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DRAFT Assessment of Reliability Prediction Methodologies

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Preface

Accurately predicting the reliability of electronic systems is becoming more important in the competitive environment because customers demand longer, more comprehensive warranties and express increasing concerns with life cycle cost. In May 1992, the U.S. Army Material Systems Acquisition Activity (AMSAA) and the CALCE Electronic Products and Systems Center (EPSC)[1], University of Maryland, briefed the Army Standardization Executive, Mr. Darold Griffen on the problems with the then reliability standards. Mr. Griffin proposed the development of dual use, non government reliability standards, in lieu of revising Military Standards or Military Handbooks. Reducing reliance on military specifications and standards was a priority of the Secretary of Defense Dr. William J. Perry, and developing dual use (commercial/military) standards is in line with the current Department of Defense (DoD) administration policy.

In 1993, a Process Action Team (PAT) was chartered by Deputy Under Secretary of Defense (Acquisition Reform), Ms. Colleen Preston, to address the transition of defense suppliers and contractors to commercial practices, processes, and products. The DoD PAT placed emphasis on participating with non-government standards bodies to jointly develop and use their standards.

AMSAA and CALCE EPSC began working with the IEEE Reliability Society to develop an IEEE Reliability Prediction Standard. The Reliability Prediction Working Group is a multidisciplinary body consisting of participants from various commercial and government agencies, both domestic and foreign. Written approval for the Project Authorization Request (PAR) from the New Standards Committee (NesCom) of the Standards Board at the IEEE Headquarters was obtained on December 13, 1994. The Reliability Prediction Working Group consulted with the IEEE Standards Review Committee (RevCom) on developing and formatting the draft. In addition, the Working Group interacted with the Electronic Industries Association, the Society of Automotive Engineers, American Society for Quality Control and the Institute for Environmental Sciences.

An IEEE reliability prediction standard was developed so that a prediction made according to the standard includes sufficient information concerning inputs, assumptions and uncertainties that the risks associated with using the prediction are understood. The standard identifies required elements for an understandable, credible reliability prediction, which will provide the users of the prediction sufficient information to evaluate the effective use of the prediction results. RevCom approved the standard on December 8, 1998. A copy of the standard is available from the IEEE at http://www.ieee.org, 1-800-678-IEEE in the U.S. and Canada, or 732-981-0060 outside the U.S. and Canada.

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[1] Formerly, the CALCE Electronic Packaging Research Center (EPRC).

Introduction

Several approaches to reliability prediction exist including: similar systems, Mil-Hdbk-217F, SAE PREL, Siemens SN 29500, Bellcore TR-332, CNET RDF 93, British Telecom HRD 5, vendor supplied data, physics of failure, RAC's System Reliability Assessment Method, and predictions based on historical field data. The approaches were identified by CALCE members with respect to their interest in receiving an evaluation. In addition, throughout project development, CALCE members were invited to add to this list any additional methodologies for which they would like to see an evaluation. The final list represents all methodologies in which CALCE members expressed an interest to have evaluated. In addition, the list of questions began as the criteria identified by IEEE 1413, and evolved as the project continued. Again, CALCE members were asked to modify the list as they saw fit, adding or deleting questions. The final list represents the list agreed upon by CALCE members as useful questions.

Each approach offers positive and negative contributions to reliability prediction. For users to make risk informed decisions regarding the selection of a reliability prediction methodology, and regarding the actions to take based on the results of the prediction methodology, a comparison of the strengths and weaknesses of the available methodologies is necessary. The results will allow the industry to capitalize on the positive points of the available approaches and to benefit from the flexibility of using data from different sources (i.e. empirical models, physics-of-failure models, field data).

Using IEEE 1413 and CALCE developed evaluation criteria, this paper presents a comparison of available reliability prediction methodologies. Reliability experts from various companies were asked to respond to questions regarding a particular reliability prediction methodology. An IEEE working group, IEEE 1413.1[2], has also contributed to the responses. The responses were used to create this document, and provide the reader with information regarding the strengths and weaknesses of the available methodologies.

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[2] The IEEE 1413.1 Reliability Prediction Working Group is continuing its efforts in reliability prediction through the development of a guide document, designed to accompany IEEE 1413. A Project Authorization Request (PAR) is being submitted to the IEEE so that a guide to accompany IEEE 1413, identified as IEEE 1413.1 and titled, Guide for Developing Reliability Predictions, may be developed. IEEE 1413.1 will define processes and identify methodologies for conducting reliability predictions. The IEEE Working group is developing IEEE 1413.1 to assist customers and users in making informed decisions regarding the selection and use of reliability prediction methodologies to build an IEEE 1413 compliant prediction.

1. Mil-Hdbk-217, Reliability prediction of electronic equipment [1]

The evaluation for Mil-Hdbk-217 was provided by Mr. Seymour Morris of IIT Research Institute at 201 Mill St, Rome NY, 13440, email 315-339-7135, email smorris@iitri.org, by Mr. Michael Cushing of U.S. Army Material Systems Analysis Activity, Aberdeen Proving Grounds, MD 21005-5071, phone 410-278-2760, and email cushing@arl.mil.

1.1 Overview of the methodology

The prediction method was developed by (its preparing activity was) the U.S. Department of Defense with the assistance of the military departments, federal agencies, and industry. General methods and models used to develop the prediction include the collection and analysis of historical field failure data. The last version to date is February 28, 1995; an updated version is not scheduled for release.

The purpose of the methodology is, "…to establish and maintain consistent and uniform methods for estimating the inherent reliability (i.e., the reliability of a mature design) of military electronic equipment and systems. It provides a common basis for reliability predictions during acquisition programs for military electronic systems and equipment. It also establishes a common basis for comparing and evaluating reliability predictions or related competitive designs. The handbook is intended to be used as a tool to increase the reliability of the equipment being designed."

The methodology is based on the parts count method and on the parts stress analysis method, which are used to estimate the reliabilities of electronic components or systems in various stages of design. The parts count method requires less information, such as generally part quantities, quality level and the application environment. This method is applicable during the early design phase and during proposal formulation. The parts stress analysis method involves a greater amount of detailed information and is applicable during the later design phase when actual hardware and circuits are being designed. Based on environmental use characteristics, piece part count, thermal and electrical stresses, subsystems repair rates and system configuration, the standard provides piece part, assembly and subassembly failure rates. In general, the parts count method results in a more conservative estimate of system reliability than the parts stress method [4].

1.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

Information regarding the sources, time frames, levels of statistical control and verification, data manipulation to derive failure rates and adjustment factors is not specified in the document, although a bibliography is provided with the methodology. Models appear to be based on data acquired from a variety of sources over a period of time and under various levels of statistical control and verification.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

No. The model does not specify the assumptions used to calculate the predicted reliability.

3. *Are sources of uncertainty in the prediction results identified?*

No. Information regarding the sources, time-frames, levels of statistical control and verification, data manipulation to derive failure rates and adjustment factors are not identified.

4. *Are limitations of the prediction results identified?*

Yes. The first limitation cited is that the failure rate models are point estimates which are based on available data. The handbook specifies that hence, the models are valid for the conditions under which the data was obtained, and for the devices covered. However, the handbook does not provide information as to the conditions under which the data was obtained, or as to the specific devices covered. The handbook states that even when used in similar environments, the differences between system applications can be significant. However, the handbook suggests that evolutionary changes may be handled by extrapolation from existing models. The handbook states that, "Hence, a reliability prediction should never be assumed to represent the expected field reliability as measured by the user (i.e., Mean-Time-Between-Maintenance, Mean-Time-Between-Removal, etc.). An indication of the value of the results is provided: Mil-Hdbk-217 is not intended to predict field reliability and, in general, does not do a very good job at it in an absolute sense [2].

5. *Are failure modes identified?*

No. The method does not address failure modes. Cause-effect relationship underlying the failure is not explored. Exponential failure distribution is assumed, irrespective of variability in failure mechanisms, modes, sites and causes. Failure often noted as "defective", "burned-out" and so forth. No insight is provided into the root cause and no corrective action can therefore be taken.

6. *Are failure mechanisms identified?*

Device failure mechanisms are accounted for in the modeling process with adjustment factors to account for device application specific factors that accelerate the predominant failure mechanisms observed in the field. Acceleration models for various failure mechanisms are lumped together and used at the package level. The method does not consider dependence of failure distribution on failure mechanism. Acceleration factors are used without an understanding of the relative dominance of failure mechanisms.

7. *Does the prediction method account for life cycle[3] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

No. The model offers 14 *USE* environments (including ground, benign; ground, fixed; ground, mobile; naval, sheltered; naval, unsheltered; airborne, inhabited, cargo; airborne, inhabited, fighter; airborne, uninhabited, cargo, and so forth), but does not account for life cycle environment. It does not consider the impact of life cycle temperature cycling, temperature changes, humidity, humidity cycling, chemically harsh environments, radiation, maintenance, packaging, storage, handling and transportation conditions, vibration and mechanical shock on reliability. Some environmental factors are implicitly accounted for with model input parameters if they were found to be in significant correlation with underlying field failure data.

8. *Does the prediction method account for materials, geometry and architecture that comprise the parts?*

No. It assumes time and stress are independent of material properties and geometries, and does not account for variabilities between materials and geometries. Components within the same class and application are assumed to have the same failure rate even when made of different materials and varying geometries. The method neglects the input of critical failure contributors: geometry, materials, architecture, and manufacturing processes.

9. *Does the prediction method account for part quality?*

No. The methodology attempts to account for part quality through the use of a π_Q factor, however, "Microcircuits have quality levels which are dependent on the number of Mil-Std-883 screens to which they are subjected." Therefore, quality is not a function of manufacturer process controls, or part variability, but simply a function of the number of tests to which the part is subjected. These parts may or may not be value added, and involve additional part handling, exposing the part to additional damage

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[3] *Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.*

potential. The methodology even recognizes this shortcoming, "Poor equipment design, production and testing facilities can degrade part quality. Total equipment program descriptions as they might vary with different part quality mixes is beyond the scope of this Handbook." For these reasons, part quality is not said to be accounted for following the method.

10. Does the prediction method allow incorporation of reliability data and experience?

No. The failure rates used in Mil-Hdbk-217 were primarily derived from accelerated life studies; therefore, the methodology does not address reliability growth and adds little or no value to current or new technology. It presents a hindrance to reliability growth as it promotes probabilistic reliability criteria rather than understanding failure cause and effect.

11. How well does the methodology predict actual failures?

Mil-Hdbk-217 does not predict specific field failures, only failure frequency over time. Experience shows that it does a reasonable job of predicting the relative reliability of systems if properly applied and properly compared with observed field data. The term “properly applied” means that the tool must be applied within the limitations and application guidelines spelled out in the introduction to the Handbook. The term “properly compared” means that it must be compared against “hard” field failures collected over a long period of time. Analyses done by Jones et al showed that Mil-Hdbk-217 could accurately predict the main cause of failure of an electronic system repeatedly independent of the complication of the system.

2. SAE Reliability prediction method

2.1 Overview of the methodology

This evaluation was conducted by Jerry Cartwright of Western Digital Corporation, phone 507-286-7405, email Jerry.L.Cartwright@wdc.com.

The Society of Automotive Engineers is the preparing activity for this standard. The method addresses the reliability needs of the automotive design engineers. The prediction models are defined by the SAE, and are based on empirical data analysis performed by IIT Research Institute on automotive data collected by the SAE Reliability Standards Committee. The models include duty cycles for operating, dormant, and non-operating failures as well as factors for evaluation of system level infant mortality corrections. Mil-Hdbk-217 data, combined with automotive environments and data, was used to develop the prediction. The most recent version dates from 1987. The date of release for an updated version is unavailable at this time.

2.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

No. Mil-Hdbk-217 data is combined with automotive data. No specific information regarding the automotive data is provided. As the extent to which 217 data is known is not defined, the extent to which SAE Method data is known is also undefined. A model is based on empirical data analysis performed by IIT Research Institute on automotive data collected by the SAE Reliability Standards Committee, but the data is not included in the prediction methodology.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

Assumptions used to conduct the prediction are identified, but those used for unknown data are not.

3. *Are sources of uncertainty in the prediction results identified?*

No.

4. *Are limitations of the prediction results identified?*

Yes. No elaboration yet provided.

5. *Are failure modes identified?*

No.

6. *Are failure mechanisms identified?*

No.

7. *Does the prediction method account for life cycle[4] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

No. In general, actual data was used to determine the failure rates from actual automotive environments, but those use environments do not address part life cycle environments.

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[4] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

8. Does the prediction method account for materials, geometry and architecture that comprise the parts?

No.

9. Does the prediction method account for part quality?

Yes. No elaboration yet provided.

10. Does the prediction method allow incorporation of reliability data and experience?

Yes. No elaboration yet provided.

3. Honeywell's reliability prediction method

This evaluation was conducted by Mr. Bruce Johnson and Mr. Lou Gullo of Honeywell CAS-SPO and ATS, respectively. Mr. Johnson may be contacted by phone at 612-957-4375 and via email at bjohnso1@cfsmo.honeywell.com. Mr. Gullo may be contacted by phone at 602-436-3907 and via email at louis.gullo@cas.honeywell.com.

3.1 Overview of the methodology

This method was developed jointly by Honeywell Commercial Aviation Systems-Sensor Products Operation and by Honeywell Air Transport Systems. A top down similarity analysis is preferred, but an alternate failure cause model methodology is included, and is intended to be used when the similarity analysis is not possible. An analysis of Honeywell's field failure database, manufacturing and development processes were used to create the model. The current version is still in development.

3.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

Yes. The plan document defines in detail the data sources used which include: field failure data, aircraft flight hour data, design process data, production build process data and product specific data.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

Yes. The similarity analysis requires assumptions regarding impact of product differences between the new and predecessor designs. The failure cause model also requires assumptions relative to impact of build and design processes on new product reliability.

3. *Are sources of uncertainty in the prediction results identified?*

Yes. Uncertainties are generated by all of the data sources, and the uncertainties of each data source are identified.

4. *Are limitations of the prediction results identified?*

Yes. The similarity analysis method can not always be applied. That is how the failure cause model was incorporated. It is more generic and can always be applied though not with as much accuracy.

5. *Are failure modes identified?*

No. Failure modes can be entered into the methodology, but the predication result does not identify failure mode.

6. *Are failure mechanisms identified?*

No. Root cause mechanisms are not included. The data can be obtained, however, for certain parts when performing failure analysis on identified trends.

7. *Does the prediction method account for life cycle[5] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

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[5] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

Yes. Since the user of the similarity methods identifies the differences any or all of the above can be applied to this method if there is a difference between the new and predecessor designs.

8. *Does the prediction method account for materials, geometry and architecture that comprise the parts?*

Yes. This is considered a characteristic of the design process and is analyzed as part of the prediction process. Since the user of the similarity methods identifies the differences any or all of the above can be applied to this method if there is a difference between the new and predecessor designs.

9. *Does the prediction method account for part quality?*

Yes. This is considered a characteristic of the design process and is analyzed as part of the prediction process. Since the user of the similarity methods identifies the differences any or all of the above can be applied to this method if there is a difference between the new and predecessor designs.

10. *Does the prediction method allow incorporation of reliability data and experience?*

Yes. The incorporation of reliability data and experience are keys to the new methods.

4. Bellcore TR-332

The evaluation was conducted by Mr. Ari Jain of Lucent and Mr. Victor Chien of Bellcore. Mr. Jain may be contacted by phone at 732-949-7618, or via email at arijain@lucent.com. Mr. Jain prepared the 1992 and 1995 versions of TR-332 while working for Bellcore, before his move to Lucent. Mr. Chien may be contacted by phone at 732-758-4047, or via email at vchien@notes.cc.bellcore.com.

4.1 Overview of the methodology

Bell Communications Research is the preparing activity for the methodology, which is based on empirical statistical modeling. Each version of TR-332 is prepared by soliciting input from industry on field data on electronic components and then reflecting this field experience through statistical models. The purpose of Bellcore's reliability prediction procedure is to document the recommended methods for predicting device and unit hardware reliability. It contains instructions for suppliers to follow when providing predictions of their device, unit, or serial system reliability. Device and unit failure rate predictions generated by using this procedure are applicable for commercial electronic products whose physical design, manufacture, installation, and reliability assurance practices meet the appropriate Bellcore (or equivalent) generic and product-specific requirements [5].

The main concepts between Mil-Hdbk-217 and Bellcore are similar. Bell Labs modified the equations from Mil-Hdbk-217 to better represent what their equipment was experiencing in the field [5]. A 'parts count' or 'part stress' analysis is also existing in Bellcore, however these different calculations are referred to as calculation methods. Bellcore offers ten different calculation methods with each of them taking into account information as stress data, burn-in data, field data, or laboratory test data.

To facilitate application, the fundamental differences are summarized in the table below.

Table 1. Comparison between Mil-Hdbk-217 and Bellcore [5][6]

	Mil-Hdbk-217	Bellcore
Focus	Military and commercial equipment	Commercial equipment, especially telecommunication
Data	Only stress data	Burn-in data, laboratory test data, and field data, helpful in calculating failure rates that are based on historical data
Parts	Printed circuit boards, lasers, SAWS, magnetic bubble memories, and tubes – not available to Bellcore	Gyroscopes, batteries, heaters, coolers, and computer systems – not available in Mil-Hdbk-217
Environments	A variety of ground, sea, air, and space environments.	• Three different variations of ground based environments • Airborne, Commercial and • Space, Commercial
Quality Levels	Component dependent and derived from specific data	Four standard quality levels, identical for all component types, and are simply based on some generalities regarding the origin and screening of components
Calculations	Pessimistic and needs more part parameters	Optimistic and needs fewer part parameters
Multiplier	Both in FIT (failure in time)	
	Failures per million hours	Failures per billion hours

4.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

No. The methodology uses data from the computer and telecommunications industries, but individual sources of data are not identified.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

Yes. No elaboration yet provided.

3. *Are sources of uncertainty in the prediction results identified?*

No.

4. *Are limitations of the prediction results identified?*

Yes. No elaboration yet provided.

5. *Are failure modes identified?*

No.

6. *Are failure mechanisms identified?*

No.

7. *Does the prediction method account for* <u>*life cycle*</u>[6] *environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

No. Some of the use conditions are addressed, i.e. power and voltage conditions, environmental exposure and duration and duty cycles at various temperatures, but life cycle conditions are not addressed.

8. *Does the prediction method account for materials, geometry and architecture that comprise the parts?*

No.

9. *Does the prediction method account for part quality?*

Yes. No elaboration yet provided.

10. *Does the prediction method allow incorporation of reliability data and experience?*

Yes. This is the only reliability standard that incorporates lab test data and/or field-tracking data with parts count data to derive a combined estimate of component reliability. This procedure encourages people to submit alternative prediction methods for device failure rates with supporting analysis.

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[6] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

5. Physics of failure

This analysis was conducted by Thomas Stadterman [7], who is currently an electronics engineer and the Physics-of-Failure Team Leader in the U.S. Army Materiel Systems Analysis Activity (AMSAA). In this position, he conducts research on applying physics-of-failure (PoF) and accelerated life testing concepts to military electronic systems. As PoF Team leader he manages the PoF analyses and research performed by his team. Mr. Stadterman has performed PoF reliability assessments to improve designs and to reduce costs of numerous Army systems including Joint STARS, Longbow, and Bradley. He also lead his PoF Team to performed numerous physics-of-failure analyses for the Army resulting in cost avoidance of over $27M. Mr. Stadterman also has five years experience in reliability test design and evaluation on major Army electronic systems for AMSAA. During this time he developed reliability methodology for growth and qualification test data evaluation. Mr. Stadterman may be reached by phone at 410-278-8785 or via email at stadt@arl.mil, or by regular mail at DIR, USAMSAA, ATTN: AMXSY-A, APG, MD 21005-5071.

5.1 Overview of the methodology

Physics of Failure (PoF) does not have one developing agency. In the most general sense, PoF is a continuously improving approach to develop reliable products that uses knowledge of root-cause failure processes to prevent product failures by incorporating robust design & manufacturing practices [8]. PoF approach incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures, and electronics technologies. One aspect of PoF is predicting the time to failure for specific failure mechanisms at particular sites.

This physics of failure approach involves:

- identifying potential failure mechanisms (e.g., chemical, electrical, physical, mechanical, structural, or thermal processes leading to failure), failure sites (e.g., component interconnects, board metallization, and external connections), and failure modes (e.g., electrical shorts, opens, or deviations which result from the activation of failure mechanisms);
- identifying the appropriate failure models for specific failure mechanisms and sites, including inputs associated with material characteristics, damage properties, relevant geometry at failure sites, manufacturing flaws and defects, and environmental and operating loads;
- determining the variability for each design parameter when possible;
- computing the effective reliability function; and
- accepting the design if the estimated time to failure meets or exceeds the requirement.

5.2 Methodology assessment

1. *Is there a definition of failure and failure criteria through which you can apply the prediction?*

Yes. The failure definition commonly used are a short or open circuit, and in some cases specific electrical parameter are used (e.g., signal shape, breakdown voltage, etc.). Other failure definitions can be readily applied.

2. *Are failure modes identified?*

Yes. The models used in this assessment technique are tailored to address specific failure mechanisms and sites, and indicate which modes can be expected based on the targeted mechanism and site. The models are derived from first principles and controlled tests--the results of which are readily available.

3. *Are the electrical parameter values that constitute a failure identified?*

Yes. The electrical parameters most commonly used are a short or open circuit, and in some cases specific electrical parameter are used (e.g., signal shape, breakdown voltage, etc.).

4. *Are failure mechanisms identified?*

Yes. The main premise of PoF is the use of failure mechanism, and models of these failure mechanisms at particular sites. The models are derived from first principles and controlled tests--the results of which are readily available.

5. *Are data sources used to develop the prediction identified?*

Yes. Models are used to conduct the analysis based on published experimental results. As each model is documented, literature may be referenced to provide details of the experiment, including assumptions and limitations.

6. *Are information input and limitations identified?*

Yes. Models are derived from first principles and controlled tests. The input and information required are clearly defined, and limitations and assumptions associated with each model are readily available.

7. *Are sources of uncertainty with the input information identified?*

Yes. The sources of uncertainty can easily be identified because the parameters used in the models are associated with physical properties (e.g., material properties, geometry values, environmental parameters). Variation in these physical properties account for the uncertainty of the model results.

8. *Are assumptions used to make the prediction identified?*

Yes. Models are used to conduct the analysis based on published experimental results. As each model is documented, literature may be referenced to provide details of the experiment, including assumptions and limitations.

9. *Are limitations of the prediction results identified?*

Yes. Models are used to conduct the analysis based on published experimental results. As each model is documented, literature may be referenced to provide details of the experiment, including assumptions and limitations.

10. *Are confidence levels for the prediction results identified?*

Yes. Confidence levels can be identified by various methods included modeling input parameters with probability distributions and performing Monte Carlo simulation. If time to failure distribution is known for a particular failure mechanism, the confidence level can easily be identified. Also if the time to failure value given by a failure mechanism model is know to be a certain value (failure free operating period or X percentile), the confidence level can be identified.

11. *Does the prediction method account for <u>life cycle</u>[7] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

Yes. Models use upon environmental and operational use profile conditions as inputs, including duration and duty cycles, power and voltage conditions, environmental exposures, duration and duty cycles at various temperatures, exposure to airborne contaminates, shock and vibration, humidity, radiation, maintenance, packaging, handling, storage and transportation conditions. All potential failure causing stresses are addressed with appropriate physics-based models.

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[7] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

12. Does the prediction method account for derating design criteria?

No. The simple assumption that if the voltage, current, temperature of an IC is reduced, the reliability increased, is not used in PoF. PoF provides direct relationships between both these factors and time to failure and eliminates simplistic derating assumptions.

13. Does the prediction method account for the materials, geometry and architecture that comprise the product?

Yes. The models are material and architecture dependent in order to address common devices and technologies as well as new devices, technologies, materials and architectures.

14. Does the prediction method account for the part quality level?

Yes. The method requires the use of parts that have been selected through a parts selection and management process, which accounts for manufacturer and distributor quality and for part quality and integrity. Also, parameters that are affected by manufacturing, which also drives the quality level, are considered in this model. The distribution of these parameters due to manufacturing variability (I.e., quality) and the robustness of the design to these factors can also be used to address the quality.

15. Does the prediction method account for the mechanical, electrical and electro-mechanical compatibility of the part with the box and system design?

Yes. The compatibility of the component/CCA/etc. to the next level of assembly is considered in PoF. In fact, PoF uses the next level of assembly to perform the PoF failure mechanism modeling. (e.g., CCA thermal analysis uses box level thermal characteristics, CCA vibrational analysis uses structural response of the box and the system, etc.)

16. Does the prediction method allow incorporation of reliability data and experience?

Yes. The models are updated with the results of additional tests and observations as they become available. The method is fluid enough to allow for incorporation of additional data.

17. How well does the methodology predict actual failures?

The accuracy of PoF output is dependent on the model used and the inputs to that model. The accuracy required from the prediction should drive what type of model and inputs are used. There are various levels of models for each failure mechanism. If a very accurate result is required, a more complicated model should be used. If a quick, first-order prediction is required, a less complicated model with fewer inputs can be used.

18. Does the method give you an expected minimum life?

Yes. By probabilistically modeling the time to failure, the output will be a probability distribution for time to failure of a particular failure mechanism at a certain site. An expected minimum life can be taken from

PoF can model random overstress conditions). By modeling the probability distribution for the strength of the item versus the probability distribution of the stress, a failure rate can be determined.

20. Is this estimated failure rate a function of service life and/or product maturity?

Yes. By probabilistically modeling the wearout and overstress failure mechanisms, an estimate of failure rate as a function of time (i.e., hazard rate) can be calculated. An increasing hazard rate during the useful life period indicates premature wear-out of the product caused by design weaknesses, sustained high stress levels, or latent defects that escaped the early life stage. As the product approaches the late-life stage, it degrades due to repetitive or sustained stress conditions that cause damage accumulation in the product. The hazard rate during the late-life stage increases dramatically as more and more products fail due to wear-out.

21. Does the prediction method relate to the process control at the various levels of product assembly (boards, sub-assemblies, final assembly)?

Yes. By probabilistic modeling the time to failure distribution using Monte Carlo simulation, the effect of process control can be modeled. The time-to-failure distribution can be determined computationally by representing input parameters with distribution functions that are a function of the process control, then performing a Monte Carlo simulation.

22. Does the prediction method relate to appropriateness or level of product screening or test coverage?

To apply a stress screen, it is necessary to know what failures result from defects in the CCA and how the application of external loads can precipitate failure of flawed CCAs. PoF is essential for screening by providing time-to-failure estimates based on material, geometry, and load conditions. A manufacturing flaw may be represented by an inappropriate geometry and/or a changed material property. A PoF analysis is necessary to determine if a stress-based screen is viable.

23. Does the prediction method relate to the level of design evaluation testing or analysis in product development? (design evaluation is a stress test process for detecting design weaknesses by various test regimes)

PoF is also critical in performing accelerated life tests, which are tests conducted at stress levels higher than expected operating stress levels to reduce the length of a test. For accelerated life testing to be effective, a PoF analysis is needed to determine how the CCA will react under these high stress conditions and to map the outcome at accelerated conditions to actual use conditions. This analysis technique can be used to help determine the test conditions and how to fixture the CCA to excite only relevant failures. In addition, PoF can be used to identify failures that occur only as a result of the accelerated test conditions, not actual use conditions. Accelerated life testing can help decrease development costs by reducing the time to conduct qualification tests.

6. CNET RDF 93

6.1 Overview of the methodology

Methodology [9] preparation was led by CNET, and was carried out with the cooperation and approval of a number of companies and working groups, including Alcatel-CIT, SAT, Crouzet, France Telecom, GEC-Alsthom, and Bull. The work was carried out in conjunction with the work at the Institut de Sûreté de Fonctionnement.

The methodology purports to provide all the information needed to calculate electronic component and equipped printed circuit board failure rates. The methodology is said to be designed as an aid to research into how to maximize equipment reliability, and to assist in the design of the equipment, by introducing various influencing factors.

The latest version was released in June 1993. An updated version is not scheduled for release at this time.

6.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

No. The methodology states only that the reliability data was taken mainly from field data concerning electronic equipment operating in three kinds of environments: a) ground: stationary; weather protected, b) ground; stationary; non weather protected, and c) ground; non stationary; benign. Actual data sources are not identified, and the extent to which the data is known is not mentioned.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

No. Section two of the methodology identifies some assumptions that are made, including that failure rates are assumed to be constant, but does not describe assumptions made for unknown data.

3. *Are sources of uncertainty in the prediction results identified?*

No.

4. *Are limitations of the prediction results identified?*

Yes. The methodology states that the predictions are based only on intrinsic reliability: they do not therefore take account of external overload conditions, that the predictions do not take account of design errors or incorrect use of components, and that the predictions do not take account of the risks involved in using lots of components with poor reliability.

5. *Are failure modes identified?*

No.

6. *Are failure mechanisms identified?*

No.

7. *Does the prediction method account for life cycle[8] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

No. Although the methodology classifies various environments and provides a broad range of temperature, humidity, and chemical exposure information, the life cycle environment is not considered. Packaging, handling, storage, transportation and maintenance conditions are also not considered. A π factor must be chosen from the available list, which does not incorporate the life cycle environmental conditions.

8. *Does the prediction method account for materials, geometry and architecture that comprise the parts?*

No.

9. *Does the prediction method account for part quality?*

No. Although a 'quality factor' is included in the methodology, this factor is largely based upon time in production and conformance to various certifying authorities, such as the IECQ or CECC, or upon qualification or supervision by the customer, which is not well defined.

10. *Does the prediction method allow incorporation of reliability data and experience?*

No. The user may interpret various parts of the prediction, to modify the π factors according to experience, but no venue exists by which to incorporate reliability data and experience into the structure of the methodology.

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[8] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

7. RAC's system reliability assessment method

7.1 Overview of the methodology

7.2 Methodology assessment

1. *Does the methodology identify the source used to develop the prediction methodology and describe the extent to which the source is known?*

No. Information regarding the sources, time frames, levels of statistical control and verification, data manipulation to derive failure rates and adjustment factors is not specified. Models are said to be based on historical field data acquired from a variety of sources over a period of time and under various levels of statistical control and verification, but no details or references are provided.

2. *Are assumptions used to conduct the prediction according to the methodology identified, including those used for the unknown data?*

No. The methodology does not detail the assumptions made about its model.

3. *Are sources of uncertainty in the prediction results identified?*

No.

4. *Are limitations of the prediction results identified?*

No.

5. *Are failure modes identified?*

No. Failure modes are not discussed.

6. *Are failure mechanisms identified?*

No.

7. *Does the prediction method account for life cycle[9] environmental conditions, including those encountered during a) product usage (including power and voltage conditions), b) packaging, c) handling, d) storage, e) transportation and f) maintenance conditions?*

No.

8. *Does the prediction method account for materials, geometry and architecture that comprise the parts?*

No.

9. *Does the prediction method account for part quality?*

No.

10. *Does the prediction method allow incorporation of reliability data and experience?*

No.

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[9] Life cycle conditions include environmental (e.g. temperature, airborne contaminates, shock, vibration, humidity, radiation) stress duration and duty cycles.

8. PredIT

The methodology was evaluated by Mr. Örjan Hallberg of Ericsson Telecom AB. Mr. Hallberg may be reached by telephone at 46-8-719 2802, or via email at orjan.hallberg@etx.ericsson.se.

8.1 Overview of the methodology

PredIT is a method to estimate future field returns of telecom hardware that was developed by Örjan Hallberg and Joakim Löfberg of Ericsson. The model is based on the measured correlation between factory test results and subsequent field return rates together with measured time dependent return rates of telecom hardware. PredIT 1.0 to be released at InterPack'99 on June 17, 1999; http://www.asme.org/conf/ipack99 no subsequent version is yet planned.

8.2 Methodology assessment

1. *Are failure modes identified?*

Yes. But this is a matter for the field return repair shop and is not a part of the prediction model.

2. *Are failure mechanisms identified?*

Yes. But this is a matter for the field return repair shop and is not a part of the prediction model.

3. *Are data sources used to develop the prediction identified?*

Yes. The model is based on over 2000 000 boards that have been running in field use for several years.

4. *Are input and information limitations identified?*

Yes. Input data is production test yields and estimated future production volumes.

5. *Are sources of uncertainty identified?*

Yes. We have empirical data on the spread of prediction accuracy.

6. *Are assumptions used to make the prediction identified?*

Yes. The assumptions are: 1. The correlation model between test and field results and 2. The time dependence.

7. *Are limitations of the prediction results identified?*

Yes. At present the model is valid for our telecom hardware. Other manufacturers may want to adjust some model parameters to fit their levels of quality.

8. *Are confidence levels for the prediction results identified?*

Yes. In the form of estimated upper and lower return levels.

9. *Does the prediction method account for application life cycle conditions?*
No. Only usage duration and duty cycles are considered.

10. *Does the prediction method account for the materials that comprise the product?*

No.

11. *Does the prediction method account for the part quality level?*

No.

12. *Does the prediction method account for the mechanical, electrical and electro-mechanical compatibility of the part with the box and system design?*

No.

13. *Does the prediction method allow incorporation of reliability data and experience?*

Yes. The whole model is based on earlier experience.

9. Siemens SN 29500 [10]

9.1 Overview of the methodology

9.2 Methodology assessment

10. British Telecom HRD 5 [11]

10.1 Overview of the methodology

10.2 Methodology assessment

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