A methodology to assess and select a suitable reliability prediction method for EEE components in space applications

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1) ABSTRACT

The rapid development of electronic components in recent times has left the standard reliability prediction methodologies behind, with a lack of models and data for some of the more modern component types.

Also due to changes in the way reliability is achieved, less accent has been placed on predictions and this has led in turn to the discontinuity of updates for a number of prediction handbooks. Besides this, general budgetary restrictions hampered failure rate data maintenance.

However, in some market sectors, such as space industry or telecommunication industry, the necessity to predict reliability still exists. The ECSS Q-60-15 working group has developed a set of criteria that will allow users to assess, and choose, between the available EEE parts reliability prediction methodologies and data sources for use in space applications. Where a standard prediction method is unsuitable, use of manufacturers data is elaborated .

This paper describes the philosophy of such an approach and provides some guidance of its application to choose prediction systems for a number of modern components.

2) INTRODUCTION

2-a) Review of available prediction methods

MIL-HDBK-217 [1] has been the mainstay of reliability predictions for about 40 years but it has not been updated since 1995, and there are no plans by the military to update it in the future. The handbook includes a series of empirical failure rate models developed using historical piece part failure data for a wide array of component types. The handbook contains two prediction approaches: the parts stress technique and the parts count technique and covers 14 separate operational environments, such as ground fixed, airborne inhabited, etc. As the names imply, the parts stress technique requires knowledge of the stress levels on each part to determine its failure rate, while the parts count technique assumes average stress levels as a means of providing an early design estimate of the failure rate. Typical factors used in determining a part's failure rate include a temperature factor (π_T), power factor (π_P), power stress factor (π_S), quality factor (π_Q) and environmental factor (π_E) in addition to the base failure rate (? $_b$).The failure rates given in the handbook have in the main derived from test bed and accelerated life studies.

EPRD (PRISM) [2] is a new approach released in 2000 based on the DoD Reliability Analysis Center's databases. It provides the ability to update predictions based on test data and addresses factors such as development process robustness. Available as an automated tool (as opposed to a handbook compendium of models like the others), PRISM interfaces directly with RAC's electronic and non-electronic automated databases and provides an elaborate methodology to assess the quality of the system development process. It includes a means to include software reliability but is limited by the fact that it does not yet include models for all commonly used devices.

Telcordia's SR-332 [3] approach is very similar to that of MIL-HDBK-217 but it's based primarily on telecommunications data and covers five separate use environments. The approach also assumes an exponential failure distribution and calculates reliability in terms of failures per billion part operating hours, or FITs. Its empirically based models are in three categories: the Method I parts count approach that applies when there is no field failure data available, the Method II includes lab test data and the Method III includes field failure tracking. Method I includes a first year modifier to account for infant mortality. Method II includes a Bayes weighting procedure that covers three approaches depending on the level of previous burn-in the part or unit has undergone. Method III includes a Bayes weighting procedure as well but it is based on three different cases depending on how similar the equipment is to that from which the data was collected.

RDF 2000 [4] is the new version of the CNET UTEC80810 reliability prediction standard that covers most of the same components as MIL-HDBK-217. The models take into account power on/off cycling as well as temperature cycling and are very complex with predictions for integrated circuits requiring information on equipment outside ambient and print circuit ambient temperatures, type of technology, number of transistors, year of manufacture, junction temperature, working time ratio, storage time ratio, thermal expansion characteristics, number of thermal cycles, thermal amplitude of variation, application of the device, as well as per transistor, technology related and package related base failure rates. As this standard becomes more widely used it could become the international successor to the US MIL-HDBK-217

Physics of Failure (PoF) is an approach for the development of reliable products that uses knowledge of root-cause failure processes to prevent product failures through robust design and manufacturing practices. At the discrete part level the current PoF approach is useful for predicting part life due to wear-out mechanisms. This approach, however, does not address part failures caused by material and process defects. The PoF approach proactively incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures, and electronics technologies. The approach encourages innovative, cost-effective design through the use of realistic reliability assessment and is an attempt to identify the "weakest link" of a design to ensure that the required equipment life is exceeded by the design. The models are very complex and require detailed device geometry information and materials properties. In general, the models are thought to be most useful in the early stages of designing devices (e.g., hybrids) but not at the assembly level when flexibility no longer exists to change device designs.

2-b) Definition of the problem

Though a lot of tools are available for reliability predictions, no one of them can replace the so far commonly used in space programs, i.e. MIL-HDBK-217. The best tool that could be tailored should :

- cover space environment by allowing space applications field return to be analysed. Space programs generally do not allow to get deep insight into component failures, if any. However, space environment (as soon as spacecraft is on-orbit) is generally governed by thermal effects, but other environments may be also representative for other space project phases.
- cover space component quality levels and especially the non-standard ones appearing in many projects. Today, HIREL quality levels are not only the one always prescribed (lower cost, higher risk programs). Also, commercial components are progressively introduced because they allow increased integrated complexity. (Very often, there is no other possibility!)

Nowadays, space applications represent such a low percentage of electronic application that space industry cannot be a driver any more in this field as it was 20 years ago. Also, manufacturing techniques have drastically evolved since the 80's. Indeed, statistical process control approaches have been developed allowing volume and quality/reliability compromises for commercial applications (telecommunications, computers, automotive,..). Such type of components are now being used on a case by case basis in nearly each space project.

The ideal data base should also :

- allow to support quick evolution in the equipment design, by allowing either a regular maintenance on a short term basis (e.g. every two years) or integrating models allowing to extrapolate reliability results (e.g. Moores'law)

Nowadays, electronic technology is evolving at such a high speed that former data bases are really out-of-date and do not integrate new technologies.

Finally, many studies [5] have shown that EEE part reliability is one contributor to the equipment reliability but not only the single one as it may have been in the past. New reliability prediction techniques involving design, project management, are being developed. Such approaches also contribute to the obsolescence approaches based on classical data bases.

2-c) Current situation

As identified already in ESCCON 2000, and as no breakthrough occurred since the last two years, space industry is missing, at least for some EEE parts, an updated standard or data base allowing to perform realistic reliability prediction. Especially, highly integrated devices (e.g. memories, microcontrollers, ASICs, ..) are the most affected by the reliability growth whereas classical components (e.g. capacitors (except Ta), resistors, discrete active (except power)) are still covered in an acceptable way by e.g. MIL-HDBK-217 [5].

However, even if reliability prediction techniques may evolve drastically in the near future, project requirements are still including "classical" reliability predictions.

3) Requirements and needs for space equipment reliability predictions

Nearly each Statement of Work (SOW) for space flight equipment or systems requires that reliability predictions are performed throughout the design and development process. Even if reliability predictions are not contractually required, most suppliers of space flight equipment or systems will perform some type of reliability calculation in order to assess the product's inherent failure probabilities and the associated liability they are prepared to take.

Reliability predictions are not only performed to demonstrate that a required mission success probability or a MTBF is achieved, they are also applied

- to justify a selected design choice against other possible design solutions
- to identify inherent design weaknesses and to support their elimination
- to determine the necessary equipment- or system-level redundancy scheme
- to determine and to justify the EEE-Parts (quality) level applied
- to assess maintenance intervals
- to quantify the risk probability of dedicated failure modes

However, data sources and methods - currently acknowledged in the space community such as MIL-HDBK-217 - for the performance of reliability predictions have either not been maintained for a long time or do not cover state-of-the-art EEE-Parts and related specific failure phenomena. Thus, applying these old fashioned reliability data (failure rates) and calculation methods will result in equipment- or system-level reliability figures, which are by far not representative for the equipment or system behaviour under operational conditions. Furthermore, using failure rate data and reliability calculation methods, which are not suitable for coverage of today's EEE-Parts technology, may lead to wrong equipment or system design decisions.

It remains to be noted, that frequent maintenance of this standard is mandatory in order to allow for coverage of the rapidly evolving EEE-Parts technology.

4) Methodology

In order to overcome this un-satisfactory situation that no universal data base or handbook can be proposed for space applications, an ECSS working group had been set up with the task to perform a survey on alternate reliability data sources and methods and to establish a suitable standard for application in (ESA) space projects. This standard including its implications on the performance of reliability predictions for space equipment is subject of this paper.

This ECSS group has quickly focused its attention on establishing a standard allowing to space industry reliability engineers to find data for reliability prediction.

After a first survey, it has not been possible to propose a direct alternative to MIL-HDBK-217. The most recently updated databases, RDF2000 and PRISM RAC Tool were not considered as covering all the needs for space programs.

Therefore, the chosen methodology was to help the reliability engineers to choose, for particular cases, the most appropriate data inputs.

Thus, the overall process flow and the decision logic reflected in the standard being drafted is as follows (see figures 1 and 2 at the end of the paper):

- propose an adequate set of selection criteria (see table below) and a corresponding quotation for selection among various databases or handbooks by considering the specific part technology (includes die technology, package,..). If many handbooks or data bases are under consideration, the quotation allows to choose the most appropriate one for the given case. If only one handbook can be considered, the quotation may allow to give a quote to a single handbook or data base under consideration to assess its suitability. When no database is adequate for the specific case, manufacturer or test data can be considered., Limitations of the MIL-HDBK-217 are identified in terms of technologies (families, complexity, package). Also, correspondences between ESA, NASA or MIL and NASDA parts quality grades are given in order to complete the MIL grades mentioned in the MIL-HDBK-217.

ITEM	QUESTION	Example Weight Factor (%)
Validity	1a) is the considered technology (1) covered by the handbook ?	GO / NO GO Criteria
	1b) is information available on the way the data are collected ?	15
Suitability for space	1c) if yes to 1a and 1b, are data collected and models implemented according to international standards (e.g. IEC) ? 2a) does the standard allow to cover space environment (2) ?	10 10
	2b) does the standard consider parts stress method ?	10
	2c) does the standard address the quality levels of the components being used (3)?	10
Maintenance of Data	3a) have the data been updated in the last 5 years ?	10
	3b) are there expectations to update data in the next 5 years ?	10
International Recognition	4a) is the standard requested by the customer ?	10
	4b) Is it recognised by the reliability community ? (4)	5
Usability	5a) is a commercial software tool available to support the standard ?	5
Suitability for new technologies	6a) does the standard provide extrapolation rules (e.g. Moore's law) ?	5
Cost	Not considered	

(1) Technology includes the component type, technology, family and package.
(2) Space environment may include launch vibrations, space vacuum, radiation, and temperature extremes
(3) In space applications, the component quality in accordance with ECSS-Q-60, its equivalent or as otherwise specified.
(4) Recognition by the reliability community may include for example :
It is an international standard / handbook
It is a national standard /handbook (e.g. MIL-HDBK-217)
It is a recognised industrial or other standard / handbook (e.g. Telcordia SR-332)
It is otherwise recognised by the reliability community

- propose the use of alternative manufacturer data when no database or handbook can be considered for the case (especially for non-standard parts, e.g. high complexity commercial parts). The standard describes (or refers to appropriate international standards) the way to collect and use those manufacturer/test data. The aim is to standardise the way reliability figures are calculated. Emphasis is placed on typical cases: no defect found, acceleration limitations and figures allow to identify the potential influence of the statistics or the number of defects on the extrapolated results.

It is not the purpose of the standard to provide data. It is also not the purpose of the standard to mention how to use the different databases or handbooks (except for MIL-HDBK-217 limitations), they have to be used in accordance with their normal procedure.

The main advantage of this standard is to be robust to further events that may occur in the reliability field. Even if no suitable data base is available (e.g. if data are not maintained), manufacturer or test data can be chosen or produced and worked out. If a new database is created (or an old one updated) and becomes the best one to be used, then the standard allows (based on selection criteria) to define it as by default input source.

The methodology developed in this standard is a short/middle term way of addressing reliability prediction. Hence, many studies have shown that parts failure rates are not any more the main contributor to equipment or system reliability and on a long-term basis, new methodologies - not only parts failure oriented - may appear.

5) Comparative Methodology Assessment

A comparative assessment was performed on two well-known (but not necessarily well-used) databases, i.e. TELCORDIA & RDF2000 in order to test and validate the ECSS-Q-60-15 identified criteria.

The first and major point is to identify if each component category covered by MIL-HDBK-217-F is also covered by these databases. Indeed, if the family is not taken into account in the database, this may be sufficient for eliminating the database.

TECHNOLOGY COVERAGE : the following families are out of consideration in :

- ➔ TELCORDIA: magnetic bubble memories, GaAs devices, SAW devices, tubes, lasers, electronic filters, passive optics, PCB & connections
- ➔ RDF2000: magnetic bubble memories, SAW devices, meters, displays, tubes, lasers, electronic filters, rotating devices, lamps.

Afterwards, the other criteria are reviewed and the relevant points are :

DATA COLLECTION :

- ➔ TELCORDIA: failure rates are data collected by several suppliers and the database was updated on the last 5 years but there is no information about the type of data or the models implemented.
- ➔ RDF2000: reliability data are mainly coming from field return in electronic devices operating in 4 types of environment.

SPACE SUITABILITY

- ➔ TELCORDIA: the space environmental conditions are not completely covered but quality levels are considered and part stress & part count methods too.
- ➔ RDF2000: space environment is covered with distinguished conditions (depending on satellite orbit and mission phases). Thermal, thermo-mechanical and voltage stress factors are considered, but parts count is not covered. Component quality levels are not considered as the standard applies only to the best commercial practice.

Results were obtained on TELCORDIA & RDF2000 databases and on MIL-HDKB-217-F accordingly to the following rules :

- when the criterion is satisfied, maximum weight is assigned,
- when the criterion is not satisfied, 0 is quoted.

The final results show that the selection criteria are not very discriminative even if a hierarchy puts RDF2000 at the first place (with 58%) followed by TELCORDIA (50%) and MIL-HDKB-217-F one step behind (45%). The former may or should improve their international recognition because they have the potential to be used in the space environment but in practice they still aren't.

6) The future ?

6-a) Reliability prediction methodology :

The purpose of the ECSS document is to be considered as a short/middle term answer to the need. Indeed, less and less effort was devoted recently to maintain reliability databases and within a few years less and less technologies will be covered in the handbooks.

Many alternatives are proposed for longer term reliability prediction approaches. Most alternatives are addressing either exchanges of data (e.g. Data Sharing Consortium of RAC in the United States) or additional contributors than EEE part to system reliability

Many projects/studies are also underway in Europe, e.g. FIDES in France, and REMM in UK.

Based on the inadequacy of the reliability assessment standards to address COTS (Commercial Off The Shelf) and the consequent slow down of their use in defence systems, FIDES consortium has been created, grouping together AIRBUS FRANCE, EUROCOPTER, GIAT Industries, MBDA missile systems, THALES avionics, THALES TRT, THALES TSA and THALES TUS, the French defence electronic actors. This consortium, sponsored by DGS (French MoD), aims at developing a reliability predictive approach for COTS which has to be an interactive methodology in design, fully useable in real time for the latest technologies, compliant with any impacting manufacturing process and with any environmental condition or mission profile.

FIDES approach takes into account 3 major contributors of the COTS reliability : its Technology, its Process and its Use. These contributors are considered throughout the life cycle, from COTS manufacturing phase to electronic system maintenance phase.

FIDES model consists of the combination of two terms:

- physical stress factors

- life cycle process contributors

Each partner will apply the methodology on different cycle steps in different systems to reach a high coverage of applications and environments.

FIDES methodology allows reliability monitoring during all the development and life cycle in accordance with ISO 9000 requirements.

The REMM (Reliability Enhancement Methodology and Modelling) programme is a collaborative project of BAE Systems, FR-HiTemp, University of Loughborough, RAF, Rolls Royce, Smiths Industries, University of Strathclyde, TRW Westlands, and University of Warwick that aims to improve the estimation of aerospace equipment reliability and to provide guidance on the choice of tools that can be used to improve dependability performance and so close any gaps between predicted and required reliability of an aerospace product.

The REMM programme is examining an alternative method for reliability assessment that uses the knowledge contained within experts within the company as well as data collected on past equipment to provide a reliability assessment of new equipment. This technique uses a process of elicitation to gauge the company experts concerns about design changes in new products and then uses a Bayesian approach to modify failure distributions derived from the historical field failure data that the company holds.

Further, the REMM programme is developing an expert system to help deal with the introduction of the reliability case. The expert system will gather knowledge about the application of various reliability tools from within the company and the expert system will then be able to provide expert guidance about which reliability tools are the most appropriate to use in any particular situation. In effect the experts system will aid the development of a reliability programme the output of which, after the reliability tasks are performed, will provide the backbone for the reliability case argument.

6-b) EEE part Manufacturer standpoint :

Over the past ten years component manufacturers have increased so much the possibilities to mix several functions in a single chip that predictions, based upon stand alone functions, is getting out of date. This trend will be confirmed in the coming years and the need for a flexible and well accepted reliability prediction methodology is becoming essential.

IC manufacturers have in their roadmaps "System in a chip" offering including logic, microcontrollers, peripherals, memories and even RF or power functions. This is achieved either on a single chip thanks to mixed technologies or by multichip packaging solutions. Plastic stacked-dies are usual in commercial and industrial applications and rapid progress of PBGAs make their use in severe environment topical as well.

As a consequence of this evolution, regular handbook updates or use of alternative prediction approaches will become necessary in order to adequately cover:

- Supply voltage decrease down to 2 volts and lower indeed
- Reduced longevity of technologies
- Variety of products and predominance of customs package diversity and complexity (fine pitch, high pin count, number PBGA families)
- Die form quality flow (KGD : known good die) and Hybrids complexity
- Embedded Software robustness

7) Conclusions

The paper presented the methodology developed to allow space reliability engineers to consider other data sources than MIL-HDBK-217 for cases where it is totally outdated. This methodology opens the gate to other data sources and to manufacturer/test data provided they satisfy some described criteria.

This methodology will be encapsulated in ECSS standard referenced ECSS-Q-60-15. The draft has been issued in August 2002 and should be released for public review before the end of the year.

It should be considered as a short/middle term solution to address EEE part reliability prediction but further recommendations will be raised by the working group to address long term evolution of this field.

8) Acknowledgement

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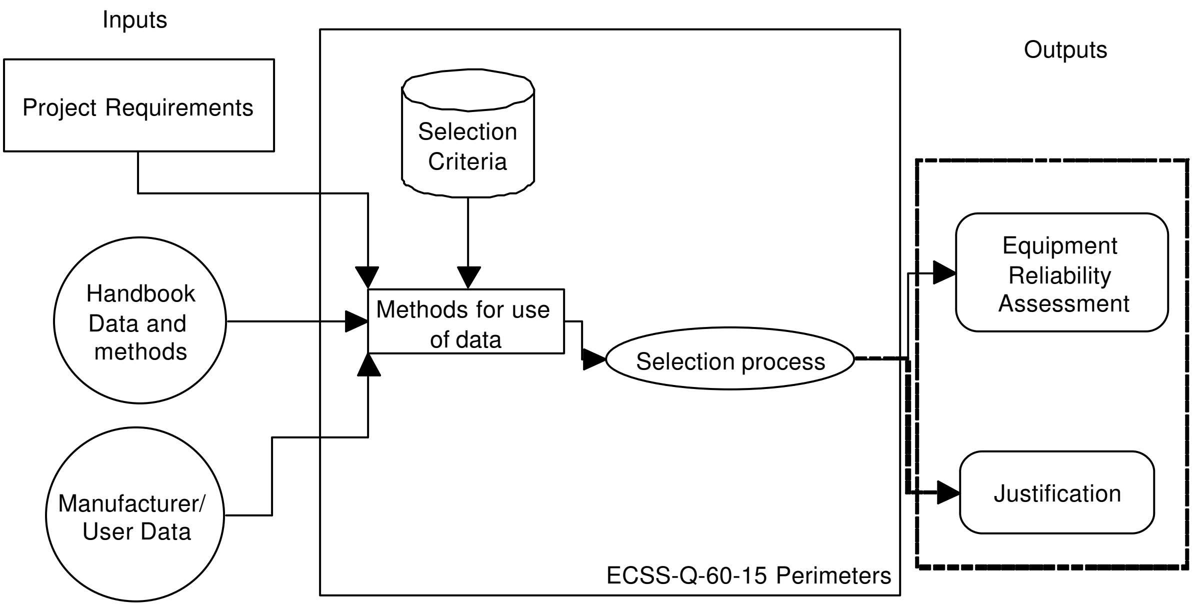

Figure 1: Perimeter of ECSS-Q-60-15 (Inputs and outputs)

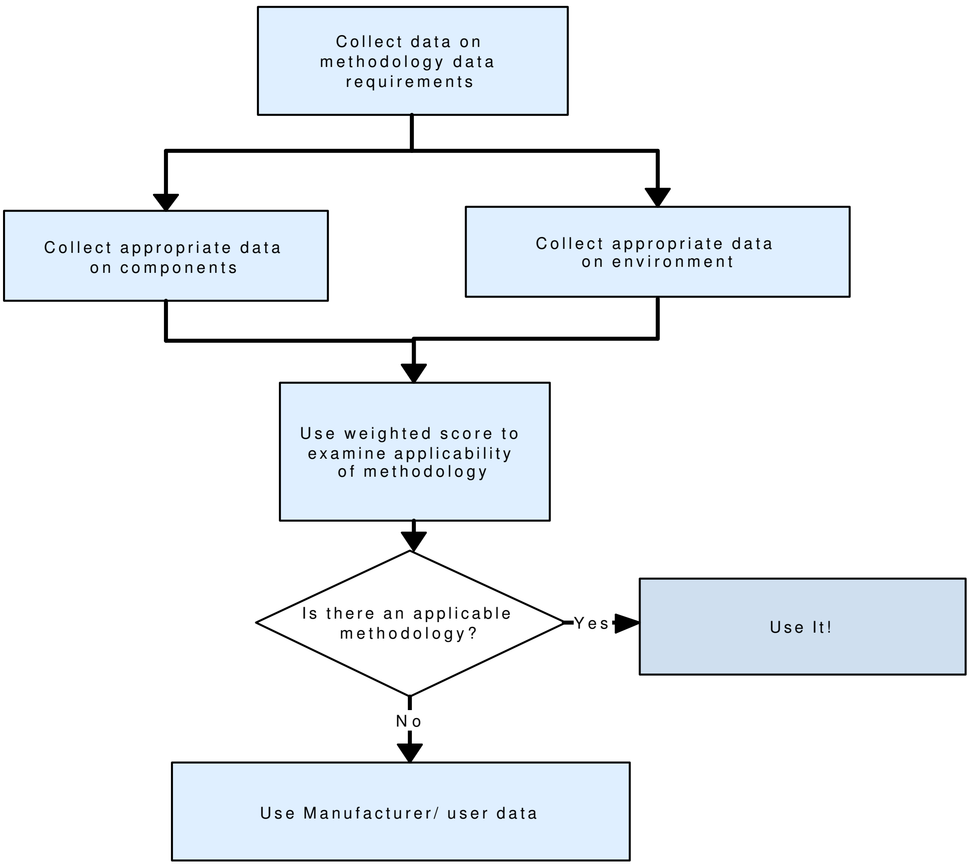

Figure 2: Decision Logic

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