New Reliability Prediction Methodology Aimed at Space Applications

TN-06/07 Fact Sheet on

Proof of concept of the NRPM and Development of the NRPM for space applications (final)

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Executive Summary
Technical Notes 6 & 7

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Introduction and role of the two Technical Notes

The Technical Notes TN-6 and TN-7 provide the findings and major results of the Task 6 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 Notes TN-6 and TN-7 for the overall study is shown in Figure 1.

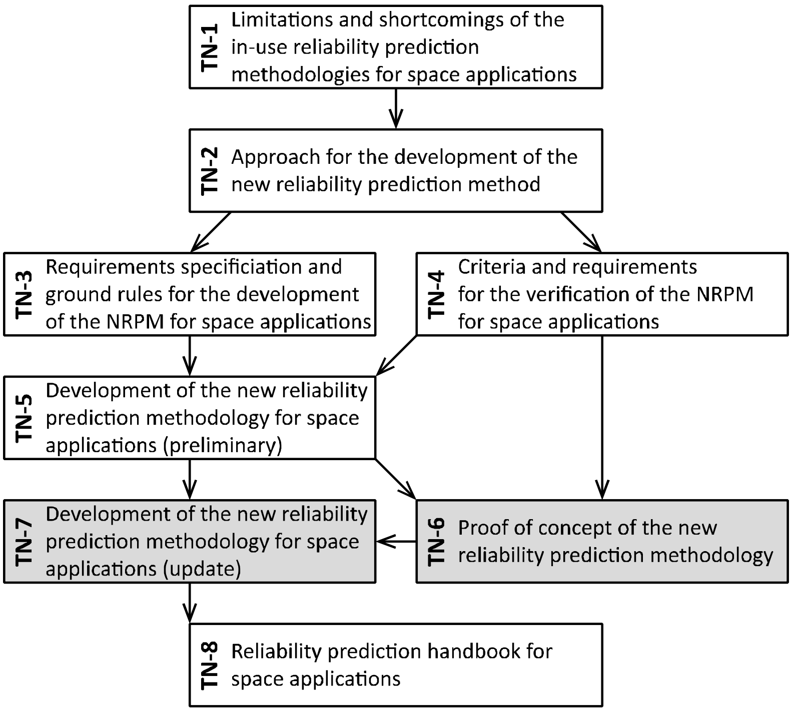

Figure 1: Overview on the content and interrelation of the Technical Notes.

The objective of TN-6 is the verification of the new reliability prediction methodology for an actual space project. This proof of concept takes basis in the preliminary methodology described in TN-5 and includes the identification of shortcomings and open areas as well as recommendations for possible improvements of the new methodology.

The objective of TN-7 is an update of the preliminary methodology described in TN-5, accounting for the recommendations and conclusions from the proof of concept presented in TN-6.

TN-6 Executive summary

The proof of concept presented in TN-6 includes a quantitative assessment and benchmarking of reliability prediction results as well as a qualitative assessment of the methodology based on the criteria defined in TN-4.

Proof of concept strategy

For the quantitative proof of concept, two real (or at least realistic) space missions – a GEO telecommunication satellite and a LEO Earth Observation mission – were selected, for which the following reliability estimates could be derived and compared:

- Predicted reliability derived with the new methodology
- Predicted reliability derived with existing methodologies
- Achieved reliability derived from In Orbit Return data

In this comparison, the in-orbit *achieved reliability* is certainly the most important benchmark for the new methodology, at least when sufficient IOR is available to derive reliable estimates. The achieved reliability was estimated using IOR data from the satellite fleets of the two involved satellite prime contractors, Airbus DS and Thales Alenia Space. To maximize the IOR availability for the benchmarking, the selected missions had to be old ones, avoiding new technologies for which IOR is not sufficient yet. At the same time, the missions had to be recent enough to allow automatic extraction of the required input data such as e.g. parts lists for the considered satellite equipment. Other criteria for mission selection were the coverage of different reliability prediction models, as well as the range of environments, use conditions, technologies and applications covered.

The benchmarking between predicted and achieved reliability was performed at equipment level. At this level, the in-orbit cumulated hours could be maximized by using data from a “reference fleet” of satellites using the same equipment under comparable conditions.

The following *existing methodologies* were considered, focussing on reliability prediction for EEE components:

- **MIL-HDBK-217-F+N1 or N2**
  Historically, this standard was the most commonly used reliability prediction methodology in space applications, thus predictions could be taken directly from the CDR reliability predictions of the selected missions. It should be noted that the CDR predictions were not necessarily based on the original MIL-HDBK-217-F, but on industry tailored versions to allow for technology extensions, and to improve the accuracy of the predictions compared to IOR.

- **FIDES Guide 2009 Ed A Rev 2010**
  The FIDES methodology was used as the basis for the development of the new reliability prediction methodology for EEE reliability prediction, making it irrelevant as a benchmark for the proof of concept. Predictions with the original FIDES Guide 2009 were made for platform units and could be used as a reference to address specific aspects of the space customization. In the following, these results are not addressed any further.
- **217Plus:2015 Notice 1**
  For one platform unit, another benchmark was made based on the 217Plus methodology, allowing a detailed evaluation also of this alternative prediction methodology.

The quantitative results of the benchmarking between methodologies and with IOR achieved reliability are summarized in the following.

In addition, a qualitative evaluation of the different methodologies from a user's perspective was performed, which will also be summarized below.

Quantitative benchmarking results

In the following, the main results of the quantitative proof of concept are summarized, focussing on reliability prediction for EEE units where comparison with alternative methodologies and IOR was possible. For Mechanical items, the information available from the documentation of the old missions considered was not sufficient to derive a meaningful benchmark. For Miscellaneous items, alternative methodologies are missing and the models proposed in the new methodology are based on the same IOR that could be used for benchmarking, making a stringent (quantitative) IOR verification impossible.

Figure 2 and Figure 3 show the main results of the quantitative benchmarking performed at unit level for the platform and the telecommunication payload of a satellite in GEO orbit. Only EEE units with sufficient IOR to perform the benchmarking are shown in these figures. The orange bars correspond to the predictions based on the preliminary version of the new reliability prediction methodology as described in TN-5, the blue bars show the predictions made for the CDR (mainly based on MIL-HDBK-217F) when the satellite was built.

The figures present relative numbers, derived as the predicted failure rate for each unit divided by the IOR failure rate estimate for the same unit. Red colour shows the IOR reference (dotted line at 1.0 in relative figures), and a band representing a factor of 2.0 around this IOR estimate (dashed lines), which was specified in TN-4 as a tentative target for the accuracy of the new methodology. For payload units (Figure 3), the IOR reference is defined as the point estimate for the failure rate, i.e. number of failures divided by the cumulated hours of units in orbit. For platform units (Figure 2), there were no failures observed and thus the Chi Square estimator at 60% Level of Confidence was used as IOR reference. To illustrate the uncertainty associated with the benchmarking, IOR estimators at 60% and 90% Level of Confidence are shown in black, using the same symbols and estimators in both figures.

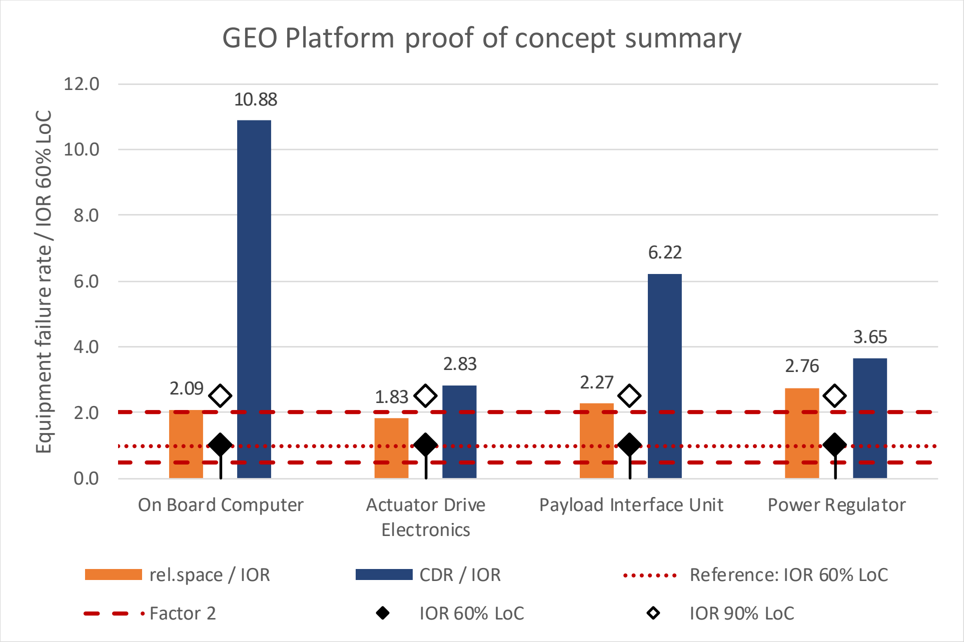

Figure 2: Summary of the proof of concept for platform units (GEO telecommunication satellite), predicted failure rates versus IOR Chi Square estimator at 60% Level of Confidence (no failures).

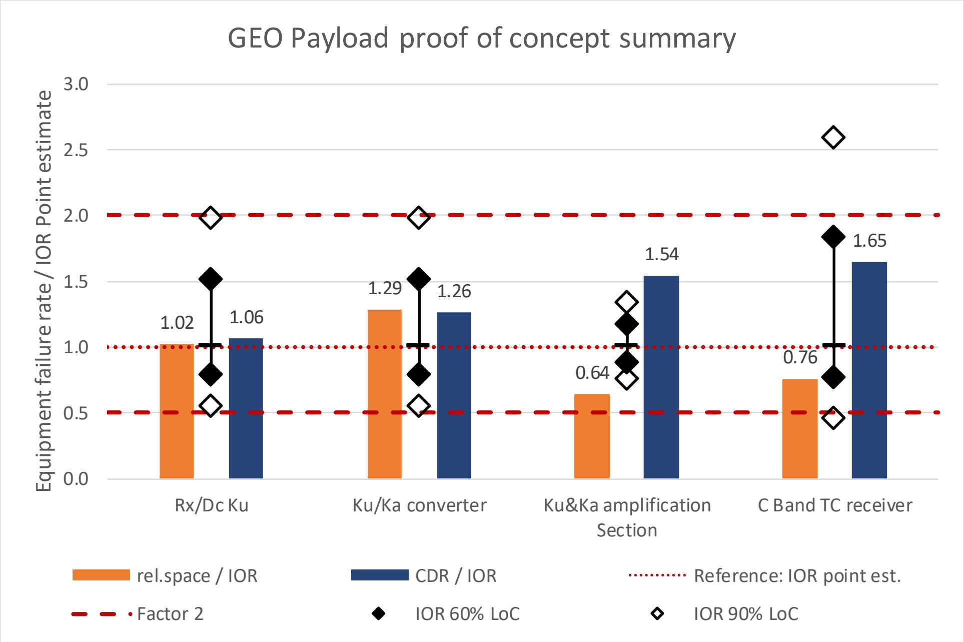

Figure 3: Summary of the proof of concept for payload units (GEO telecommunication satellite), predicted failure rates versus IOR point estimate.

The platform results in Figure 2 show a clear trend of original CDR predictions being pessimistic, and considerable improvements of accuracy when switching to the new methodology. For the On Board Computer, a prediction with 217Plus was made as well, being almost as pessimistic as the CDR prediction: the 217Plus predicted failure rate was a factor 9.16 higher than the IOR reference.

For payload units, the predictions from CDR were already closer to the IOR estimate, leading to smaller improvements when switching to the new methodology. However, the comparison with IOR clearly shows that the new methodology results are reaching the tentative target defined in TN-4.

The benchmarking results for the LEO Earth Observation platform are shown in Figure 4. The cumulated hours in orbit for these platform units (no failure observed) were considerably smaller than for GEO satellites, and thus not sufficient to conclude about the accuracy of the predictions: even though from the figure, it may seem that the predictions with the new methodology (and the CDR predictions as well) are rather optimistic, the ratio may be expected to improve with more observations – at least as long as no failure occurs. The comparison between the predictions with the new methodology and those made for CDR shows a similar trend as for platform units in GEO satellites, i.e. failure rates predicted with the new methodology are generally smaller than those derived from MIL-HDBK-217F.

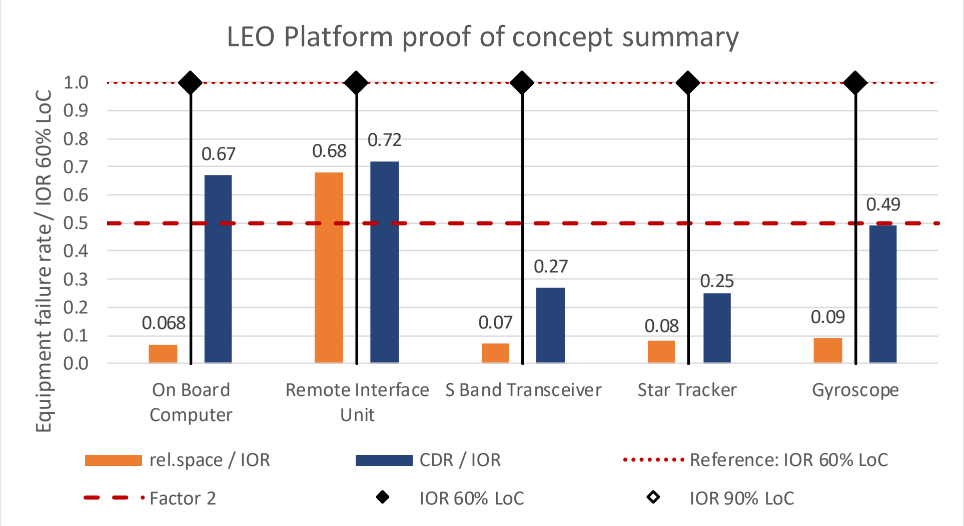

Figure 4: Summary of the proof of concept for platform units (LEO Earth Observation satellite), predicted failure rates versus IOR Chi Square estimator at 60% Level of Confidence (no failures).

For payload units, the in flight experience was not sufficient to assess the unit level failure rate (achieved reliability) in LEO missions.

Results of the qualitative evaluation

In addition to the quantitative benchmarking, a qualitative assessment of the different methodologies was made based on a set of criteria defined in TN-4, i.e. prior to the development of the new methodology. These verification criteria were derived from a discussion of different needs for reliability predictions in space applications. They are formulated as open questions addressing specific aspects of the methodology, which can be grouped under the headings “practicality”, “applicability” and “pertinence” (accuracy) of the prediction methodology. For each criterion, a set of evaluation requirements is specified, allowing to assess the strengths and weaknesses of the different methodologies.

The qualitative assessment results for the new reliability prediction methodology are summarized in Table 1, addressing the methodology as a whole (i.e. covering the methodology for EEE, Mechanical and Miscellaneous items). For comparison, the results for MIL-HDBK-217-F and 217Plus:2015 (both focussing on EEE) are also provided in the table, although it should be noted that the criteria statuses have been derived with a somewhat less rigorous approach than in the case of the new methodology.

Table 1: Qualitative assessment results for the different reliability prediction methodologies based on verification criteria defined before the development of the new methodology.

Groups of verification criteria	**Criteria statuses by methodology (“Yes” implies full compliance with a criterion)**					
	NRPM		**MIL-HDBK-217F**		**217Plus:2015**	
Practicality: 5 Criteria to assess the feasibility and practicality of the new reliability prediction methodology from a model user’s perspective	**Yes:**	3/5	**Yes:**	4/5	**Yes:**	3/5
	Partly:	2/5	**Partly:**	1/5	**Partly:**	0/5
	No:	0/5	**No:**	0/5	**No:**	2/5
Applicability: 7 Criteria for the area of application and coverage of the new methodology from a space domain perspective	**Yes:**	6/7	**Yes:**	2/7	**Yes:**	2/7
	Partly:	1/7	**Partly:**	1/7	**Partly:**	0/7
	No:	0/7	**No:**	4/7	**No:**	5/7
Pertinence: 8 Criteria for the relevance of the methodology regarding its scope and foundations, and for the comparison between prediction and reality	**Yes:**	5/8	**Yes:**	2/8	**Yes:**	2/8
	Partly:	3/8	**Partly:**	0/8	**Partly:**	0/8
	No:	0/8	**No:**	6/8	**No:**	6/8

The table generally shows satisfactory assessment results for the new reliability prediction methodology, as only few criteria are assessed to as “partly compliant”. The highlighted drawbacks were caused mainly by the following reasons:

- **Practicality:** for EEE reliability predictions, the methodology is not fully self-contained, referring to the FIDES 2009 guide for detailed models. The handbook is seeking a compromise between document size and completeness, which still implies some references to FIDES. Note that the FIDES guide is available for free, and all model equations are explicit both in the handbook and in FIDES.
- **Applicability:** Despite an improvement achieved compared to other methodologies, the new methodology does not cover all technologies used in space applications.
- **Pertinence:** All partial compliances in this group refer to the lack of (publicly available) information on the statistical background of the models, especially those for EEE components. Note that none of the existing methodologies offers a higher level of transparency with respect to the statistical background.

The comparison with the other methodologies shows that the new methodology has led to improvements on all axes. Only in terms of practicality, the simple models provided in MIL-HDBK-217F received a rating that is slightly better, yet at the price of many limitations in terms of applicability and pertinence of the models when used in space applications.

Identification of shortcomings and recommendations for improvements

Besides the methodology assessment discussed above, an important outcome of the proof of concept was also the identification of shortcomings and gaps in the new methodology, as well as the formulation of recommendations for an update of the new methodology. The TN-7 Executive summary discussed how these recommendations have been considered in the final methodology. Any remaining shortcoming of the new methodology will be reported in the final handbook (TN-8).

TN-7 Executive summary

In the following, it is briefly discussed how the recommendations from the proof of concept were considered in the methodology update in TN-7.

The updates made for the modelling of **EEE components** are briefly summarized in the following.

- **Clarifications and simplifications:** To ease the application of the handbook, several clarifications and justified simplifications have been made for various component level models and for different parameters and factors used by all models.
- **Model updates:** The models for the following components have been updated after observing unexpected results during the proof of concept
    - Ceramic capacitors: Classification of Type II ceramic capacitors adapted to account for a well-known weakness of this FIDES model
    - Surface Acoustic Wave filters: Changed categories to achieve coherency with current technologies used in space applications
    - Dual state relays: Use a common value for the base failure rate of mono- and bi-stable relays (bi-stable relays are not covered by FIDES 2009)
- **Missing models:** Some comments regarding missing component models (for Ferrite switches and Thyristors) in the preliminary methodology version could be solved by adding clarifications and/or proposing the use of models for similar technologies.
- **Simplified methods:** Experimentation with the parts count and family count methods proposed by FIDES showed inconsistent results that could not be fully explained during the proof of concept of the new methodology. Therefore, the final handbook does not recommend the use of these methods for space applications, proposing the use of the parts stress method with default values when quick preliminary assessments are required.

For **Miscellaneous items**, the comments from the proof of concept mainly addressed missing models. The following two updates were implemented for the final methodology:

- **Dormant failures**: A clarification has been added to explain that dormant failures must be modelled by the user considering the specific characteristics of the item under analysis and its conditions of use.
- **Amplification channel:** A model has been proposed to divide the overall failure rate for the channel (standard model based on IOR) into separate estimates for the Electronic Power Conditioner (EPC), Channel Amplifier (CAMP) and Travelling Wave Tube (TWT).

For **Mechanical reliability prediction**, due to the lack of quantitative modelling possibilities during the proof of concept, the recommendations have led only to some clarifications in the methodology description.