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Reliability, Availability, and Maintainability Forecasting for Newly Developed Satellite Communication Systems

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ABSTRACT: *Developing complex Satellite Communication (SATCOM) systems require ideal Reliability, Availability, and Maintainability (RAM) parameters. Forecasting RAM parameters of a system within the planning stages can include a high level of uncertainty and risk. Preparing a strategy to meet requirements for a newly developed SATCOM system is essential for producing an operational available system. Utilizing the QuART PRO software tool assists developers to provide a cost effective product by recommending specific tasks during the product lifecycle. Obtaining Operational Availability (A_o) requirements and details from stakeholders would indicate the maximum allowable downtime for the system. Using the QuART PRO software tool along with known RAM / A_o requirements would increase the success of producing a new SATCOM system.*
KEYWORDS*– RAM, Reliability,Availability, Maintainability, RAM,Operational Availability, Ao, SATCOM Systems*

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I. INTRODUCTION

Obtaining RAM / A_orequirements for a new SATCOM system would assist with design planning. Stakeholder(s) that provide these requirements may base their needs on improvements to a currently fielded system, mission requirements, or a necessity for a new capability. If a new system were based on an older fielded system, historical data would be used for analysis. Stakeholder(s) may base their A_o requirements on an end of life system stating that the new system would have to maintain certain A_o to meet mission objectives. Acquiring stakeholder expectations early in the system's life cycle is ideal for creating a baseline to design to. Not all A_o requirements are prevalent at the beginning of the system's life cycle; however, known values may reveal information associated with overall operational criteria.

Reliability is the probability of an item to perform a required function under stated conditions for a specified period of time. Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time. Maintainability is the ability of an item to be retained in or restored to a specified condition[1].

RAM criteria of a system is critical for overall A_o of SATCOM systems. A_o of a system is essential for continuous operations without interruption. Forecasting A_o of a system sets a baseline target for developers to design to. RAM factors assist with A_o metrics for analysis purposes. A combined value of RAM measures would define the overall A_o of a system or a group of systems. Using QuART Pro software along with known A_o requirements assists with forecasting and planning for new SATCOM system development.

II. QUART PRO

The QuART Pro software tool identifies various areas within the system lifecycle where increased emphasis and attention needs to be administered. By selecting the characteristics of the system, the criteriaisupdated to depict the activities that are recommended to be performed during particular areas of the system's lifecycle. These activities are also highlighted to indicate the criticality of that activity. Parallel efforts would be performed during each stage of the system's life cycle to promote concurrent development of a new SATCOM system. Scheduling these activities with allocating appropriate resources would be done in the planning stages. Selecting reliability tailoring criteria within the tool produced an output of tasks listed in order of effectiveness with respect to the recommended timing to which these tasks are to be performed. The output of the QuART Pro tool is shown in Figure 1.

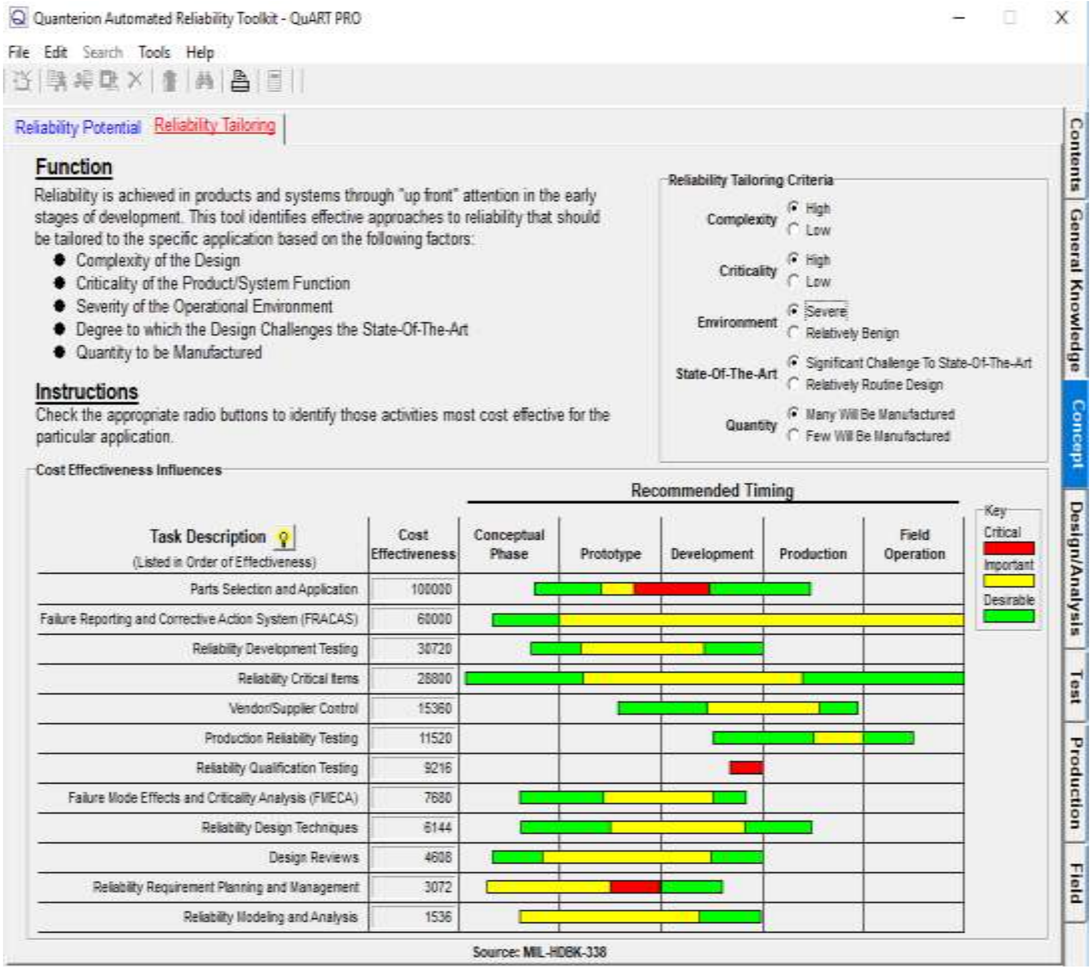

Figure 1QuART Pro Reliability Tailoring Results

The reliability tailoring criteria consists of complexity, criticality, environment, state of the art, and quantity. Each area is given a value to obtain the recommended timing to perform particular tasks. These tasks provide overall cost effectiveness to the development of the new SATCOM system and are prioritized in order. The complexity, criticality, and environment of this system were labeled high / severe due to the system being new technology in a mission critical environment. This state of the art system would be a significant challenge to produce and was denoted within the QuART Pro software. The military would adopt and utilize the system in which the system would be manufactured in large amounts.

Selected Reliability Tailoring Criteria were chosen and the QuART Pro software automatically prioritized tasks based on the order of effectiveness. These tasks included Parts Selection and Application, Failure, Reporting and Corrective Action System (FRACAS), Reliability Development Testing, Reliability Critical Items, Vendor / Supplier Control, Production Reliability Testing, Reliability Qualification Testing, Failure Mode Effects and Criticality Analysis (FMECA), Reliability Design Techniques, Design Reviews, Reliability Requirement Planning and Management and Reliability Modeling and Analysis. These tasks are listed in the order of effectiveness which provides an approach that would contribute to overall reliability of the system.

The Parts Selection and Application task assists with long term reliability factors including life cycle costs. Analyzing and researching parts used within the system take the most precedence out of all the tasks. Obtaining parts that meet requirements of withstanding a severe environment would lower the likelihood of failure when the system is fielded. Risk management would be practiced to assess concerns with part obsolescence and new technologies. Proper attention to parts/materials control can minimize the proliferation of different items within a company, or even on the same program by different engineers, thereby reducing the cost of inventory and limiting the number of specification control drawings to support a product/system [2]. This task would desirably begin in the conceptual phase, become important and critical during the prototype / development phase, and desirably continue through the later parts of the development phase into production.

Failure Reporting Analysis and Corrective Action System (FRACAS) is used to perform root cause analysis, track issues, and provide solutions for failed parts within a closed loop. The "closed loop" in a FRACAS refers to the systematic manner in which every issue that is reported is addressed, ensuring that no failure or incident is missed [3]. Metrics are obtained from FRACAS to assess trends over a period of time. These trends assist with predicting potential issues along with RAM criteria. FRACAS would have to be a collaborative system where stakeholders input information. Initiating, analyzing, correcting, and reviewing are recurring tasks that are performed within FRACAS desirably from the conceptual phase all the way through field operation.

Reliability Development Testing would ideally begin in the conceptual phase and become important during the prototype and development phase. Reliability growth analysis is assessed during reliability development testing. Reliability growth analysis is the process of collecting, modeling, analyzing and interpreting data from the reliability growth development test program (development testing) [4]. Simulation testing of the SATCOM system using software tools assists with developing a prototype for reliability testing. After simulation testing is complete, a prototype would be developed to go through stress testing with vibration, environmental, and EMI. These tests identify any issue with parts or components that can be assessed and corrected.

Reliability Critical Items are top items that need to be resolved or accepted throughout the life cycle of the system. A critical items list would be composed to track reliability aspects of the SATCOM system. The purpose of the critical items list is to focus management's attention on items that need to be resolved during the design phase as a corrective action loop for influencing the life time costs [5]. Recurring reviews of reliability critical items would facilitate correction. Prioritizing these critical items from the conceptual phase through field operations is essential for managing life cycle costs. Providing additional resources during the prototype, development, and early production phases is required based on the QuART software Reliability Tailoring tool.

Vendor and Supplier Control activities would begin desirably during the prototype phase but is important during the middle of the development phase through the production phase. Parts and material availability are assessed along with costs. Multiple vendors and suppliers would bid on developing / producing the system by providing the most technically feasible approach to delivering the systems on the defined schedule.

Production Reliability Testing would be planned for within the development phase and be conducted during production and field operations. These reliability tests would assist with the newly fielded system. During the early stages of the system lifecycle the failure rate would be high due to unforeseen circumstances. The bathtub curve in Figure 2 depicts the failure rate at a high level and decreasing after reliability testing / failure correction is performed over time.

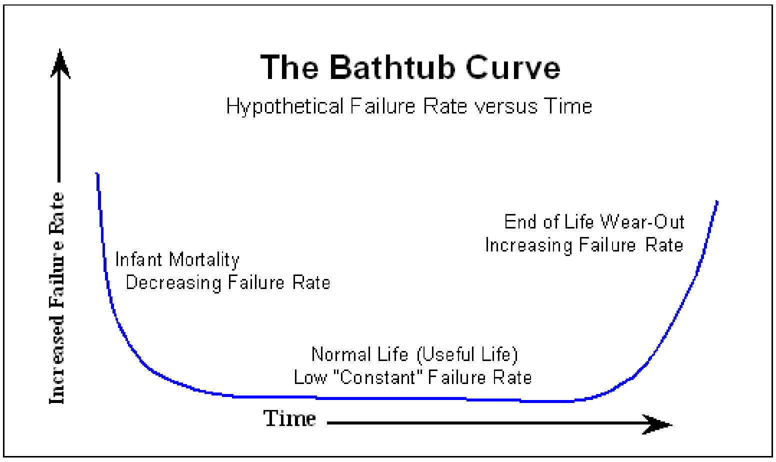

Figure 2 Bathtub Curve [6]

Performing onsite reliability testing along with lab based production reliability testing assists with identifying and mitigating potential issues with failed parts. Production reliability testing is important during the later stages of production since mitigating potential issues would cost less prior to fielding the system. After the system is fielded, onsite visits would increase overall costs to correct / repair defective parts.

Reliability Qualification Testing would verify that the design standards were met. Qualification testing is critical in the later stages of development, and is needed prior to going into the production phase. Additional resources would be needed for this task in order to meet milestones for the SATCOM system to be produced and fielded.

Failure Model Effects and Criticality Analysis (FMECA) tasks would take place during the conceptual phase through development with an increased effort through the prototype / development phases. A Failure Mode, Effects, and Criticality Analysis (FMECA) is a "bottom up" assessment of the design of a system (hardware, software and/or process) to determine the consequences of a failure on the overall performance or effectiveness of the system [7]. Defining system requirements, accomplishing functional analysis, accomplishing requirements allocation, identifying failure modes, determining causes of failure, determining effects of failure, identifying failure detection means, rating failure mode severity, rating failure mode frequency, rating failure mode detection probability, and analyzing failure mode criticality are activities that constitute performing FMECA [8]. These activities are shown in Figure 3 where a feedback and correction loop is incorporated with each activity block.

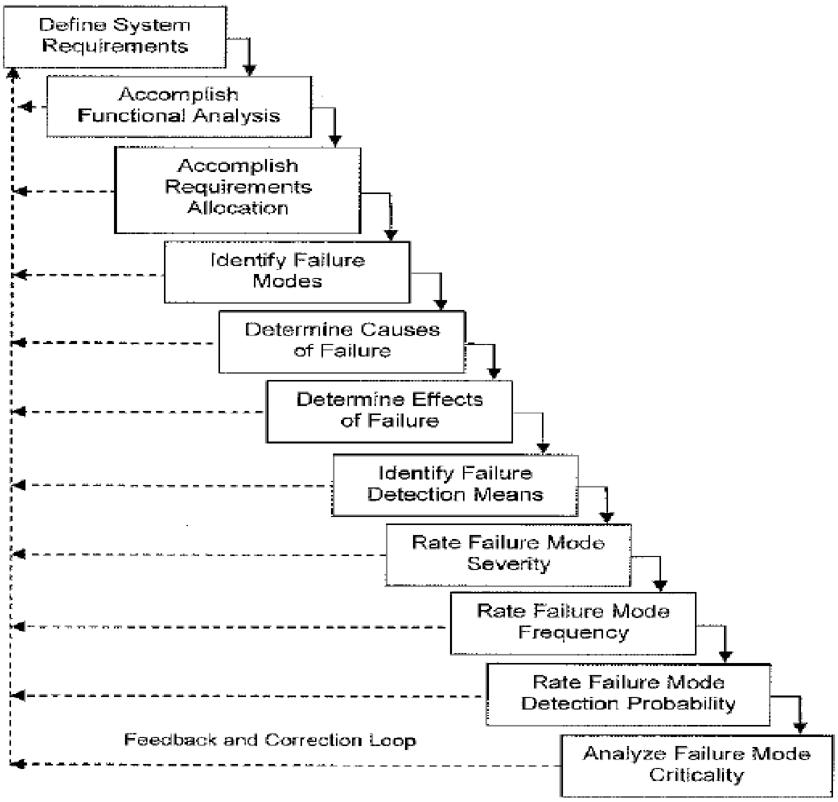

Figure 3 Approach to Conducting a FMECA [8]

FMECA activities assist with identifying, analyzing, mitigating, controlling, and monitoring critical failure items. In essence FMECA performs a variant of common Risk Management pertaining to parts failure. FMECA assists with increasing reliability, safety, and information pertaining to maintenance requirements.

Reliability Design Techniques involve defining requirements pertaining to survivability of the system within a harsh environment, tolerating encountered faults, and reducing stress elements that affect the system. Obtaining similar design plans from past projects with proven results would assist with validating particular design approaches for reliability. This task would ideally begin in the conceptual phase and continue through production.

Design Reviews are important during the conceptual phase throughout the development phase. The Preliminary Design Review (PDR) is performed during the prototype phase where the Critical Design Review (CDR) is the entry criteria leading into the development phase. The PDR consists of stakeholders reviewing the conceptual design to ensure that the planned technical approach will meet the requirements, and the CDR assesses system detailed design completeness towards meeting requirements and the development entity's readiness to begin fabrication and or coding [9]. These design reviews encompass testing, logistics, environmental issues, information security, risks, as well as cost schedule and performance parameters.

Reliability Requirement Planning and Management is important throughout the conceptual phase, critical in the prototype phase, and desirable to continue into the development phase. Defining requirements for reliability is essential to perform early in the system life cycle to prevent rework. Involving management with the overall cost of reliability efforts, the timeline for reliability testing / parts control, and risks associated with reliability criteria would assist with budget and resourcing strategies.

Reliability Modeling and Analysis involves taking reliability requirements and developing models and simulations to portray system survivability within a harsh environment. These models and simulations would detect potential failures by using known reliability data of parts and components. The need for redundancy and estimated A_o associated with the system would be calculated using analytical software to perform failure analysis. This task would be important to accomplish from the conceptual phase through the development phase.

Critical tasks for the development of this system would include parts selection / application reliability qualification testing, and reliability modeling and analysis. The parts selection and application tasking would be performed during the conceptual phase all the way through production. The prototype and development phases would need additional support to select and procure parts. Key components would be identified to meet the requirements of the SATCOM system being developed. Reliability qualification testing would be performed during the development phase after the prototype is designed, and would require adequate resources to execute.

III. PREDICTING MAXIMUM DOWN TIME

A_ois defined as the ratio of the system's uptime over the the system's uptime and downtime. The system's downtime includes Logistics Down Time (LDT), Administrative Delay Time (ADT), Corrective Maintenance Time (CMT), and Preventative Maintenance Time (PMT). Figure 4 Operational Availability depicts A_o in relation to the system's uptime and downtime.

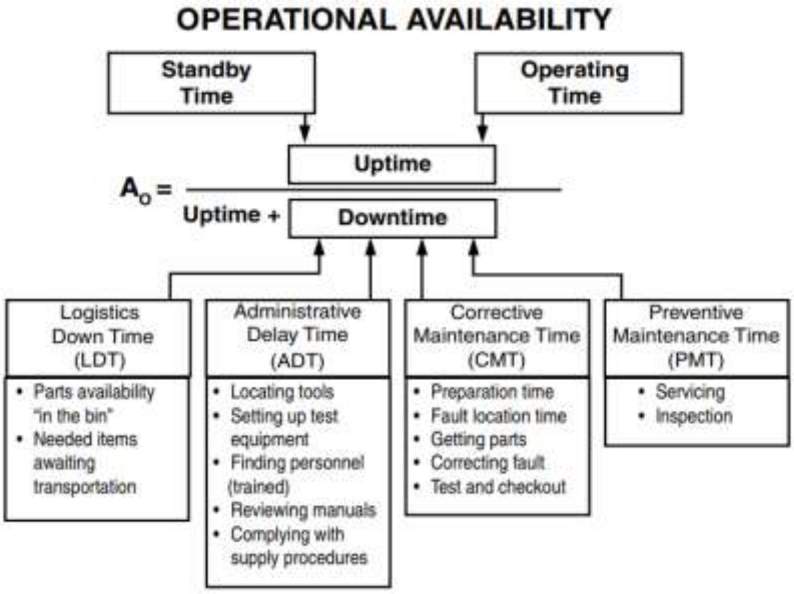

Figure 4 Operational Availability [10]

The A_o expression has twomajor deficiencies. Uptime and downtime can only be measured for a system in operational inventory and are not measurable for a system in development. If measurement period is short compared with reliability and maintainability system parameters, the equation will not give true indication of availability being achieved [1].

Predicting maximum down time with a providedA_o, uptime, and number of maintenance actionsis found when applying the A_o formula [11] along with the Mean Time Between Maintenance (MTBM) formula [12]. A newly developed SATCOM system may not have historical data pertaining to LogisticDown Times (LDT), Corrective Maintenance Times (CMT) and Administrative Delay Times (ADT). A newly developed SATCOM system would not be in operational inventory, and data captured for failure rates that affect the system's uptime and downtime would need to be assessed over time.

An example would include the sponsor stating that the SATCOM system shall maintain a .985A_o. This requirement sets a baseline for the A_o being 98.5%. The Mean Time Between Maintenance (MTBM) can be assumed as one instance per a 30 day month (720) hours for maintenance actions such as communication security rekeying, configuration backups, etc. Using these known values, a Mean Delay Time (MDT) is calculated as shown in the example below.

Operational Availability (A_o) = $\frac{MTBM}{MTBM+MDT}$

$$\text{MTBM} = \frac{Uptime}{No.of\ Maintenance}$$
$$\text{MTBM} = \frac{720}{1}$$
MTBM = 720 hours
$$A_o = \frac{720}{720+MDT}$$
$$.985 = \frac{720}{720+MDT}$$
.985(720+MDT)=720
709.2 + .985MDT =720
MDT= 10.96 hours
To maintain at least a 98.5% system availability rating, no more than 10.96 hours per month can be used for downtime. This downtime would include LDT, ADT, CMT, and PMT. Metrics for these values would be recorded as failures occur along with maintenance actions over time.

IV. CONCLUSION

Projects that are developing new, state of the art SATCOM systems should focus on forecasting and planning RAM related tasks throughout the system's life cycle to prevent cost overruns, schedule slips, rework, and future performance issues. Including RAM activities within the system's life cycle would improve the probability of developing a highly reliable system that is cost effective. Additional emphasis in particular RAM tasking during areas of the system's life cycle would include allocating additional personnel to assist with the effort.

The QuART Pro software depicts the system's life cycle in relation to reliability tasking by including the conceptual phase, prototype, development, production, and field operation phases. The user of the software would adjust the reliability tailoring criteria based on the system's criteria that is being developed. This reliability tailoring criteria would adjust the RAM task descriptions by the order of effectiveness along with the recommended timing to perform these activities. These activities would be labeled critical, important, or desirable to be performed during different phases of the system's life cycle. Extra emphasis on a particular RAM task description would be shown on the recommended timing section correlating to the system's life cycle.

Utilizing the QuART PRO software tool to obtain the most effective approach, and obtaining A_o requirementsis recommended for developing a newly state of the art SATCOM system. The criteria relating to complexity, criticality, environment that the system is in, difficulty of the design, and the quantity of systems manufactured would determine the importance of specific tasks performed throughout the system life cycle. With obtaining A_o requirements from stakeholder(s), maximum down times would be calculated to set an objective for developers to design to. Forecasting and planning for a newly developed SATCOM system using QuART PRO software along with gathering $A_o$requirements prepares an integrated product team in providing a cost effective, reliable SATCOM system solution.

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