New Reliability Prediction Methodology Aimed at Space Applications

TN-01 Fact Sheet on

Limitations of the in-use reliability prediction methodologies

Under a programme of and funded by the European Space Agency

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TN-1 Executive summary

The Technical Note TN-1 provides the findings and major results of the Task 1 prepared in the frame of the study "New Reliability Prediction Methodology Aimed at Space Applications", under a programme of and funded by the European Space Agency.

The objective of the study is the development of a new methodology for reliability prediction (RP) for space applications, aiming to overcome the limitations and shortcomings of the methods and approaches currently used in practice. The final outcome of the study will be a handbook for reliability prediction in space applications, which will serve as an input for the development of a new ECSS handbook. The role of the Technical Note TN-1 for the overall study is shown in Figure 1 below.

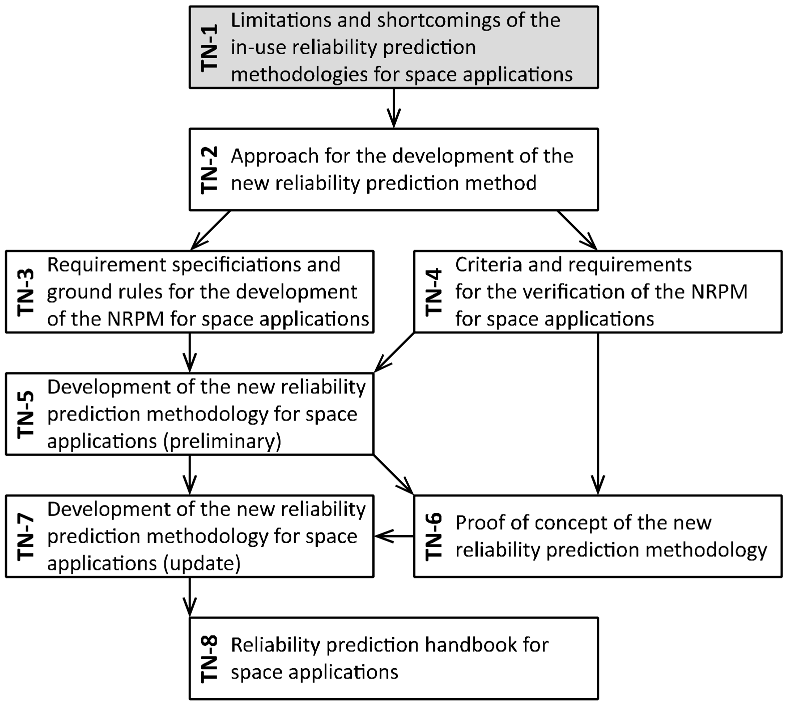

Figure 1: Overview on the content and interrelation of the Technical Notes.

The objective of TN-1 is to provide an assessment of the current state of reliability predictions in space applications and their inherent limitations and shortcomings. As such, no recommendations are made in TN-1 for possible improvements of the in-use methodologies; it is simply a description and evaluation of the status quo.

To agree on a common terminology, the following basic concepts are introduced and discussed:

- Taxonomy of failures (failure types, root causes and contributors)
- Space products and different levels in the system hierarchy (from part to system)
- Different types of elements (electrical, mechanical, miscellaneous)
- Modelling approaches (statistical methods, Physics of Failure)

Four categories of failures are distinguished by focussing on the root causes of failure, see Figure 2 for an overview on the classification

FAILURE CATEGORY	ROOT CAUSE	REMARK
RANDOM FAILURE (RF)	• UNKNOWN RESIDUAL DEFECT / WEAKNESS - CONSISTENT WITH QUALITY LEVEL - UNDER NORMAL STRESSES (REFER TO DATA SHEET) - ONE-OFF EVENT	Relevant for • PART LEVEL (in particular EEE)
SYSTEMATIC FAILURE (SF)	• DESIGN ERROR • MANUFACTURING ERROR • OPERATIONS ERROR	Relevant for • PART LEVEL • UNIT / EQUIPMENT LEVEL • INTERFACES • SYSTEM (FUNCTIONAL)
WEAR-OUT (WO)	• NORMAL PHYSICAL PROCESS → TIME / EQUIVALENT TIME - OPERATIONS-RELATED (e.g. O/O, duty cycle) - ENVIRONMENT-RELATED (e.g. Radiations)	Considered as SYSTEMATIC FAILURE when failure occurs (loss of mission/ performances) before the design lifetime
EXTRINSIC (EX)	• VACUUM (Outgassing, cold-welding, heat transfer) • THERMAL (Solar radiation, Solar albedo, Earth OL Radiation) • MAGNETIC FIELD • MECHANICAL VIBRATIONS / SHOCKS (launcher, pyro activation) • ATOMS (EROSION (O) → considered as WO) • RADIATIONS (CUMULATED EFFECTS → considered as WO) • UV (degradation → considered as WO) • PLASMA (ESD) • SEE: DESTRUCTIVE / NON-DESTRUCTIVE • µMETEORITS • DEBRIS	Space environment phenomena inducing external failure causes Considered as SYSTEMATIC FAILURE when the extrinsic effects are underestimated before the design lifetime

Figure 2: Failures classification.

The analysis is further framed in regard to the objectives of reliability prediction that different space stakeholders - space agencies, insurers, customers, prime contractors, suppliers - may have. The objectives identified include both traditional ones, related e.g. to design support, reliability allocation or verification, and some new stakes, related to reduced budgets and increasing cost pressure, to satellite safe disposal in the light of new Space Debris Mitigation requirements, to the support of constellations of satellites, and to the anticipation of innovative technologies.

After a brief description of the general process for reliability predictions in space projects, a qualitative and quantitative gap analysis is carried out on the basis of three reference missions selected from the satellite portfolios of Airbus Defence and Space and Thales Alenia Space, including telecommunication (GEO), science (space probe) and Earth Observation (LEO) missions.

In the following, the main results of this gap analysis are presented, addressing different characteristics of reliability predictions in space applications in no particular order. Each of these “key characteristics” is given a score, ranging from “not considered” over “insufficient” and “partly” to “sound”. As the purpose of TN-1 is restricted to an assessment of the status quo, the ranking indicates to which extent a certain characteristic is considered in current reliability predictions. The importance and priority of each item and the way forward will be discussed in the following tasks of the study.

Characteristics: the quality metrics of the RPs.

- **Pertinence of RP:** *incomplete*
  Reliability prediction should be consistent with operational field data. Currently, there are many discrepancies between the predictions and in-orbit feedback. Depending on the perimeter of the prediction (spacecraft elements and/or failure root causes coverage), current predictions may be either pessimistic or optimistic.
- **Level of confidence:** *incomplete*
  The level of confidence is not quantified in current RPs.

Inputs data: the data used to populate the RP models.

- **Manufacturer input data:** *not considered*
  The use of data provided by the manufactures is limited to some very specific and limited cases.
- **Test data:** *incomplete*
  The use of data from on-ground tests for reliability prediction is currently limited to some mission critical parts (e.g. Charge Coupled Devices) for which no reliability data and/or model exists.
- **In-orbit return data:** *partial*
  In-orbit return is currently used for reliability prediction by prime contractors only at unit level and for some generic products.
- **Failure mechanisms:** *not considered*
  Reliability predictions are mostly based on statistical approaches.

Methodology: the approaches used to model the reliability.

- **Statistical approach:** *sound*
  The statistical processes and tools are available to support reliability prediction.
- **Physics of Failure (PoF):** *incomplete*
  The consideration of Physics of Failure is very limited for current reliability predictions.

Items & technology coverage: the elements and technologies supported by the reliability models.

- **Elements coverage:** *incomplete*
  Currently reliability predictions do not cover all satellite elements, focusing mainly on EEE.

- **Innovative technology coverage:** *not considered*
  Current reliability predictions do not anticipate (or even do not support for complex EEE parts) innovative technologies.

Levels: the level of occurrence of the failure in the system architecture.

- **Failure levels:** *incomplete*
  Only part-related failures are modelled in current RPs. The modelling of unit level contributions is insufficient, and failures at interface and satellite levels are not considered.

Failure root causes: the classification of the failures into four categories.

- **Random failures:** *sound*
  Only random failures are considered in the current RPs.
- **Systematic failures:** *not considered*
  Design, manufacturing and operation errors are excluded from the RPs.
- **Wear-out failures:** *not considered*
  Wear-out failures are considered in the safe life qualification process, but not in the RPs.
- **Extrinsic failures:** *not considered*
  Extrinsic failures (such as radiations or µmeteorits) are considered by the designers, but not in the frame of RP.

Stress contributors: the factors which define the stresses applied on the system.

- **Environment:** *partial*
  The current RPs do not account for all the stresses induced by the space environment.
- **Use conditions:** *partial*
  The major contributors to reliability are partially considered (e.g impacts of on/off cycling are not modelled).

Quality level: it defines the quality characteristics (e.g. test, inspection, review) of a part.

- **EEE parts quality level:** *incomplete*
  The quality level modelling does not fully reflect the EEE parts quality levels in the ECSS system. In particular, there is a lack of quality level modelling for COTS components.
- **Mechanical and Miscellaneous parts quality level:** *not considered*
  The quality level is generally addressed for EEE parts only.
- **Units, interfaces and system quality level:** *not considered*
  The quality level is generally addressed only at part level.

Mission: the mission definition which represents the perimeter of the RP.

- **Design lifetime:** *sound*

  The design lifetime specified in the technical specification is considered in the RPs.

- **Functions:** *sound*

  The major functions of the satellite are considered in the reliability models.

- **Performances:** *partial*

  The performances, quantifying the functions, are limited to the major satellite performances. Degraded system modes are assessed when required.

System model: the method(s) and process(es) supporting the system reliability model.

- **System reliability modelling:** *sound*

  The system reliability theory is soundly supported by different reliability techniques & tools.

- **System probability solving:** *partial*

  The probability calculations cannot be systematically solved through analytical solutions. Numerical solutions are used for some applications.