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ALMA PROGRAMME

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Reliability Calculation Guidelines

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CHANGE RECORD

ISSUE	DATE	SECTION/PARA. AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
1	2000-06-05		
2	2000-09-21	Para 6. Added new Para 6.1.	Updated operational considerations for availability.

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1. Scope

In order to obtain the high availability, which is required for the ALMA radio telescope and instruments, high reliability is necessary. The reliability of a development shall be estimated already in the design phase in order to locate weak design points as early as possible and also to provide an indication of whether the design meets the requirements or not.
Unless the contractor (or developing institute) wants to apply a recognized reliability analysis method, which fits his working routines and can be agreed upon, the ALMA Systems Engineering Group allows the contractor to apply the Parts Count method, as it is described in MIL-HDBK-217F.
The present instruction is established as a guideline for preparing reliability analysis, based on the Parts Count method.

2. Documents and Abbreviations

2.1 Applicable Documents

[1] MIL-HDBK-217F, Reliability Prediction of Electronic Equipment,
US Department of Defence, 2 December 1991, (incl Notice 1 of 10 JULY 1992 and Notice 2 of 28 February 1995)

[2] NPRD-95, Non-electronic Parts Reliability Data - 1995,
US Department of Defense, July 1994

2.2 Data Sources

Data (including failure rates) for the Parts Count Method Reliability Assessment may be found in (either of) the following documents:

[1] MIL-HDBK-217F (for Electronic Equipment/ Electro Mechanic Equipment)
[2] NPRD-95 (for Mechanical Equipment)
[3] Manufacturers' Data Sheets (for all Equipment)

2.3 Acronyms

ESO	*European Southern Observatory*
MIL-HDBK	*Military Handbook*
MTBF	*Mean Time Between Failure*
MTTR	*Mean Time To Repair*
NPRD	*Non Electronic Part Reliability Data*
TPM	*Time needed for Preventive Maintenance*

3. Method Selection.

Reliability Assessments for a new design is based on empirical data fed into an algorithm. Even though the outcome of such calculation is (and only can be) a prediction, it is, when it is carefully prepared, useful as a rough indicator for the probability of a design to meet an expected reliability level. And it can be a useful tool to assist location of reliability weak points in the design.

The method described for performing reliability analysis and recommended in this paper is selected on the basis of its accuracy, (low) complexity, and data availability. “The Parts Count Analysis Prediction”, was developed by the US Army and has been used world wide for military as well as non-military equipment for many years. The method is described in the publicly available Military Handbook MIL-HDBK-217F.

The Parts Count method comes out with a slightly conservative result. Another, but more time consuming – and considered more accurate, less conservative – method, the Parts Stress Analysis Prediction, is described in the same publication, available for use. This may be used in the case where the result of the Parts Count method does not comply with the ALMA reliability requirement.

The MIL-HDBK-217F describes in detail both methods. The present paper is meant as an introduction to the Parts Count method and a guideline for calculating predicted availability of a design to verify compatibility with ALMA specifications.

4. The Parts Count Reliability Prediction Method

The method is based on the assumption that the failure rates for all components are constant over time. In other words it means that the early infant mortality and the late wear-out related failures are not taken into consideration. Under such assumption, the failure rates simply can be added together and the calculated system failure rate can be expressed as follows:

$$MTBF_{System} = (\lambda_{System})^{-1} \qquad (1)$$

Where

$$\lambda_{System} = \sum_{i=1}^{i=n} N_i(\lambda_g \pi_Q \pi_E)_i \qquad (2)$$

λ_{System}	:	Total equipment failures rate (Failures per 10^6 hours)
N_i	:	Quantity of i^{th} generic part
λ_g	:	Generic failure rate for the i^{th} generic part *)
π_Q	:	Quality factor for the i^{th} generic part *)
π_E	:	Environment factor for the i^{th} generic part *). In the MIL-HDBK-217F Appendix A generic failure rates are given under various environmental conditions.
n	:	Number of different generic part categories in the equipment

*) data available in the MIL-HDBK-217F or in the NPRD-95.

In the case of redundancy (two or more parallel systems/components) the following applies:

$$MTBF = \quad \sum \frac{1}{\lambda i} - \sum \frac{1}{sum\ of\ \ pairs\, \lambda i} + \sum \frac{1}{sum\ of\ triples\, of\ \lambda i}, \quad etc$$

For example in the case of redundancy with two parallel systems/components ***A*** and ***B***), the following applies:

$$MTBF_{(A,B)} = \frac{1}{\lambda_A} + \frac{1}{\lambda_B} - \frac{1}{\lambda_A + \lambda_B} \qquad (3)$$

which implies, provided $\lambda_A = \lambda_B = \lambda$, *that*

$$\lambda_{(A,B)} = \frac{2\lambda}{3} \qquad (4)$$

5. Application of the Parts Count Reliability Prediction Method for The ALMA Telescope

The ALMA Radio Telescope will be erected in an environment, where temperature and pressure are factors, which might decrease the MTBF for the electronic as well as for the mechanical equipment. In order to account for such environmental constraints, the failure rates, selected for the components shall be multiplied with the environmental factor, AU or AUC (for Uninhabited Cargo aircraft), as it is found in the referenced documents. (Appendix 1 of the MIL-HDBK-217F provides generic failure rates for various environments). That selected environmental factor takes into account: extreme (low) pressure and low temperature. It also takes into account shock conditions. The environmental conditions on the ALMA site includes high possibility of earthquakes, and local on-site transport of the ALMA elements introduces shock as well.

6. Availability.

The availability is defined as follows:

$$Availability = \frac{MTBF}{MTBF + MTTR + TPM} \qquad (5)$$

where:

MTBF = Mean Time Between Failure
MTTR = Mean Time To Repair
TPM = Time for Preventive Maintenance

For the calculation of the unit antennas failure rate it is acceptable to reduce the subsystems failure rates with an operational rate (OpsRate) factor, respectively, reflecting the fraction of operational time, the individual subsystem is active.

Example: If a mobile telescope is moved only once a week and the average transport time for each such redeployment is 2 hours and only done during non observational time (which then becomes the theoretical operational time for the transporter), then the following factor can be applied to the calculated failure rate:

Average observation time per 24 hours: 10 hours
Average observation nights per week: 7 days

(2 hours per redeployment)(1 redeployment per week) /(7 days per week)(14 hours per day) = 2/(14 x 7) ~ .02

The initially calculated failure rate for the subsystem can be multiplied with the OpsRate, which in this case equals .02

6.1 Operational Availability Requirements

The ALMA telescope array is not like optical telescopes to be operated during the dark hours only. This situation leaves no natural opportunity for maintenance work, which means that a certain number of antennas constantly will be subject to scheduled preventive maintenance.
For the operation of ALMA, it is not yet defined what number of antennas is required for an observation in general. It might also be that a specific antenna configuration is required for a certain observation. If the ALMA will facilitate such flexibility, specific requirements for array configuration for the specific observation may be requested by the observer.
As the basis for availability calculations, until the operational requirements and possibilities have been clarified, it is taken that there for each observation will be dedicated as many antennas as technically possible, and that the array is not going to perform parallel observations.
The necessary preventive maintenance time is yet neither required nor indicated from the designers. And neither is the MTTR.
Presently it is not possible to obtain a complete picture of the ALMA availability. And it is not yet possible to define the requirement for availability.

This paper will be updated, when the project is further developed, and when the scientific needs and requirements are more precisely available.

7. The practical approach for the calculation

The systematics in the calculation includes the division of the overall system into sub systems. Note that the sub systems might have individual operational characteristics and thereby need to be dedicated individual OpsRates.

A spreadsheet is a practical calculation tool for the purpose. Also dedicated tools are available (eg. Relex, Milstress)The sub systems need first to be structured in a reliability tree, providing the opportunity to analyze the overall system and easily define where to introduce improvements.

8. Proposed Sequence of Steps for the Calculation

The following is a proposed sequence of actions for setting up the reliability calculations:

1. Define subsystems, or even sub-subsystems, preferably based on the ALMA product tree, which can be considered individually functional systems.
2. Create a reliability tree, showing the individual subsystems and their parent-child relationships.
3. Create a spreadsheet system, which facilitates calculations from component level up to system level, respecting the structure break down (reliability tree) and individual OpsRates for the subsystems. The top-level sheet shall give the system MTBF and a one glance overview down to a sub-subsystem level.
4. Fill in the failure rates for components, following for example the Parts Count Method. (See paragraph 4 above).
5. Determine and fill in - for each subsystem - the OpsRate. (See paragraph 5 above)