CTAO RAM calculation methodology Guideline

Prepared by .... Digitally signed by George Pruteanu Date: 2020.04.14 13:48:48 +02'00'

G. Pruteanu Date

Approved by .... Digitally signed by member: E037291C-F55D-4EEE-8A00-A26A4F77473F 2DF5B145-06FF-4A2A-8EE5-44DEE396200A DN: o=member: E037291C-F55D-4EEE-8A00-A26A4F77473F 2DF5B145-06FF-4A2A-8EE5-44DEE396200A, cn=member: E037291C-F55D-4EEE-8A00-A26A4F77473F 2DF5B145-06FF-4A2A-8EE5-44DEE396200A Date: 2020.04.23 16:41:47 +02'00'

N. Whyborn Date

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W. Wild Date

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Issue	Revision	Date	Section/Page affected	Reason/ Remarks / Initiation Documents
1	a	15.11.2019	all	New document
1	b	29.11.2019	All	Comments from Nick.

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Tables

1 Scope

This document defines the Reliability Maintenance and Availability CTA guidelines and methodology to follow to estimate the RAM parameters as well as Spare Parts management activities.

2 Applicable Documents

The following documents of the exact issue shown form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement.

ID	Document type	Document name
1	MIL-STD-756B	Reliability Modeling and Prediction
2	MIL 217 HDBK	Reliability Prediction Standard
3	CTA-TRE-SEI-312000-0001 1b	Maintenance Concept
4	MIL-STD-471A	Maintainability Verification/ Demonstration/ Evaluation
5	MIL-HDBK-472	Maintainability Predictions
6	QS Predict10	Reliasoft Lambda Predict guideline
7	System Analysis Reference	Reliasoft analysis guideline
8	Maintenance Table	Excel template summarizing maintenance activities and calculations.

3 Terms and Definitions

3.1 Availability Instrument (A_i)

The probability that the instrument can perform its intended functions during observation time. The Availability in this case (A_i), depends upon Mean Time Between Observing Affecting Failures *(MTBOAF)*, Mean Downtime *(MDT)* and can be expressed as:

$$A_i = MTBOAF_i / (MTBOAF_i + MDT)$$

3.2 Availability, System (A_{system})

The probability that a system can perform its intended functions during observation time. The Availability of the system (A_{system}) depends upon Mean Time Between Observing Affecting Failures *(MTBOAF),* Mean Downtime *(MDT)* and can be expressed as:

$$A_s = MTBOAF_{system} / (MTBOAF_{system} + MDT)$$

3.3 Corrective Maintenance (CM)

Corrective maintenance is defined as the set of actions carried out after fault recognition (i.e. interrupted service or breakdown) with the intention to put a product in a state in which it can perform the required function(s).

3.4 Corrective Maintenance Time (CMT)

The corrective maintenance time is defined as the summation of elapsed time intervals actively expended to fault isolate a functional failure, remove and replace/repair faulty items and perform functional checkout to verify restoration to operational status.

3.5 Degraded Mode

A system condition with a known and accepted percentage level of functionality in which the system continues to operate, following failure detection and reaction, or when ‘manual’ selected mode of operation function is opted.

3.6 Engineering Hours

The hours, usually established during the day light, used for maintenance (preventive, corrective and predictive maintenance activities) and any other activities suitable to service the system.

3.7 Fault detection

The process of determining that a problem has occurred.

3.8 Fault isolation

The process to ‘pinpoint’ the exact cause and location of the problem.

3.9 Failure

Failure is defined as the state of an item or equipment that prevents it to deliver one or more functions that affects the equipment/system ability to perform its intended operation, or, requires manual intervention for safe operation (any incident, malfunction, intermittent condition or failure that prevents the equipment from performing its intended function).

3.10 Failure Modes and Effects Analysis (FMEA)

A reliability evaluation and design review method/technique that examines the potential failure modes within a system or lower indenture level in order to determine and assess the effects of failure on equipment or system performance. Each hardware or software failure mode is classified according to its impact on system operating success and personnel safety. FMEA uses inductive logic (a process of finding explanations) on a 'bottom up' system analysis. Information developed in this procedure is integrated with reliability, logistics, operations, maintainability, and troubleshooting procedures.

3.11 Failure Reporting, Analysis, and Corrective Action System (FRACAS)

FRACAS is a management tool established to identify and correct deficiencies in equipment and thus prevent further occurrence of these deficiencies. The purpose of FRACAS is to collect failure mode data, provide procedures to determine potential failure cause(s), document corrective action taken and analyze eventual failure trends with feedback to suppliers or manufacturers to take necessary actions.

3.12 Failure Rate (FR or λ)

Failure Rate is the mathematical reciprocal of Mean Time Between Failures, hence, is a measure of reliability for repairable components/systems (see 3.22 MTBF definition)

$FR = 1/MTBF$ or $\lambda = 1/MTBF$

3.13 First Level Corrective Maintenance *(FLCM)*

First Level Corrective Maintenance *(FLCM)* is defined as the repair of equipment performed at the location of the failure (e.g. loose connectors, reset buttons etc.) or by the removal and replacement of the defective subassembly/module or LRU and subsequent functional verification and confirmation of successful repair/restoration

3.14 Second Level Corrective Maintenance *(SLCM)*

The SLCM repair will be performed at a CTAO local repair shop and consists of the action of basic diagnosis, removing/replacing of the defective units identified at the FLCM (LRU) or subcomponents (*LLRU*), followed by a subsequent functional verification of the replacement(s).

3.15 Third Level Corrective Maintenance *(TLCM)*

TLCM is defined as repair and restoration of the LRU/LLRU at the manufacturer or responsible intermediate supplier agreed by CTAO. Usually this level is used when the

LRU/LLRU repair would need specific test bench, specific adjustments, tools and procedures not available at SLCM.

3.16 Line Replaceable Unit (LRU)

A modular unit designed to be easily exchanged for a replacement part in a relatively short time by only opening and closing fasteners and connectors.

NOTE: CTA product design shall reduce, where possible, the variety of LRU's by using common components (i.e. one type of power supply, one type control system and motors for azimuth and elevation, one type of Photon Detector Plain one type of Readout System

3.17 Lowest Level Replaceable Unit (LLRU)

The smallest faulty unit the maintenance personnel can identify and isolate at first two levels of maintenance (FLCM, SLCM) within a given Mean Time to Repair (the smallest part of an item that can be replaced to provide an effective repair). Repairs of LLRU's will be undertaken in the specialized workshop.

3.18 Maintainability

Maintainability is a characteristic of design and installation. This characteristic is the measure of the ability of an item to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels and using prescribed procedures and resources at each prescribed level of repair

3.19 Maintenance

Maintenance is essentially the response to the maintainability program, i.e., the series of actions necessary for retaining materiel in, or restoring it to a serviceable condition.
Maintenance actions are of two types:
1. Corrective Maintenance. An action required when equipment fails or malfunctions.
2. Preventive Maintenance. An action required to maintain equipment in an operable condition through periodic servicing and/or replacement of components at specified intervals. Preventive maintenance can, and should, be conveniently scheduled to avoid interference with operating schedules.

3.20 Mean Corrective Time (Mct)

Mct is defined as the average direct time required by maintenance personnel, after their arrival at the site of the failure, to locate and isolate the faulty Line Replaceable Unit (LRU), make repairs, or replacement of the component and complete a functional check to verify that the equipment has been restored to operational status.

NOTE: The *Mct* is based on the availability of **all documentation, tools, test equipment, and spare parts at the site of the failure**. Logistic time required to obtain any of these items is excluded from the *Mct*.

Mct, the mean time required to complete a maintenance action, i.e., total corrective maintenance downtime divided by total corrective maintenance actions for a given period, given as:

$$M_{ct} = \frac{\sum \lambda_i M_{ct_i}}{\sum \lambda_i}$$

Where:

λi **=** failure rate for the i'th repairable element of the item for which maintainability is to be determined.

3.21 Mean Preventive Maintenance Time (MPMT)

MPMT is defined as the direct time required by maintenance personnel, perform recommended preventive maintenance tasks.

3.22 Mean Time Between Failures (MTBF)

The average time an item is expected to work before a failure occurs. MTBF is considered a reliability measure for the **repairable** components/systems.

NOTE: MTBF is calculated as the total operating hours during a specific interval of time divided by the total number of confirmed failures during same interval. Alternately, MTBF is also known as the reciprocal of the Failure Rate.

3.23 Mean Time to Failures (MTTF)

The average time an item is expected to work before the first failure occurs. MTTF is a measure of reliability for **non-repairable** components (they are always replaced with new components in case of failure or malfunction).

3.24 Repairable Unit

Repairable Unit at CTAO is defined as units designed to be repaired and restore the initial function(s) to a satisfactory level.

3.25 Non-repairable unit

Non-repairable components are the ones cannot be repaired due to either economic justification or design intent. The first failure of such components will trigger the replacement with a new one (i.e. some proximity sensors, limit switches, fuses)

3.26 Mean Time to Repair/Restore (MTTR)

The **average** time an item is expected to be repaired before goes back into the system. MTTR is a measure of repair for repairable components. Commonly, in CTAO, can be also used as nomenclature Mean Time to Restore particularly to array element level.
NOTE: In CTAO maintenance analysis important parameter is also the maximum time to repair for an item
The fundamental maintainability parameter is the **repair rate**, $\mu\,(t)$, which is the reciprocal of the **Mean Time to Repair/Restore** ($MTTR$) and expressed by the following formula: $MTTR = \frac{1}{\mu} = \frac{\sum_{i=1}^{n} Mct_i}{N}$

Where:

Mct_i = Mean time of individual unit corrective maintenance actions.
N = Total number of individual corrective maintenance actions.
μ = Repair Rate.

3.27 System Mean Time to Repair/Restore ($MTTR_{system}$)

($MTTR_{system}$) for a specific maintenance level is calculated as the weighted average of all the MTTR for each LRU in that system for that level of maintenance.

The following equation expresses mathematically this task:

$$MTTR_{system} = \frac{\sum_{i=1}^{n} (QTY_i * \lambda_i * MTTR_i)}{\sum_{i=1}^{n} (QTY_i * \lambda_i)}$$

Where:

QTY_i = number of units per system

λ_i = individual unit failure rate

$MTTR_i$ = Mean Time to Repair of the I'th components

3.28 Mean Time Between Observing Affecting Failures (MTBOAF)

A measure of the CTA **system reliability** knowing and accepting that the system can perform functions in 'degraded mode' [3.5].
MTBOAF is the average time between all failure causing interruptions of the observing time.

3.29 Observing Affecting Failure (OAF)

Any failure or multiple failures, triggering an interruption of the observing time.
NOTE 1: At the instrument level, certain functions are acceptable in a degraded mode (i.e. accepted percentage of degradation of mirror reflectivity or accepted percentage of malfunctional camera sensors)
NOTE 2: At the area level, observation function can be acceptable if the quality of collected data is still be above the accepted level (i.e. the situation when one or more array elements or instruments can be unavailable, for different reasons, but).

3.30 Single Point Failure (SPF)

A failure of a single item which can result in the failure of the system.

3.31 System

The word system is used at multiple levels in the CTAO hierarchy to refer to an element implemented in hardware or software or both that performs a function or functions identified in the design of CTAO. CTAO is therefore a System of Systems.

3.32 Turn Around Time (TAT)

TAT is the time between a defective LRU will be sent to manufacturer/supplier for repair/replace and the time the unit will come back fully functional to the spare parts pool. Also, TAT can imply sometime the 'lead manufacturing time' (time between a purchase order is released and the part reaches the CTAO inventory) or 'procurement time'.

4 Reliability Prediction methodology

Knowing the product reliability and the estimation/prediction of Failure Rate/MTBF of each LRU is critical for any other further activities in respect to RAM analyses. Estimated FR shows really the frequency of potential failures of each individual unit. Moreover, FR is used to estimate essential corrective maintenance parameters (i.e. Maintenance Man-Hour per Operating Hour - MMH/OH), to define the Safety Integrity Level (SIL) of safety hardware and have an essential role in the availability calculation or simulation.

4.1 Reliasoft software

CTAO project office decided some time ago to use a single platform to do reliability maintainability and availability analyses and simulations, with the same general assumptions, so the roll-up to system level will be easy to be made.
Following an analysis of several software it was decided that the Reliasoft is a common platform software offering a series of RAM analysis and management tools (structured in connected modules) with granted access to all in kind contributors (IKC). The software provides a powerful range of solutions to facilitate a comprehensive set of reliability engineering modeling and analysis techniques.

4.2 The CTAO Failure Rate prediction guideline

The Reliasoft Lambda Predict module helps estimating/predicting LRU's Mean Time Between Failures (MTBF) or Failure rate (FR). The following are some CTA prediction guidelines:

- As a first prediction priority CTA recommends obtaining LRU failure rates directly from the manufacturer/supplier. The provided FR or any other parameters that can be converted into reliability measures, must be sustained by acceptable methods of calculations or reasonable explanation to support confidence that the numbers are closed as possible to reality.
- Second option to estimate FR, is using Reliasoft software free access to the 'PartLibraries.org' website portal, which allows users to search and import parts failure rate and other useful information. Potential similar parts can be found under MIL-M-38510, EPRD-97 or NPRD-95 (free to all users) as well as more than 300,000 specific commercial electronic components.
- The third option to estimate failure rate is to use Reliasoft 'Lambda Predict' module with embedded reliability prediction standards, commonly used in most industries like

MIL-HDBK-217F (MIL-217), Bellcore/Telcordia, FIDES, Siemens SN 29500 (for electric electronic components) and NSWC for mechanic/hydraulic/pneumatic components.

It is up to the IKC's to use any above standard for prediction, or even a combination of them, but few ground rules are to be followed to balance the base failure rate offered by each standard:

- Use "Ground, benign" as Environment Factor for components in enclosed spaces (i.e. camera body, assuming the camera is isolated from external conditions and offers a controlled temperature/humidity environment)
- Use "Ground, fixed" for components designed for outdoor use, directly affected by the environmental conditions.
- Use 30°C as reference temperature inside the camera or other enclosed spaces with some level of controlled temperature, when more specific values are not available.
- For Mil 217HDBK standard use the Quality Factor "M" by default (corresponding to a multiplicative factor 'x 0.1' of the base failure rate).
- When necessary, use the failures rates from the parts manufacturers when they are referred to 55°C and 60% confidence level (CL).
- FIDES prediction module for electronic components, 'PI process' parameter by default is '4'. To align to other standards 'base failure rate', this parameter must be modified to '1'.

Project Office, Head of RAM continuously offers support for other situations where the failure rate is difficult to estimate.
Training to use the Reliasoft were provided by PO ([6] and [7]), and the following links give the guidelines on how to use all modules:

http://reliawiki.org/index.php/Main_Page
http://reliawiki.org/index.php/System_Analysis_Reference

5 CTAO Maintenance Concept

5.1 General

During night-time, no repair on instruments is allowed which makes the 'downtime' under no direct control to be reduced following any failure during observing/night-time.
Maintenance characteristics are largely determined through the module/board design and the hardware platform design.
CTAO Maintenance analysis is performed by completing the following steps:
• Identify a list of corrective maintenance activities required to support the system and characterize them as first, second, third line corrective maintenance events (FLCM, SLCM or TLCM).
• Identify the detailed tasks required in order to complete each of the following sub-activities:

- Fault diagnostic,
- Access to faulty item: time to gain access to the potential failed unit and then

restore to operational state (this may include, for example, the time to align the cherry picker and afterwards park it, time for the removal of access covers and their replacements, etc),

- Removal and replacement of faulty item,
- Restart / Calibration / Configure and
- Confirmation of successful repair.

• Evaluated the time to complete each detailed task either through direct measurement or published standardized task times as per Table D-IV, Elemental Maintenance Actions, Appendix D of MILHDBK-470A.
• Perform an average time calculation to restore for each maintenance level. The average is to be weighted by failure rate of failure modes initiating the maintenance activity.
• Identify a list of preventive maintenance activities required to reduce the probability of failure or the performance degradation of the equipment, such as:

- Inspection, e.g., to determine the state of the system or component,
- Servicing (e.g., cleaning and adjustments, filters replacements, oil contamination measurements and change etc),
- Removal and replacement of limited life items,
- Removal and replacement of components subject to restoration to "as new" condition,
- Overhaul and
- Periodic testing of equipment.

5.2 Corrective Maintenance (CM)

The CTAO approach to equipment corrective maintenance is based on the principle that fault isolation time must be minimized at the first level of maintenance to minimize the time to repair/restore system functionality. Minimization is achieved by limiting fault isolation to those modules that lend themselves to **fast and easy replacement** (using fasteners and connectors only)

Corrective Maintenance in CTAO is to be done at three different levels:

- **First Level Corrective Maintenance** *(FLCM)*

To be effective at FLCM, the maintenance personnel should access any or all the following fault indications while troubleshooting:

- Test points accessible while the assembly or LRU is mounted in the fixed location,
- Built-in test and external indicators,
- Built-in software diagnostic and indicators,
- Health monitoring fault indications,
- External, visual observation and

- Mechanical and/or optical measurement made without undue physical or electrical disassembly.

- **Second Level Corrective Maintenance** *(SLCM)*

CTAO will have two small repair shops where basic repair activities will be performed for removed LRUs confirmed as failures.

Isolation and identification of the defective assemblies or parts at Second Line Corrective Maintenance are possible by using any or all the following fault indications in addition to, and with the standard second level maintenance test and diagnostic equipment when and where applicable:

  - Test points accessible through suitable test connectors or adapters, while the defective LRU is powered on or mounted in a test bench,
  - Operational connectors (connectors helping to simulate the mounting unit at the telescope),
  - Built-in fault and test hardware indicators,
  - Built-in diagnostic software and indicators (alarms, flags),
  - External, visual observation and
  - Mechanical or optical measurements made without undue physical or electrical disassembly.

- **Third Level Corrective Maintenance** *(TLCM)*

TLCM consists of activities requiring specialized skills, tools and test equipment of the manufacturer/supplier or an approved repair and overhaul agency. All third level corrective maintenance activities are recommended to be undertaken by the supplier or original manufacturer or their authorized agent.

The identification of maintenance activities for individual LRU/LLRU shall be summarized in the following suggested tables which contains the analysis of the timing needed to perform such activities (Table 1 and Table 2). The Legends of those two tables are in the excel spreadsheet “Maintenance Tables” [8]

ID #	LRU PART NAME	Part Number	Failure Mode Indiation	Qty/ Telescope	FR (per million hours) / Unit	CORRECTIVE MAINTENANCE TIME (CMT)					Total CMT HRS.	Persons Required for the task	Mct/hour/task	Person/Hour/Week	Tools/Special tools required	MTTR	MMH PER 10^6 OH (MI)	MAINTENANCE LEVEL (FLCM,SLCM,TLCM)
						Fault Isolation HRS.	ACCESS HRS.	Remove & Replace HRS.	Align, Calibration/Configure /Adjustments HRS.	Test and final repair validation HRS								
													0	0			0	
													0	0			0	
													0	0			0	
													0	0			0	
													0	0			0	

Table 1: Corrective Maintenance Table

5.3 Preventive Maintenance (PM)

Preventive Maintenance it is a sum of all activities recommended by manufacturer/suppliers to maintain each LRU, combined with previous experience and aligned with economics and safety principles.

PM is encompassing the following type of scheduled activities, summarized in the Table 2:

- Inspection, e.g., to detect the state of the system or component,
- Servicing, e.g., cleaning and adjustments,
- Removal and replacement of limited life items and
- Removal and replacement of components subject to restoration to "as new" condition by overhaul.

ID #	Component/Unit description	PM ACTION	Component/Unit Part Number	Qty/Instrument	Required Person/Hour/ Task	Elapsed time (HRS)	TASK INTERVAL (measured in weeks)	Task per Year	REPAIRABLE (Yes/No)	SPECIAL TOOL/TEST EQUIPMENT REQUIRED	MAINTENANCE LEVEL (FLCM,SLCM)	Person/Hour/ Week	Person-Hour/year
								0				0	0
								0				0	0
								0				0	0
								0				0	0
								0				0	0

Table 2: Preventive Maintenance Table

5.4 Predictive Maintenance (PdM) / Condition Based Monitoring (CBM):

Predictive Maintenance known also as Condition Based Monitoring (CBM) is a strategy that tries to ensure that a piece of equipment requiring maintenance is only shut down right before an imminent failure.
CBM takes the approach that maintenance should only be performed when certain indicators show signs of decreasing performance or an upcoming failure.
CBM triggers maintenance activities only after a degradation (to still acceptable level) in the condition of the equipment has been observed. This allows the interval between preventive maintenance or maintenance repairs to be increased because the activities will be performed on an 'as-needed' basis, **reducing** if not, **eliminating,** the corrective actions due to failures and considerably reducing the overall operational cost.

6 Maintenance Summary

A summary of the preventive, corrective maintenance following the next recommended tables, will help rolling up to system level maintenance needs.
The PM Summary (Table 3) should summarize the total Person/Hour/Week needed to higher level of assembly needed to roll-up to system level and to help determine if different skill level needed (i.e. for 'structure' may need also mechanical skilled personnel besides the electrical ones)

EQUIPMENT DESCRIPTION	Person/Hour/Week
XST Telescopes Structure	
XST Telescopes Camera	
All other supporting elements	
SYSTEM TOTAL	0

Table 3: PM Summary (suggested table)

The CM Summary (Table 4) should summarize the total Person/Hour/Week needed to higher level of assembly needed to roll-up to system level.

EQUIPMENT DESCRIPTION	MTTR	Person/hour/week
XST Telescope Structure		
XST Telescope Camera		
All other supporting elements		
	SYSTEM TOTAL	0

Table 4: CM Summary (suggested table)

Table 5 should summarize the necessary Person/Hour/Week for first and second level corrective maintenance activities and preventive maintenance to each area element level:

EQUIPMENT DESCRIPTION	Maintenance Level	Person/Hour/Week
XST Telescopes Structure (Including Drives and Optics)	FLCM	
	SLCM	
	Preventive	
XST Telescopes Camera	FLCM	
	SLCM	
	Preventive	
All other supporting auxiliary elements	FLCM	
	SLCM	
	Preventive	
Instrument type	FLCM	
	SLCM	
	Preventive	
	SYSTEM TOTAL	0

Table 5: Person/Hour/Week summary

NOTE: the 'instrument type' in the Table 5, refers to common elements used at the observatory area.

7 Spare Parts List Template

7.1 Spares Allocation

Provides an overview of how spares are determined, the allocation of first and second level corrective maintenance spares, how repairable components, non-repairable and consumable components are treated, and sample spare calculations.

CTAO PN	Manufacturer PN	QTY /Instrument	FAILURE RATE (failures per 10^6	CLASS (Repairable/Non-	Recommended Number of Speres	Additional Comments

Table 6: Recommended Spare Parts List (suggested table)

7.2 Spare Parts estimation for repairable components

CTAO general formula to estimate the number of spare parts **for repairable units [3.25]** is:

$$P(X \le x) = \sum_{x=0}^{n} \frac{(n * \lambda_i * t_i)^x * \exp(-n * \lambda_i * t_i)}{x!}$$

Where:

P (X ≤ x): The probability that a spare part is available when needed from the store with the required level of confidence.

n: The total population or **quantity** of the item installed in the system analysed.

λ_i: **Failure rate** of component i'th (in this formula is **failures per hour**).

t_i: The **total exposure time** (hours) accumulated by component i'th during the **turnaround interval/time (TAT)** which is the product of the TAT (days) and daily utilization (hours).

X = The **number of spares required**.

x = The dependent event of having '0, 1, 2 ... n' spares on the shelf (spare parts pool)

The probability of the number of spares required for the system to be less than the number of existing spares on the pool is the sum of individual failures (total of n components), given by the Poisson distribution with a mean of $\lambda_i * t_i$.

The assumption for the above formula is that all components have a constant failure rate.

7.1 Spares estimation non-repairable components

CTAO general formula to estimate the number of spare parts for **non-repairable units [3.25]** is:

$$N = n*\lambda*Y*24*365$$

Where:

N = The quantity of spares to be supplied for an item

n = The number of items installed per telescope

λ = The failure rate of the item (estimated **failures per hour**)

Y = The number of years of support or coverage.

CTAO will accept also the Spare Parts suggested numbers based on Monte Carlo simulation when Reliasoft Block Sim module is used.

8 Bill of Material (BOM)

CTAO needs the list of installed items in the telescopes and instruments. Additional procurement information for the all installed components as per the following suggested table:

CTAO PN	PART DESCRIPTION	Manufacturer PN	PRICE (EURO)	PRICE VALIDITY PERIOD (yrs)	MANUFACTURER		DRAWING REFERENCES	MAINTENANCE MANUALS
					PRIME	ALTERNATE		

Table 7: BOM with added logistic information

9 Special Tools and Test Equipment

It is useful to have an inventory of minimum needed tools (generally commercial tools) to do basic repairs (summarized in Table 8). CTAO design shall minimize the need to use special tools or test equipment (Table 9) while apply corrective maintenance action (particularly remove and replace components).
The following recommended tables are to collect the basic info:

FLCM / SLCM COTS Tools & Test Equipment Needed					
ID #	Maintenance Equipment	Technical Description	Model/Part Number	Recommended Qty	FLCM/SLCM
xST_COTS_1					
xST_COTS_2					
xST_COTS_3					
xST_COTS_4					
xST_COTS_5					

Table 8: First and Second level 'cost off the shelf' tools and equipment.

FLCM / SLCM Special Tools & Test Equipment Needed					
ID #	Maintenance Equipment	Technical Description	Model/Part Number	Recommended Qty	FLCM/SLCM
xST_ST_1					
xST_ST_2					
xST_ST_3					
xST_ST_4					
xST_ST_5					

Table 9: Special Tool and test equipment needed for the telescope/instrument

10 Availability Analysis through simulation

Reliasoft BlockSim module offers the possibility to model the instrument using diagrams and fault trees and then generate Failure Reporting, Evaluating and Display (FRED) Reports (see:

http://reliawiki.org/index.php/Repairable_Systems_Analysis_Through_Simulation). Those reports provide a graphical demonstration of the reliability and maintainability/availability characteristics of the components in a system and help to identify the components that may require improvement.

Availability estimation approved by CTAO is the Monte Carlo simulation. The Reliability Block Diagram correctly modeled in Reliasoft BlockSim module and minimum maintenance information applicable to each RBD bloc, are the requirements to simulate the availability of the system (also of individual units (LRU). The software will randomly ‘induce’ failures to random blocks according to the predicted failure rate and counting the maintenance actions will estimate via several simulations the availability of the system.
CTAO recommends a minimum number of Reliasoft Monte Carlo simulations to be 1000, but for the upper confidence level, this number can be increased (the higher the number of simulations, the higher confidence, simulation time raises accordingly).

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