6. ECS Availability Math Models

6.1 Availability Math Models

The following sections present the math models that support the availability calculations for all required ECS RMA functions.

6.1.1 Operational Availability (A_0).

The operational availability is defined as follows:

$$Ao = \frac{MTBM}{MTBM + MDT}$$

where: MTBM is the Mean Time Between Maintenance in hours and

MDT is the Mean Down Time in hours

For systems with backup redundant capability, the operational availability is defined as follows:

$$Ao = \frac{MTBM}{MTBM + ST}$$

where: ST is the Switchover time to a backup component in hours

6.1.2 Mean Time Between Maintenance (MTBM)

The MTBM consists of two components: the Mean Time Between Preventive Maintenance (MTBPM) and the Mean Time Between Corrective Maintenance (MTBCM). These two components of the ECS equipment each will contribute to the calculation of the MTBM and follow the relationship:

$$\frac{1}{MTBM} = \frac{1}{MTBPM} + \frac{1}{MTBCM}$$

Normally when equipment is required to have a scheduled maintenance, the COTS vendor will provide to the ECS contractor the time interval for this task. This time interval is the MTBPM.

For example, the D3 Tape Drive has a head life of 2,491 hours (MTBPM) and a MTBCM of 35,000 hours. Its MTBM is calculated to be 2,325 hours which is the value used in the availability modeling.

The MTBCM is the same as Mean Time Between Failures (MTBF) which is the inherent reliability of the equipment. MTBF can be obtained from the COTS vendors, reliability predictions or Non-Electronic Parts Reliability Data (NPRD) handbook.

6.1.3 Mean Down Time (MDT)

The MDT includes the Mean Time To Repair (MTTR) plus any Administrative Logistics Delay Times (ALDT):

$$MDT = MTTR + ALDT$$

6.1.3.1 Mean Time To Repair (MTTR)

The MTTR is defined by the following equation: $$MTTR = \frac{\sum_{i=1}^{i=n} \lambda i Mcti}{\sum_{i=1}^{i=n} \lambda i}$$

where: - λ i is the failure rate of the ith component in Failures Per Million Hours (FPMH) or $\frac{1}{MTBFi} \times 10^6$.

-*Mcti* is the Mean Corrective Time of the ith component which is the sum of maintenance task times such as: localization, isolation, disassembly, interchange, reassembly, alignment, and checkout times. These times can be obtained from COTS vendors or Maintainability predictions report, document 518-CD-002-002

6.1.3.2 Administrative Logistics Delay Time To Repair (ALDT)

The ALDT is defined as the delay time which prevents the system from returning to an available state, including travel time, administrative delays, and logistics delays. ALDT is equipment and site specific and is defined by the ECS COTS Maintenance Plan, document 613-CD-002-001. For calculation purposes the ALDT is assumed to be six (6) hours for all ECS hardware configuration items (HWCIs). This time includes system fault diagnostic time and is assumed to be a conservative estimate.

6.1.4 Switchover Time (ST)

The switchover time (ST) is the time required by the system to restore its functions by switching from the downed equipment to the backup equipment. The backup equipment can be redundant active on-line (hot backup) or inactive off-line (warm standby). Switchover times are best engineering estimates and were based on ECS fault management and recovery capabilities or COTS equipment fault diagnostics capabilities. The relationship of ST and MDT is as follows:

$$MDT = \frac{\sum_{i=1}^{i=r} \lambda_{ri} ST + \sum_{i=1}^{i=s} \lambda_{si} MDT_i}{\sum_{i=1}^{i=n} \lambda_i}$$

where λ_i, λ_{ri}, λ_{si} are the failure rates of the i^{th}, redundant and serial components respectively.

6.2 Systems Availability Math Models

The following sections present the mathematical models at the system or functional level.

6.2.1 Serial Systems

For systems with n components in series, the following equations are applied:

$$\text{System Availabilty } (A_s) = \prod_{i=1}^{n} A_i$$

$$\text{System MTBM: } \quad MTBM_s = \frac{1}{\sum_{i=1}^{n} \frac{1}{MTBM_i}}$$

$$\text{System MDT: } \quad MDT_s = \frac{\sum_{i=1}^{n} MDT_i \times \lambda_i}{\sum_{i=1}^{n} \lambda_i}$$

where: A_i, $MTBM_i$, and MDT_i are the availability, MTBM and MDT of the ith component respectively.

6.2.2 Redundant System MTBF with Repair Model (Warm Standby)

For redundant systems with inactive off-line equipment (or warm standby) which allow repair, the following equations are applied.

6.2.2.1 Redundant Systems with n out of n+1 components required

The redundant $MTBF_R = \dfrac{\mu + n(P+1)\lambda}{n[n\lambda + (1-P)\mu\lambda]}$

where: -μ is the repair rate: $\mu = \dfrac{1}{MDT + SwitchOverTime}$

-P is the probability switching mechanism that will operate properly when needed and it is equal to 1.0 (perfect switching by maintenance personnel)

The above equation is for redundant systems with *n* out of *n*+1 components required, where *n* is the number of components or equipment required for mission success and *n*+1 is the total number of available components.

6.2.2.2 Redundant Systems with Configuration other than n out of n+1 Components Required

The equations in the following table are applied to systems where the total number of components minus the number of required components are greater than one. (Reference: Rome Air Development Center (RADC) Reliability Engineer's Toolkit).

Total Number of Components	1	2	3	4	5
3	$(3\lambda^2 + 3\lambda\mu + 2\mu^2)/\lambda^3$				
4	$(4\lambda^3 + 6\lambda^2\mu + 8\lambda\mu^2 + 5\mu^3)/\lambda^4$	$(6\lambda^2 + 3\lambda\mu + \mu^2)/4\lambda^3$			
5	$(5\lambda^4 + 10\lambda^3\mu + 20\lambda^2\mu^2 + 30\lambda\mu^3 + 24\mu^4)/\lambda^5$	$(16\lambda^3 + 12\lambda^2\mu + 8\lambda\mu^2 + 3\mu^3)/8\lambda^4$	$(27\lambda^2 + 9\lambda\mu + 2\mu^2)/27\lambda^3$		
6	$(6\lambda^5\mu + 15\lambda^4\mu + 40\lambda^3\mu^2 + 90\lambda^2\mu^3 + 144\lambda\mu^4 + 120\mu^5)/\lambda^6$	$(20\lambda^4 + 20\lambda^3\mu + 20\lambda^2\mu^2 + 15\lambda\mu^3 + 6\mu^4)/8\lambda^5$	$(36\lambda^3 + 18\lambda^2\mu + 2\mu^3)/27\lambda^4$	$(24\lambda^2 + 6\lambda\mu + \mu^2)/32\lambda^3$	
7	$(7\lambda^6 + 21\lambda^5\mu + 70\lambda^4\mu^2 + 210\lambda^3\mu^3 + 504\lambda^2\mu^4 + 840\lambda\mu^5 + 720\mu^6)/\lambda^7$	$(24\lambda^5\mu + 30\lambda^4\mu + 40\lambda^3\mu^2 + 45\lambda^2\mu^3 + 72\lambda\mu^4 + 15\mu^5)/8\lambda^6$	$(135\lambda^4 + 90\lambda^3\mu + 60\lambda^2\mu^2 + 30\lambda\mu^3 + 8\mu^4)/81\lambda^5$	$(128\lambda^3 + 48\lambda^2\mu + 16\lambda\mu^2 + 3\mu^3)/128\lambda^4$	$(75\lambda^2 + 15\lambda\mu + 2\mu^2)/125\lambda^3$

Number of Required Components

Note: 1- λ is the component's failure rate in failures per million hours.

2- μ is the component's repair rate (1/MTTR)

The equations in paragraphs 6.2.2.1 and 6.2.2.2 can only be used with the following assumptions:

- All standby equipment failure rates are equal
- Once the on-line equipment fails, the standby equipment will be switched on-line
- The downed or failed equipment will in turn be replaced with a spare unit or will be repaired within its repair rate
- All units are functional at the start
- Maintenance personnel are always available at the site
- One equipment can only be repaired at a time

6.2.3 Duty Cycle Calculation

In some cases at the DAAC sites, certain equipment such as peripheral devices (i.e archive robot arm, 6250 tape drive, 8mm tape stacker, etc.) are not constantly operated. Their inherent failure rate is therefore "duty cycled" by their utilization estimates. The following equation is applied to arrive at the equipment's MTBF given a specific duty cycle.

$$\text{Effective Failure Rate (F / R)} = \left[\text{Inherent F / R} \times \text{Duty Cycle}\right] + \left[\text{Inherent F / R} \times (1 - \text{d.c.}) \times 10\%\right]$$

10% is the rule of thumb estimate for stand-by failure rate by Rome Air Development Center (RADC).

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