Reliability Prediction Analysis

The reliability analyses can be used to define the quantitative parameters for an item, equipment or a complete system, and may be expressed in number of failures in a given set period of time, set number of cycles or set number of operations, such as rounds fired from a small caliber gun, etc.

A common expression used to define an item's reliability is its Mean-Time-Between-Failure, commonly known as its MTBF. Once this figure is known it can be used to determine the reliability of an item in terms of a probability of success or failure, over a given operating period.

The following activities are covered for the quantitative reliability analysis:

- Reliability Analysis (methods)
- Reliability Probability
- Reliability Block Diagrams (Modeling)
- Reliability Analysis (Methods)

There are methods available for determining the reliability of an item (this could be a piece part to a complete system) and are:

Reliability Prediction: This is the process used to determine the MTBF of an item. This is achieved by performing a prediction analysis.

Similarity: This method is used to determine what the reliability of a new product will be based upon the "known" reliability of an existing product with similar attributes. These attributes can be the type of technology used, digital circuitry, complexity of components and also comparable operating environments and scenarios.

Field Data: This is the result of determining the reliability of a product based upon its operational performance in the field. Normally an organization would establish a process designed to collect fielded data. The MTBF will be determined by dividing the total cumulative operation hours for all fielded products by the number of failure occurrences.

In the design and development of a new product, the design and reliability engineers, may not have available field data (reliability performance data), due to the simple fact that the system has not been fielded. In this case the reliability engineer must use alternative methods to determine the reliability of the proposed system. Early in the concept phase, with a minimum depth of knowledge of the proposed system, a high level understanding of the system could be determined.

> **Example:** An airfield radar, the basic system will consist of a transmitter, receiver, antenna assembly and data processing equipment and possible some data communications equipment. From these function groups of equipment we can estimate that there will be power supplies, digital circuit card assemblies, motors and servos etc. With this we can start the preliminary process of estimating the systems MTBF.

For preliminary estimation the MTBF may be determined by similarity, in other words, the MTBF of a known system (previously developed and fielded) is available, and therefore this data will be used until more information becomes available.

Important to most people is the numeric performance value for an equipment or system. It maybe a figure such as the Mean Time Between Failure (MTBF) for a piece of communication equipment or the Mean Distance Between Failures (MDBF) for a transportation System. Whatever the numeric value, what is important is how it is derived for the equipment or systems.

A good method is to put "x " number of systems in the operational field and wait to see how many items fail and are returned for repair. However this reliability information is required long before the fielding of an equipment or system.

Apportionment

The purpose of the apportionment method to assign a reliability figure to an item. This is particularly useful in the early conceptual and design phase. The apportionment allocates the reliability figure to the item in question, allowing the overall budgetary control of a system's end reliability. This will also allow the development of reliability figures that could be introduced into the performance specifications for subsystems. The apportioned reliability will be reviewed, as the design of the equipment becomes more solid.

Similarity

The similarity method is employed when there is enough design clarity of an item. Basically it utilizes known predicted or fielded data from other components similar in nature, in terms of technologies and complexity.

This method should also take into consideration the operational environment and quality of the product, of the new item and that to which it is been compared to. For instance an electronic computer module, has an Input Buffer Module (12 discrete inputs) and, is being designed for a new naval application. A previous module was developed for an aviation application, using the same component quality and density. As this item was previously developed for another project there is some reliability prediction data available. This data can be utilized for the new design, when it has been modified by a factor to take into account the differences between the two operating environments.

Prediction

This method, considered by some to be controversial, is used in the design of equipment to permit a predictive assessment of its reliability. Predictions of electronic components can be achieved by using MIL-HDBK-217 or Bellcore.

There are several standards (handbooks) widely used by the reliability engineering world, these include military and commercial. The following concentrates on the application of Military Handbook MIL-HDBK-217. This particular handbook has been constantly revised over the years and is now at revision F, notice 2, which is reflected in its number MIL-HDBK-217F.2. This handbook is focused on the electronic parts reliability predictions. The fundamental approach of this document is to commence the development of a reliability prediction, from the discrete component upwards, using specific algorithms for generic electronic components.

In the case of MIL-HDBK-217, there are two methods, a parts count and a full stress. To implement either of these two methods requires certain knowledge with respect to the electronic components and the maturity of the product design. The Parts count is performed when for example, a Printed Circuit Board's design is such as to be able to determine the main component type, quality and quantity. This method makes general assumptions on the applied stresses for each electronic component.

The full stress method is invoked when the design of a Printed Circuit Board is nearly complete and subject to possibly only minor changes. This particular method evaluates the thermal and electrical stresses that are applied to a component under given environment conditions (operational environment and ambient temperature). This method will afford an analyst to assess if specific design practices are been adhered to such as stress derating. Therefore it is possible identify if a component is been operated outside allowable stresses.

A mechanical system or component may be subjected to stress/ strength interference modeling or in the case bearings to L10 or L05 life calculations. Also generic reliability figure can be sourced from documents such as NPRD 95. The user should also be aware of the actual design margins of a mechanical component. Implementing stress analyses to determine the Margin of Safety and the Safety Factor of a particular item can assess these.

Parts Count

The parts count method is utilized in the bid phase or early design phase when there is insufficient information available, thus not enabling a full stress method to be conducted. There is sufficient information or data available to allow for a preliminary reliability prediction to be conducted. MIL-HDBK-217 provides a set of default tables that provides a generic failure rate (Λ_g) for each component type and is based upon the intended operational environment. This component generic failure rate is also modified by a quality factor ($"\pi_q"$), which represents the quality of the component(s) in question. E.g. the component is manufactured and tested to a full Military Standard or to a lesser commercial standard. In addition for microelectronic circuits a learning factor ($"\pi_L"$), is used and represents the number of years that a component has been in production. Using a components generic failure for a given environment and modifying it to give consideration for its quality and in the case of microelectronics the learning factor, its final failure rate is established. The summation of the individual component's failure rates will yield the overall failure for the circuit card assembly they populate. With this and the summation of other Circuit Card Assembly failure rates, the failure rate of a line replaceable unit will be established. This process will provide an overall failure rate for a system

Full Stress

The full stress method, like the parts count method, provides a failure rate for an electronic component. The summation of the failure rates for all components on a circuit card, and all the circuit cards within a black box, and all the black boxes, within a system will yield the overall failure rate for an system. To enable a full stress analysis to be conducted there must be sufficient details on the systems design available to the reliability engineer. In essence the design of the system must be such that the electronic and electrical design of the hardware is to

the components level. There will be detailed parts lists and circuit schematics available. This is required because the stress analysis takes into consideration the electrical and thermal stress that will be experienced by the each component.

The full stress analysis is completed by the reliability engineer, who with the detailed knowledge of the electrical and electronic design, in addition he/ she will require specific data pertaining to each component type used within the design. Component information, or data sheets, are supplied by the manufacturer, and recently this information is available over the Web. In the case of a full stress analysis, the mathematical models are detailed in MIL-HDBK-217 for each component type, i.e., microelectronics, resistors, capacitors and electromechanical devices.

The general approach used by MIL-HBK-217, is each generic component type is assigned a base failure rate () and is modified by influential factors. These factors, as listed below are used when modifying the base failure rate. Some of the factors will result in a linear degradation of the base failure while others will cause an exponential degradation, in particular factors associated with temperature. These factors are as follows:

> $"\pi_E"$ =Use Environment: This factor is set based upon the intended operating environment for the equipment/ system.

> $"\pi_Q"$ =Quality Factor: This is a general look up factor that represents the quality of the component in question. Generally the base failure rate is modified by the multiplication of this factor.

Depending on the type of component under analysis the base failure rate will be subject to additional modification by various factors, the following is a sample of the many types of factors used by the full stress analysis in MIL-HBDK-217:

> $"\pi_{NR}"$ =Represents the number of resistors in use on a resistor network.

> $"\pi_{TAPS}"$ =Is a derived factor, representing the number taps on a variable resistor.

> $"\pi_L"$ =Represent a factor for the number of years that IC has been in production.

There are many operating environments that may be considered in MIL-HDBK-217 and in the case of Bellcore they are limited to the commercial field. However the following are a selection of some of the environments stated in MIL-HDBK-217:

Ground Benign (GB) Nonmobile, temperature and humidity controlled environments readily accessible to maintenance: includes laboratory instruments and test equipment, medical electronic equipment, business and scientific computer complexes, and missile and support equipment in ground silos.

Naval Shelter (NS) Includes sheltered or below deck conditions on surface ships and equipment installed on submarines

Airborne, Uninhabited Cargo (AUC) Environmentally uncontrolled areas which cannot be inhabited by an aircrew during flight. Environmental extremes of pressure, temperature and shock may be severe. Examples includes areas of long mission aircraft such as the C130, C5, B52 and C141. This environment also applies to uninhabited areas of lower performance smaller aircraft such as the T38.

Space Flight (SF) Earth Orbit. Approaches Ground Benign conditions. Vehicles neither under powered flight nor atmospheric reentry: includes satellites and shuttles

Mathematical models

Mathematical Model: Microcircuits, Gate/ Logic Arrays and Microprocessors

The following algorithm is a general model used by MIL-HDBK-217 for microcircuits that include Bipolar and MOS devices, digital and linear gate/ logic arrays, Field Programmable Logic Arrays (PLA) and Programmable Arrays Logic (PAL) and Microprocessors.

$$\lambda_P = (C_1 \pi_T \pi_A + C_2 \pi_E)\pi_Q \text{ failures per million hours (fpmh)}$$

Where:

C_1= The die complexity (number of gates or transistors): A lookup table provides a figure depending on the number gates/ transistors of the device under analysis, plus if it is linear, digital (or PLA/ PAL) or in the case of a microprocessor the bit word complexity, e.g. up to 8, 16 or 32 bit word

"π_T" = The temperature factor is derived from a formula. Given below is the formula for silicon devices. A look up table provides a figure for specific devices, based upon its junction temperature. This is calculated based upon the case and ambient

$$\pi_T = (.1)exp\left[\frac{-Ea}{8.617x10^{-5}}\left(\frac{1}{T_j + 273} - \frac{1}{298}\right)\right]$$

temperatures, taken into consideration the junction to case and case to ambient thermal resistance.

C_2= Is the package Failure Rate factor used for microcircuits, this takes into consideration how the device is packaged in a flatpack, can, hermetic sealed etc.

"π_E" = Is the environmental factor. Depending on the intended operational environment this factor is modified accordingly. This includes many factors such as Ground Benign, Naval Sheltered, Airborne Inhabited Cargo, Canon Launch etc. For example the factor applied to a device used in a Ground Benign would use 0.5, whereas for the Naval Sheltered a factor of 4.0 would be used and in the case of a server environment such as the Cannon launch Environment a factor of 220 would be applied.

"π_A" = Application factor is applied to for the intended use of the device, for MMIC devices used in a high power application a factor of 3 would be applied, where as a digital device would use an applied factor of one

"π_Q" =The Quality Factor is applied to the quality standard that the devices has be manufactured to, whether commercials to Mil-Spec Quality levels

"π_L" = Learning Factor. This factor is applied to represent the number of years that a device has been in production

Field Data

A deployed (or fielded) system will after a given period of time reveal its actual reliability performance. Only when a system is fielded can its performance be readily measured to determine its design adequacies or in some cases inadequacies. The reliability performance is derived from observing the failures that have occurred in the field. For the system/ product user/ provider to determine actual reliability performance, a data collection system needs to be

established and put into place. The system to implement this would be conducted under a FRACAS

An existing mature system maybe proposed as a hardware solution for another project, which itself has been operating in an operational environment for sometime. In assessment of this field data, it must be clearly understood how this system was operated and in which environment, under what conditions, and what the total system fleet cumulative operating hours are. In addition the quality of the data needs to be established. Was the data collected and obtained in a realistic way, or were some data elements obtained by making assumptions. For example, were all reported failures actually caused by the inherent reliability characteristics of the equipment or were failures induced through poor management and maintenance practices, such as poor preventive maintenance, operator and/ or maintainer induced failures etc. Further to this was the data accurately collected and reported.

Data presented and furnished by suppliers cannot always be taken at face value. Some suppliers might have made assumptions about the equipment and its utilisation For example, a supplier of COTS equipment, such as commercial computer equipment, may only have visibility on how their equipment is performing by those items returned to them under warranty or as part of a service contract. In deriving their actual reliability they may have factored in a duty cycle with respect to the total number of hours that the equipment (on average) is used or powered up. If one was to use this data as is, not knowing this fact, and decide to apply an operating duty cycle for their own intended environment, then a clear case of double dipping has occurred.

The ramifications of not fully understanding how field data was derived could have a profound impact on the conclusion of a system/ equipment reliability performance assessment, which would directly influence spare parts holding, warranty and Life Cycle Cost.