Reliability & Maintainability (R&M) By Design

Andrew Monje

Office of the Deputy Assistant Secretary of Defense for Systems Engineering

17th Annual NDIA Systems Engineering Conference

Springfield, VA | October 27, 2014

DASD, Systems Engineering Mission

Systems Engineering focuses on engineering excellence – the creative application of scientific principles:

- To design, develop, construct and operate complex systems
- To forecast their behavior under specific operating conditions
- To deliver their intended function while addressing economic efficiency, environmental stewardship and safety of life and property

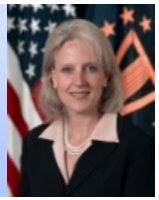
DASD(SE) Mission: Develop and grow the Systems Engineering capability of the Department of Defense – through engineering policy, continuous engagement with component Systems Engineering organizations and through substantive technical engagement throughout the acquisition life cycle with major and selected acquisition programs.

A Robust Systems Engineering Capability Across the Department Requires Attention to Policy, People and Practice

- ***US Department of Defense is the World's Largest Engineering Organization***
- ***Over 99,000 Uniformed and Civilian Engineers***
- ***Over 39,000 in the Engineering (ENG) Acquisition Workforce***

DASD, Systems Engineering

DASD, Systems Engineering
Stephen Welby
Principal Deputy Kristen Baldwin



Systems Analysis
Kristen Baldwin (Acting)

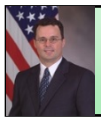
Addressing Emerging Challenges on the Frontiers of Systems Engineering

- Analysis of Complex Systems/Systems of Systems
- Program Protection/Acquisition Cyber Security
- University, FFRDC and Industry Engineering and Research
- Modeling and Simulation

Major Program Support
James Thompson

Supporting USD(AT&L) Decisions with Independent Engineering Expertise

- Engineering Assessment / Mentoring of Major Defense Programs
- Program Support Reviews
- OIPT / DAB / ITAB Support
- Systems Engineering Plans
- Systemic Root Cause Analysis



Mission Assurance
Robert Gold

Leading Systems Engineering Practice in DoD and Industry

- Systems Engineering Policy & Guidance
- Development Planning/Early SE
- Specialty Engineering (System Safety, Reliability and Maintainability Engineering, Quality, Manufacturing, Producibility, Human Systems Integration)
- Counterfeit Prevention
- Technical Workforce Development
- Standardization

Providing technical support and systems engineering leadership and oversight to USD(AT&L) in support of planned and ongoing acquisition programs

Tutorial Outline

- **Section 1: Introduction**
  - Objective
  - Need for R&M Engineering
- **Section 2: Policy**
  - Joint Capabilities Integration and Development System (JCIDS) 3170
  - Department of Defense Instruction (DoDI) 5000.02
  - Acquisition Strategy (AS)
  - Systems Engineering Plan (SEP)
  - Defense Acquisition Executive Summary (DAES) Reliability Growth Curve (RGC)
- **Section 3: Practical R&M Concepts**
  - Definitions and Measures
  - Performance Requirements
  - R&M Acquisition Considerations
  - R&M Fundamentals
- **Section 4: Key R&M Activities by Phase**
  - Materiel Solution Analysis (MSA)
  - Technology Maturation and Risk Reduction (TMRR)
  - Engineering and Manufacturing Development (EMD)
  - Production and Deployment (PD)
  - Operations and Support (O&S)
- **Summary**

Section 1: Introduction

- **Objective**
- **Need for R&M Engineering**

Objective

- **To provide an understanding and appreciation of:**
  - Basic R&M Engineering Materiel Acquisition Fundamentals
  - Basic elements of an effective R&M Engineering program
  - R&M assessments to inform decisions during key technical and milestone reviews

Need for R&M Engineering

- **Department of Defense (DoD) emphasis to increase readiness and reduce life-cycle costs**
- **Need to understand R&M Engineering fundamentals**
- **Need to ensure R&M Engineering principles are properly applied to DoD programs**
- **Need to tailor R&M Engineering disciplines to ensure cost effectiveness for DoD programs**

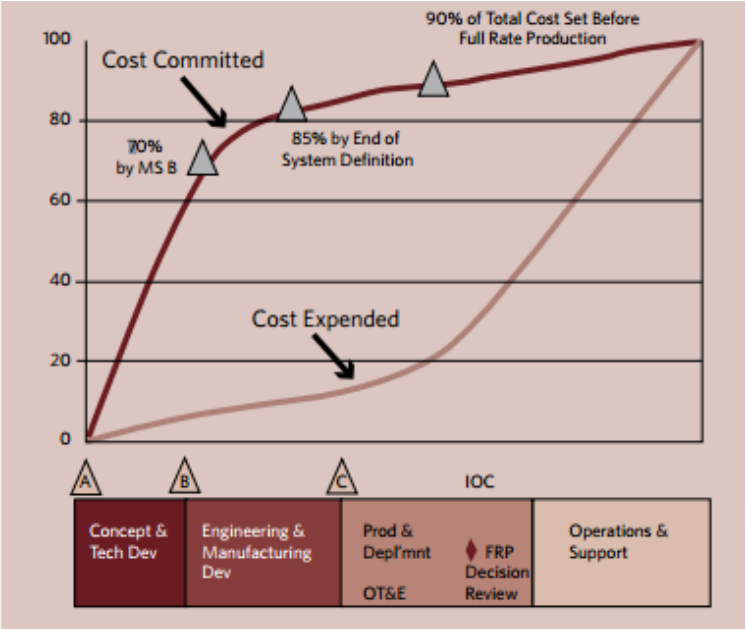
Need for R&M Engineering

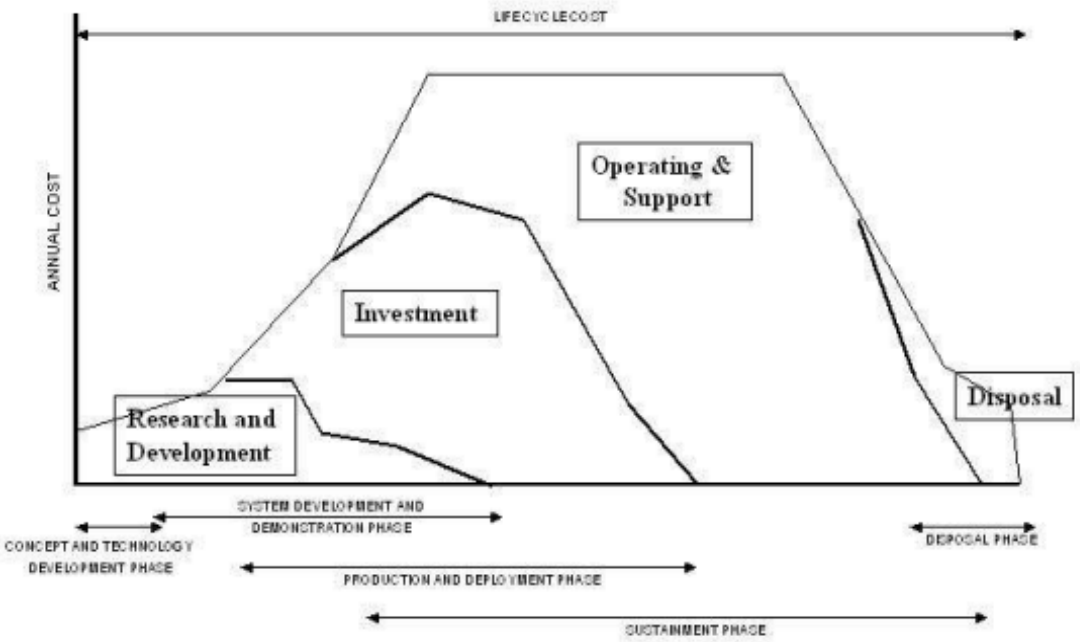
- **Benefits of an Effective R&M Program:**
  - For the Weapons System/Equipment:
    - Reduced life-cycle costs
    - Decreased logistics costs
    - Increased mission capabilities
    - Increased readiness
  - For the Program Manager and DoD:
    - Minimize cost increases & schedule delays
    - Reduce R&M risks associated with Milestone Reviews
    - Reduce R&M risks associated with Initial Operational Test and Evaluation (IOT&E)

"It's cheaper in both time and money to do it right the first time"

Fixing low reliability, poor maintainability and Built-in Test (BIT) via Engineering Change Proposals (ECP) is both costly and causes major program delays

Need for R&M Engineering
R&M and Life-Cycle Costs





Early application of R&M Engineering is essential to influencing the life-cycle cost of the program

Need for R&M Engineering
Key Objectives

- **Management commitment and attention**
- **Well defined mission oriented requirements**
- **R&M design and test activities correctly applied and tailored to all acquisition phases**
- **Realistic schedule associated with R&M disciplines**
- **Sustained reliability growth and maintainability maturation**
- **R&M activities monitored for effective implementation**
- **R&M assessments to inform decisions at key program reviews and milestones.**

Section 2: Policy

- **JCIDS 3170**
  - Sustainment
  - Availability
  - Reliability
  - Maintainability
  - Ownership Cost
- **DoDI 5000.02**
  - Reliability Analysis, Planning, Tracking and Reporting
  - Enclosure 3 Overview
- **Acquisition Strategy**
- **Systems Engineering Plan**
- **DAES RGC**

JCIDS 3170

- **The Sustainment Key Performance Parameter (KPP) is a mandatory KPP intended to ensure an adequate quantity of the capability solution will be ready for tasking to support operational missions.**
- **At a minimum, the sustainment KPP consists of:**
  - Materiel Availability KPP
  - Operational Availability KPP
  - Reliability Key Systems Attribute (KSA)
  - O&S Cost KSA
- **The supporting Reliability KSA and Operating and Support (O&S) Cost KSA, ensure that the Sustainment KPP is achievable and affordable in its operational environment.**
- **The KPP and supporting KSAs ensure early sustainment planning, enabling the requirements and acquisition communities to provide a capability solution with optimal availability and reliability to the warfighter at an affordable life cycle cost.**

Availability KPPs

- **Materiel Availability: measure of the percentage of the total inventory of a system operationally capable, based on materiel condition, of performing an assigned mission.**
  - Number of operationally available end items/total population.
  - Includes systems for training, attrition reserve, depot maintenance, etc.
  - Covers the timeframe from placement into operational service through the planned end of service life.
  - Takes into account all calendar time that a system is in the inventory, including "out-of-reporting" status.
- **Operational Availability: the measure of the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission and can be expressed as (uptime/(uptime + downtime)).**
  - Determining the optimum value for Operational Availability requires a comprehensive analysis of the system and its planned concept of operations (CONOPS), including the planned operating environment, operating tempo, reliability and maintenance concepts, and supply chain solutions.

Operational Availability KPP

- **<u>Operational Availability (unit)</u>: the measure of the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission and can be expressed as (uptime/(uptime + downtime)).**
  - Determining the optimum value for Operational Availability requires a comprehensive analysis of the system and its planned CONOPS, including the planned operating environment, operating tempo, reliability and maintenance concepts, and supply chain solutions.
  - Operational Availability may be equivalent to Materiel Availability if the total number of a system or group of systems within a unit is the same as the total inventory.

Reliability KSA

- **Reliability is a measure of the probability that the system will perform without failure over a specific interval, under specified conditions.**
- **For continuous use systems (such as an aircraft), reliability should be measured in terms of its primary usage metric (such as operating hours, miles or flight hours). For discrete systems (such as a single use munition), reliability should be measured as a probability.**
- **Reliability parameters fall under two categories:**
  - Mission Reliability. The measure of the ability of an item to perform its required function for the duration of a specified mission profile, defined as the probability that the system will not fail to complete the mission, considering all possible redundant modes of operation.
  - Logistics Reliability. The measure of the ability of an item to operate without placing a demand on the logistics support structure for repair or adjustment, including all failures to the system and maintenance demand as a result of system operations.
- **More than one reliability metric may be specified, as KSAs and/or Additional Performance Attributes (APA), for a system as appropriate.**

Maintainability Attributes

- **Maintainability – The ability of the system to be brought back to a state of normal function or utility. Includes supportability attributes such as diagnostics capabilities. These attributes which may be considered as KSAs or APAs:**
  - Corrective Maintenance – All actions performed as a result of any failure, to restore a system, subsystem, or component to a required condition.
  - Mission Maintainability – The ability of the system to be retained in or restored to a specified mission condition.
  - Maintenance Burden – A measure of maintainability related to the system's demand for maintenance manpower.
  - Built-In Test (BIT) Fault Detection – A measure of recorded BIT indications which lead to confirmed hardware failures.
  - BIT Fault Isolation – A measure of recorded BIT indications which correctly identify the faulty replaceable unit, either directly or through prescribed maintenance procedures.
  - BIT False Alarms – A measure of recorded BIT indications showing a failure when none has occurred.

Ownership Cost KSA

- **Provides balance to the sustainment solution by ensuring that the total Operations and Support (O&S) costs across the projected life cycle associated with availability and reliability (e.g., maintenance, spares, fuel, support).**
- **The O&S cost should cover the planned O&S timeframe, consistent with the timeframe and system population identified in the Sustainment KPP.**

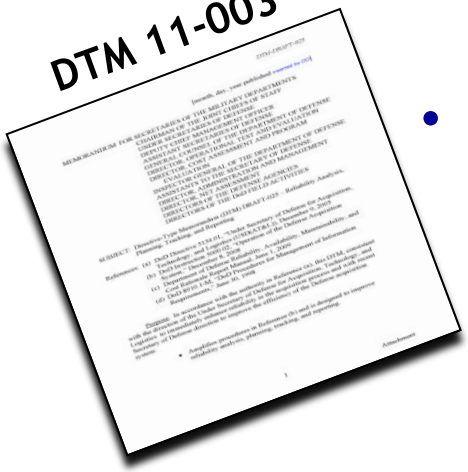
DoDI 5000.02

"Reliability Analysis, Planning, Tracking and Reporting"

USD AT&L MEMO

DoDI 5000.02

DTM 11-003



- **Impetus for Reliability Policy**
  - Directed by Dr. Carter in response to memo from Director, Operational Test & Evaluation (DOTE)
  - DASD(SE) to assess existing reliability policy and propose actions to improve effectiveness
- **DoD Acquisition Policy (DoDI 5000.02)**
  - Does not adequately or uniformly consider R&M engineering activities throughout the acquisition process
  - Fails to capture R&M planning in new or existing acquisition artifacts to inform acquisition decision making
- **Directive Type Memorandum (DTM) 11-003* (Approved 21 Mar 2011)**
  - Amplifies current DoDI 5000.02 by requiring PMs to perform reliability activities
  - Institutionalizes planning and reporting timed to key acquisition activities

*** Incorporated and cancelled by Interim DoDI 5000.02**

DoDI 5000.02
Enclosure 3 Overview

- **Engineering activities**
  - R&M allocations, block diagrams and predictions
  - Failure definitions and scoring criteria
  - Failure Mode, Effects and Criticality Analysis (FMECA)
  - Built-in Test (BIT) and maintainability demonstrations
  - Reliability Growth testing at system/subsystem level
  - Failure Reporting, Analysis and Corrective Action System (FRACAS)
- **Preliminary Reliability, Availability, Maintainability – Cost (RAM-C) Report in support of Milestone (MS) A and updated for MS B & C**
  - Provides early (Pre-MS A) reliability, availability, maintainability and ownership cost feasibility assessments of alternative concepts
    - Includes early formulation of maintenance & support concepts
  - Provides an audit trail that documents and supports JCIDS thresholds
  - Ensures correct balance between the sustainment metrics (Availability-KPP, Materiel Reliability-KSA, and Ownership Cost-KSA)
  - Provides early risk reduction by ensuring requirements are realistic and correct

DoDI 5000.02
Enclosure 3 Overview

- **Reliability Growth Strategy**
  - Documents system-level reliability growth curves in the SEP beginning at MS A and updated in the Test & Evaluation Master Plan (TEMP) beginning at MS B
  - Establishes intermediate goals for reliability growth curves that will be tracked through fully integrated system-level test and evaluation events until the threshold is achieved
  - Requires MS C PMs and Operational Test Agencies to assess reliability growth required to achieve the reliability threshold during Initial Operational Test and Evaluation
- **Tracking and Monitoring**
  - Requires PMs to report status of reliability objectives and/or thresholds as part of the formal system engineering review process
  - Incorporates Reliability Growth Curves into the Defense Acquisition Executive Summary (DAES) review process

Acquisition Strategy
Section 7.5.10

- **Specify how testing and systems engineering requirements, including life-cycle management and sustainability requirements, have been incorporated into contract requirements.**
  - Identify the engineering activities to be stated in the RFP and required of the contractor to demonstrate the achievement of the reliability and maintainability design requirements.
  - Provide a table to specify how the sustainment key performance parameter thresholds have been translated into reliability and maintainability design and contract specifications.
  - The reliability threshold is often expressed as Mean Time Between Failure (MTBF). Use the appropriate life units (e.g., hours, cycles, etc.). "MTTR" is "mean time to repair;" "N/A" may be entered if an item is not applicable.

Reliability and Maintainability Requirements		
Parameter	**Threshold**	**Contract Specification Requirement**
Reliability (e.g., MTBF)		
Maintainability (e.g., MTTR)		

SEP Annotated Outline
R&M Activities

Describe planning and timing to generate R&M artifacts.

R&M Engineering Activity	Planning and Timing
R&M Allocations	
R&M Block Diagrams	
R&M Predictions	
Failure Definitions and Scoring Criteria	
Failure Mode, Effects, and Criticality Analysis (FMECA)	
Maintainability and Built-in Test Demonstrations	
Reliability Growth Testing at the System and Subsystem Level	
Failure Reporting , Analysis, and Corrective Action System (FRACAS)	

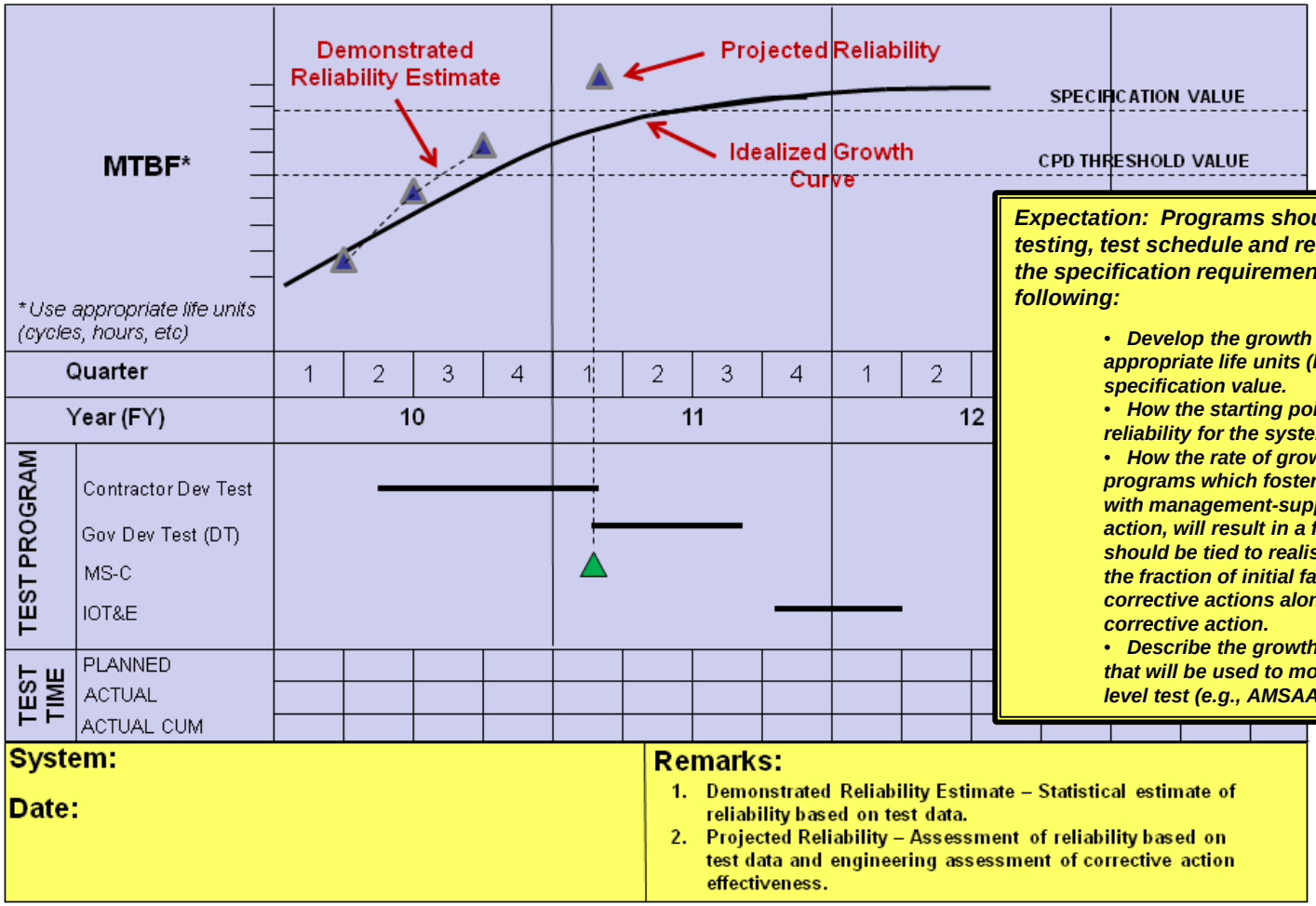
Table 4.6-2 R&M Activity Planning and Timing (mandated) (sample)

•Expectation: Programs should understand that the content of the R&M artifacts need to be consistent with the level of design knowledge that makes up each technical baseline.

- ***R&M Allocations – R&M requirements assigned to individual items to attain desired system level performance. Preliminary allocations are expected by SFR with final allocations completed by PDR.***
- ***R&M Block Diagrams – The R&M block diagrams and math models prepared to reflect the equipment/system configuration. Preliminary block diagrams are expected by SFR with the final completed by PDR.***
- ***R&M Predictions – The R&M predictions provide an evaluation of the proposed design or for comparison of alternative designs. Preliminary predictions are expected by PDR with the final by CDR.***
- ***•Failure Definition and Scoring Criteria – Failure definitions and scoring criteria to make assessments of R&M contract requirements.***
- ***FMECA – Analyses performed to assess the severity of the effects of component/subsystem failures on system performance. Preliminary analyses are expected by PDR with the final by CDR.***
- ***Maintainability and Built-In Test – Assessment of the quantitative and qualitative maintainability and Built-In test characteristics of the design.***
- ***Reliability Growth Testing at the System and Subsystem Level – Reliability testing of development systems to identify failure modes, which if uncorrected could cause the equipment to exhibit unacceptable levels of reliability performance during operational usage.***
- ***FRACAS – Engineering activity during development, production, and sustainment to provide management visibility and control for R&M improvement of hardware and associated software by timely and disciplined***

SEP Annotated Outline
Reliability Growth Curve

Document the Reliability Growth Curve beginning at MS A, updated at each successive milestone, …

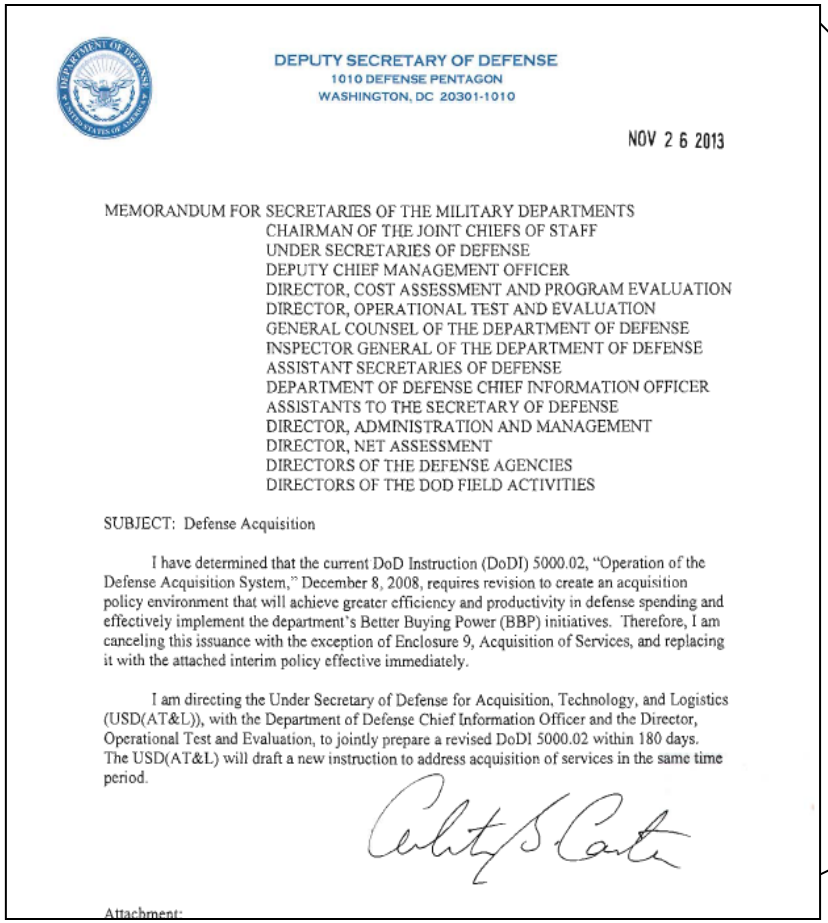


Expectation: Programs should understand the amount of testing, test schedule and resources available for achieving the specification requirement. Programs should consider the following:

- ***Develop the growth planning curve as a function of appropriate life units (hours, cycles, etc,) to grow to the specification value.***
- ***How the starting point that represents the initial value of reliability for the system was determined.***
- ***How the rate of growth was determined. Rigorous test programs which foster the discovery of failures, coupled with management-supported analysis and timely corrective action, will result in a faster growth rate. The rate of growth should be tied to realistic management metrics governing the fraction of initial failure rate to be addressed by corrective actions along with the effectiveness of the corrective action.***
- ***Describe the growth tracking and projection methodology that will be used to monitor reliability growth during system-level test (e.g., AMSAA-Crowe Extended, AMPM).***

DAES RGC

- **DoDI 5000.02 requires reliability growth status to be reported**



DEPUTY SECRETARY OF DEFENSE
1010 DEFENSE PENTAGON
WASHINGTON, DC 20301-1010

NOV 2 6 2013

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
DEPUTY CHIEF MANAGEMENT OFFICER
DIRECTOR, COST ASSESSMENT AND PROGRAM EVALUATION
DIRECTOR, OPERATIONAL TEST AND EVALUATION
GENERAL COUNSEL OF THE DEPARTMENT OF DEFENSE
INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE
ASSISTANT SECRETARIES OF DEFENSE
DEPARTMENT OF DEFENSE CHIEF INFORMATION OFFICER
ASSISTANTS TO THE SECRETARY OF DEFENSE
DIRECTOR, ADMINISTRATION AND MANAGEMENT
DIRECTOR, NET ASSESSMENT
DIRECTORS OF THE DEFENSE AGENCIES
DIRECTORS OF THE DOD FIELD ACTIVITIES

SUBJECT: Defense Acquisition

I have determined that the current DoD Instruction (DoDI) 5000.02, "Operation of the Defense Acquisition System," December 8, 2008, requires revision to create an acquisition policy environment that will achieve greater efficiency and productivity in defense spending and effectively implement the department's Better Buying Power (BBP) initiatives. Therefore, I am canceling this issuance with the exception of Enclosure 9, Acquisition of Services, and replacing it with the attached interim policy effective immediately.

I am directing the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)), with the Department of Defense Chief Information Officer and the Director, Operational Test and Evaluation, to jointly prepare a revised DoDI 5000.02 within 180 days. The USD(AT&L) will draft a new instruction to address acquisition of services in the same time period.

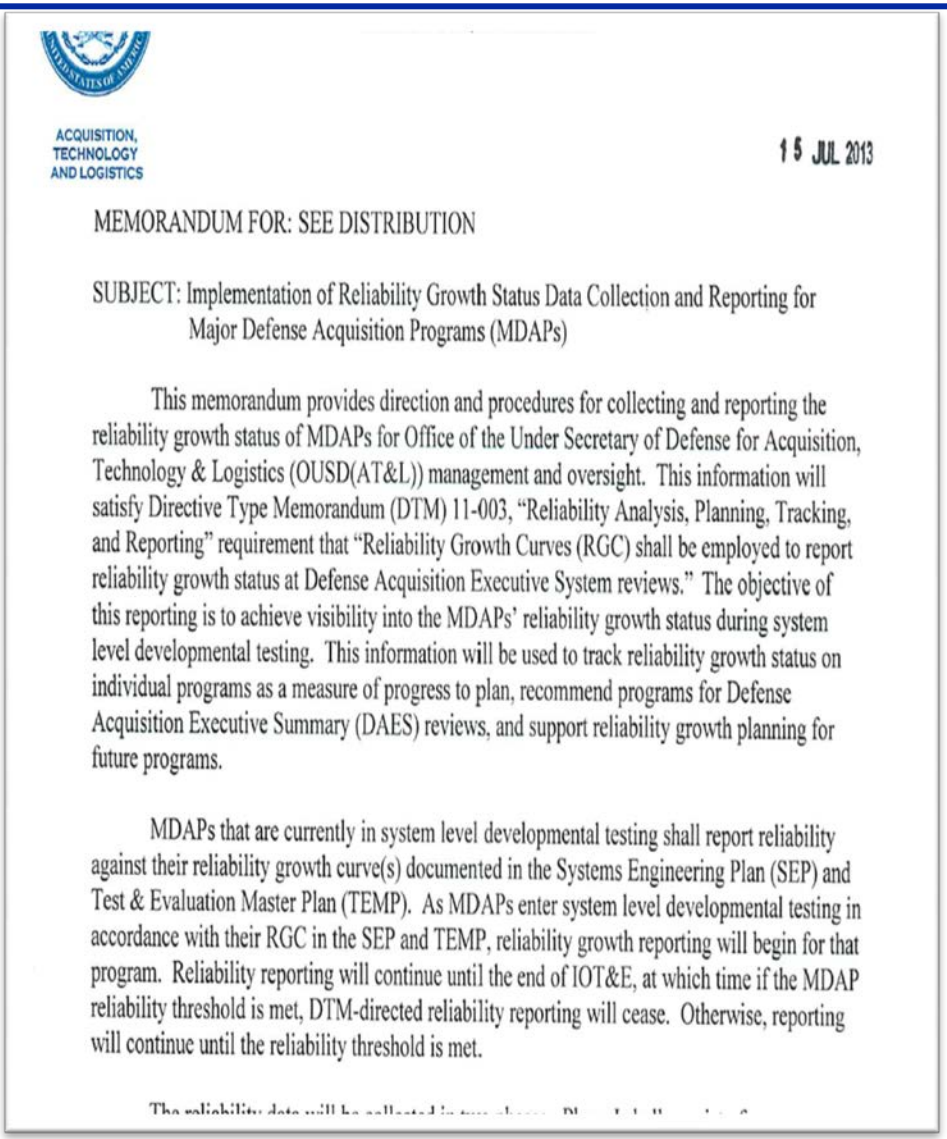
Attachment:

"Reliability growth will be monitored and reported throughout the acquisition process. PMs will report the status of reliability objectives and/or thresholds as part of the formal design review process, and during Systems Engineering Technical Reviews or other reviews. **RGC will be employed to report reliability growth status at Defense Acquisition Executive Summary reviews**."

Purpose of Data

- **Collect the minimal set of data to track reliability progress**
- **Track Major Defense Acquisition Program (MDAP) reliability performance to plan**
  - Planned versus Demonstrated Reliability (cumulative and quarterly)
  - Projected reliability for next quarter
- **Support program selection for DAES reviews**
- **Evaluate reliability growth strategies for future acquisitions**

DAES RGC Memo



ACQUISITION, TECHNOLOGY AND LOGISTICS

15 JUL 2013

MEMORANDUM FOR: SEE DISTRIBUTION

SUBJECT: Implementation of Reliability Growth Status Data Collection and Reporting for Major Defense Acquisition Programs (MDAPs)

This memorandum provides direction and procedures for collecting and reporting the reliability growth status of MDAPs for Office of the Under Secretary of Defense for Acquisition, Technology & Logistics (OUSD(AT&L)) management and oversight. This information will satisfy Directive Type Memorandum (DTM) 11-003, "Reliability Analysis, Planning, Tracking, and Reporting" requirement that "Reliability Growth Curves (RGC) shall be employed to report reliability growth status at Defense Acquisition Executive System reviews." The objective of this reporting is to achieve visibility into the MDAPs' reliability growth status during system level developmental testing. This information will be used to track reliability growth status on individual programs as a measure of progress to plan, recommend programs for Defense Acquisition Executive Summary (DAES) reviews, and support reliability growth planning for future programs.

MDAPs that are currently in system level developmental testing shall report reliability against their reliability growth curve(s) documented in the Systems Engineering Plan (SEP) and Test & Evaluation Master Plan (TEMP). As MDAPs enter system level developmental testing in accordance with their RGC in the SEP and TEMP, reliability growth reporting will begin for that program. Reliability reporting will continue until the end of IOT&E, at which time if the MDAP reliability threshold is met, DTM-directed reliability reporting will cease. Otherwise, reporting will continue until the reliability threshold is met.

The reliability data will be collected in two phases. Phase I shall be [illegible]

- **DAES RGC Reporting to begin Oct 1, 2013 per Director, ARA memorandum**
  - **Who: MDAPs in system-level Developmental Testing (~20 MDAPs required to report)**
  - **What: Report planned reliability data and subsequent quarterly updates of progress-to-plan**
  - **When: Quarterly submissions based on DAES groups (A, B, or C)**
  - **Why: Allow assessment of planned versus demonstrated reliability for MDAPs**
  - **How:**
    - **Phase 1 – Manual submission of data via spreadsheets**
    - **Phase 2 – Automated submission directly into DAMIR (implementation TBD)**

Section 3: Practical R&M Concepts

- **Definitions and Measures**
- **Performance Requirements**
- **R&M Acquisition Considerations**
- **R&M Fundamentals by Phase**
  - Overview
  - Reliability Block Diagrams and Math Models
  - Allocations
  - Predictions
  - FMECA
  - FRACAS
  - Maintainability and BIT Demos
  - Reliability Growth Strategy

Definitions

- **Reliability:**
  - The Duration or probability of failure-free performance under stated conditions, or
  - The probability that an item can perform its intended function for a specified interval under stated conditions
- **Maintainability:**
  - Is a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources

Reliability Measures

- **Mean Time Between Failure (*MTBF*)**
- **Mean Time To Failure (*MTTF*)**
- **Mean Time Between Maintenance *(MTBM)***
- **Mean Time Between Critical Mission Failure *(MTBCMF)***
- **Mean Time Between Operational Mission Failure *(MTBOMF)***
- **Mean Time Between Aborts *(MTBA)***
- **Mean Cycles Between Failure *(MCBF)***

Maintainability Measures

Provide a breakout by corrective and direct maintenance categories including BIT

- Mean Time to Repair (*MTTR*) or Mean Corrective Maintenance Time, $\overline{M}_{ct}$
- Mean Preventive Maintenance Time, $\overline{M}_{pt}$
- Mean Down Time (*MDT*)
- Percent Built-in-Test (BIT) Fault Detection (*Pfd*)
- Maintenance Labor Hours/Operating Hours (MLH/OH)

Built-in-Test (BIT) Measures

FD - Fault Detection (coverage):

$$\text{Percent Coverage Detection} = \frac{\text{Number of BIT Detected Failures x 100}}{\text{Number of Failures}}$$

FI - Fault Isolation:

$$\text{Percent Coverage Fault Isolation} = \frac{\text{Number of Failures Correctly Isolated to One WRA x 100}}{\text{Number of BIT Detected Failures}}$$

FA - False Alarm:

$$\text{Mean Time Between False Alarms} = \frac{\text{Number of Hours}}{\text{Number of False BIT Indications}}$$

$$\text{Percent Coverage False Alarm} = \frac{\text{Number of False BIT Indications x 100}}{\text{Number of BIT Detected Failures}}$$

Performance Requirements Overview

- R&M specification requirements must be translated from the thresholds in the Capabilities Requirements Document
- R&M quantitative performance measures must be realistic
- Specification requirements are design controllable with a good design margin
- Use Contractor's Predictions to assess risk of achieving Operational thresholds
- Operational Test R&M thresholds must be equal to the thresholds in the Capabilities Requirements Document

Operational Mode Summary/ Mission Profile

- **Required by Interim DoDI 5000.02**
- **The operational mode summary (OMS), and mission profile (MP), describe the planned deployment, employment, and operation of the weapon system.**
  - OMS - Describes the anticipated ways the equipment will be used in carrying out its operational role
  - MP - Provides a time-phased description of the operational events and environments a system experiences from the beginning to end of a specific mission

Operational Mode Summary/Mission Profile (OMS/MP)

- **An OMS/MP projects the anticipated mix of ways a system will be used for each moment of time to include both peacetime and wartime. It also includes the percentage of time the system will be exposed to each type of environmental condition and movement terrain.**
- **The Combat Developer produces the OMS/MP following development of the system CONOPS and uses the OMS/MP to conduct an analysis to determine the maintenance and support concepts describing the levels of maintenance and the maintenance activities that will be conducted at each level.**
- **Reliability growth testing and R&M demonstration testing should be reflective of the OMS/MP**

Table 1 - Marine Corps and Army Joint Major Combat Operation (MCO) Scenario with Mission Tasks *								
Operational Mode Summery (OMS)	Mission Profiles (MP)							
	Offense				Defense		Stability	Total
Full Spectrum Element MCO War Game Phases	Littoral/Air Assult	Movement to contact	Attack	Pursuit	Area Defense	Mobile Defense	Civil Security	
Duration (hours)	5.7	11.4						
Distance (miles)	4.6	128.9						
Engine Operations (hours)								
Dynamic Operation or Movement Time	0.9	6.4						
Static Operation or Idle Time	1.2	1.6						
Total Operating Time (Dynamic + Static)	2.1	8.0						
Systems & Engine Off Time	1.8	3.4						
Auxiliary Power or Battery Power (hours)								
Silent Watch Operating Time	1.8	0.0						
Exportable Power	2.1	8.0						
Cycles (Numbers)								
Engine on/off Cycles	1	2						

Vehicle and Trailer Percent Payload for RAM Testing				
Payload On-Board the JLTV FOV	Payload On-Board Trailer			
	No Trailer	Empty Trailer	Half Loaded Trailer	Fully Loaded Trailer
Empty JLTV (CW + Crew - All Payload)	1%	2%	1%	5%
Half Loaded JLTV (GVW + Crew - 1/2 Payload)	35%	1%	8%	3%
Fully Loaded JLTV (GVW + Crew)	24%	2%	3%	15%

RAM-C Manual Background

- **Manual published on June 1, 2009**
  - The intent of the RAM-C Manual is to capture the process and analysis required for sustainment requirements development to ensure the system is sustainable and affordable throughout its lifecycle.
  - Based on Army's RAM Rationale Report dated 1 February 1985
  - 78 pages (Core content: 58 pages; Report Outline Appendix: 5 pages)
  - Existing Annotated Outlines (e.g. SEP, AS) range from 17 to 38 pages
- **RAM-C policy directed through Interim DoDI 5000.02**
  - 5000.02 states "this report provides a quantitative basis for reliability requirements and improves cost estimates and program planning"
    - Requires a preliminary report in support of the MS A decision
    - Attached to the SEP starting at MS A and updated at the Development Request For Proposal (RFP) Release Decision Point, MS B, and MS C

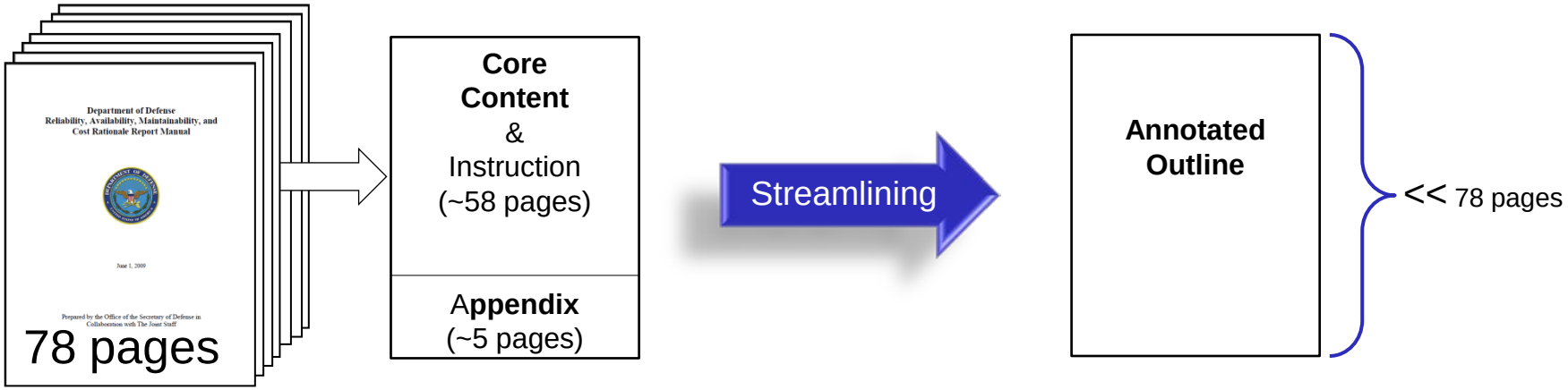
Reasons For Update

- **Policy changes**
  - DoDI 5000.02 update (incorporated and cancelled DTM 11-003)
  - Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01H and JCIDS Manual
- **Content and Instructional Changes:**
  - Elaborate on the RAM-C process
    - More Analysis of Alternatives (AoA) involvement
    - Support the requirements document
    - Use of trade-off/sensitivity analysis
  - Streamline report structure
  - Clarify team membership and report development interaction
  - Include all sustainment parameter content (maintainability, BIT, cost, etc.)
  - Stress the linkage between requirements
  - Remove the example

Improvements address both Program Office feedback and DASD(SE) review comments

RAM-C Update Strategy

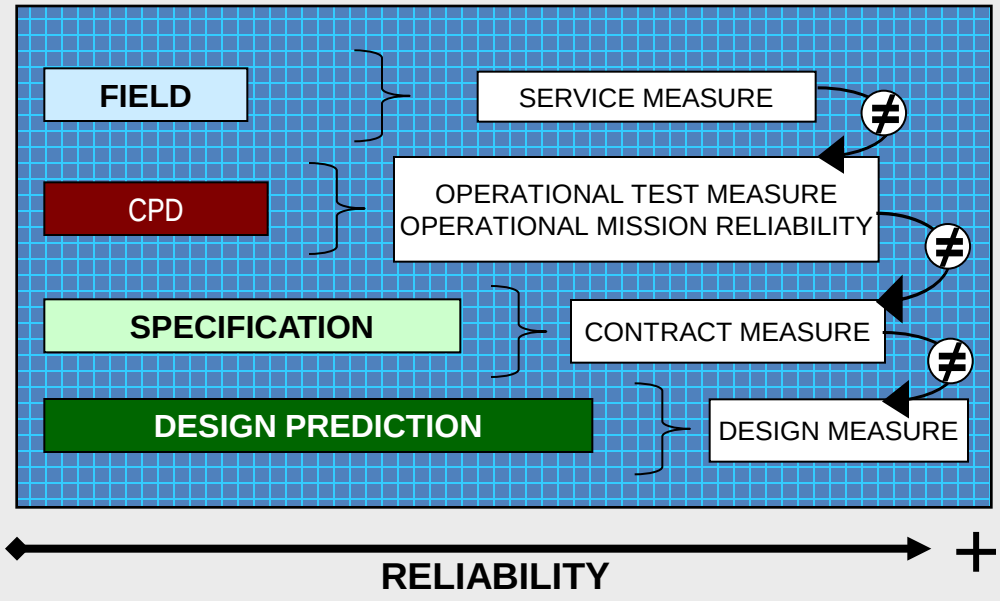
Annotated Outline link in SEP



- **Streamline the Core Content & Instruction into the Annotated Outline format**
  - Focus content on validity, feasibility, and proper balance of requirements
  - Delete example and redundant information/instruction
  - Utilize supporting policy and guidance
  - Provides direction (“Call out what is needed in the report”)
  - Allow reports to flow and get to the point

Translation of Requirements

Relative Relationship of Reliability Measures



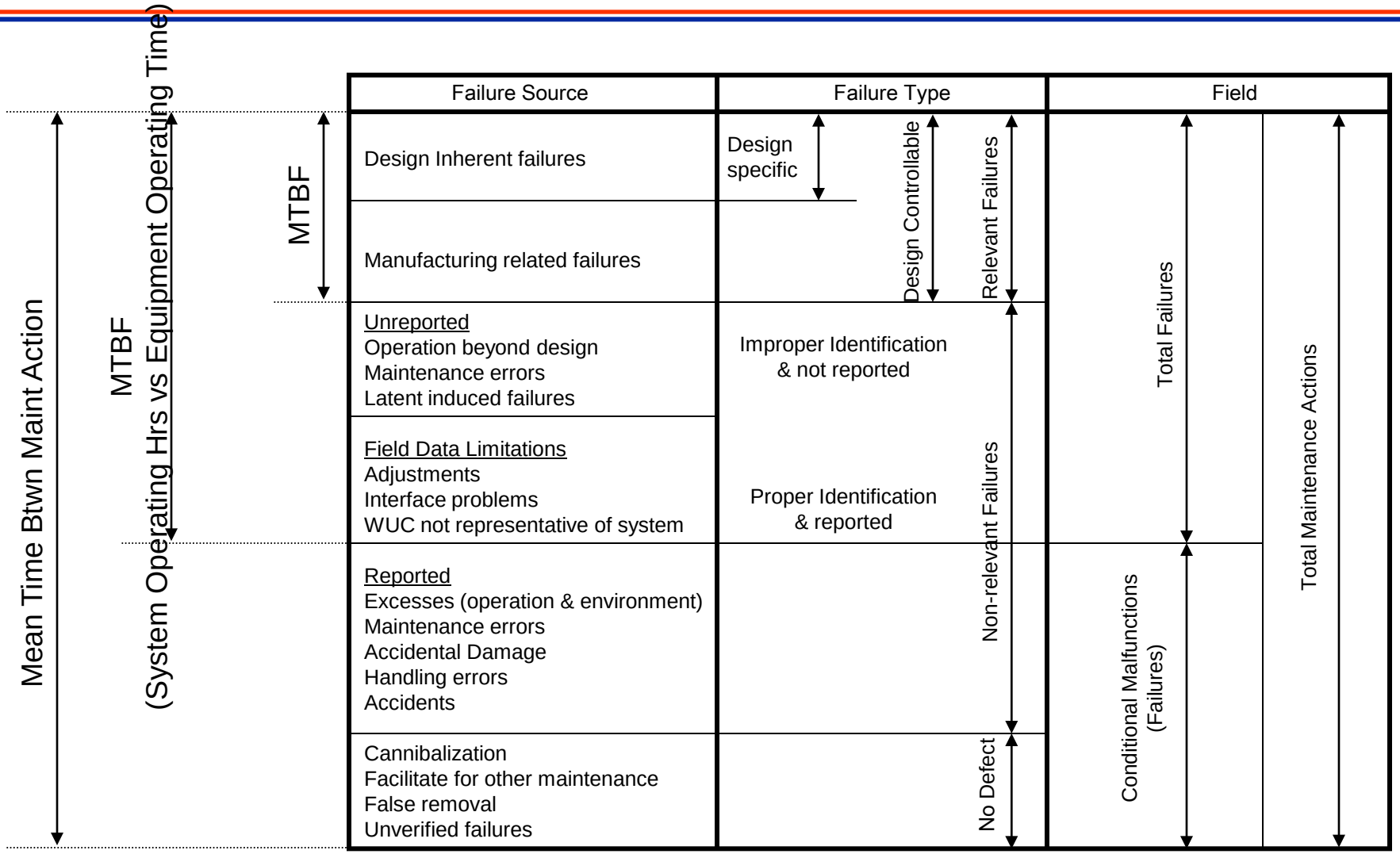
FIELD RELIABILITY: SERVICE GROUND RULES, SERVICE LOGISTICS RELIABILITY MEASURE.

CAPABILITY PRODUCTION DOCUMENT (CPD) OPERATIONAL MISSION FAILURE REQUIREMENT: OPERATIONAL TEST AGENCY GROUND RULES, MISSION RELIABILITY MEASURE.

SPECIFIED RELIABILITY: DESIGN CONTROLLABLE TERMS, MEASURED DURING DEVELOPMENTAL TESTING.

RELIABILITY PREDICTION: INHERENT RELIABILITY.

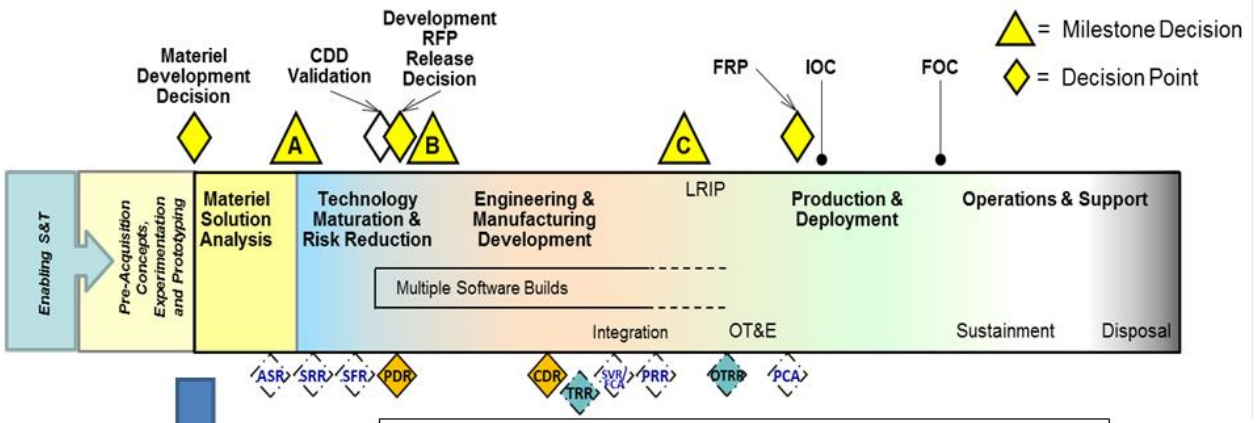
Failure Definition Factors



R&M Acq Considerations
Schedule Considerations

- **It takes finite time to conduct R&M testing, engineer corrective actions, and incorporate them into equipment:**
  - Incorporate changes in software and hardware between Government Developmental Test (DT) and IOT&E
  - Make effective use of applied R&M design/test disciplines (i.e. Reliability Development Growth Testing (RDGT), Highly Accelerated Life Testing (HALT), Maintainability-Demos (M Demos), etc.) to sustain reliability growth and maintainability maturation
  - Maximize use of production representative units for both Government DT and IOT&E
- **No hardware or software design maturity occurs without sufficient time**
- **Government DT should be the final measure of design and development effort for R&M**

R&M Acq Considerations
Program Considerations



GFE = Government Furnished Equipment

COTS = Commercial Off The Shelf

NDI = Non-Developmental Item

SOW = Statement of Work

Identify program phase and acquisition strategy (Requires newly designed equipment and major changes, GFE/COTS/NDI, or modified equipment and minor changes)

Tailor R&M engineering activities based on program phase and equipment type

Identify sample language from SOW guidance

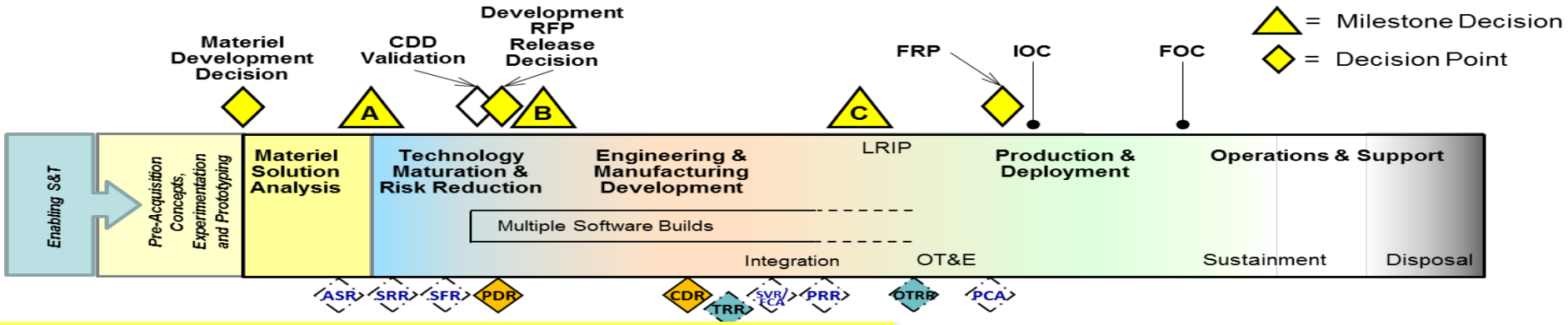
The type, phase, and acquisition strategy of the program are prime drivers of the R&M disciplines needed to develop a cost-effective R&M program.

Contracting Tailoring Guidance

R&M Discipline	MSA	TMRR	EMD	P&D	O&S	New Design "Major" Change	Modified "Minor" Change	NDI/COTS
Program Requirements								
R&M and BIT Program	✓	✓	✓	✓	✓	✓	✓	✓
R&M and BIT Organization		✓	✓	✓		✓	✓	
Subcontractor R&M and BIT Requirements		✓	✓	✓		✓	✓	✓
Trade Studies	✓	✓	✓			✓	✓	✓
Market Survey		✓	✓					✓
Spares Reliability Provisions			✓	✓	✓	✓	✓	
Design Analyses								
Mission Profile Definition	✓	✓	✓			✓	✓	✓
Environmental Effects Analysis		✓	✓			✓	✓	✓
Reliability Math Models, Allocations, and Predictions	✓	✓	✓			✓	✓	✓ (1)
Maintainability and BIT Allocations, Predictions and Analysis	✓	✓	✓			✓	✓	✓ (2)
FMECA and Reliability Critical Items		✓	✓			✓	✓ (4)	✓ (3)
Worst Case / Sneak Circuit Analysis			✓			✓		
Thermal Analysis and Survey			✓			✓	✓	✓
Parts, Material and Processes Program		✓	✓	✓		✓	✓	
Documentation/Data Items	✓	✓	✓	✓	✓	✓	✓	✓
Tests								
Subsystem/Equipment Level Reliability Growth Test		✓	✓	✓		✓		
Subsystem/Equipment Level BIT Assessment Tests			✓			✓		
System-Level Reliability, Maintainability and BIT Demo			✓			✓	✓	✓
Manufacturing Screening			✓	✓		✓	✓	
System Test Monitoring			✓	✓		✓	✓	✓
FRACAS		✓	✓	✓	✓	✓	✓	✓

Notes:
1. Excludes parts count or stress analysis prediction, analysis generally limited to equipment end-item.
2. Maintainability analysis generally limited to equipment end-item.
3. Applicable to the interfaces of COTS/NDI equipment.
4. Applicable to the modified portions and interfaces.

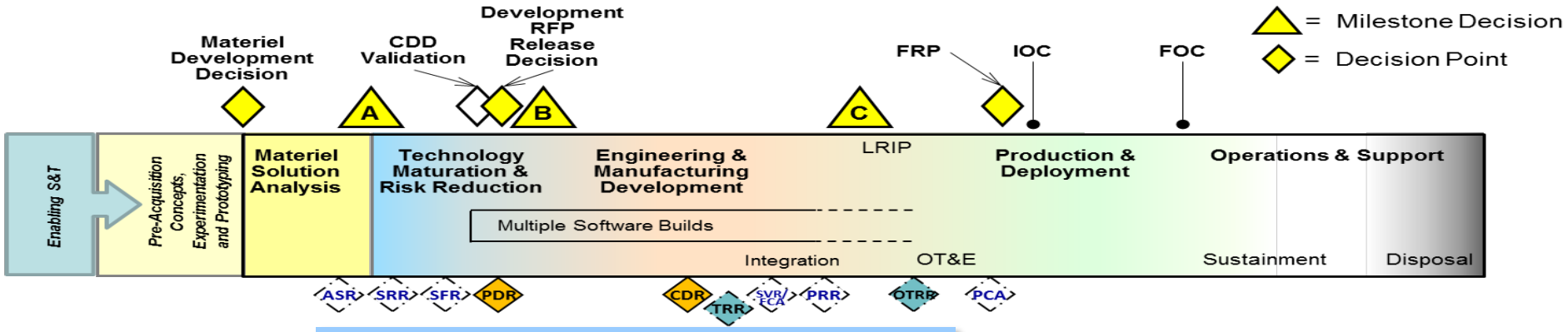
R&M Fundamentals by Phase Overview



MSA Phase

- Review Initial Capabilities Document (ICD) for R&M objectives
- Develop R&M planning for MSA phase
- Prepare R&M input to MSA phase Request for Information (RFI) or study contracts
- Perform R&M requirements analysis
- Review MSA phase RFI or study contracts
- Perform design trade-off studies
- Prepare R&M analysis reports
- Prepare RAM-C Report Summary
- Develop R&M planning for TMRR phase
- Provide R&M input to Test & Evaluation Master Plan (TEMP)
- Provide R&M input to AS
- Provide R&M input to SEP
- Prepare R&M input to RFP for TMRR phase

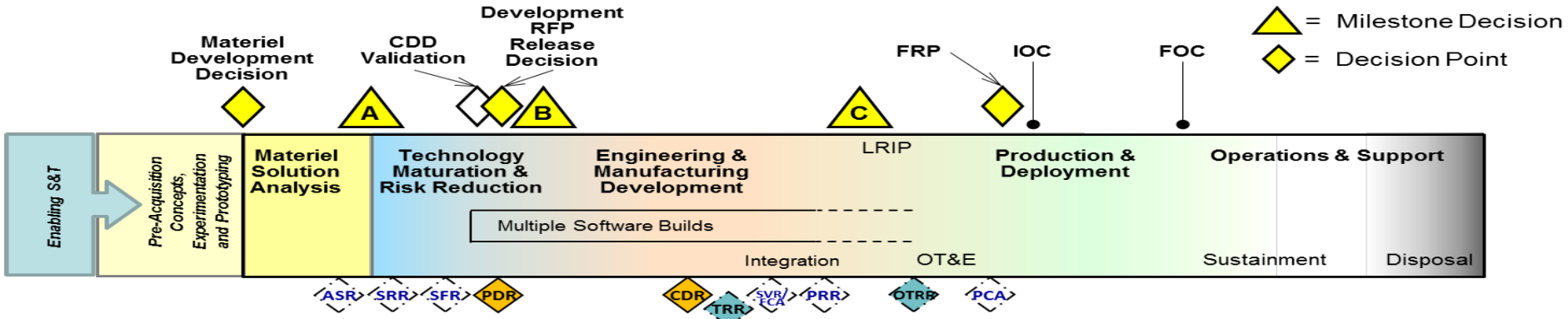
R&M Fundamentals by Phase Overview



TMRR Phase

- Evaluate proposals
- Provide R&M design support
- Develop/review R&M planning for TMRR phase
- Review TMRR phase contract
- Evaluate GFE/COTS
- Perform design trade-off studies
- Conduct design verification tests
- Provide R&M input to Acquisition Strategy
- Develop R&M planning for EMD phase
- Update SEP and RAM-C Report
- Provide R&M input to TEMP for EMD
- Prepare R&M input to RFP for EMD phase
- Conduct preliminary R&M design analyses
- Conduct program review

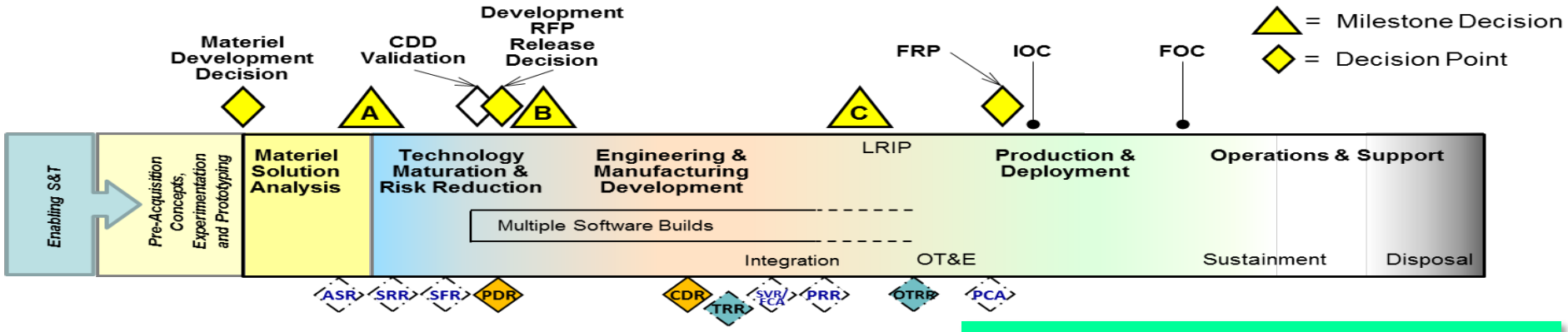
R&M Fundamentals by Phase Overview



EMD Phase

- Evaluate proposals
- Review EMD phase contract
- Develop/review R&M planning for EMD phase
- Review integrated test plan
- Provide R&M design support
- Conduct program review
- Perform subsystem tests
- Perform system test
- Provide R&M input to Acquisition Strategy
- Perform Government system test
- Develop R&M planning for P&D phase
- Update SEP and RAM-C Report
- Review PD R&M test plan/input to TEMP
- Prepare R&M input to RFP for P&D phase

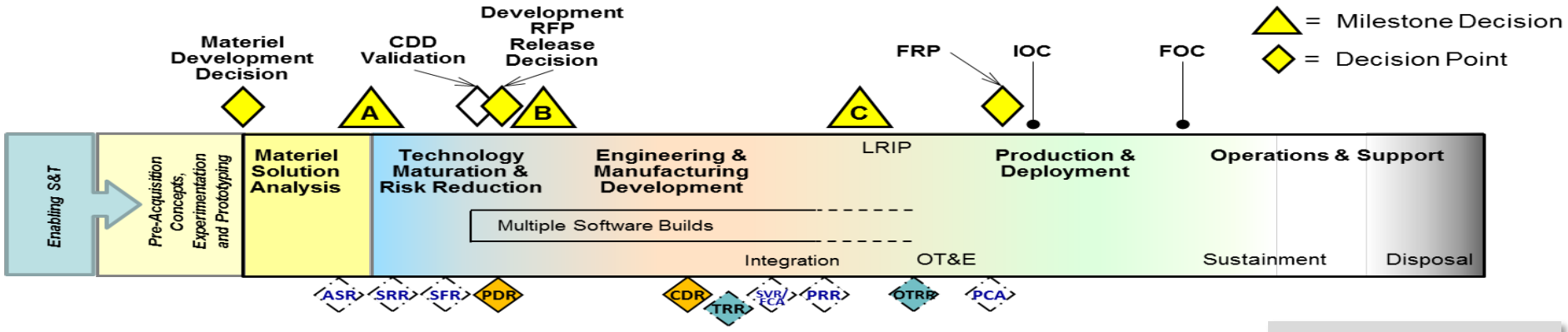
R&M Fundamentals by Phase Overview



PD Phase

- Review PD phase contract
- Review Integrated Test Plan
- Review R&M Planning for PD phase
- Provide R&M production support
- Perform Production Reliability Acceptance Test
- Evaluate R&M Program
- Perform System Test
- Perform R&M engineering
- Provide R&M Input to Acquisition Strategy
- Evaluate FRACAS
- Perform Government System Test
- Provide R&M input to TEMP
- Monitor R&M in production

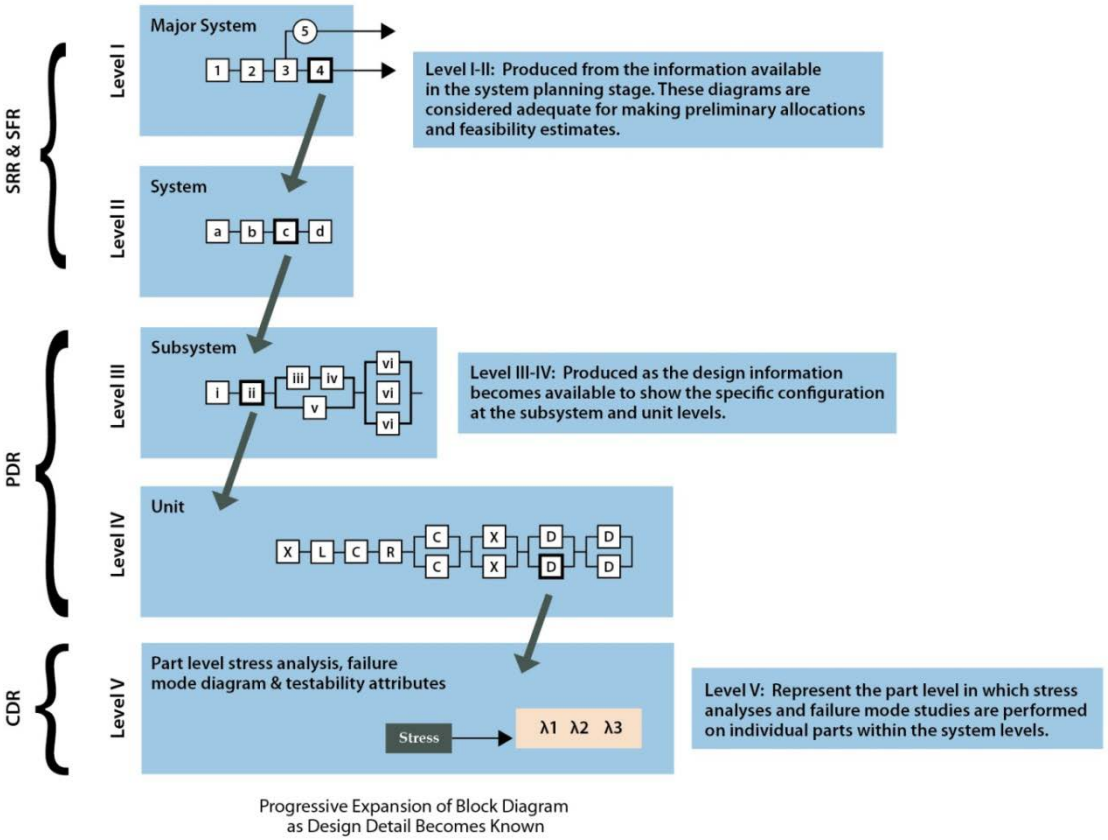
R&M Fundamentals by Phase Overview



O&S Phase

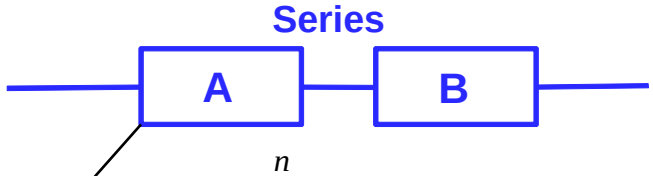
- Develop R&M planning
- Perform R&M engineering
- Conduct R&M demonstrations and tests
- Support ECP procurement
- Support Service operational tests

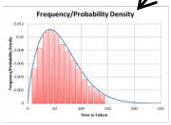
Reliability Block Diagram and Math Models



Progressive Expansion of Block Diagram as Design Detail Becomes Known

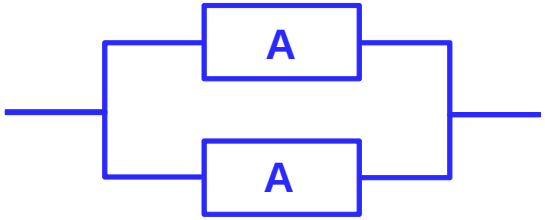
Series





$$R = \prod_{i=1}^{n} R_i = R_A R_B$$

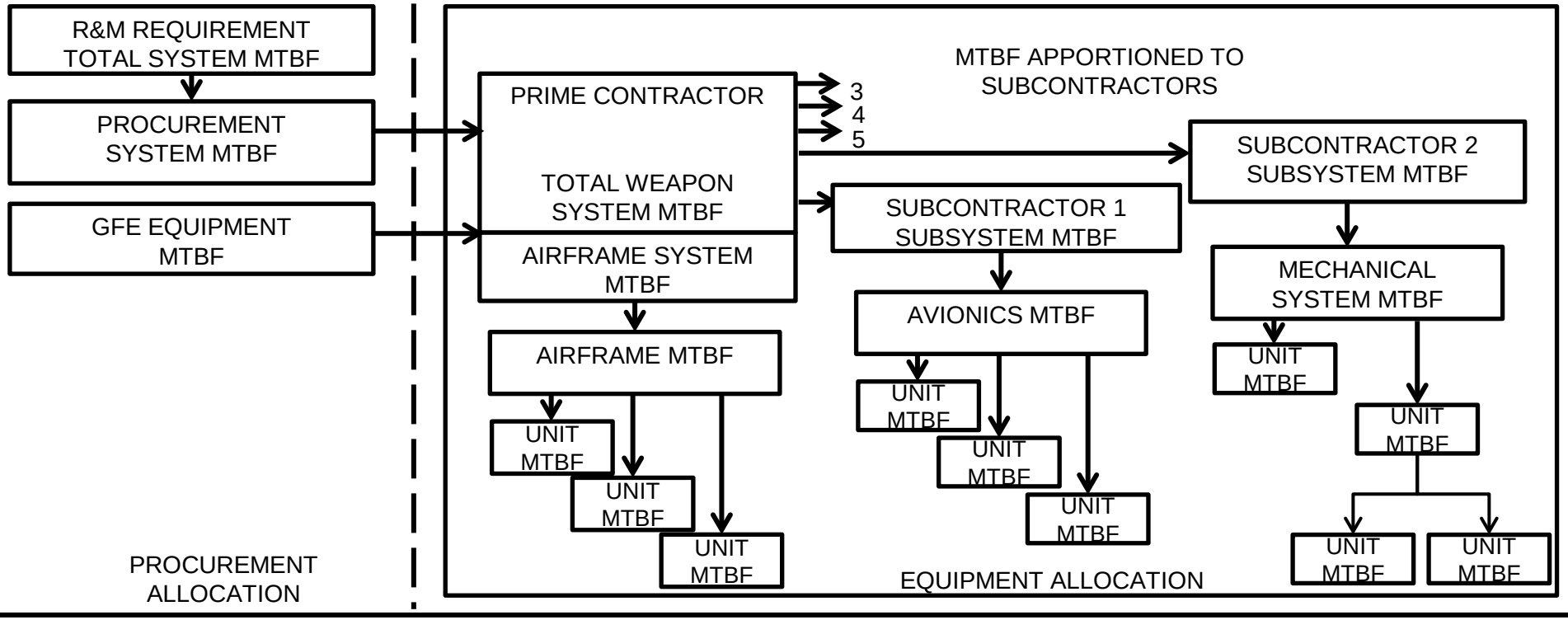
Parallel



$$R = 1 - \prod_{i=1}^{n} (1 - R_i) = 1 - (1 - R_A)^2$$

Systems can be represented as a combination of series, parallel, and complex segments (subsystems). Consequently, by finding the reliability of the distinct segments of the system, the overall reliability of the system can then be found as the product of the segment reliabilities.

R&M Allocations



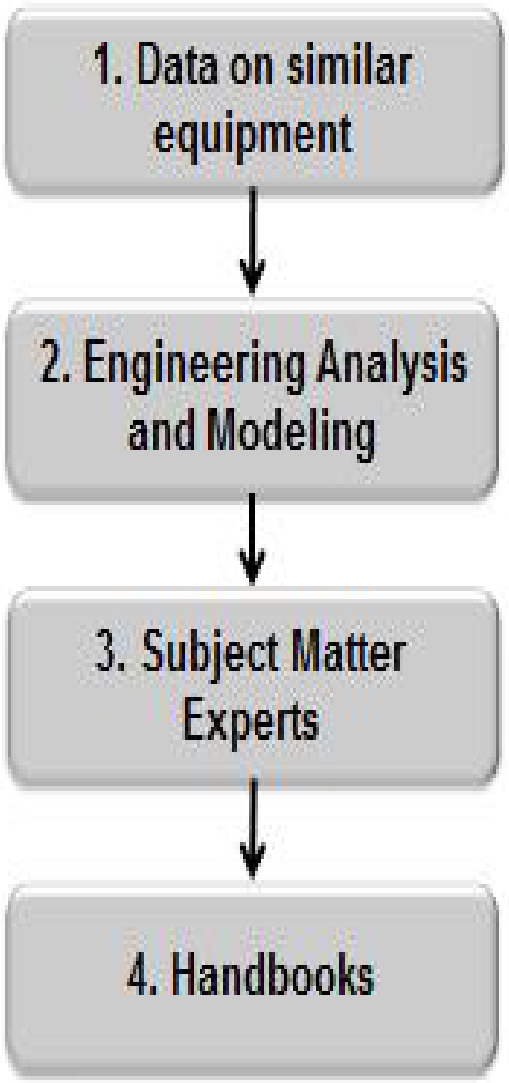
Apportionment or division of reliability requirements to achieve overall reliability and mission objectives

<u>Purpose</u>

<u>Engineering</u> – Assign system reliability requirements compatible with mission demands

<u>Procurement</u> – Assign unit hardware reliability values compatible with the procurement allocation

R&M Prediction



- Four prediction methods can be used to produce deterministic or probabilistic predictions for reliability of components
- Existing test or field data from a similar system is the most desirable approach
- Second preference is analysis and physics-based modelling or accelerated life testing. A FMEA process combined with experience can help identify leading causes of failure
- Third preference is to consult SMEs that can develop a range of likely reliability values in a short time
- A combination of the first three methods is the best way to produce accurate predictions
- Fourth preference is to use reliability prediction handbooks such as MIL-HDBK-217, *Reliability Prediction of Electronic Equipment*

An engineering analysis of a system design to determine its future behavior

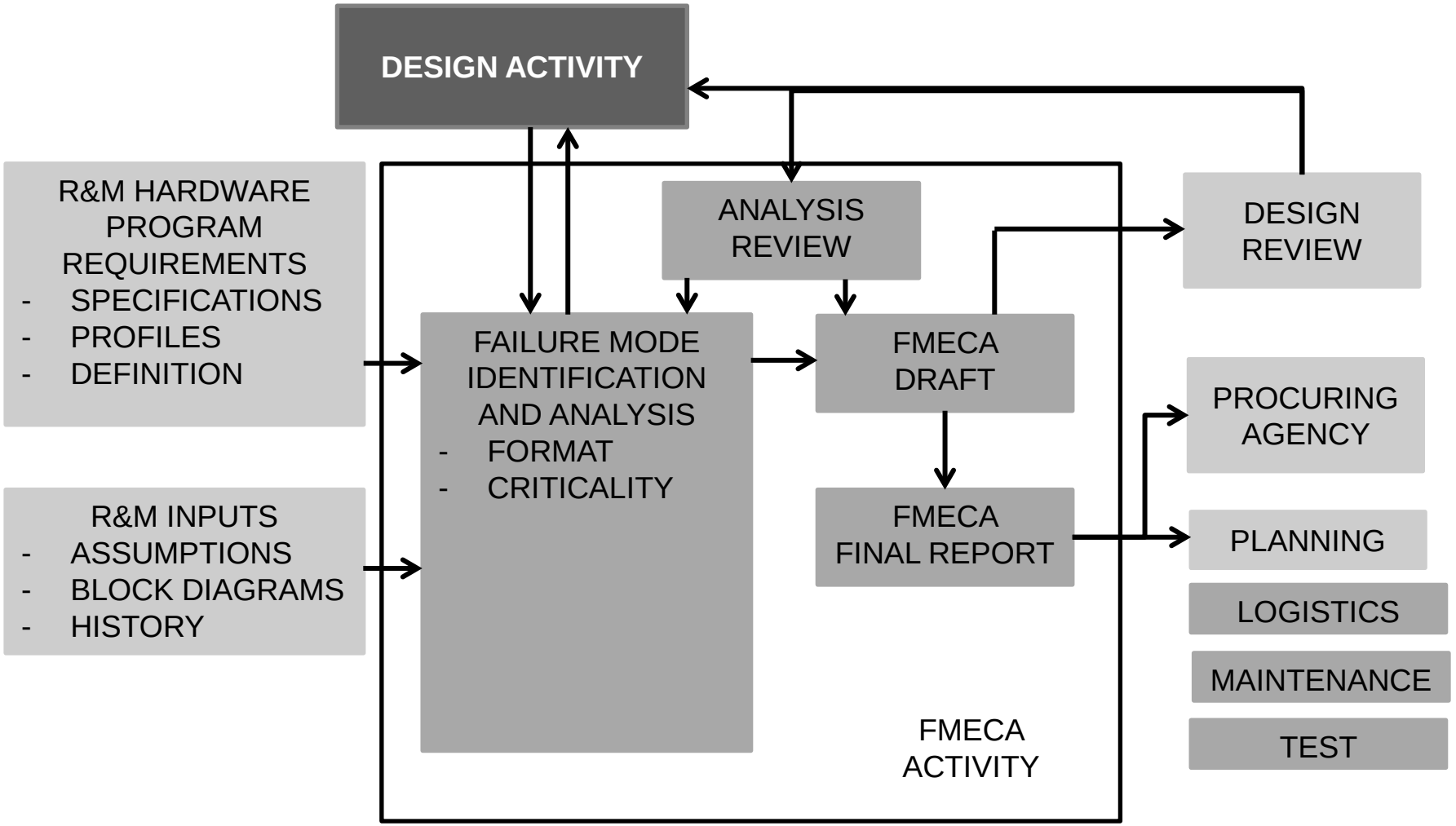
Estimate future:
- **Equipment and system behavior**
- **Mission performance**

Prediction Application:
- **Design corrective actions**
- **Design trade-off studies**
- **Allocations**
- **Failure prediction to logistics and maintenance**
- **Flight and mission operations**

Failure Mode, Effect and Criticality Analysis (FMECA)

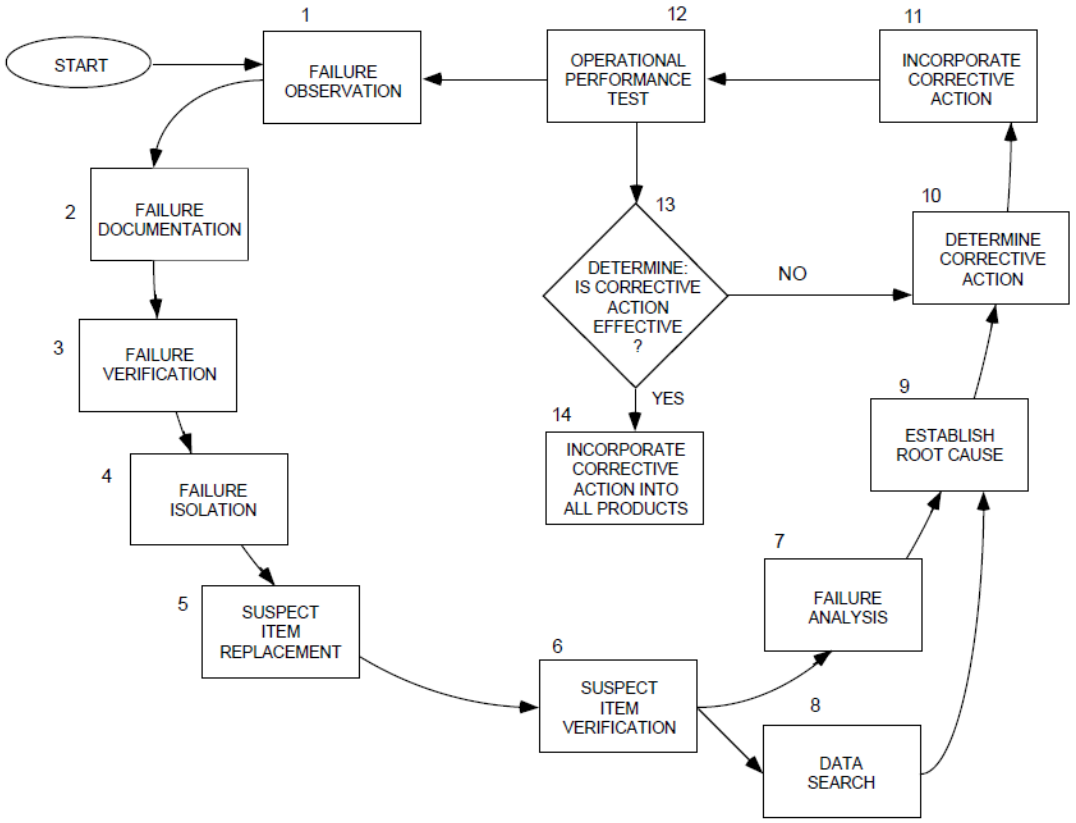
- **A systematic analytical technique performed by reliability engineering**
  - Early identification of all catastrophic safety and mission failure possibilities
  - Systematic identification and analysis of all predictable failure modes within a system
  - Systematic identification of all predictable mission critical and safety critical failure modes (criticality)
  - An analysis format organized for later product support roles
- **FMECA Application**
  - Corrective design action
  - Reliability for design, trade-off studies and design reviews
  - Reliability and maintainability analyses
  - System safety and hazard analyses
  - Test and evaluation
  - Logistics, maintenance, and Failure Reporting, Analysis, and Corrective Action

FMECA Flow Chart



FRACAS

- **FRACAS (Failure Reporting, Analysis, & Corrective Action System)**
  - To be implemented by the program at all levels
  - All failures are analyzed to identify failure cause and devise corrective actions
  - Initiated with the start of the test program and continues through the stages of development



Closed Loop FRACAS Diagram

Maintainability & BIT Demos

- **Subsystem/Equipment BIT Assessment Test: Provides an early indication of actual hardware and software BIT capabilities in the areas of fault detection and fault isolation**

- **Maintainability Demo: Assesses maintainability critical areas, verifies conformance of system maintainability requirements and maintenance concepts, and identifies installation physical interface problems for correction**

- **System-level BIT Demo: Verifies compliance with BIT requirements and the adequacy of all applicable BIT recording, reporting, and display functions for both the operator and maintainer**

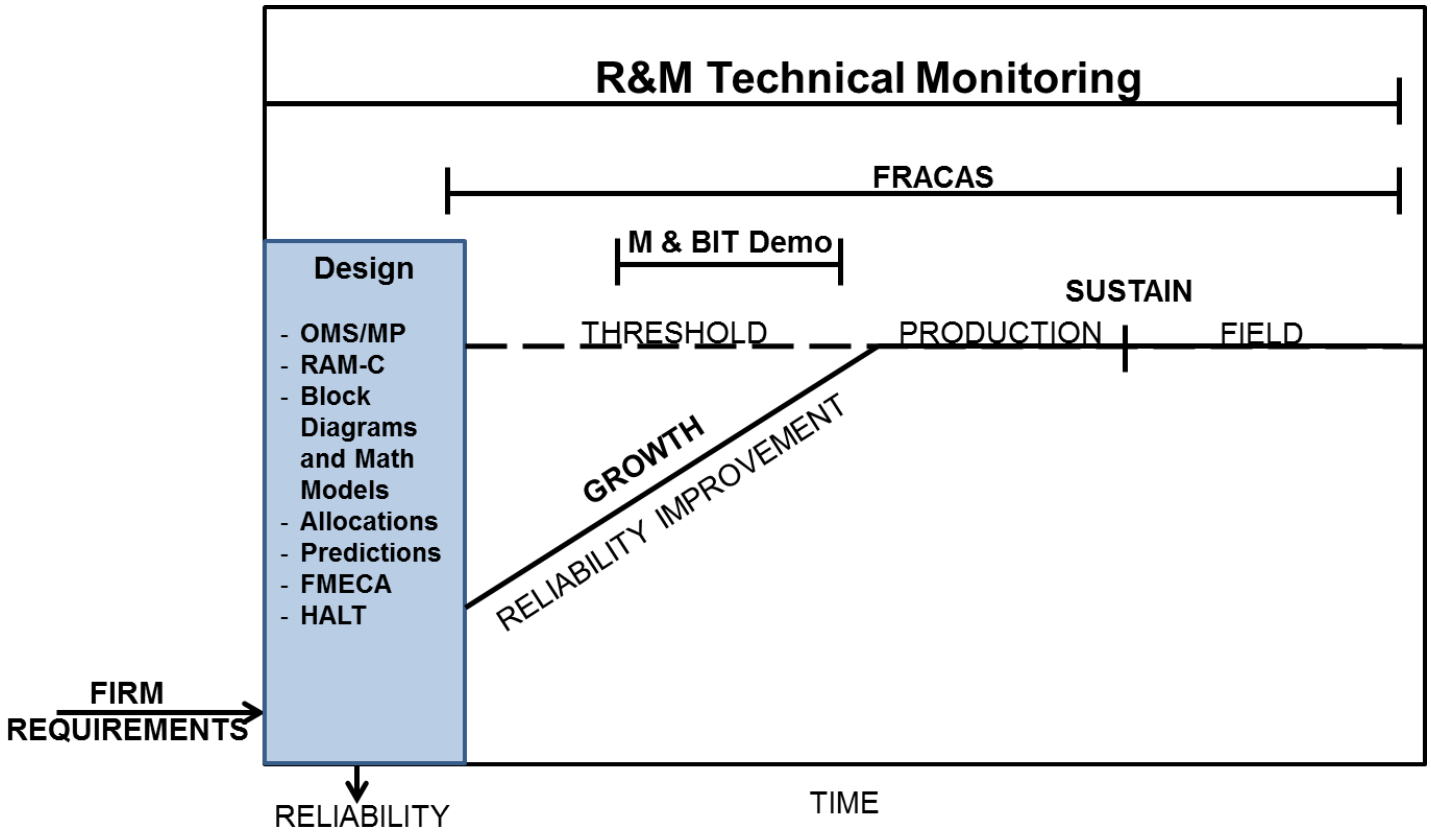
Reliability Growth Strategy

- **Reliability growth is possible at any point in the system life cycle.**
  - Changes accomplished early in the life cycle cost less and affect reliability more significantly, but the information upon which early changes are based tends to contain many unknown factors.
  - Design changes made later in the life cycle tend to be better applied as there are fewer unknowns in the information.
  - Programs should not rely only on testing but should use a number of information sources to grow reliability.
  - Reliability Growth Curves should be used to plan, monitor, and track reliability progress-to-plan.

Reliability Growth Strategy

- **Reliability Growth Through External Experience and Lessons Learned**
  - Historical data, publications, technical experience of personnel, lessons learned, and information from currently operating systems
- **Reliability Growth Through Design Techniques**
  - Design simplification, redundancy, margins of safety, probabilistic design, physics of failure techniques, and derating.
- **Reliability Growth Through Engineering Analysis**
  - Block diagrams, predictions, and Failure, Mode, Effects, and Criticality Analysis (FMECA), Fault Tree Analysis, Design Reviews
  - Saves test time and resources
- **Reliability Growth Through Testing**
  - Design verification tests, conventional reliability growth tests, accelerated life tests, HALT, environmental and functional qualification tests, environmental stress screens, FRACAS.
- **Reliability Growth Through Production Experience**
  - Quality assurance and control
- **Reliability Growth Through Operational Experience**
  - Monitoring fielded systems. Least desirable, but inevitable in most cases.

R&M Technical Monitoring



- **Design and Manufacturing Monitoring**
  - Post Award Reviews
  - Technical Reviews
  - Test Readiness Review
- **Test Monitoring**
  - RDGT
  - H/ALT
  - M Demo
  - System Level Testing

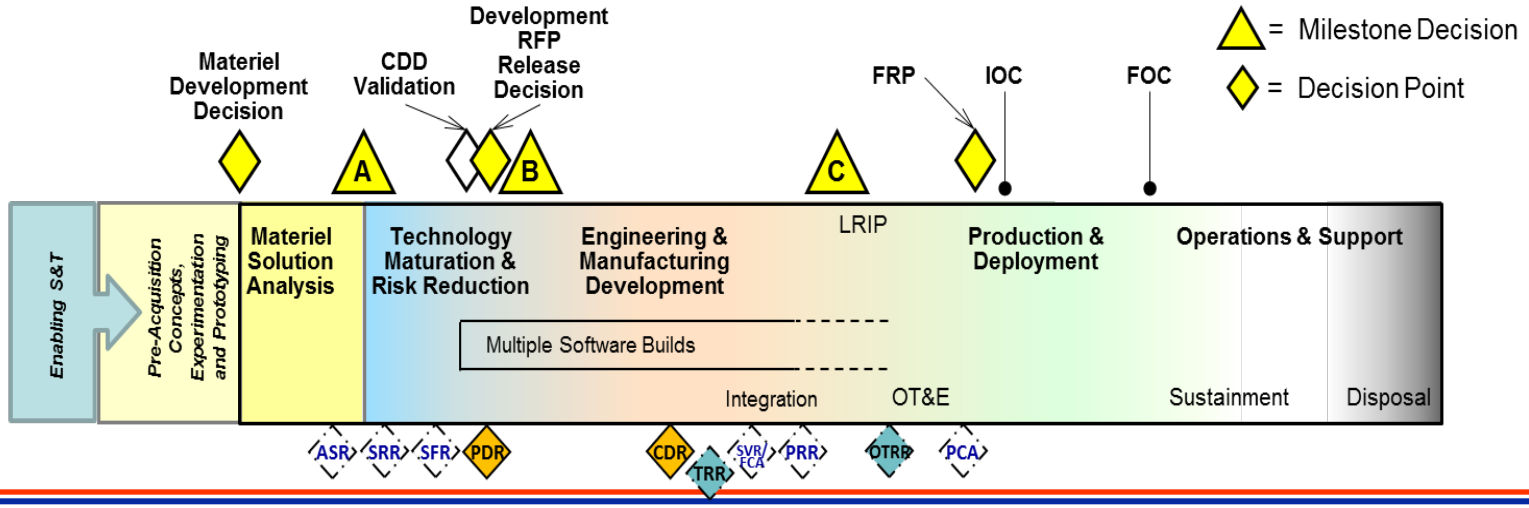
R&M Technical Monitoring must be continuous throughout the life-cycle of the program.

R&M Engineering Disciplines

Activity	Description	Purpose	Benefit
Mission Profile Definition	Provides an accurate representation of actual mission characteristics, pertinent environments, and functions	To develop realistic functional and environmental design requirements for all equipment	Ensures effective design requirements are used, and that ensuing tests use realistic environments
Environmental Study	Detailed evaluation of the environment the system will operate in	Determine the impact the operating environment has on reliability; basis for future test profiles	Establishes system environmental design limits and test profiles
Allocations	Apportions numeric targets to lower level assemblies	Provides IPTs with R&M targets	Management tool to attain top level R&M requirements
Block Diagram and Math Models	Describes relationships of elements that make up the design	Create the necessary models for allocation and predictions	Identifies critical elements and need for redesign or redundancy
Predictions	Numeric R&M analysis of the item	Predicts inherent R&M to determine if requirement can be met	Establishes if design can meet the requirements
FMECA	Analysis of each failure mode to determine the resulting effects on system performance	Identifies critical part and single point failures for redesign opportunity	Systematic identification of failures that negatively impact mission success and safety
FRACAS	A closed loop process that documents failures and establishes trends and corrective actions	Process to identify corrective actions for failures experienced during system development	Essential to mature reliability
Design Reviews	Series of reviews to assess the Contractor's design progress	Forum used to make known current progress of R&M efforts	Program vehicle to raise R&M issues to the highest levels in order to obtain resolution
M and BIT Demo	Exercises the BIT functions on all equipment and systems in the laboratory and on the actual system	Determines whether required M & BIT performance are achieved	Matures M and BIT by finding and correcting problems in both HW and SW
Equipment/Subsystem RDT/HALT	Application of environmental stresses to identify and eliminate failure modes	To mature the system design	Matures reliability to achieve system requirements

Section 4: Key R&M Activities by Phase

- Materiel Solution Analysis (MSA)
- Technology Maturation and Risk Reduction (TMRR)
- Engineering and Manufacturing Development (EMD)
- Production and Deployment (PD)
- Operations and Support (O&S)



MSA Key R&M Activities

- Analyze conceptual design approaches and estimate the feasibility with respect to R&M ICD performance capabilities
- Translate ICD performance capabilities and draft CDD thresholds to R&M specification requirements based on operational mode summary / mission profile (OMS/MP), failure definitions, and utilization rates
- Develop a system reliability growth planning curve and attach it to the SEP. If a single curve is not adequate to describe overall system reliability, curves for critical subsystems, with rationale for their selection, should be provided
- Define contractor R&M engineering activities in the RFP and contract SOW for the TMRR phase

TMRR Key R&M Activities

- **Review results of R&M engineering analyses, verification tests, design approach, availability assessments, and maintenance concept optimization to verify conformance to requirements, and to identify potential R&M problem areas**
- **Contribute to integrated test planning to avoid duplication and afford a more complete utilization of all test data for R&M assessment**
- **Define contractor R&M engineering activities in the RFP and contract SOW for the EMD phase**

EMD Key R&M Activities

- Ensure the final FMECA identifies failure modes, and their detection methods, and ensure they are mitigated in the design
- Ensure the detailed R&M prediction to assess system potential to meet design requirements is complete
- Verify through appropriate subsystem/equipment-level tests the readiness to enter system-level testing at or above the initial reliability established in the reliability growth-planning curve in the SEP and the TEMP
- Implement a FRACAS to ensure feedback of failure data during test and to apply and track corrective actions
- Coordinate with the Chief Developmental Tester (T&E Lead) and Operational Test Agencies (OTA) to ensure that the program office and OTA data collection agree on R&M monitoring and failure definitions

PD Key R&M Activities

- Verify R&M characteristics, maintenance concept, repair policies, Government technical evaluation, and maintenance procedures by T&E
- Identify R&M and production-related BIT improvement opportunities via FRACAS and field data assessment
- Review Engineering Change Proposals (ECP), operational mission/deployment changes, and variations for impact on R&M
- Update R&M predictions and FMECAs based on production tests, demonstration tests, operational evaluation, and field results and apply them to the models previously developed to assess impacts on maintenance procedures, spares, manpower, packaging design, test equipment, missions, and availability

O&S Key R&M Activities

- **Assess operational data to determine adequacy of:**
  - R&M and BIT characteristics performance
  - Maintenance planning, features, and procedures
  - Provisioning plans
  - Test equipment design
  - Maintenance training
- **Identify problem areas for correction through ongoing closed-loop FRACAS and field data assessment**
- **Monitor availability rates and respond to negative trends and data anomalies**

Need for R&M Engineering
Key Objectives

- **Management commitment and attention**
- **Well defined mission oriented requirements**
- **R&M design and test activities correctly applied and tailored to all acquisition phases**
- **Realistic schedule associated with R&M disciplines**
- **Sustained reliability growth and maintainability maturation**
- **R&M activities monitored for effective implementation**
- **R&M assessments to inform decisions at key program reviews and milestones.**

Summary

- **Reliable, maintainable systems are NOT normally produced by routine development**
- **Application of appropriately tailored disciplines are needed to produce reliable and maintainable systems**
- **R&M design disciplines require vigorous pursuit and must be imposed on the contract**
- **R&M analyses can predict equipment behavior needed to reduce risk**
- **Timeliness essential in analysis**

R&M by Design and Not by Chance

For Additional Information

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Systems Engineering: Critical to Defense Acquisition










Defense Innovation Marketplace
http://www.defenseinnovationmarketplace.mil

DASD, Systems Engineering
http://www.acq.osd.mil/se