        viii. A full listing of the limitations for the model (e.g., the model is applicable to Fin Field Effect Transistor [FinFET] devices that are nonplanar, double-gate transistor, built on a silicon-on-insulator substrate)

    f. A full listing of the constraints of the model (e.g., temperature range, bias conditions)
    g. Uncertainty limits (when possible)
    h. An indication as to from where the data required for calibration and validation will be coming (e.g., physical constants, testing requirements, dimensional data)

2. Plan approval or customer review and concurrence.
3. Secure funds and resources.
4. Execute validation plan (i.e., purchase test articles, secure facilities).
4. Collect data and conduct failure analysis of the units that failed in the test.
5. Analyze data and vet the model.
6. Approve or peer review the results.
7. Publish report.

2.3.3.1.2 Steps in Validation by Field Data

Validation by field data is performed in seven steps, as follows:

1. Develop and document a validation plan.

    a. Acceptance criteria (i.e., approval process, if applicable)
    b. Established standards for how accurate the industry needs the prediction to be (i.e., how much risk can be tolerated)—that is, establish a metric for validation accuracy
    c. Roles/responsibilities (e.g., independent contractor to conduct study)
    d. Schedule/budget
    e. Field data collection plan

        i. Identify field data to collect

            - Understand environments, especially at the part level.
            - Atmospheric radiation exposure.
            - Embedded sensors may be useful to characterize environmental profile (conditions and cycles).
            - Record for each event what frequency, voltage, and measured temperature were used.
            - Components in different locations will have different environments, but separating them in the data set may be challenging.
            - Overall population statistics may obscure effects of the extreme environments within the population.

        ii. Data collection standards and processes:

            - Data completeness (i.e., are all failures documented?)
            - Environmental profile understood

- Product history understood (e.g., is the line replaceable unit [LRU] mature or are there potentially relevant issues being addressed by mods?)
- Flight hours available
- Circuit application noted (e.g., radio frequency, power supply, or digital)

iii. Failure analysis

- Were a high percentage of repairs troubleshot to piece part level?
- Is the unconfirmed percentage (i.e., no fault found percentage) related to false alarm rate high?
- Is there a plan for addressing uncertainty introduced by troubleshooting to assembly level (printed board assembly)?

iv. Periodic review of data

- Is the current performance within statistical bounds?
- Is the failure rate changing?
- Have there been any changes to the device design?

2. Plan approval or customer review and concurrence.
3. Secure funds and resources.
4. Execute validation plan.
5. Analyze data and vet the model.
6. Approve or peer review the results.
7. Publish report.

2.4 MECHANISM FOR REVIEW AND UPDATE OF MODELS

The final step in the life cycle of a reliability prediction methodology involves setting up mechanisms for review and updating of the models. Technologies continue to grow and change, and the failure mechanisms to which they are subject also change. Before the subproject team disbands and pursues other endeavors, they will recommend that guideline be put in place for maintenance of the methodology. This could be a periodic refresh of the parameters, or it may be predetermined thresholds for changes in key characteristics of the models. There may be a need for setting up an Internet-based user community for feedback on the models. A custodian will need to be identified with a small but dependable source of funding. It is recommended that this custodian be responsible for basic maintenance of the methodology, with the details of the custodian's responsibilities and operational constraints determined by the needs of the sponsors of the developmental projects.

The AFE 80 project team explored the needs and requirements for a maintenance program. These are predicated on the amount of funding that would be needed/available for ongoing maintenance.

Reliability models have to be updated periodically as technologies change. Empirical data may show an increase or decrease in the failure rate of a technology over time, depending on many factors, such as the maturity of the manufacturing processes, changes in product susceptibility to environments usage stresses, and material property changes.

There are considerable challenges for getting the data to support updates of reliability models. The AFE 80 project asked the Reliability Information Analysis Center (RIAC) for advice from their experience managing reliability methodologies and obtaining and handling data. They provided detailed information from the 1996 RAC Data Sharing Consortium and recent Web-Accessible Repository of Physics-based Models (WARP) database. The AFE 80 project team also looked at the RSC efforts to establish a semiconductor reliability data repository.

A key hurdle all these efforts encountered was the establishment of satisfactory data-sharing agreements between the organization and members of industry who represented potential contributors of experience data. There also must be incentives for members to contribute, such as reciprocal benefits of using the pooled data or using the expertise available through the consortium.

An outline for conducting a maintenance program is provided in appendix A.

2.4.1 Ongoing Maintenance of Models

The need for ongoing maintenance of models is driven by the need to ensure accuracy and currency for existing and future technologies. This is particularly difficult for technologies that change rapidly, such as those in the semiconductor industry. It is important to constantly revisit underlying assumptions of the models and revise them to better represent new failure mechanisms dominating the current devices.

Finding funding sources for maintenance of the models will be particularly challenging because funding for maintenance is more difficult to justify than funding for new development. Preventive measures are more difficult to recognize because the scope of the problems that they avoid is not evident and does not cause concern until the impact is recognized and felt. There are, however, definite advantages to proactive preparation rather than after the fact correction.

Low-cost methods must be sought to effectively accomplish the periodic maintenance and updating of the models. User community collaboration via the Internet (e.g., Wiki page, blogs, and social media) and the use of consortia (e.g., AVSI and RSC) may provide low-cost solutions.

Maintenance protocols must include configuration control, version control, and vetting of new contributions. This can be accomplished by identifying an entity owning the model, such as a standards organization or an AVSI project PMC.

Data sharing outside an AVSI project PMC will need to address IP issues among relevant industry companies. Liability needs to be addressed in the data-sharing agreements.

The diversity of the models represented in the AVSI reliability roadmap provides an additional challenge, as it creates the need for multiple authorities to contribute to the maintenance.

2.4.2 Ground Rules for Periodic Updates

Ground rules for the periodic updates must be established early in the maintenance process. This includes not only the programmatic issues of collaborative agreements and data sharing, but it must also include technical considerations. An update may be triggered by technology changes or scheduled on a regular interval, or on the discovery of the loss of predictive reliability capability.

Establishment of an industry-wide, or industry-segment-wide, clearing house for field failure data would be beneficial because it would provide a broader basis for updates to the models, especially if integrated across multiple companies and sources. It would provide a resource for the maintenance of the models.

Failure data collected must be complete and include unfailed units. Standard data-reporting procedures should be established to provide consistent reporting. It will be challenging to capture complete information that characterizes the environmental stress conditions, so a statistical evaluation of a partial data set may become necessary.

If technologies change too rapidly, field data may not relate adequately to future technologies. The maintenance processes should also allow new information to be used based on device testing and analysis. The existing centers for field/test data and failure rate modeling, such as CALCE, should be recognized and integrated into the plan.

2.4.3 Use of Field Data

Reliability information that is derived from the actual usage of the item in the customer application is generally called “field data.” Field data are better than test data at reflecting the complexities of the usage environment, because they are collected from the usage environment. Likewise, field data reliability assessments are more credible than those derived from testing but may be more challenging to obtain.

Collaboration with an ongoing “crowd sourcing” (see section 5 for definition) resource may provide a source of field data for maintenance of the reliability models. Funding for the collection of field failure data needs to be ongoing, although initially a low-level concern may be enough to sustain a well-defined system.

The AFE 80 project team identified the following roadblocks for getting the data:

- Funding
- Limitations of mil-aero data
- Restrictions on social media participation for mil-aero industry
- Lack of a good business case to do it, preventing a company from providing reliability data
- Particularly challenging (sharing field data) at the OEM level
- Difficulty in capturing validation data

To meet these challenges, the project team suggests the following strategy:

- Make the costs as low as possible by utilizing automation.
- Show a good value in the pooled resource created by the collaboration.
- Quid-pro-quo strategy—ask an OEM for LRU-level design info; give them reliability information in return.

2.5 ELECTRONIC-BASED METHODOLOGY

Information—such as books, videos, technical papers, and even works of art—is increasingly being accessed via electronic media. Paperbound books have been replaced by tablet-style readers. Television is being phased out in favor of Web-based video sources. Cell phones now provide instant access to the Internet, available at all times, day or night.

The underlying change that has driven these electronic conveniences is the revolution in all aspects of data handling. Advances in data mining allow faster and more thorough access and processing of information. Internet technologies, such as cloud computing (if secure), have enabled widespread storage and retrieval of data from any device. New algorithms for analyzing data trends have enabled targeted Internet ads and a more personalized experience interacting with applications on the Web.

Traditional reliability prediction methodologies in the past have been published as government or industry standard documents in a static form that required periodic review, vetting, and approvals for publication. Revisions were periodic and controlled. The published document may have been provided in some electronic format, such as a .pdf file, but it would have only limited hyperlink ability and no underlying data organization structure.

The advantage of a highly vetted and deliberate publication process for reliability prediction methodologies is the assurance that the material is correct and has been thoroughly checked by multiple experts. The disadvantage is that a slower process is necessarily less accurate because it lags the rapidly changing technologies that it is trying to assess. If a standard takes 3 years to be developed, reviewed, approved, and published, then anything within it is at least 3 years old on the date of publication. This is two generations of Moore’s law and the new standard will be obsolete the day it is released.

The challenge is to find a good balance between caution and expedience. The advantages of electronically published media are numerous. This mode provides a more accessible user experience, the potential for far broader industry involvement (i.e., crowd sourcing), and an expeditious process for updating the models and revising the documentation. Migrating from a paper to an electronic dissemination process will speed the process up but will not totally resolve the standards approval processes.

3. CONCLUSION

The AFE 80 project team investigated the feasibility of an electronic-based reliability prediction methodology. This was done with a review of industry electronic databases (SD-18, WARP, and the proposed RSC database) for lessons learned. Appendix D has the detailed information gathered from this review. The review was organized using the following outline:

1. Issues to resolve (e.g., configuration control) to achieve an accelerated (over paper publication), but still deliberate, process
2. Vetting of new contributions
3. Processes for updating
4. Usage standards, user policy
5. Defaults

3.1 GENERAL LESSONS LEARNED (FROM SD-18, WARP, AND RSC)

The review of the SD-18, WARP, and the proposed RSC databases provided the following lessons learned:

1. An expeditious publication approach, such as a Web-based resource, requires the same disciplined rigor in development and vetting of, for example, new models, data, and parameters as a paper publication. This protocol must be established and documented early in the development of the resource. A central manager (i.e., an individual or organization providing oversight, vetting, and control of the content) helps keep the content credible. Even if the Web-based publication allows some amount of crowd sourcing, it will need someone assigned to adjudicate the contributions.

2. Policy for handling IP must be defined early. This must include protections for member contributions of data and any IP generated by the activity.

3. Expectations of the user community are very high. With the proliferation of efficient mobile devices, information access of Web content is growing along with the expectation of well-constructed Web content. Anything provided on the Web will need to meet new and constantly changing standards.

3.2 ISSUES TO RESOLVE

There are many issues to resolve toward establishing an electronic-based methodology. Early in the process, it will be important to establish a technical requirements document and central authority to enforce standards to manage updates, and establish the process and policies for contributors and users. The technical requirements document, planning documents, and central authority will need to address these issues.

1. Data-sharing agreements (e.g., Reliability Simulation Council [RSC] challenges–see appendix D).
2. Policy for handling IP (e.g., RSC challenges–see appendix D).

    a. Protection for contributors' IP
    b. IP that is generated by the activity

3. Funding (e.g., SD-18 had limited funding).

    a. Setup
    b. Maintenance

4. Existence of a tool/models/methodology must not discourage due diligence on the part of the user to understand and use the tool/models/methodology responsibly.

    a. Need to provide the user with sufficient information to measure risks and uncertainties.
    b. Encourage users to verify/validate the tool/models/methodology for themselves.
    c. Electronic tool can encourage user community discussion of the use of the tool/models/methodology, which may provide information useful for updating the tool/models/methodology.

5. Knowledge capture enhanced by the electronic medium.

    a. App analogy–Opinions captured through blogs can be used to judge merit of new app.

6. Need recognized authority for vetting.

    a. Vested interest in product and process

7. Security must be established—protect against malicious intent intrusions.

    a. Data assurance, digital signatures
    b. Use of encryption for data that must be private

8. Data loading considerations.

   a. How many users will be expected on a given day?
   b. How many viewers versus how many contributors?

9. Policy for user access.

   a. Whether there are licensed seats
   b. Foreign access—any restrictions
   c. Jurisdiction issues—policies of hosting location

10. Need user protection if you are asking for feedback.

   a. Anonymity helps facilitate candid feedback.
   b. Named/identified users provide more credible assessment.
   c. Confidentiality is better than anonymity (e.g., assurance, through non-disclosure agreement [NDA], to not divulge names).
   d. Forum can be used for feedback.
   e. Not all input will be valuable (i.e., there may be fallacious input for various reasons).
   f. Large participation should be encouraged and one vocal individual should not be allowed to dominate (if the goal is consensus building).

11. Important to document the definitions (of verification, etc.) and provide it as part of the general documentation that is included on the website or in the user documentation.

   a. Definitions, which may differ in other contexts, were developed for this project (see section 5 for these definitions).
   b. Establishing a standard is a good goal but may be difficult to accomplish because of varying views.

3.3 PROPOSALS FOR FOLLOW-ON AEROSPACE RESEARCH AND DEVELOPMENT

Because currently available reliability models have not been updated with newer and validated versions, developers will not have accurate methods to design and manage the reliability of future electronics systems. Rapidly changing electronics technologies continue to introduce new failure mechanisms and require new reliability models to be accurately assessed for all types of electronic parts. The complexities of integrated systems make it difficult to maintain systems containing limited life components.

Low R&D funding levels require that every dollar spent must be put to good use. The AVSI reliability roadmap was developed to encourage the coordinated and consistent development of needed technology reliability models to grow the capability over time. The roadmap was prioritized by industry consensus using QFD to organize the inputs of a wide variety of industry viewpoints to address the need for high-reliability electronic systems. Projects that are drawn from the roadmap will continue to support the needs expressed by the industry and build the

envisioned capability. These results will hopefully be shared broadly for the benefit of all those in the industry, government, and academia who need them. Past project results (e.g., the AFE 83 spreadsheet containing the semiconductor reliability models) have been shared openly to encourage best practices.

During AFE 80, a new AVSI project was proposed with support of the members of the AFE 80 project team. The project, AFE 83, semiconductor reliability, launched in April 2013 and has enjoyed great support from the sponsors and user community. Two projects that were developed during AFE 74S1 (AFE 81 and AFE 82) have not yet launched but are potential future projects. These three projects are summarized here. The detailed proposals (AFEs) are available from AVSI.

3.3.1 AFE 81 Photonics Reliability

This project will develop a methodology for predicting the reliability of photonics components and systems in high-reliability applications.

There is a growing interest in photonics for use in military and aerospace applications. The benefits of optical over copper-based electronics are numerous. Optical systems offer higher speeds and higher bandwidth while being more lightweight and requiring less power to operate. In military aerospace applications, the added benefit of a lack of electromagnetic interference (EMI) makes optical computing systems very attractive.

Past reliability studies of photonics have focused on ground-based telecom applications. As more optical systems are being sought for mil-aero applications, a need has arisen for methods to accurately assess and manage the reliability of such components and systems in airborne environments.

Photonics reliability was identified by the reliability roadmap project, AFE 74, as a high-return, lower-effort, low-hanging fruit project resulting from a past work by partner organizations in optical component reliability. The University of Maryland's CALCE has conducted research into the failure mechanisms and prognostics of components, such as light-emitting diodes. The RIAC has conducted field data reliability studies of a wide variety of ground-based optical electronics. Both organizations contributed to the development of the reliability roadmap and will be contributors to this study.

In summary, the photonics project:

1. Leverages prior research at CALCE and RIAC to address the growing need to model the reliability of optical electronics.
2. Addresses a need for airborne applications.

    a. Optical systems offer higher speeds and higher bandwidth while being more lightweight and lower power with less EMI susceptibility
    b. Growing availability of optical technologies

3. Uses physics of failure and empirical studies to develop an integrated reliability solution.

3.3.2 AFE 82 Electrolytic Capacitors

This project will address knowledge gaps regarding electrolytic capacitor reliability and component life modeling. It will additionally develop methods for assessing the reliability impact of electrolytic capacitor life degradation and failure mechanisms on electronic systems in aerospace and high-performance applications.

AFE 82 will organize and systematize information from a broad range of sources including publicly available information from industry and academia, as well as prior and current research in this area by the CALCE. The focus will be on synthesizing information about electrolytic capacitor life models and developing actionable quantitative and qualitative guidance.

In summary, the electrolytic capacitors project:

1. Uses expertise and prior results from CALCE to develop quantitative life models of electrolytic capacitors: aluminum liquid and tantalum solid electrolytic capacitors.
2. Provides application guidance for reliable design with interpretation of life data.
3. Supports the AVSI reliability roadmap.

3.3.3 AFE 83 Semiconductor Reliability

The AFE 83 semiconductor reliability project was formed around the vision that reliability practitioners at all levels can apply microcircuit device-level physics of failure models to support the use of COTS electronics in reliable systems design.

The AFE 83 strategy has been to use industry collaboration to develop a practical microcircuit reliability prediction methodology, implemented in a spreadsheet tool that can be used by mil-aero integrators, avionics OEMs, and their device suppliers. It is hoped the spreadsheet will foster a collaborative approach to managing the growing reliability challenges of device scaling to enable the use of technology advances to meet the application needs of airborne systems.

The AFE 83 project launched in April 2013 and continued through the end of 2015. It has provided the AFE 80 team with a great example of how the AFE 80 framework can support the successful development of a new reliability modeling methodology.

3.3.4 AFE 84 In-Service Reliability Program

Launched in June 2015, AFE 84 is, in part, an example of responding to the framework developed by AFE 80. The projects in AFE 84 stemmed from the reliability prediction methodology needs identified by AFE 74's roadmap. AFE 84 was launched with the goal of investigating three issues regarding the reliability and safety of electronic products:

1. Lead-free electronics alloy risk assessment.
2. The single event effects occurring within microelectronics due to their susceptibility to atmospheric radiation.
3. Semiconductor package reliability and wearout aspects, which include the calibration/ validation of the physics of failure models agreed on through the research done by AFE 83. This task will be achieved by using the calibration/validation framework developed by AFE 80's research.

4. REFERENCES

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5. GLOSSARY

Accreditation–The acceptance by industry, regulatory agencies, or standards organizations based on the technical quality proved by the validation.

Calibration–The adjustment of the parameters of a model to better align it with standards, published data, or controlled test data.

COTS scaling–The progression of COTS electronics to smaller features sizes and higher processing speeds and densities.

Crowd sourcing–Use of Internet resources such as social media to gain large participation in the development of a concept, definition, document, or design.

Failure cause–The circumstances during design, manufacturing, or use that have induced or activated a failure mechanism.

Failure mechanism–The physical process by which a combination of thermal, mechanical, electrical, chemical, and magnetic stresses damage the materials comprising the product.

Failure mode–A physically observable change caused by a failure mechanism (e.g., open, short, or any other electrical parameter change in an electronic product).

Failure site–The location of a failure mechanism.

Methodology–An integrated collection of models.

Model–A mathematical representation of the failure rate due to a single failure mechanism.

Subproject–A reliability model development project that supports the AVSI reliability roadmap.

Tool–A realization of the methodology, typically a software implementation (e.g., spreadsheet, special purpose software, iPhone app, etc.).

Validation–The process of determining the degree to which a model or simulation is an accurate representation of the real-world entities from the perspective of the intended uses of the model or simulation.

Verification–The process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification.

APPENDIX A—RELIABILITY MODEL MAINTENANCE

This appendix provides an example outline of a reliability model maintenance plan. It provides a list of possible model support features and the implementation considerations. This outline should be used as a starting point and is developed, as needed, to support reliability model maintenance planning.

A-1 APPENDIX A: RELIABILITY MODEL MAINTENANCE

1. Internet-linked model library
2. Electronic database

    a. Component data
    b. Test data
    c. Field data
    d. Model-generated data and analyses & performance data

3. Operational services

    a. Reliability model tools and services

        i. Reliability models mapped to the components used in avionics
        ii. Reliability model spreadsheet

    b. Reliability model management

        i. Reliability model programs and issue management

            - Contractual requirements
            - Manufacturing data availability and adequacy
            - Reliability models availability, gaps, and issues
            - Reliability guidelines
            - System-level reliability

        ii. Configuration/change control

            - Cross-organizational change control and support
            - Cross-domain change control and support
            - Change control boards

        iii. Ownership and access management

iv. Research and development

- New technology requirements for reliability modeling

  – Limited life components
  – Wearout
  – System failure risk, analyses, and prediction

- New reliability model development
- Industry and regulatory coordination

c. Reliability standards support services

APPENDIX B—AVSI RELIABILITY ROADMAP

This is an excerpt from the AFE 74 final report, which has a more comprehensive coverage of the derivation of the roadmap. This appendix provides a summary of the background and findings from that project and a description of the roadmap. The subtitles below should be read within the context of the AFE 74 project.

B-1 ACRONYMS

AFE	Authority for expenditure
AVSI	Aerospace Vehicle Systems Institute
CALCE	Center for Life Cycle Engineering
DfR	Design for reliability
DoD	Department of Defense
FAA	Federal Aviation Administration
FR	Failure rate
HW	Hardware
IC	Integrated circuit
MBU	Multiple bit upset
nm	Nanometer
Pb	Lead
pdf	Probability density function
PoF	Physics of failure
PWA	Printed wiring assembly
QFD	Quality function deployment
SEE	Single event effect
SEL	Single event latchup
SEU	Single Event Upset
SnPb	Tin-lead
SW	Software
VITA	VMEbus International Trade Association
VME	Versa-module European

B-2 AFE 74 EXCERPT

B-2.1 INTRODUCTION

The AVSI project AFE 74 engaged a community of reliability subject matter experts to develop a reliability prediction technology roadmap based on a collaborative quality function deployment (QFD) industry assessment. The QFD provided a means to capture multiple viewpoints in a detailed enumeration of the needs, priorities, and potential solutions for new reliability prediction methods to better support reliable system design processes.

The project also developed reliability prediction capabilities identified as Module A by the 2009 AVSI project AFE 70. This included a methodology for modeling sub-100 nm semiconductors with some guidelines for a simplified approach, a conversion method from Weibull wearout to constant failure rate, and a method to convert a failure rate from calendar hours to operating hours.

This project was sponsored by the Department of Defense (DoD), FAA, Honeywell, and The Boeing Company as a follow-on project to the 2009 AVSI project AFE 70. During AFE 70, a smaller-scale QFD was conducted and used to develop an initial roadmap. The 2009 QFD was developed based on the expertise of the project team members from Honeywell and Boeing, with some input from the sponsors from the DoD and FAA [B-1]. Although limited in scope, the 2009 study illustrated the value of QFD as a tool to organize and assess details of needs, features, and offerings. This follow on was chartered to repeat the steps of the QFD while engaging a broader spectrum of stakeholders from industry, government, and academia.

The discussions that were inspired by conducting this QFD have provided an opportunity to open communications on some very divisive reliability prediction issues and helped bring the community together to solve the challenges of improving the utility of reliability predictions for the future.

B-2.2 PURPOSE AND SCOPE

The purpose of this project is to provide a new reliability prediction roadmap that can be used to develop updates to MIL-HDBK-217 [B-2], or an equivalent reliability prediction method. Use of the results of this project in standard practices will assure that updated data, models, and other information are accessible, useful, and widely accepted by suppliers and users of aerospace and high-performance electronic systems.

The scope of this project is to investigate electronic and electromechanical failure rate modeling. The project is not intended to answer broader reliability program issues, except to the extent of determining how reliability prediction and assessment methods can provide value to the broader goals of a design for reliability program.

B-2.3 ASSESS ALTERNATIVES

An assessment of alternative offerings was conducted (see table B-1) to rate how well reliability prediction methods address the stakeholder needs. Alternative offerings initially selected for this study included 217Plus™, VITA 51.2, Telcordia, FIDES, MIL-HDBK-217FN2, MIL-HDBK-217G, CALCE PWA, Sherlock, and the IC Calculator.

The core team tried to avoid making the assessment judgmental, and decided not to calculate the overall total score for each tool. The purpose of step 5 of the QFD was the identification of strengths and gaps in industry offerings, and the selection of one of the tools was not a goal.

The tools were rated based on their ability to satisfy the needs identified in prior QFD steps. This was used to identify gaps and opportunities.

Table B-1. Assessment of alternative tools

Stakeholder Needs / Requirements	Stakeholder Priority	Alternative Products & Planning										
		217Plus (P)	VITA 51.2 (V)	Telcordia (T)	FIDES (E)	MIL-HDBK-217F N2 (F)	MIL-HDBK-217G (G)	CALCE SARA (S)	Sherlock & PoF IC Calc (D)	Gaps	Best Fit	Count of >5
Coverage of Legacy, contemporary and near future technologies	9	6	7	6	6	4	5	8	8		**S,D**	6
Coverage of comprehensive range of electronic and electromechanical d	9	7	5	7	7	5	6	8	6		**S**	6
Assessments of physical failure mechanisms	9	6	8	0	6	1	1	8	8		**V,S,D**	5
Results are reproducible	9	7	3	1	1	8	8	5	5		**F,G**	3
Models are validated	9	6	6	1	1	3	5	6	6		**P,V,S,D**	4
Results support a design for reliability program	8	5	8	0	3	5	5	9	8		**S**	3
Mil-aero environments and operating loads	8	5	7	0	5	5	5	7	8		**D**	3
Solder joint integrity including effects of lead-free materials	7	6	6	0	3	1	1	8	9		**D**	4
Impact of lead-free solder/finishes tin whisker risk	7	0	1	0	1	0	0	7	0	X	**S**	1
Consistent methods to aggregate results	7	2	3	0	3	0	0	5	5	X		0
Non-operating (storage), operating and mixed results	7	5	0	0	5	0	0	8	5	X	**S**	1
Models account for design for environment	7	4	5	0	4	1	1	5	5	X		0
Adjustment based on data such as test and/or in-service results	7	8	3	9	1	0	0	7	8		**T**	4
Widely accepted / used in aerospace / Hi Rel	7	6	4	1	3	7	7	6	5		**F,G**	4
Literature elaborating bases of the models available	7	7	7	5	1	7	6	5	5		**P,V,F**	4
Time dependent results & constant, fixed rate	5	3	3	0	0	1	1	5	3	X		0
Estimates of statistical confidence or other uncertainty measures.	5	5	0	9	0	0	0	7	4		**T**	2
Progressive refinement from ROM to high fidelity	5	8	0	9	0	8	8	3	0		**T**	4
Easy to use and implement with limited data	5	9	1	6	3	9	9	3	3		**P,F,G**	4
Support widely and readily available	5	6	0	6	1	9	9	6	6		**F,G**	6
Readily implemented through software	5	9	9	9	9	9	9	9	9		**all**	8
Transient and cumulative effects due to atmospheric radiation	4	1	4	0	0	0	0	0	0	X		0
Software/firmware reliability	4	7	0	0	0	0	0	0	0	X		1
Widely accepted / used in general industry	4	7	4	6	1	5	5	6	5		**P**	3
No Fault Found removal rate	1	4	0	0	0	0	0	1	0	X		0

Score 0 or 1
Score >5

B-2.4 DEFINE TECHNICAL SOLUTIONS

An important consideration for future developmental planning is the relative level of effort that will need to be used to develop the features. A rough assessment (i.e., high, medium, low) of effort was used to sort the features into four categories (see figure B-1) such as "jewels" (low effort, high coverage), "low hanging fruit" (low effort but low coverage), etc. This provides another dimension to consider for future planning, especially for multiyear developmental roadmaps.

Features labeled "jewels" are good candidates for small scale projects. If they are placed early in the planned developmental roadmap, they can rapidly provide capabilities to address needs.

The "low hanging fruit" are features that may address only one need, or have limited usefulness to the participants of the QFD. As these are considered easier to do, they are good candidates for combining with other higher coverage efforts.

The "high-hard" features will require time, resources, and significant effort, but will provide a good return on the invested effort. They are good candidates for funded efforts or multiyear projects.

The "low return" features have low coverage and are viewed as high effort. They may cover higher priority needs as considered by a small number of participants, but the needs they cover scored lower in priority for the larger group of participants. These features are included in the roadmap as candidates for exploratory studies or combined with other features.

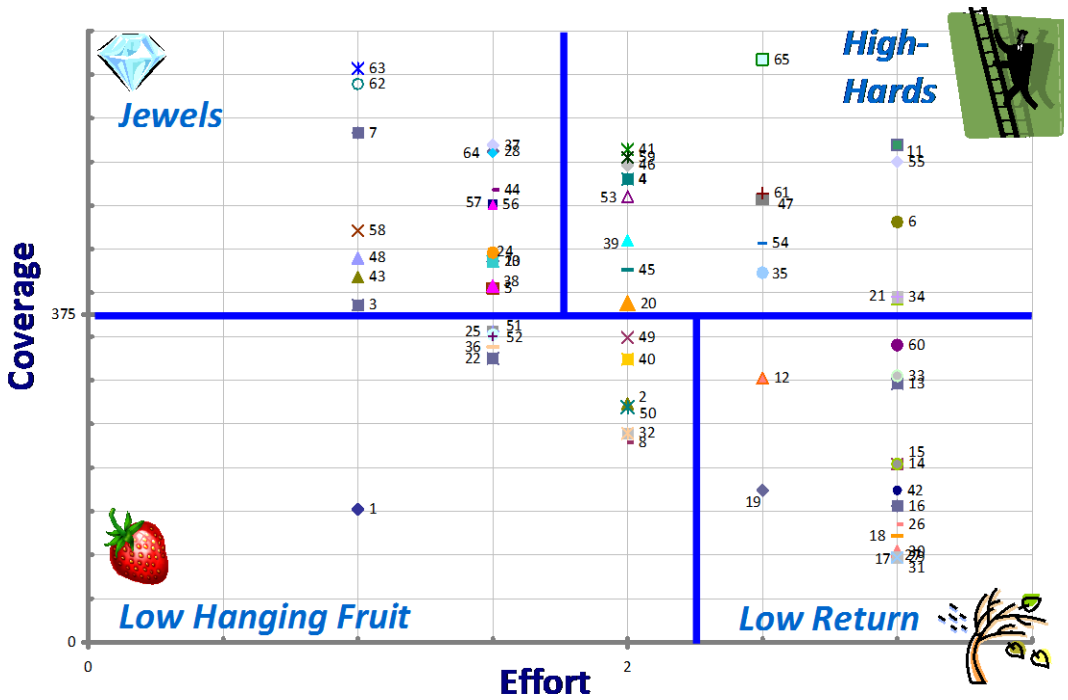

Figure B-1. Features coverage (value) vs. effort

B-2.5 ROADMAP

The reliability QFD has provided a detailed, integrated assessment of the existing needs, priorities, and design features, based on the combined wisdom and experience of a large number (72 participants) of industry reliability experts. Consideration of the features coverage scores, the correlations and the relative effort involved provide the basis for the proposed roadmap.

The reliability prediction capability envisioned in this study will not be quickly or easily put in place because the framework includes features that are new or are being considered in a novel context. There are also features, such as consideration of "human in the loop," that are mostly unknown and have no prior examples of their use as considerations in a reliability prediction. Creative, systems-level thinking will be required to address these needs.

The capability envisioned for the future is more than a discrete sum of the constituent features. A more holistic view of the need/feature space was considered by utilizing the QFD correlations analysis (step 4) and clustering the features into focus areas.

The roadmap presented in this document is a proposed starting point and will be refined and updated as stakeholders and industry working groups review the analysis and contribute to the development of a coordinated plan.

B-2.6 FOCUS AREAS

The reliability prediction features were clustered into four focus areas: Data and Methods, Applications, Components and Packaging, and Environments. Use of these focus areas organized the roadmap into a more systemic view, so that a top-down approach could be used to develop the roadmap. It also divided the list of 65 features into more manageable, smaller groups that made considerations of coverage, effort, and correlations easier to consider.

The "data and methods" focus area comprises features that are primarily mathematical or theoretical derivations and any that relate to methods of handling data. Some examples include features related to confidence intervals, Weibull distribution, combined distributions, conversions from cycles to hours, providing methods for models to be self-contained, substantiated, validated by test, or validated by comparison with industry-accepted models.

The "applications" cluster focuses on the customer view, and includes features related to issues and problems mostly owned, controlled, understood, and cared about by the end user or customer of a product. Examples include support for the design for reliability (DfR) process, assessment of system failure modes and mechanisms, easy "what if" analyses, integrated systems, software failures, human in the loop considerations, facilitation of risk identification, design for environment, and validation by field experience.

The "components" focus area contains component models. This includes: comprehensive suite of models for parts in common use, connectors, electrolytic capacitors, electrochemical cells, photonics, and semiconductor physics of failure (PoF) models.

The “packaging, environments” focus area comprises features that relate to failure mechanisms at the packaging level and the effects of environments and environmental fatigue life issues. This includes: solder joint fatigue (including lead-free), packaging, storage/dormant, temperature cycling, humidity, tailorable environments, combined environments, electrical operating load/stress, duty cycle, variability of material properties, and design for environment.

B-2.7 HIGH-LEVEL AND MID-LEVEL ROADMAP

Figure B-2 shows the conceptual, high-level roadmap. The focus areas support each other by providing information and complementary capabilities as they are developed. The resulting reliability predictions capability will grow over time, with the growth rate increasing over time.

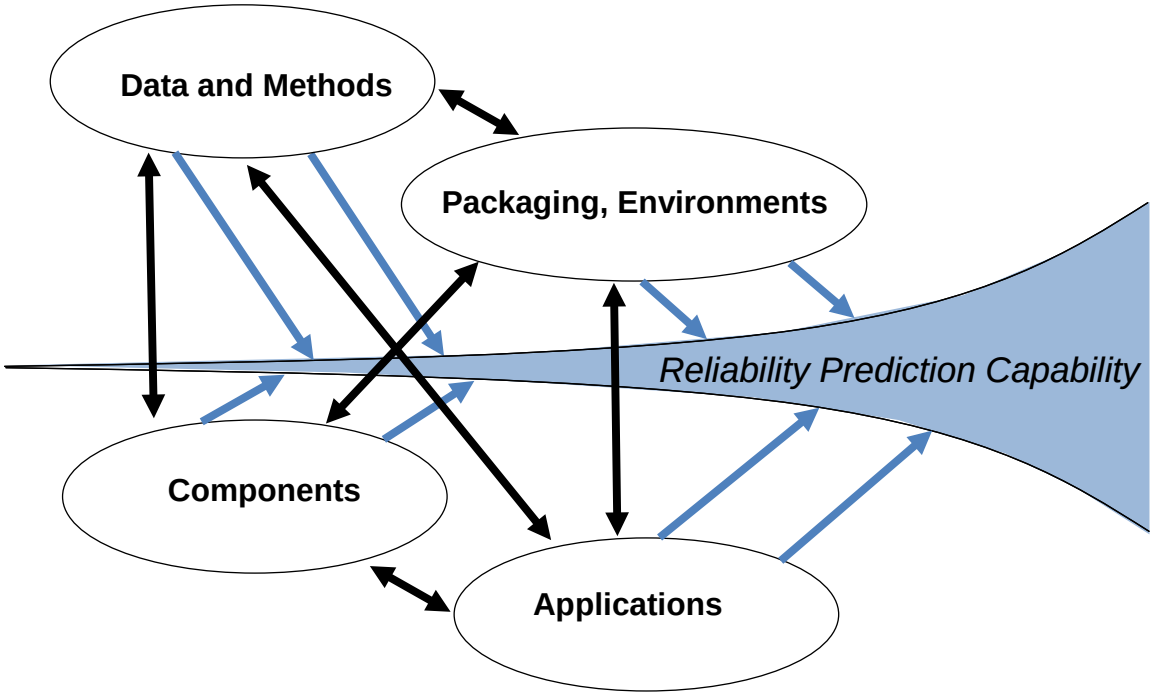

Figure B-2. High-level roadmap

Figure B-3 shows the midlevel roadmap with the additional detail of the individual features provided in terms of their numbers as established in the QFD. The colors denote the feature label from step 6, the coverage and effort assessment, as depicted in table B-2.

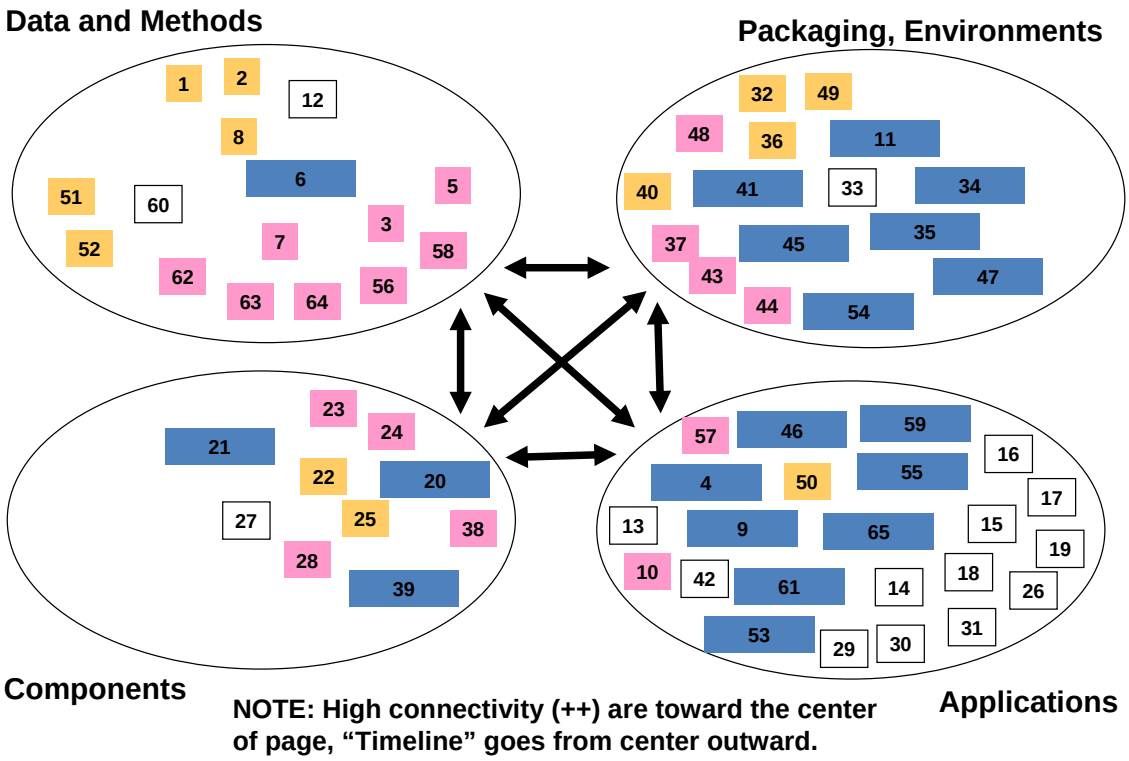

Figure B-3. Midlevel roadmap

Table B-2. Features coverage versus effort

ID	Feature	Feature Score	Effort	Labeled as:
1	Results include confidence intervals	152	1	Low Hanging Fruit
2	Result includes estimate's risk or maturity level	273	2	Low Hanging Fruit
3	Component model provides failure distribution parameters, e.g. Weibull, where not constant	386	1	Jewel
4	Result includes estimate of useful system life	530	2	High Hard
5	Provides explicit conversion method from time-dependent failure rate to constant failure rate	405	1.5	Jewel
6	Allow for combined probability distributions (pdf and cdf)	481	3	High Hard
7	Model results in failure rates directly in a specific cyclic measure, e.g. operating hour	583	1	Jewel
8	Method for adjusting failure rates to a single measure	229	2	Low Hanging Fruit
9	Model includes assessment of individual failure modes and mechanisms	736	2.5	High Hard
10	Allows for easy "what if" analyses	436	1.5	Jewel
11	Models include combined environmental effects	569	3	High Hard
12	Results seamlessly compatible with other reliability tools	302	2.5	Low Return
13	Systems are modelled as integrated elements of hardware, software and human interaction producing an overall system reliability predictor	296	3	Low Return
14	Supports Simulated Guided Testing	204	3	Low Return
15	Supports Simulated Aided Testing	204	3	Low Return
16	Model considers the SW and all of the environment layers as appropriate	156	3	Low Return
17	Coverage of comprehensive range of software issues and characteristics	95	3	Low Return
18	Coverage of comprehensive range of human reliability issues	122	3	Low Return
19	Models include a component for SW FR	174	2.5	Low Return
20	Includes comprehensive semiconductor PoF models	388	2	High Hard
21	Comprehensive suite of models for parts in common use.	393	3	High Hard
22	Connector Models	325	1.5	Low Hanging Fruit
23	Electrolytic capacitor life model	436	1.5	Jewel
24	Reliability, durability & life models for electrochemical cells	446	1.5	Jewel
25	Photonics	356	1.5	Low Hanging Fruit
26	Predict SW impact on HW architecture	135	3	Low Return
27	Provide SW errors per single lines of code.	99	3	Low Return
28	Programmable device data retention/wearout modeled	562	1.5	Jewel
29	Model considers human in the loop in individual capability and response.	97	3	Low Return
30	Model considers human in the loop in the operating environment.	104	3	Low Return
31	Model consider human in the loop in the organizational context.	97	3	Low Return
32	Conformal Coat Model	239	2	Low Hanging Fruit

Table B-2. Features coverage versus effort (continued)

ID	Feature	Feature Score	Effort	Labeled as:
33	Tin whisker models, including stress-dependent failure mechanisms for SnPb and Pb-free solder	305	3	Low Return
34	Includes time-dependent radiation failure modes	395	3	High Hard
35	Includes SEE upset models for SEU, MBU, & SEL	423	2.5	High Hard
36	Solder joint models, including temperature-dependent failure mechanisms for Pb-free solder	338	1.5	Low Hanging Fruit
37	Provides Package model, e.g.config & complexity factors	569	1.5	Jewel
38	Includes models for <130nm IC technology	408	1.5	Jewel
39	Model accounts for die complexity	460	2	High Hard
40	Include storage / dormant environment models	324	2	Low Hanging Fruit
41	Provides temperature cycling fatigue model at hot/cold extremes	564	2	High Hard
42	Includes method to quantify transient/intermittent failures	174	3	Low Return
43	Provides coverage for hot/cold extreme temperature effects	418	1	Jewel
44	Provides shock/vibration (high-cycle) fatigue effects	518	1.5	Jewel
45	Provides a humidity factor	426	2	High Hard
46	Provides tailorable environments defined by application	546	2	High Hard
47	Provides for electrical operating load/stress	507	2.5	High Hard
48	Provides ability to account for device operating duty cycle	440	1	Jewel
49	Takes into account power cycling rate	349	2	Low Hanging Fruit
50	Facilitates risk identification	269	2	Low Hanging Fruit
51	Models include a simplified version (e.g. parts count method)	352	1.5	Low Hanging Fruit
52	Context driven defaults are provided for factors	350	1.5	Low Hanging Fruit
53	Addresses variability in design, development and manufacturing processes	510	2	High Hard
54	Addresses variability in materials properties	457	2.5	High Hard
55	Addresses impact of complexities in the "natural" environment	550	3	High Hard
56	Model allows for adjustment based on test/in-service results	501	1.5	Jewel
57	Provides capability to incorporate field experience reliability data.	501	1.5	Jewel
58	Model includes similarity methodology (definition & adjustment)	471	1	Jewel
59	Models account for design for environment	555	2	High Hard
60	Models are self-contained	340	3	Low Return
61	Mechanism for review and update of models	514	2.5	High Hard
62	Models are substantiated	639	1	Jewel
63	Validated by test	657	1	Jewel
64	Validated by industry accepted models / tools	560	1.5	Jewel
65	Validated by field performance	667	2.5	High Hard

B-3 REFERENCES

B-1 Aerospace Vehicle Systems Institute. (2010, December). AVSI AFE 74 reliability quality function deployment (QFD), roadmap and module A.

B-2. U.S. Department of Defense. (1995, February). *Reliability prediction of electronic equipment.* (Military Handbook MIL-HDBK-217F Notice 2) Washington, D.C.: U.S. Government Printing Office.

APPENDIX C—INDUSTRY REVIEW OF VERIFICATION, CALIBRATION, AND VALIDATION

This appendix provides the background information of an industry review of how verification, calibration, and validation are defined by different industry organizations. The AFE 80 project team found there are differing views of verification, calibration, and validation across different industries. This causes difficulty in establishing clear standards and expectations.

The project team looked at:

1. RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware
2. DoD Modeling and Simulation (M&S) Glossary, DoD 5000.59-M, January 1998
3. Procedures for the Acquisition and Management of Technical Data, DoD 5010.12-M, May 1993
4. Tech America–HB-0009
5. IEEE 1332
6. IEC Dictionary

A review of how verification, calibration, and validation are defined by the following partially/wholly excerpted references.

C-1 RTCA/DO-254, DESIGN ASSURANCE GUIDANCE FOR AIRBORNE ELECTRONIC HARDWARE

Note: RTCA documents are used by the FAA and suppliers of commercial airborne applications.

In RTCA/DP-254, Section 6, Validation and Verification:

> "The validation process provides assurance that the hardware item-derived requirements are correct and complete with respect to system requirements allocated to the hardware item. The verification process provides assurance that the hardware item implementation meets all of the hardware requirements, including derived requirements."

C-2 DOD MODELING AND SIMULATION (M&S) GLOSSARY, DOD 5000.59-M, JANUARY 1998

P2.22.1. Validation. The process of determining the degree to which a model or simulation is an accurate representation of the real-world entities from the perspective of the intended uses of the model or simulation. (DoD Directive 5000.59 and DoD Instruction 5000.61 (references (f) and (h)).

P2.22.5. Verification. The process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification. Verification also evaluates the extent to which the model or simulation has been developed using sound and

established software engineering techniques (DoD Directive 5000.59 and DoD 5000.59-P (references (f) and (g)).

P2.4.7. Data Certification. The determination that data have been verified and validated. Data user certification is the determination by the application sponsor or designated agent that data have been verified and validated as appropriate for the specific M&S usage. Data producer certification is the determination by the data producer that data have been verified and validated against documented standards or criteria (DoD 5000.59-P (reference (g)).

P2.4.29. Data Verification, Validation, and Certification (VV&C). The process of verifying the internal consistency and correctness of data, validating that it represents real-world entities appropriate for its intended purpose or an expected range of purposes, and certifying it as having a specified level of quality or as being appropriate for a specified use, type of use, or range of uses. The process has two perspectives: producer and user process (DoD 5000.59-P (reference (g)).

C-3 PROCEDURES FOR THE ACQUISITION AND MANAGEMENT OF TECHNICAL DATA, DOD 5010.12-M, MAY 1993

DL1.1.31. Validation. As used, validation is the process by which the contractor (or other activity as directed by the DoD component procuring activity) tests technical documents for accuracy and adequacy, comprehensibility, and usability. Validation is conducted at the contractor's facility or at an operational site and involves the hands-on, unless otherwise agreed on by the DoD component, performance of operating and maintenance procedures including checkout, calibration, alignment, and scheduled removal and installation instructions (for validation of data rights, see “Data Rights Validation”).

DL1.1.32. Verification. The process by which technical data are tested and proved under DoD component control to be technically accurate and complete, comprehensible, and usable for operation and maintenance of equipment or systems procured for operational units. Verification is conducted by using personnel with skill levels equivalent to those of the people who will be required to maintain the equipment or system in the operational environment. Verification consists of the actual performance of operating and maintenance procedures and associated checklists, including checkout, calibration, alignment, and scheduled removal and installation procedures.

C-4 TECH AMERICA–HB-0009

- Line 708: Verification and validation methods and approaches should incorporate all potential environmental and operational stress factors that the end item will be expected to be subjected to in the field. Such techniques will verify that the customer requirements and expectations are met and that the system/product is functional, reliable, and durable. These same elements of SE and the EP are shown in Figure 2.1-3 within the context of Table 2.1-1.

- Line 766: A Design Verification Plan and Release (Report) (DVP&R) is essentially a plan of the verification test(s) that will be used to verify and demonstrate reliability at the subsystem or component level and rolled up to the product level. The DVP&R tests can be based on previously performed inputs to the DFMEA/FMECA FTA, FEA, M&S, etc. These tests address prioritized potential failure modes and their corresponding mechanisms of failure and verify that proposed failure mode mitigation strategies are sound and efficient.

- Line 6978 (Method 3.41, PoF): Perform physical testing to validate the modeling process. This validation could include life testing, accelerated-life testing, instrumented terrain tests, instrumented drop tests, or other tests. The objective of the testing is to validate the stressors and stress analysis, to verify that the identified failure mechanisms will occur, and to determine if there are unexpected failure mechanisms.

- Line 8145 (Method 3.54, Reliability Assessment): Limitations inherent to the modeling methodology (which technologies it applies to or doesn't apply to, confidence levels of the data, verification/validation of the model, calibration of the modeling parameters, and limits of scaling).

- Reliability Verification, Activity 2.11: Design verification is the process of formally determining whether the customer's quantitative reliability requirements have been met. During verification, system/product level reliability should be verified with suitable statistical confidence, ensuring a high probability of future success of the system/product in the customer's hands. Verification and validation methods and approaches should incorporate all specified environmental and operational stress factors that the end item will be expected to see in the field. Such techniques will verify that the customer requirements and expectations are met and that the system/product is functional, reliable, and durable.

C-5 IEEE 1332

IEEE 1332 references the IEC Dictionary for definitions.

C-5.1 IEC DICTIONARY

Definition for calibration: "All the operations for the purpose of determining the values of errors and, if necessary, other metrological properties of a measuring instrument."

APPENDIX D—REVIEW OF ELECTRONIC-BASED RELIABILITY METHODS

The AFE 80 team conducted a review of electronic-based reliability methods. The purpose of the review was to determine the feasibility of an electronic-based reliability prediction methodology for a future revision of MIL-HDBK-217. The review focused on three representative electronic databases (SD-18, Web-Accessible Repository of Physics-based Models [WARP], and the proposed Reliability Simulation Council [RSC] database). The owner or the originating organization was engaged to help with the assessment. Section 2.5 of this report provides the conclusions resulting from this review.

The review was organized with the following outline:

a. Issues to resolve (e.g., configuration control) to achieve an accelerated (over paper publication), but still deliberate, process

b. Vetting of new contributions

c. Processes for updating

d. Usage standards, user policy, and defaults

What do we mean by electronic?

- Simple document on electronic source (e.g., SD-18)
- Search/data accessing (e.g., WARP)
- Model development environments (e.g., what RSC is thinking of):
  - Graphical user interface on the front end to enable participation and utilization of the resource
  - Users contributing data from test and field returns
  - Users able to tap into a broad dataset and develop models that include the latest information
  - New modeling methods

Review of existing electronic methodologies.

- SD-18
- WARP
- RSC database (proposed)

D-1 SD-18 PARTS REQUIREMENT & APPLICATION GUIDE

General description:

The SD-18 methodology was established approximately 12 years ago and provides derating guidelines for electronic components. It is a Web-based document that provides part acquisition guidelines for program managers, system designers, system program offices, and original equipment manufacturers. It contains guidelines for the use and application of commercial parts in military environments as well as derating information and lessons learned.

Attributes from AFE 80:

1. Issues to resolve (e.g., configuration control) to achieve an accelerated (over paper publication), but still deliberate, process.

   Sections are configuration controlled with revision letter and date. Revision process is faster than previous hard copy revisions.

2. Vetting of new contributions.

   Review process is internal. Naval Sea Systems Command (NAVSEA) must review and approve all changes. There is an online questionnaire that has space to submit issues/suggestions and lessons learned.

3. Processes for updating.

   The process for revising a page is that once a revision has been identified (perhaps by a user suggestion), the Naval Surface Warfare Command (NSWC) Crane Division team prepares the revision and sends it to NAVSEA for review and approval. Once approved, the new page is posted on SD-18.

   The revision-control process within SD-18 is managed by having a revision mark in the top left corner of each page, unless it is unchanged from the original release. For pages that have been revised, the older versions are available on a link in the lower left corner.

4. Usage standards, user policy.

   SD-18 is available online worldwide. No user registration is required to access its contents.

5. Defaults.

   Not applicable for this application.

Although maintaining SD-18 does not require a lot of funding, it does require some, estimated at between $5K and $10K per year. In addition to revisions, there is basic overhead for maintaining the website. Although SD-18 appears fairly static, there are links within it to maintain. External links are more problematic than internal ones (those that link to other areas within SD-18) because the external links have to be checked periodically and fixed if broken.

NSWC Crane is a technical custodian and a provider of webmaster services, but SD-18 is owned by NAVSEA. The Defense Standardization Program Office has provided funding for NSWC Crane—both for the original development of SD-18 as well as its annual maintenance.

Revisions are easier on a Web-based document. An SD-18 section revision involves about a 1-month turnaround time.

On a Web-based tool, feedback can be requested from the user community. SD-18 gets about 10–15K hits per month. Traffic is tracked both generally and for the derating pages.

NSWC Crane would like to revamp SD-18 more thoroughly, but they have not had enough funding to do so. The DoD is considering making MIL-HDBK-217 a Web-based document similar to SD-18, but efforts to revise MIL-HDBK-217 have been on hold for 3 years.

D-2 THE WEB-ACCESSIBLE REPOSITORY OF PHYSICS-BASED MODELS (WARP)

Sources of information on WARP:

- http://www.theriac.org/WARP/about.html (accessed 8/13/13)
- WARP User Manual – http://www.theriac.org/WARP/users-manual-rev-2.pdf (accessed 8/13/13)
- Nicholls, D. and Riesbeck, A., “The Web-Accessible Repository of Physics-based Models (WARP),” IEEE Reliability and Maintainability Symposium (RAMS), January 2011.

General description:

The objective of the WARP effort is to collect, analyze, and verify the existence and characteristics of PoF models for electronic, electromechanical, and mechanical components to provide a centralized Web-based repository that is accessible to researchers and engineers to enhance their understanding of the following:

1. What individual PoF failure mechanism models should be used to assess the part-level reliability of specific component types (covering both internal device and packaging-related failure mechanisms)?
2. What PoF failure mechanism models currently exist to assess the part-level reliability of specific component types (covering both internal device and packaging-related failure mechanisms)?
3. What PoF failure mechanism models need to be developed or should be added to the WARP repository to accomplish that goal (i.e., gap analysis)?
4. What physical data/information are needed to exercise each identified PoF failure mechanism model, and where can it be obtained?
5. How a PoF model may be used to help with reliability assessment.

Attributes from AFE 80:

1. Issues to resolve (e.g., configuration control) to achieve an accelerated (over paper publication), but still deliberate, process

WARP is a repository of PoF models. The administrators do not attempt to select the one best model for any particular failure mechanism, but they do ensure that any PoF model within WARP is credible. The issue of configuration control is not really a problem, as anyone using WARP can reference the source of a model rather than reference WARP itself.

2. Vetting of new contributions

The WARP repository is populated based on user submittals through the Reliability Information Analysis Center (RIAC) WARP website interface. While there are no restrictions to accessing the WARP website (including the ability to view the WARP forum or perform searches), the ability to submit PoF model information for RIAC verification or participate in the WARP forum is restricted to only those members who have registered with, and been approved by, RIAC technical personnel.

Submitted PoF model information from registered and approved WARP members are screened and verified by specific RIAC administrative personnel prior to it being made public on the RIAC WARP website.

3. Processes for updating

The process is user-driven and centrally managed by RIAC. Registered members are able to suggest a new PoF failure mechanism model for WARP or identify where a component/technology type may require a PoF failure mechanism model where one does not yet exist (see figure D-1).

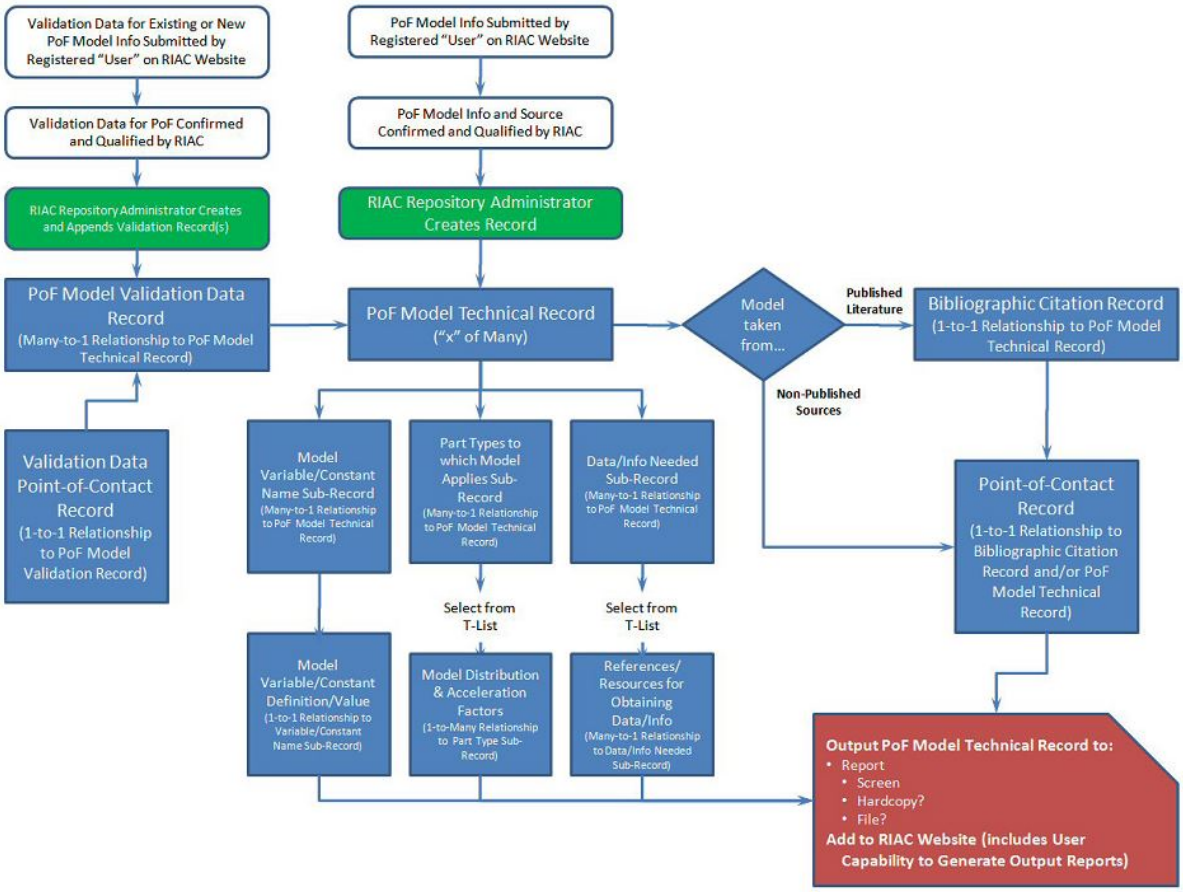

Figure D-1. The WARP database (Nicholls, D., RAMS 2011 paper)

4. Usage standards, user policy

Anyone may use WARP. Registration is required to post to the forum. Approved membership is required to contribute models and validation data into WARP.

5. Defaults

The data elements associated with the PoF failure mechanism model technical record include:

- Descriptive title for model
- Covered failure mechanism(s)
- Basic model form (captured image)
- Basic submodel form(s) (for submodels embedded within the Basic Model) (captured image(s))
- Basic and sub-model variable and constant names and definitions
- Technical background and guidelines for use of the model
- PoF model technical assumptions, limitations, constraints, and risks
- Uncertainty limits (if available)
- Component/technology type(s) to which the PoF failure mechanism model applies
- Fundamental time-to-failure distribution of the PoF failure mechanism model for the specific component/technology type (if available)
- Acceleration factor(s) for the PoF failure mechanism model for the specific component/technology type
- Data/information needed to exercise the model*
- References/resources for obtaining the necessary data/info

* Note: Does not state "defaults" per se, but these could be included in the "data/information needed to exercise the model."

WARP currently has 335 registered members and 22 registered contributors. The WARP database has had issues with hackers trying to get in and change things, but they have been successfully fought off by the site's security systems.

Although WARP provides a complete and standardized view of the model, there is no embedded calculation capability. A user has to use something else (spreadsheet or math software) to make calculations based on the model documentation that WARP provides. One handy feature that WARP does provide is the ability to see all relevant PoF models for a particular component technology. The list includes device-level mechanisms as well as packaging mechanisms.

D-3 RSC DATA SHARING PROPOSAL

General description:

The Reliability Simulation Council (RSC) is still negotiating a contract with the RIAC to create a secured database for RSC to share their data. The effort is still at a proposal state pending the official formation of RSC membership.

Although the database has not yet been created, the proposed structure was reviewed along with the broader issues that RSC has experienced in trying to establishing it.

RSC has a proposed project to develop the database, which is under consideration by the membership.

Database attributes:

1. Scope will depend on the technical requirements specification, which is currently to be discussed.
2. Intent is to establish a highly secured data collection engine.
3. Any approved RSC member can upload data to the database.
4. The Data Summary, which is an approved document, will be reviewed and approved for posting by a third party (most likely the College of Nanoscale Science and Engineering [CNSE]).
5. Members can propose reliability models with supporting data, models to be vetted by CNSE.
6. CNSE will be the focal point for resolving any issues with submitted data by contacting different contributors. It is important to use a third party.
7. CNSE will provide data updates and maintenance (under a separate maintenance contract).

RSC lessons learned:

1. Need to establish the sponsoring organization with a solid commitment and adequate budget.

2. Need to know the capabilities of the sponsoring organization:

    a. Stability of organization
    b. Large versus small shop
    c. Capabilities of members

3. Importance of establishing a technical requirements specification early.

4. Successfully establishing intellectual property (IP) agreements will be key to the success of the endeavor.

Quanterion Solutions, Inc. proposed a database development activity, which included developing the technical requirements specification and then developing a database and website. CNSE would manage the content of the database.

The database Quanterion Solutions, Inc. proposed was intended to be a highly secure database. Members would provide data, under a non-disclosure agreement, to CNSE. In turn, CNSE would develop reliability assessments that would be provided back to the members. Aggregated data would be available to the members; these data would be prepared with diligence to protect the identity of the sources and prevent reverse engineering of any company's data.

CNSE would act as the central manager for the database and would be the focal point for resolving any issues related to its use.

The maintenance of the database may be contracted to a third party, but the choice of third party is a decision for the future.

One of the key challenges RSC faced was settling IP agreements. Reliability data is fundamentally sensitive information, so this is not a problem unique to the RSC.