Department of Defense
Reliability, Availability, Maintainability, and Cost Rationale Report Manual

June 1, 2009

Prepared by the Office of the Secretary of Defense in Collaboration with The Joint Staff

Department of Defense
Reliability, Availability, Maintainability, and Cost Rationale Report Manual

Prepared by the Office of the Secretary of Defense in Collaboration with The Joint Staff

Citation of this work should appear as follows:

Department of Defense Reliability, Availability, Maintainability, and Cost Rationale Report Manual. 2009. Washington, DC: Office of the Secretary of Defense.

Point of Contact:

Office of the Deputy Under Secretary of Defense for
Acquisition and Technology
Systems Engineering
3090 Defense Pentagon
Washington, DC 20301

CONTENTS

TABLES

FIGURES

This page intentionally blank.

Foreword

The Department of Defense (DoD) needs to acquire reliable and maintainable products that are of high quality and readily available to satisfy user requirements in meeting mission capability and operational tasks. The Department must acquire these products at the most reasonable cost to the taxpayer. The cost to the government, however, is not just computed by the procurement costs, but also must balance the long-term costs incurred in maintenance, driven by reliability, availability, and other factors throughout the system life cycle.

The DoD Guide for Achieving Reliability, Availability, and Maintainability (RAM), published in 2005, is a useful document for project managers and engineers to plan for and design RAM into systems early in a program. This manual describes the development of the RAM and Cost Rationale Report (hereafter referred to as RAM-C Report). The guide was written to help capability document requirements writers and their supporting engineering organizations think through the top-level sustainment requirements for RAM-C early in the requirements generation and refinement phases of a program to ensure the system is sustainable and affordable throughout its life cycle.

The purpose of this manual is threefold:

1. Provide guidance in how to develop and document realistic sustainment Key Performance Parameter (KPP)/Key System Attribute (KSA) requirements and related supporting rationale
2. Provide guidance so the acquisition community understands how the requirements must be measured and tested throughout the system life cycle
3. Describe desired processes for the Office of the Under Secretary of Defense, Joint Staff, and other stakeholders to interface with Services and programs when developing the sustainment requirements.

Use of the processes outlined in this document will assist in assessing RAM-C for the alternatives considered in the Analysis of Alternatives and articulating the requirements and the supporting rationale in the Capability Development Document and Capability Production Documents and the Life Cycle Sustainment Plan.

Ashton B. Carter
Under Secretary of Defense for Acquisition, Technology and Logistics

Dr. Charles E. McQueary
Director
Operational Test and Evaluation

LTG Kathleen M. Gainey, USA
Director for Logistics
J4, The Joint Staff

This page intentionally blank.

1 INTRODUCTION

1.1 Background

The Department of Defense (DoD) expects to acquire reliable and maintainable products that are of high quality, readily available, and able to satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price. Developers of Joint Capabilities Integration and Development System (JCIDS) requirements documents (hereafter referred to as combat developers) and program managers must work together in developing mission and sustainment requirements that facilitate achieving this objective throughout the system life cycle.

The Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) issued new reliability, availability, and maintainability (RAM) guidance in the recent DoDI 5000.02, based upon a July 2008 policy memorandum. This guidance directs Services to implement RAM practices that ensure effective collaboration between the requirements and acquisition communities in the establishment of RAM requirements. The July 2008 policy memorandum also directed the publication of this manual.

The Department and some Services have issued policy letters to increase attention on reliability and maintainability during program acquisition phases. If reliability, maintainability, and logistics are not adequately designed into the system, there is risk that programs will breach Acquisition Program Baseline thresholds with significantly higher development or acquisition costs due to resulting corrective action costs; will cost more than anticipated to own and operate; or will fail to provide availability expected by the warfighter.

As a result of these concerns, the Chairman of the JCIDS Manual defined three mandatory sustainment requirements to ensure that effective sustainment is addressed and accomplished over the life cycle for all newly developed and fielded systems. These requirements include a Key Performance Parameter (KPP), Availability; and two Key System Attributes (KSA), Reliability and Ownership Cost.

In an August 2007 memorandum, the Joint Staff summarized the need in this way:

> *Sustainment is a key component of performance. Including sustainment planning "upfront" enables the acquisition and requirements communities to provide a weapon system with optimal availability and reliability to the warfighter at value.*
>
> *The value of the Sustainment KPP is derived from the operational requirements of the weapon system, assumptions for its operational use, and the planned logistical support to sustain it. In order for the program manager to develop a complete system to provide warfighting capability, sustainment objectives must be established and performance of the entire system measured against those metrics.*

Note that other metrics may be appropriate for a particular weapon system. For example, the warfighter may determine that the logistics footprint, manpower requirement, sortie generation rate, and so on, of a weapon system in a combat or mission environment is critical to the system's usefulness to the warfighter. Operational metrics of this type are not replaced by the Materiel Availability portion of the Sustainment KPP, and they must be considered throughout system development.

1.2 Sustainment Requirements Summary

The mandatory KPP and two supporting KSAs noted in section 1.1 are summarized here (see current version of the JCIDS Manual for full definition):

- *Availability KPP.* Availability will consist of two components: Materiel Availability (fleet) and Operational Availability (unit). The components provide availability percentages from a corporate, fleet-wide perspective and an operational unit level, respectively. The Operational Availability metric is an integral step to determining the fleet readiness metric expressed by Materiel Availability. The following provides guidance for development of both metrics:
  - Materiel Availability. Materiel Availability is a measure of the percentage of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given time, based on materiel condition. This measure can be expressed mathematically as number of operational end items/total population. The Materiel Availability addresses the total population of end items planned for operational use, including those temporarily in a non-operational status once placed into service (such as for depot-level maintenance). The total life cycle time frame, from placement into operational service through the planned end of service life, must be included. Development of the Materiel Availability metric is a program manager responsibility.
  - Operational Availability. Operational Availability indicates 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 use as identified in the Concept of Operations (CONOPS), including the planned operating environment, operating tempo, reliability alternatives, maintenance approaches, and supply chain solutions. Development of the Operational Availability metric is a requirements manager responsibility.
- *Reliability KSA.* Reliability measures the probability that the system will perform without failure over a specified interval under specified conditions. Reliability must be sufficient to support the warfighting capability needed in its expected operating environment. Considerations of reliability must support both availability metrics. Reliability may be expressed initially as a desired failure-free interval that can be converted to a failure frequency for use as a requirement.
- *Ownership Cost KSA.* Ownership Cost provides balance to the sustainment solution by ensuring that the Operations and Support (O&S) costs associated with availability (e.g., maintenance, spares, fuel, support.) are considered in making program decisions. For consistency and to capitalize on existing efforts in this area, the Cost Analysis Improvement Group O&S Cost Estimating Structure will be used in support of this KSA. (See the structure at the following website: http://dcarc.pae.osd.mil/reference/osd_ces/ndex.aspx). Appropriate sections of this document cover the specific elements involved in cost estimation.

1.3 Purpose

The intention of this manual is to assist combat developers and program managers in developing sustainment requirements and documenting the rationale used in a Reliability, Availability, Maintainability-Cost (RAM-C) Report, and help the development contractor to design and develop a successful product. This manual:

- Provides guidance in how to develop and document realistic sustainment KPP/KSA requirements and related supporting rationale
- Provides guidance so the acquisition community understands how the requirements must be measured and tested throughout the life cycle
- Describes desired processes for OUSD(AT&L), Joint Staff, and other stakeholders to interface with Services and programs when developing the sustainment requirements. (Services will implement a similar process for programs other than Joint Requirements Oversight Council (JROC) Interest.)

DoDI 5000.02 requires program managers to formulate a viable RAM strategy and document it in the Systems Engineering Plan (SEP) and (Life Cycle Sustainment Plan (LCSP). A RAM-C Rationale Report (RAM-C Report) documents the rationale behind the development of the sustainment requirements along with underlying assumptions. Understanding these assumptions and their drivers will help warfighters, combat developers, and program managers understand the basis for decisions made early in a program. When the requirements and underlying assumptions are not clearly documented, the project may be doomed to suffer from subsequent decisions based on incorrect assumptions. The Appendix provides the recommended format and content structure for a RAM-C Report.

1.4 Applicability

For materiel solutions designated “JROC Interest,” the combat developer (requirements writer) shall develop RAM-C Reports as part of the Analysis of Alternatives (AoA) and requirements generation processes, per the Appendix. Programs other than JROC Interest shall develop RAM-C Reports as determined by the DoD Component or program manager.

This requirement assumes a Materiel Development Decision (MDD) was made as a result of a JCIDS Capability-Based Assessment (CBA) and that a capability document is required and supported by an AoA, an approved Joint Operations Concept, CONOPS, and/or Functional Solution Assessment (FSA).

When an AoA is required and directed by the Office of the Under Secretary of Defense, Program Analysis and Evaluation (OUSD (PA&E)), the DoD Component tasked with completing the AoA will develop the initial RAM-C Report for Milestone A. Subsequently, the combat developer, with the program manager, will develop or update the RAM-C Report using the instruction in this manual throughout the program life cycle and include it in the program’s LCSP for Milestones B and C. The combat developer will summarize the RAM-C Report in an Executive Summary (between four and eight pages) attached as an annex or appendix to the Capability Development Document (CDD) or Capability Production Document (CPD) as appropriate. Information contained in the RAM-C Report, such as the Availability KPP and related KSAs rationale, operational mode summary, mission profile, failure definition, and scoring criteria should be included in system specifications and contract documents as appropriate.

The Executive Summary of the RAM-C Report will be entered into the JROC Knowledge Management/Decision Support (KM/DS) tool for staffing for applicable CDD and CPD requirements documents. Combat developers shall submit the RAM-C Report for JROC Interest programs to the Joint Staff, OUSD(AT&L), and Director, Operational Test and Evaluation (DOT&E) for review when submitting the JCIDS requirements document for JROC staffing.

1.4.1 Milestone A Decision

The initial RAM-C Report should be appended to the AoA in preparation for a Milestone A decision. This report may be limited in scope due to the many unknowns at this stage of program, but will still articulate the RAM and sustainment requirements in terms of a preferred system concept, support and maintenance concept, and technology development strategy. However limited the scope may be, it is essential to document the reliability, maintainability, and supportability assumptions and rationale made early in the program.

1.4.2 Milestone B Decision

The combat developer and the program manager will develop or update the RAM-C Report from the AoA to support the development of the CDD in preparation for a Milestone B (MS B) decision. Whether a program is initiated at MS B or has been through a Technology Development (TD) Phase, this RAM-C Report will be the first detailed report that includes a comprehensive analysis of the system and its planned use. This analysis includes the planned operating environment, operating tempo, sustainment requirements, maintenance concept and product support approaches, and supply chain solutions with appropriate assumptions. The RAM-C Report will provide a clear statement of how the system's sustainment requirements will be measured throughout Engineering and Manufacturing Development (EMD), Production and Deployment, and the Operations and Support Phase. At MS B, the RAM-C Report will be submitted with the Life Cycle Sustainment Plan. The combat developer will include an Executive Summary of the RAM-C Report as an annex or appendix to the CDD. Sustainment requirements in the CDD will reflect the insights gained from the development and evaluation of competitive prototypes in the TD phase and will provide a balanced solution of what desired technologies can be developed realistically within program cost, schedule, performance, and sustainment parameters.

1.4.3 Milestone C Decision

The combat developer will update the RAM-C Report in conjunction with the program manager to support the development of the CPD in preparation for a Milestone C decision based on demonstrated performance during test and evaluation, along with appropriate trades to balance cost, schedule, and achievable requirements. Whether a program is initiated at Milestone C (MS C) or has been through an EMD phase, this RAM-C Report will include a comprehensive analysis of the system and its planned use. If MS C follows an EMD phase, this RAM-C Report will update the RAM-C Report submitted prior to the MS B decision and will be submitted with the Life Cycle Sustainment Plan. It will show where assumptions were valid or not valid, as well as changes made to the system or planned operating use or environment as a result of test results, and will become the measurement baseline for follow-on phases in the life cycle. Combat developers and program managers for the system will coordinate and approve the RAM-C Report prior to the CPD being submitted to the Joint Staff. The combat developer will include an Executive Summary of the RAM-C Report as an annex or appendix to the CPD.

1.4.4 Full-Rate Production

The combat developer, with assistance from the program manager, will update the RAM-C Report for the Full-Rate Production decision using test data and evaluation reports. At a minimum, these updates should cover Initial Operational Test and Evaluation (IOT&E) data (including minimum test length, minimum number of units tested, and demonstration of the maintenance concept during Operational Test (OT)), RAM concerns from the Operational Test Activity (OTA) report, and DOT&E Beyond Low-Rate Initial Production (BLRIP) data.

1.4.5 Exceptions

Programs already operating under an Operational Requirements Document (ORD), CDD, or CPD approved prior to when the Sustainment KPP and KSAs were mandated in May 2007 are exempt from developing a RAM-C Report unless directed by the JROC. If subsequent revisions to a CDD or CPD include sustainment requirements, a RAM-C Report will be developed. However, Acquisition Category (ACAT) I and Major Automated Information System program managers shall develop appropriate metrics by which to measure and report materiel availability, reliability, and Ownership Costs.

2 Reliability, Availability, Maintainability, and Cost Development Report Overview

Figure 2-1 shows the significant activities conducted during the life cycle to develop the RAM-C Report and which stakeholder is primarily responsible for that activity. Table 2-1 provides program phase-level activities related to sustainment requirements and measures. Table 2-2 covers stakeholder tasks and responsibilities. The figure and tables are provided to support the discussion of this section.

2.1 "Who"—Documents Sustainment Requirements Rationale?

The combat developer, having received insights or inputs from the warfighter regarding requirements and failure definitions, is primarily responsible for documenting the sustainment requirements, with significant assistance from the program manager (to include program management, systems engineering, and logistics support). The RAM-C Report development process includes stakeholders from the lead DoD Component, Services, the combat developer, program manager, Office of the Under Secretary of Defense, Joint Staff, and appropriate Operational Test Activities and other relevant Test and Evaluation activities.

The identified perspectives of each stakeholder, by program phase, as well as their objectives and responsibilities are shown in Table 2-2. The intent of this discussion is to ensure that each community's inputs are recognized and addressed as a part of the sustainment requirements development processes.

The initial RAM-C goals should be articulated by the lead DoD Component and its combat developer in the Analysis of Alternatives prior to the Milestone A decision. The subsequent RAM-C sustainment requirements are documented in the RAM-C Report by the combat developer as the CDD or CPD is being drafted, with significant support from the program manager.

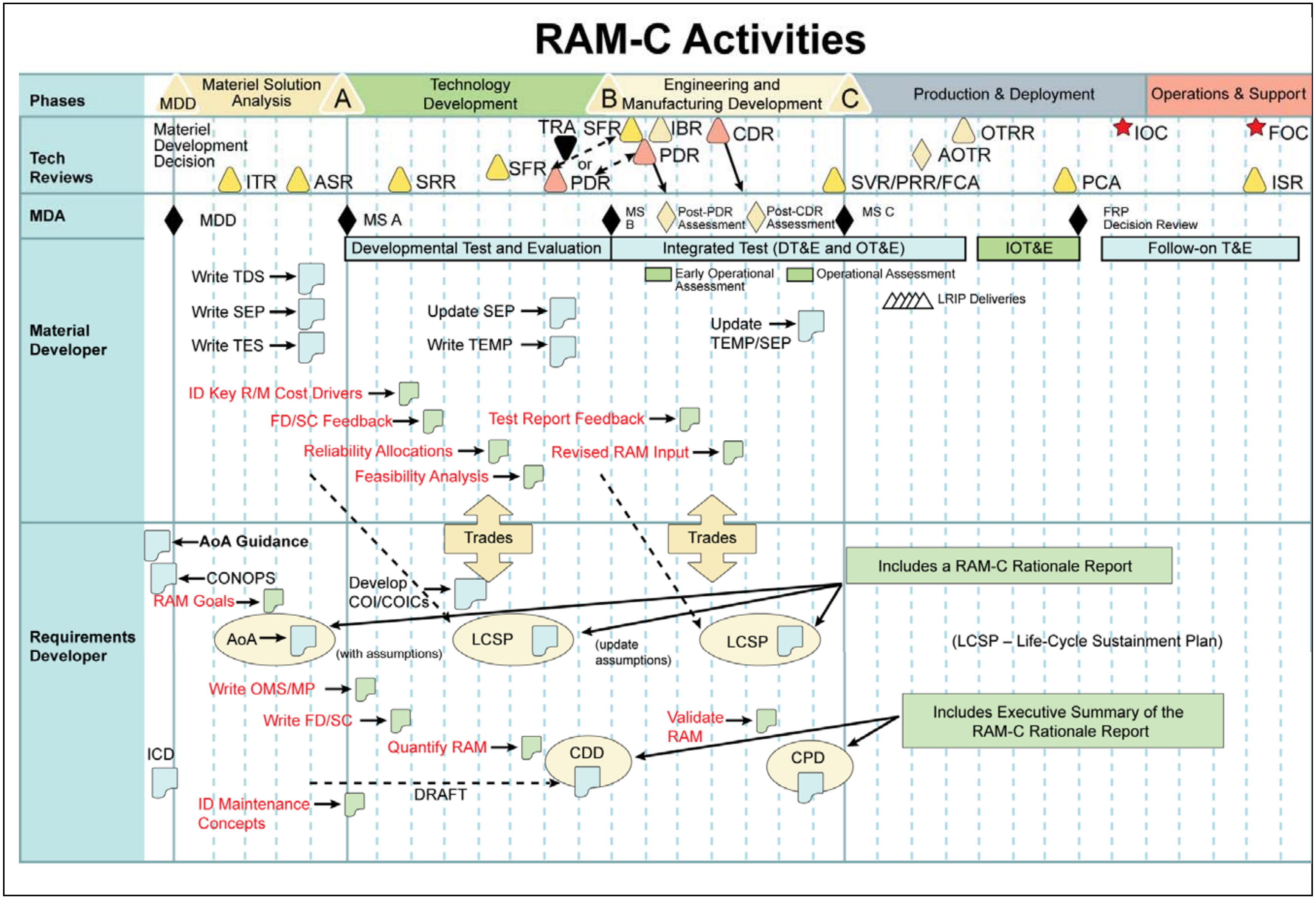

Figure 2-1 RAM-C Activities Throughout the Life Cycle

∞

Table 2-1 Sustainment Requirements and Measures by Phase

Metric	Milestone	How Measured	Responsible Activity	When Measured	Program Phase Metric
Availability Materiel Availability (A_M) Operational Availability (A_O)	A	Comparative Analysis with Legacy Systems and/or Engineering Assessment	Program Manager (PM) or Program Sponsor if PM Not Assigned	Pre-Alternative System Review (ASR) for All Candidate Systems Post-ASR for Preferred System Selected	$\frac{\text{(number of operational end items)}}{\text{(total number of end items acquired)}}$ or $\frac{\text{uptime}}{\text{uptime} + \text{downtime}}$ Value is "as planned" given the expected system use and support concept.
(KPP)	B	Demonstrated through Testing Plus Modeling/ Simulation Where Needed	Test and Evaluation Activity	During DT and Early Operational Assessments	Scored failure rate per FD/SC MTBF if all failures classified as critical and MTBM otherwise MDT* modeled from MTTR, LDT, and ADT values MDT estimates from early in program; Replaced by data as available
	C	Demonstrated through Testing and Analysis of Early Fielded System Performance	Test and Evaluation Activity and Program Manager	During DT, DT/OT, and Operational Assessments	Scored failure rate per FD/SC MTBF if all failures classified as critical and MTBM otherwise MDT* modeled from MTTR, LDT, and ADT values
	FRP and beyond	Demonstrated through Analysis of Fielded System Performance	OTA and Program Manager	During IOT and throughout Remainder of System Life Cycle	$\frac{\text{(number of operational end items)}}{\text{(total number of end items acquired)}}$ or $\frac{\text{uptime}}{\text{uptime} + \text{downtime}}$

**Note: MDT = MTTR + mean ADT + mean LDT. For the purposes of estimating the value of AM achieved, MTBF and MTTR are determined from test results while mean ADT and mean LDT shall be representative of the fielded system ADT and LDT as planned and implemented. See Section 3.2.3 for a discussion of why the definition for AM is different from definitions of AO.*

Table 2-1 Sustainment Requirements and Measures by Phase *(continued)*

Metric	Milestone	How Measured	Responsible Activity	When Measured	Program Phase Metric
Reliability (R_M) (KSA)	A	Comparative Analysis with Legacy Systems and/or Engineering Analysis	Program Manager or Program Sponsor if PM Not Assigned	Pre-ASR for All Candidate Systems Post-ASR for Preferred System Selected	MTBF/MTBM derived from warfighter's stated needs and translated into contract-level testable values.
	B	Demonstrated through Testing, Analysis, and Modeling/ Simulation	Test and Evaluation Activity	During DT and Early Operational Assessments	Scored failure rate per FD/SC MTBF if all failures classified as critical and MTBM otherwise
	C	Demonstrated through Testing, Analysis, Modeling/ Simulation, and Analysis of Early Fielded System Performance	Test and Evaluation Activity and Program Manager	During DT, DT/OT, and Operational Assessments	Scored failure rate per FD/SC MTBF if all failures classified as critical and MTBM otherwise
	FRP and beyond	Demonstrated through Analysis of Fielded System Performance	OTA and Program Manager	During IOT and throughout the Remainder of System Life Cycle	Scored failure rate per FD/SC MTBF if all failures classified as critical and MTBM otherwise

Table 2-1 Sustainment Requirements and Measures by Phase *(continued)*

Metric	Milestone	How Measured	Responsible Activity	When Measured	Program Phase Metric
Ownership Cost (OC) (KSA)	A	Comparative Analysis with Legacy Systems or Documented Analysis when Legacy Systems Unavailable	Program Manager or Program Sponsor if PM Not Assigned	Pre-ASR for All Candidate Systems Post-ASR for Preferred System Selected	Initial, rough approximation based on projected energy and maintenance costs for assumed inventory and operating tempos and "placeholders" for Sustaining Support and Continuing System Improvements
	B	Results of Prototype Testing; Projected Requirements for Sustaining Support and Continuing System Improvements As Described in the Cost Analysis Requirements Description (CARD)	Program Manager with Inputs from Test and Evaluation Activity and Contractors	During DT and EUT	For energy and maintenance, refined estimate based on demonstrated results in testing. Estimates for Sustaining Support and Continuing System Improvements, as described in the CARD, are refined based on analysis of test results and similar, legacy systems.
	C	Results of Prototype Testing During EMD; Approved Sustainment Plan, As Described in the CARD.	Program Manager with Inputs from Test and Evaluation Activity and Contractors	During DT, DT/OT, and LUT/ Operational Assessment	Further refined estimates for all four OC elements, based on EMD test results and validated requirements for Sustaining Support and Continuing System Improvements
	FRP and beyond	Demonstrated through Analysis of Fielded System Performance	OTA and Program Manager	During IOT and throughout the Remainder of System Life Cycle	Updates based on actual energy consumption, maintenance, Sustaining Support and Continuing System Improvements costs.

Table 2-2 Stakeholder Tasks/Responsibilities

Stakeholder	Tasks/Responsibilities
Combat Developer	• Has primary responsibility for drafting sustainment requirements and rationale articulated in the RAM-C Report • Drafts the Operational Mode Summary/Mission Profile and Fault/Failure Definition and Scoring Criteria • Develops the maintenance and support concepts articulated in the CONOPS, CDD, and CPD • Solicits warfighter insights or inputs into sustainment requirements, fault/failure definition and scoring criteria, maintenance/support concepts
Program Manager (Program Sponsor if PM not yet assigned)	• Supports the combat developer in providing expert engineering and supportability analysis in developing sustainment requirements detailed in the applicable JCIDS document (CDD and CPD) • Responsible for implementing design for R&M and demonstrating it through M&S, analysis, and event-driven component, subsystem, and system-level testing • Ensures development of the Product Support Elements (IETMs, provisioning, training, support equipment, etc.) required to implement the support concept • Establishes Performance-Based Agreement (PBA) with Product Support Integrators/Providers • Provide data for calculation/estimation of Ownership Cost metric
Office of the Secretary of Defense (OSD)	• Provides management, test, and technical oversight as appropriate • PA&E provides Analysis of Alternative Guidance • CAIG will conduct assessment of RAM-C Reports when conducting independent cost estimates in support of Milestone Reviews
Joint Staff	• Staffs and approves requirements in accordance with the JCIDS process
DoD Component (Lead Service)	• As directed, conducts the Analysis of Alternatives and includes the results of sustainment analysis in the briefings and final report
Test and Evaluation Activities	• Provides appropriate input into the statement of requirements to ensure they are articulated in measurable and testable terms while also providing input into the validity and clarity of assumptions • Confirms sufficiency of test assets and schedule to support the RAM evaluation efforts to measure system reliability and demonstrate maintenance concepts • Verifies test program includes sufficient time for retest of any needed corrective actions • Measures and evaluates A_M, A_O, and R_M

2.2 "Why"—Develop a RAM-C Report?

Historically, systems have been found unsuitable due to RAM issues identified during Developmental Testing and Operational Testing because the RAM was ill-defined or was traded away without understanding the impact of doing so. This manual, requiring the development of a RAM-C Report, helps avoid these pitfalls. A RAM-C Report documents the rationale behind the development of the sustainment metric requirements along with underlying assumptions. Understanding these assumptions and their drivers will help warfighters, combat developers, and program managers understand the basis for decisions made early in a program, and is essential to subsequent implementation and evaluation.

Particular emphasis is given to the interactions required between the various stakeholders to develop the CDD and the CPD. These documents form the basis of the solutions that integrate acquisition and sustainment and produce systems that meet warfighter needs. To develop the sustainment requirements, the combat developer must first understand the operational context in which the system will operate. Finally, the RAM-C Report makes sure that the combat developer identifies reasonable sustainment requirements to support a formalized process ensuring that the program manager understands the requirements. From here, the program manager can implement activities to design in RAM to increase the probability that systems are operationally suitable during use (as early as the IOT&E), and actual Ownership Costs do not exceed projections.

2.3 "When"—RAM-C Report from Start to Finish Overview

Figure 2-2 provides the timeline for major RAM-C Report submittals throughout the Defense Acquisition System Framework. The lead Component, working with the combat developer and the program manager, starts drafting the RAM-C Report at the beginning of the TD and EMD phases. The RAM-C Report in the AoA is updated prior to submittal of the CDD and CPD documents for each Milestone decision.

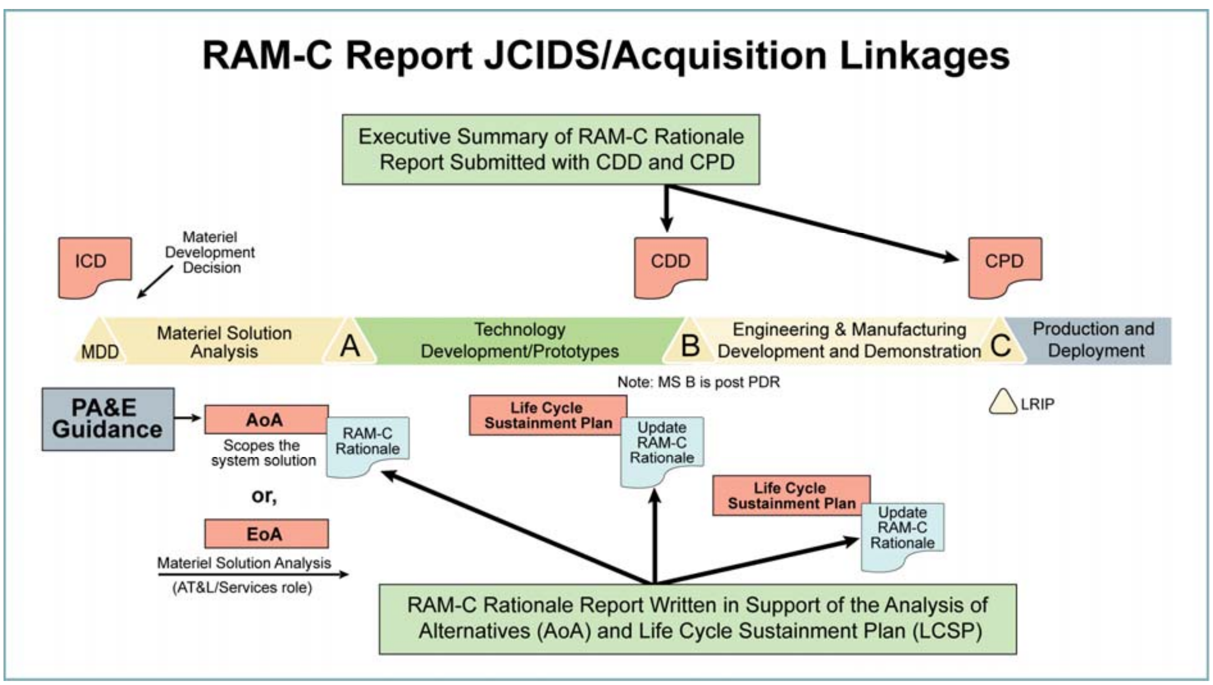

Figure 2-2 Defense Acquisition System RAM-C Report Submittal Events

2.4 "How"—RAM-C Report From Start to Finish Overview

The logical process of developing sustainment requirements includes well-defined activities to arrive at values that are realistic, achievable, measurable, documented, and therefore defendable. The activities are summarized below and discussed in detail in Section 3. Results of these activities are documented in the RAM-C Report and define the proposed sustainment requirements.

The first step in developing sustainment requirements is the preparation of a draft CONOPS by the combat developer. The CONOPS identifies the role of the system in providing the capability needed by the warfighter in terms of how it will be used operationally.

Following the development of the CONOPS, the combat developer must articulate the mix of ways the system performs its operational role in an Operational Mode Summary and Mission Profile (OMS/MP). This includes the relative frequency of the various missions, which systems will be involved in those missions, and the types of environmental conditions to which the system will be exposed during the system life cycle. The OMS/MP describes the tasks, events, durations, frequency, operating conditions, and environment of the system for each phase of a mission.

Following the development of the CONOPS and OMS/MP, the combat developer must decide what minimal operational tasks the system must be able to perform in order to accomplish its mission, as well as what the associated mission essential functions are in order to identify and classify potential failures. This information is documented in the Failure Definition and Scoring Criteria (FD/SC). The combat developer should receive assistance in developing the FD/SC from the program manager, to include sustainment and appropriate OTAs and relevant test activities.

The combat developer uses the OMS/MP and FD/SC 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. All of this information is used to draft initial Availability, Reliability, and Ownership Cost goals and to document supporting rationale and assumptions.

The program manager takes the above information from the combat developer and determines what is achievable based on technology maturity, and other factors. The combat developer and program manager must enter into a continuous dialogue so that appropriate trade studies can be completed and further analysis conducted to inform appropriate combat developer trade decisions.

Once the combat developer and program manager have reached agreement on a balanced solution with acceptable trades based on the state of the possible, the combat developer needs to identify the appropriate sustainability requirements for inclusion in the CDD/CPD.

If done correctly, the combat developer will avoid writing requirements with language such as, "equal to or greater than predecessor system," or "50 percent less to support than the predecessor system." Doing so can make the requirements difficult to measure, because many times the predecessor system requirements are not known or are incompatible with the new system. The written requirement must be measurable and testable.

The combat developer then includes the requirements in the RAM-C Report along with the definitions of the measurable parameters, and the rationale and assumptions behind the determination of the requirements.

In the end, the sustainment requirements must enable warfighter functional requirements and be measurable and obtainable. Unrealistic, missing, ambiguous, or conflicting requirements affect the development process, result in unacceptable or unachievable performance levels, and drive acquisition and sustainment costs. All requirements must carefully balance technological feasibility with operational needs and desires, and are subject to tradeoff in order to optimize Availability.

The requirements development process concludes when all inputs are translated into Materiel Availability (A_M), Operational Availability (Ao), Materiel Reliability (R_M), and Ownership Cost (OC), accompanied by supporting rationale. The resulting lower-level requirements, as identified by the combat developer, and rationale are documented in the CDD and the CPD, depending on the program phase. The lower level requirements, such as Mean Time to Repair (MTTR), Administrative Delay Time (ADT), and Logistics Delay Time (LDT), are used in evaluating the resulting sustainment requirement values.

2.5 General Documentation Approaches when Developing the Sustainment Metrics

2.5.1 Sustainment Metric Tracking Matrix

Development of a program performance, systems indicator, and requirements metric matrix is a suggested tool for documenting the program's progress in determining and demonstrating the Sustainment Metrics. At a minimum, the matrix should contain:

- Definition of each metric (A_M, A_O, R_M, and OC)
- Threshold and Objective values
- Explanation of the methodology used to determine the values and how they will be calculated
  - This explanation should include the data sources, models, estimating relationships, and/or tools used
- Planned approach to monitoring (i.e., how data will be collected and measured) and validating the value achieved
- Current and historical projected values updated as the system matures

2.5.2 Components of the Tracking Matrix

1. A_M—When identifying the A_M goal, all key logistics elements must be considered and evaluated for their effect on sustainment prior to declaring an achievable A_M. The SEP should document the process (modeling, simulation, etc.) used to derive the A_M metric. Sensitivity analysis should be employed in determining what is achievable and what is not. Some examples of these key logistics elements are:
   - Depot repair constraints

- Effects on transition from commercial transportation solution to Government transportation process
- RESET or recertification effects
- MTTR
- R_M

2. A_O—The effects on A_O of the key logistics elements described above will be different than they are for A_M since A_O applies to a subset of operationally fielded systems. For example, A_O is affected by how long it takes to replace a failed system with a spare when a spares/float concept is in place. Unlike A_M, in this case A_O is not affected by the time it takes to restore the failed system to operational readiness. Sensitivity analysis on A_O must include clear definitions of the varied operational states being considered as most systems will have different A_O values for each OMS/MP combination.

3. R_M—This is the total operating hours divided by the total number of failures during the total operating hours. Note that both mission reliability (e.g., failures that cause mission aborts) and basic reliability (all failures requiring maintenance) must be considered separately. In general, mission reliability supports calculations of A_O while basic reliability supports calculations of A_M. The SEP should provide the rationale for the R_M goals and state what engineering design elements have been selected as targets in order to achieve the specified reliability. The SEP should also include any requirements for Reliability Centered Maintenance, Condition Based Maintenance, and RESET/recertification if these activities are required to achieve the stated R_M.

4. OC—Implicit in the effort to reduce OC is the effort to reduce maintenance burden, infrastructure requirements, and logistics footprint as all of these are logistics degraders. To achieve these reductions in a systematic fashion, the PM should develop a defined starting point, or baseline, from which to measure the value of the evolving engineering design as it relates to reducing total ownership costs. For example, rather than developing a requirement to "reduce ownership costs by 25%" as a goal, the real goal should be to reduce OC to the minimum through a calculated systems engineering process with the end result achieved through the best engineering design possible. This is done by measuring the value of each identified logistics degrader of the system to be replaced or modified by determining a realistic cost of each degrader in a deterministic fashion.

   The PM should ensure that the frequency of occurrence (F), duration (D), and cost (C) elements of each degrader has been identified and captured in the baseline assessment, which should occur during the initial Supportability Analysis. The frequency of the disable occurring is, of course, driven by its reliability, by the duration of its maintainability attributes, and cost by the required labor/tools/test equipment to affect repair. This assessment, supportability = F x D x C, provides not only a realistic value to each disabler, but also provides the PM visibility as to what the major cost drivers were in the system being baselined.

   Inputs to the baseline can be derived by data mining from multiple sources, including, but not limited to, field maintenance data, FRACAS, and user experience. The baseline may be developed by contractual means through a vendor or by the Combat Developer. From this baseline the PM should ensure that the system design specification contains those design requirements targeting the frequency, duration, and cost of each identified disabler, targeting the high cost drivers as a priority. The PM should, with the concurrence of the user community, challenge the systems engineer and logistics engineer to synergistically develop a design that will reduce, in a measurable way, the OC of the system. This comparison of baseline ownership costs against the measurable design solution anticipated costs should be provided in the SEP to define what the intended reduction in OC is as a measurable percentage improvement. The design solution should be presented in WBS format as the basis for design scheduling.

5. MDT—The SEP should document the planned design approach to reduce MDT since this an obvious major degrader of system A_M.

2.6 Maintenance Concept and Support Plan Considerations

A discussion of maintenance concept and support plan concepts is included here in order to support the sustainment requirements development discussion in Section 3.

The maintenance concept is a general description of the maintenance tasks required in support of a given system or equipment and the designation of the maintenance level for performing each task. The maintenance concept is eventually implemented through a Life Cycle Sustainment Plan.

As an example, assume the "system" is a computer, with a CPU, keyboard, and mouse. The maintenance concept for the system is a two-level concept, organizational and depot. The organizational level maintenance will restore the computer to service by the removal and replacement of the Line Replaceable Units (LRU) (e.g., the CPU, mouse, and keyboard). The organizational level will forward the failed LRU to the depot for repair by removal or replacement of failed assemblies, subassemblies, or parts based on economic criteria (i.e., repair or discard).

Product support consists of the management/technical activities and resources needed to implement the maintenance concept, and establish and maintain the readiness and operational capability of a weapon system, its subsystems, and its sustainment infrastructure. Product support encompasses materiel management, distribution, technical data management, maintenance, training, cataloging, configuration management, engineering support, repair parts management, failure reporting and analyses, and independent logistics assessments. It also includes related support elements that may not be directly under the program manager's purview, such as cryptographic support. While the provider of the support may be public, private, or a public-private partnership, the focus is to achieve maximum weapon system availability at the lowest Total Ownership Cost (TOC). Life Cycle Sustainment Plans detail how the sustainment requirements and resources are managed over the life cycle.

3 SUSTAINMENT REQUIREMENTS DEVELOPMENT

3.1 Developmental Considerations of Sustainment Requirement Elements

3.1.1 Materiel Availability Is Not an Operational Readiness Metric

Discussion of the Materiel Availability (A_M) portion of the KPP must begin with the differences in purpose between A_M and operational readiness metrics. A_M measures the percentage of systems in operational use—providing a meaningful snapshot of the overall efficiency of the program elements (design, support structure, use profiles, planned and unplanned maintenance downtimes, and so on) to provide the necessary capability to the warfighter or end user. A_M is not a substitute for operational readiness metrics (such as Operational Availability (A_O), Mission Reliability, Mission Capability Rate). A_M provides the trade space between acquisition and support costs related to the system design and support approach. A_M applies to all end items acquired throughout their life cycle, while operational readiness metrics apply to end items in the operational environment only—excluding float/spare systems, systems at depot for overhaul or repair, systems that have not been operationally assigned, and so on. During tradeoffs, A_M should be optimized—not maximized—so that the system developed reflects a balance between acquisition and support costs and operational effectiveness. To be complete, system requirements must include operational readiness metrics, ensuring the capability developed is suitable for its intended use, and the mandatory sustainment KPP, ensuring that system life cycle cost is affordable and optimized.

3.1.2 Materiel Availability

The definitions of Availability (A_M) herein are taken from the JCIDS Manual establishing the applicability of the sustainment KPP. A_M is a characteristic of the system's design, support structure, and operational use profile. Definitions of A_M depend on the type of system, family of systems, or system of systems under development. Examples are provided below.

The most significant factor in A_M is system downtime. System downtime is strongly affected by decisions made during the development of the system design (pre-Milestone B). Downtime is a main driver of system life cycle costs partly due to the necessity for additional system acquisition (as spares or float items) to meet operational needs as system downtime increases. Section 3.2 describes how the program manager (or sponsor if a program manager has not yet been assigned) must balance the sustainment requirement elements (A_M, A_O, R_M, and OC) to optimize utilization—and thus life cycle costs—during design if the system is to be suitable and affordable for the warfighter. Section 3.2.3 provides a more detailed discussion of the differences between A_M and A_O.

This manual does not address Materiel Availability for networking or information technology systems. The combat developer and program manager must propose a different method of measuring Materiel Availability to the JROC in this case.

3.1.2.1 Development of End Items with Float/Spares

When a system capability that includes planned float/spare systems is fielded, A_M is defined by the following equation:

$$A_M = \frac{\text{number of operational end items}}{\text{total number of end items acquired}}$$

Assessment of the achieved A_M involves determining the number of operational end items (i.e., those ready for tasking) divided by the total number of end items acquired at the time the sample is taken.

Note that the total number of end items acquired at a given point in time is the total produced and accepted for use minus those items removed from the inventory due to battle attrition, planned retirement, accidental loss, or any other reason as defined by the program manager in the Component-approved RAM-C Report. The program manager develops the method for post-fielding assessment of A_M with the agreement of the combat developer; the combat developer then documents it in the RAM-C Report prior to Milestone C.

For systems using an operational float concept, the A_M requirement should be determined based on whether float items are defined as "up" or "down." Defining float/spare systems as down will lead to calculated achieved A_M values that do not penalize the program for utilizing float/spare systems to replace operational systems. Defining float/spare systems as up reduces the calculated value of achieved A_M whenever a spare/float is put into use to replace a previously operational system. The chosen approach to float/spare system status must be clearly defined in the RAM-C Report.

3.1.2.2 Development of End Items without Float/Spares

Examples of end items without float/spares include ships, cargo aircraft, and telephone networks. In this case, all acquired end items are put into operational service and remain there unless maintenance is required. Under these conditions, the following equation is used:

$$A_M = \frac{(\text{uptime})}{(\text{uptime}) + (\text{downtime})} = \frac{(\text{MTBM})}{(\text{MTBM} + \text{MDT})}$$

Where:

Uptime = Time the system is available to perform designated mission

Downtime = Total time – Uptime = Time system is unavailable for tasking

MTBM = Mean time between maintenance actions requiring removal of system from operational use

MDT = Average system downtime expected given the anticipated support structure.

Note that the "downtime" in this definition includes all temporary non-operational states (e.g., undergoing depot repair, awaiting assignment to operational unit, etc.) as described in Section 3.1.1.

The Maintenance Down Time (MDT) value is usually not resolved until after Initial Operating Capability (IOC). For the purpose of pre-IOC estimates of A_M attained, estimated values of MDT components (i.e., mean ADT, mean LDT, and MTTR) must be used. These estimated values should be reasonable, given the planned system operation and support tempos. All assumptions and supporting rationale for the values selected must be documented in the RAM-C Report. As maintenance demonstrations are performed, estimated values of MTTR should be replaced by measured values as soon as practical.

3.1.2.3 Development of Systems That Are Part of Other End Items

Examples of systems developed as part of other end items include catapults for aircraft carriers, avionics upgrades for aircraft, joint communications systems, and cryptography equipment. In this case, the appropriate metric must be selected. Systems that are not line replaceable, like catapults and avionics upgrades, are usually developed without planned system level spares, and A_M should be evaluated as described in Section 3.1.2.2. Line replaceable systems, like communications devices or cryptography equipment, are usually developed with system level spares, in which case the evaluation methods of Section 3.1.2.1 are applicable.

3.1.2.4 One-Shot Devices

One-shot devices are a special case that must be considered. One-shot devices (missiles or munitions for example) usually include large inventories in stock for replenishment of assets as they are expended. Items of this type in the inventory are not technically spares or float items and the program should document how they are to be handled for Materiel Availability purposes (i.e., what percentage of the inventory are spares vice intended for asset replenishment and whether the asset replenishment items are categorized as "up" or "down" when in stock).

For example, consider a missile with a "wooden round" support concept during operational assignment with performance of scheduled maintenance, unscheduled maintenance, and software updates during planned non-operational periods. When calculating an achievable missile Materiel Availability for inclusion in the CDD, it is essential to properly model activities relating to operation, maintenance, expenditure, and logistics. Some of the activities to cover are:

Operation

- OPTEMPO
- Number of host platforms deployed
- Intended missile load
- Durability (maximum operational time before RESET or Recertification)

Maintenance

- Durability
- Pre-use BIT failure rate
- Inspections
- Stockpile reliability
- Shoot to Kill reliability
- Scrap rate

Expenditure

- Rate of expenditure
  - Effect on A_M of expended missiles (since each missile expended is now out of the inventory—the program must detail how it will deal with missiles expended when calculating A_M)

Logistics

- Depot MTTR
- Number of shifts/test sets (often not available at early fielding stage)
- Retrograde time
- Transit time (dock to dock during repair/modifications, etc.)

It is entirely feasible for the missile community to have a 100 percent Operational Availability at the line units with a much lower Materiel Availability for the overall inventory. For this reason details of how the program will calculate Materiel Availability must be established during concept development and documented in program systems engineering documents (SEP, ICD, CDD, RAM-C Report, etc.).

3.1.3 Materiel Reliability

Materiel Reliability (R_M) is a characteristic of the final system design and is designated a KSA as defined in Section 1.2. R_M is defined by the Basic (aka Logistics) Reliability (Mean Time Between Failures (MTBF)) of the system:

$$MTBF = \frac{1}{\lambda_{System}}$$

Where λ_{System} is the failure rate of the system.

See Section 3.2.4 for a more detailed discussion.

3.1.4 Ownership Cost

Ownership Cost (OC) is designated a KSA as defined in Section 1.2. For the sustainment requirements, a minimum set of cost elements are included in determining the system OC. The required elements are described in Section 3.2.4.3.

Because the effects of tradeoffs performed during sustainment requirement development are complex, the discussion of how OC considerations are involved is included in Section 3.2 and is not repeated here.

3.2 Developing a Balanced Solution: Performance and Sustainment

3.2.1 The Effect of Requirements on Life Cycle Costs

One important purpose of the sustainment metrics is to ensure that system performance and program cost are properly balanced, leading to the materiel capability developed being operationally effective, suitable, and affordable for the warfighter.

Figure 3-1 shows the theoretical effect of reliability and sustainment cycle time on Life Cycle Costs (LCC). For example, a system that exhibits low reliability may require high sustainment cycle times, mainly due to numerous repair cycles being required, which will result in high OC and thus high LCC. The objective is to achieve a balance between development, production, and operating and support costs that results in minimal life cycle costs.

The balanced solution will determine the optimal points for reliability and sustainment cycle time early in program development, thus ensuring an acceptable LCC for the system consistent with needed mission functional performance. Note that the optimal reliability value must be sufficient to meet the most strenuous warfighter requirements, which may result in the system having higher than the minimum possible LCC.

Supportability and maintainability concepts considered should include system MDT optimization and ease of system maintenance. MDT is reduced by limiting LDT through pre-positioning sufficient spares and an efficient supply system ensuring the spares are available at the right place at the right time. Limiting ADT is another way to limit overall system downtime. ADT is time required to initiate a maintenance action after an issue surfaces. Designing maintainability into the system will reduce MTTR, again reducing MDT. The systems engineering process ensures implementation of activities intended to design supportability into the system during the Material Solution Analysis, Technology Development, and Engineering and Manufacturing Development phases when large returns on investment are available.

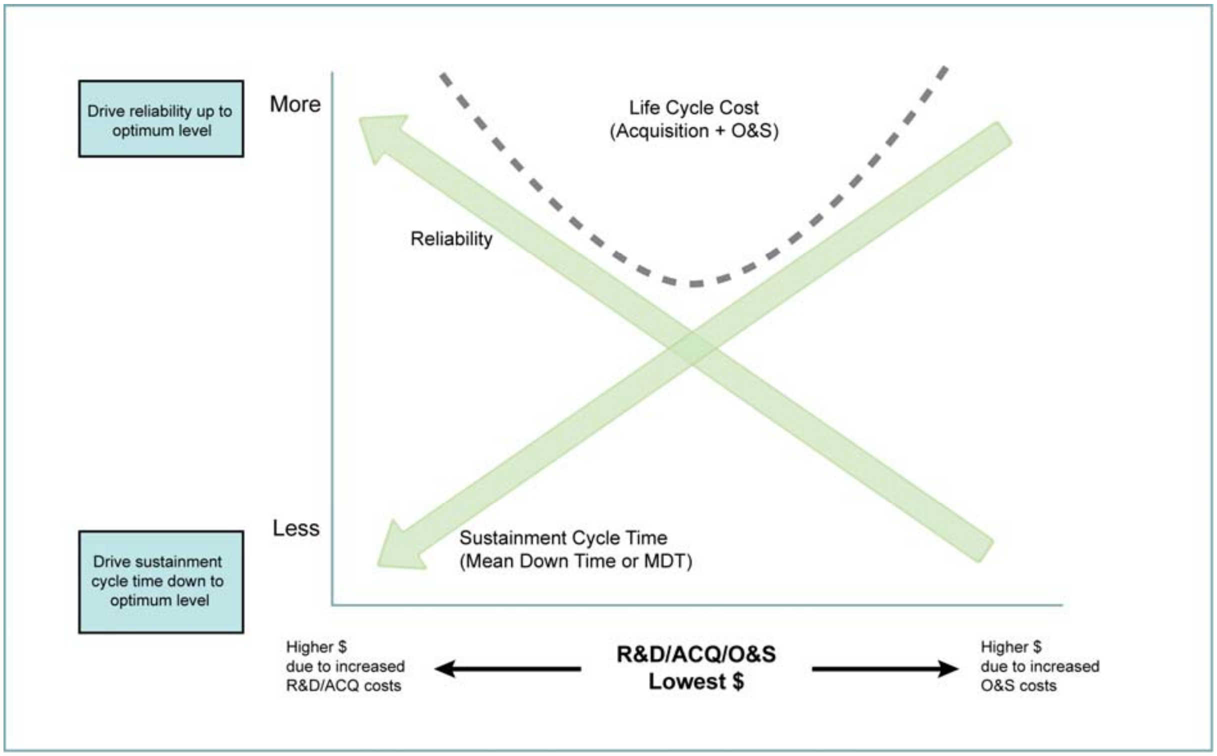

Figure 3-1 Optimum Life Cycle Cost Curve

3.2.2 How Warfighter Capability Needs Are Used To Establish System Requirements

Warfighter needs are the basis for development of materiel systems. These needs are usually framed by the combat developer as a required capability to perform a mission. For example, a typical requirement for a system might be that it has a "95 percent chance of completing a 12-hour mission with no mission-affecting failures." The program manager translates the combat requirements into specific Availability, Materiel Reliability, and Ownership Cost metrics. The resulting metrics must fully define warfighter requirements in a manner that can be included in the materiel developer's requirements, the implementing contract, and all test and evaluation plans.

Multiple reliability and maintainability metrics may be applicable to a given program. For simplicity, this discussion uses the metrics in Table 3-1.

3.2.2.1 Use of Non-Time-Based Reliability Metrics

Reliability metrics other than MTBF may be used to determine A_M and R_M (for example, Mean Miles Between Failure (MMBF), Mean Rounds Between Failure (MRBF), Mean Cycles Between Failure (MCBF), and other metrics appropriate for a given procurement program). When required, these measures should be converted to time-based values using the OMS/MP operational tempo descriptions to determine failures/calendar unit. This method is also used to determine uptime for systems with cyclical or other non-time-related requirements.

Conversion to time-based metrics is required because the maintainability metrics (Mean Time Between Maintenance (MTBM), MTTR, MDT, LDT, and ADT) are of necessity time based (usually measured in hours). Reliability and maintainability metrics must use the same time basis in all calculations, and the conversion of the R_M value to time is usually the most straightforward method available. Assessment of one-shot devices is performed in the same manner.

Table 3-1 Metric Definitions

Metric	Nomenclature	Definition
A_M	Materiel Availability	Fraction of total systems available for operational use or, as defined in Sections 3.1.2.2 and 3.1.2.3, percentage of time a given system is available for operational use
A_O	Operational Availability	Percentage of time an operationally assigned system is available for operational use
R_M	Materiel Reliability	The probability that the system will perform its intended function over a specified time period
MTBF	Mean Time Between Failures	The average time between system failures under specified conditions
MTBM	Mean Time Between Maintenance	The average time between system maintenance activities under specified conditions
$MTBM_S$	MTBM—Scheduled	The average time between scheduled system maintenance activities (e.g., oil changes, structural inspections, overhauls, etc.)
$MTBM_U$	MTBM—Unscheduled	The average time between unscheduled system maintenance activities (usually due to system failures)
MDT	Maintenance Down Time	The average downtime for maintenance actions (includes MTTR, LDT, and ADT)
MTTR	Mean Time To Repair	The average time required to repair the system after failure (active repair time only)
LDT	Logistics Delay Time	All non-administrative maintenance delays involved in repair actions—including transportation of the system to the repair location, time required to obtain necessary spares, time waiting for repair personnel availability, etc.
ADT	Administrative Delay Time	Time associated with processes or tasks not directly involved in restoration or repair activities, such as processing of requests, short-term non-availability of repair facilities, or delays due to establishment of higher priorities

3.2.2.2 *Warfighter Requirements Determine Minimum Materiel Reliability Value*

The Materiel Reliability (R_M) minimum value is established from the minimum system reliability value required by the warfighter's stated requirements. The program manager must analyze the warfighter requirements to determine the most strenuous mission(s) the system is to undertake. The reliability required to complete this mission with the required probability is then established as the minimum operational reliability value for the system. Further discussion is provided in Section 3.2.4.2.

3.2.3 Why Materiel Availability Is Different from Operational Availability

3.2.3.1 *End Item Populations Included in Calculations Vary*

The JCIDS Manual states: "The Materiel Availability addresses the total population of end items planned for operational use, including those temporarily in a non-operational status once placed into service." Examples of end items temporarily in a non-operational status once placed into service include those at depot for system repair, float, preventive maintenance, or upgrade. Definitions of Operational Availability are restricted to those end items in operational service, such as this one from the Reliability Information Analysis Center's Supportability Toolkit: "Operational Availability is the probability that a System, when in an actual operating environment, will be ready for commitment to system mission operations at any point in time."

The inherent difference between the two measures of availability is in the definition of the end item population included in the calculation. Materiel Availability and Operational Availability are equal when both metrics are calculated using the total population and there is no scheduled maintenance requiring the system to be taken off line.

Note that the goal is to balance the sustainment metrics—not to maximize A_M (as current approaches usually attempt to maximize A_O). A_M is a system design value that will decrease only when there are more systems "down" than originally planned (if float/spare systems are defined as down during development of the A_M requirement). An example would be a program with a total acquisition quantity of 100 units in which 75 are operationally assigned and 25 are float/spares. In this case, the system's maximum design A_M is 0.75. As float/spare units are committed to replace failed or out-of-service units (and assuming instantaneous replacement to simplify the discussion), A_M achieved will remain 0.75 until there are 26 or more operational units failed at the same time. Operational units that fail are replaced by a float/spare if one is available so there will always be 75 units operational—unless 26 or more of the units are in a down state. For this reason, defining float/spare units as down does not adversely penalize the program's achieved A_M value for using up to the planned number of spares. A_M will fall below the design goal only if 26 or more units are down at the same time.

3.2.3.2 *Analysis Time Frames Vary*

The JCIDS Manual requires that "the total life cycle time frame, from placement into operational service through the planned end of service life, must be included" in determining the Materiel Availability KPP. Operational Availability calculations based on the time the system is in the operational environment usually exclude some portions of the system life cycle (such as inactive periods where a system is not assigned to an operational mission or when the system has been removed from operational service for maintenance). The total life cycle time frame approach is necessary to allow accurate calculation of the Ownership Cost KSA discussed in Section 3.2.4.3.

3.2.4 Sub-Components of the Availability KPP: Reliability KSA and Ownership Cost KSA

3.2.4.1 Preliminary Concepts Required for Materiel Reliability Discussion

In the application as a sustainment requirements KSA, calculation of Materiel Reliability (R_M) may require determining the overall MTBM actions for the individual end items in question. There are two standard components of MTBM: scheduled ($MTBM_S$) and unscheduled ($MTBM_U$). Some examples of scheduled maintenance actions are planned overhauls, preventive maintenance, and block upgrades. Unscheduled maintenance activities mainly result from failures, both “critical” (sometimes called “mission” failures) and “non-critical” (failures that do not prevent the end item from completing the assigned mission even if in a degraded mode).

Two considerations must be understood in this case. First, the reason MTBM is a critical measure (as opposed to MTBF) is that not all system failures result in a “down” condition, but the maintenance actions discussed here are those that do result in the system being down throughout the activity. (Note that one method to increase MTBM is to perform maintenance while keeping the system “up”—for example, performing inspections or minor repairs at the unit or organizational level.) Second, to calculate the value of A_M using the equations in Section 3.1.2, the correct definition of “downtime” must be used. Defining applicable maintenance activities as downtime for the individual end item properly accounts for non-failure-related system off-line time that would not be included in the calculation of A_O.

3.2.4.2 Materiel Reliability

The JCIDS Manual defines the mandatory Materiel Reliability (R_M) portion of the Reliability KSA as “a measure of the probability that the system will perform without failure over a specific interval.” The specific interval may vary with application, but overall, “reliability must be sufficient to support the warfighting capability needed.” The specific interval is defined in the OMS/MP developed by the combat developer.

The JCIDS Manual expresses the R_M of operational systems in terms of an MTBF where:

$$\text{MTBF} = \frac{\text{operating hours}}{\text{number of failures during operating period}}$$

This definition is used during testing and fielding to evaluate system MTBF. Additional discussion of the development required to establish R_M KSA values follows.

Combat Developer Requirement Format

The combat developer will usually express the reliability requirement for the capability as a desired failure-free interval that is then used in the development of an MTBF for the R_M KSA. For the failure-free interval to be valid, there must be an associated probability of achieving the stated value (given that a 100 percent chance of achieving a reliability value requires a failure rate of zero).

For example, valid expression of a reliability requirement may be any of the following:

- 95 percent probability of completing a 12-hour mission free from mission-degrading failure
- 90 percent probability of completing five sorties without failure
- 85 percent probability of achieving 1,000 mean miles between failures (MMBF)
  - Cyclical requirement—must be converted to time using techniques discussed in Section 3.2.2.1
- 99 percent probability of firing 500 rounds without failure
  - Cyclical requirement

The full definition of the R_M KSA includes criteria for defining operating hours, including supporting analysis and rationale for one-shot system requirements or systems for which other units of measure are appropriate (as in the third and fourth example requirements above).

Failures included in R_M demonstration test results should be those scored as mission critical according to the agreed FD/SC applicable to the test. Non-mission-critical failures shall be recorded in order to estimate the non-mission-critical failure rate of the system to be used during Ownership Cost analysis.

Adaptation of R_M for Systems with Non-Critical Failures and/or Scheduled Maintenance

For systems that have non-critical failure modes requiring repair and/or scheduled maintenance, the definition of R_M provided in Section 3.2.4.2 is sufficient for determining the value of A_O but is insufficient for determining the value of A_M. If the MTBF calculation excludes non-critical failures as described in Section 3.2.4.2.1, then the total system maintenance rate related to scheduled maintenance and repair of non-critical failures must be determined before A_M can be estimated.

The frequency of scheduled (μ_S) and unscheduled (μ_U) maintenance for the system is:

$$\mu_{Ssytem} = \mu_U + \mu_S = \lambda_{Critical} + \mu_S$$

The rate of unscheduled maintenance actions is determined by the system failure rate for critical failures and the system unscheduled repair rate for non-critical failures (because the system may be operated with non-critical failures). If non-critical failures not affecting completion of the assigned mission are not considered, as in Section 3.2.4.2.1, then μ_U is equal to the system's critical failure rate ($\lambda_{Critical}$). (Non-critical failure rates ($\lambda_{Non\text{-}Critical}$) are used during the calculation of OC as described below. The FD/SC developed by the combat developer is the determinant of whether or not a failure is mission critical.)

R_M for the system is thus defined by:

$$MTBF = \frac{1}{\lambda_{Critical} + \lambda_{Non-Critical}}$$

The Mean Time Between Maintenance is given by:

$$MTBM = \frac{1}{\mu_U + \mu_S} = \frac{1}{\lambda_{Critical} + \mu_S}$$

Note that MTBM reduces to MTBF in the case where $\lambda_{Non\text{-}critical} = 0$, and no scheduled maintenance actions are required.

For those cases where non-critical failure repairs and/or scheduled maintenance actions require taking the system off-line, then MTBM should be used instead of MTBF in the calculation of A_M.

3.2.4.3 Ownership Cost KSA

According to the JCIDS Manual, the OC KSA is designed to provide "balance to the sustainment solution by ensuring that the Operating and Support (O&S) costs associated with materiel readiness are considered in making decisions."

As a minimum, the KSA is to include the following elements, as defined in the Cost Analysis Improvement Group (CAIG) Operating and Support Cost-Estimating Guide (October 2007):

- 2.0 Unit Operations Element 2.1.1 only:
  - 2.1.1 (only) Energy (fuel, petroleum, oil, lubricants (POL), electricity)
  - Note: The fully burdened cost of fuel is to be included after the ongoing pilot programs have been completed and policy has been formalized.
- 3.0 Maintenance (all elements)
- 4.0 Sustaining Support (all elements except 4.1 System Specific Training)
- 5.0 Continuing System Improvements (all elements).

OC estimate development includes several important fundamentals:

- All costs must be considered regardless of funding source (family of systems-related costs such as cryptography equipment should also be included).
- The analysis must be based on a notional service life that extends many years (notional service lives are described in the Operating and Support Cost-Estimating Guides).
- Analysis must be supported, including sources of reference data, cost models, parametric cost-estimating relationships, and any other estimating techniques of tools used.

- OC estimates should be based on characteristics of the system being acquired as well as O&S costs of predecessor systems. Analysts should use the Visibility and Management of Operating and Support Costs (VAMOSC) systems as the primary source for predecessor system data. Analysts can also base their OC estimates for new systems on actual experience during operational tests and evaluations.
- The analysis must include a plan for maintaining the traceability of costs incurred to estimates along with the planned approach to monitoring, collecting, and validating operating and support cost data associated with the system.

The Operating and Support Cost-Estimating Guide provides more detailed descriptions of the four elements that constitute the OC KSA. Equivalent measures must be used for non-ACAT I/II programs without available CAIG analysis. Section 3.2.5.9 of this manual offers suggested techniques for estimating the four elements.

3.2.5 Considerations for Developing Sustainment Metric Requirements

3.2.5.1 Requirement for Detailed Failure Definition and Scoring Criteria

Table 3-2 provides descriptions of the purpose and contents of the FD and SC. The purpose of the FD/SC is to provide a common basis for determining chargeability for failures that is understood and concurred with by all stakeholders. Defined failures must be testable. The failures of interest to the developer of the sustainment requirements are those scored in the Essential Mission Function (critical failures), Essential Maintenance Actions (non-critical failures requiring correction before the next mission), and Unscheduled Maintenance Actions (non-critical failures that are deferrable indefinitely). Note that per the discussion in Sections 3.1.2 and 3.2.4, the critical failure rate determines the R_M value of the system. The FD/SC also indicates chargeability to either inherent hardware/software or operational factors such as crew/operator, training, technical manuals, maintainer, accident, and so on. Contractual reliability is derived from critical operational reliability and is normally higher than the critical operational reliability.

3.2.5.2 Requirement for Operational Mission Summary and Mission Profile

The OMS/MP, detailed in Table 3-3, is required to determine the duration and frequency of events and environments that the system encounters throughout its life cycle. Careful analysis of the entire life cycle is necessary to determine the reliability (both mission and basic reliability) that must be designed into the system in order to meet the operational needs of the warfighter. For example, vehicles must be able to perform during the individual mission profiles defined by the warfighters, but also must be able to perform these missions multiple times over their life cycle, which necessitates increased reliability over the single mission requirement.

3.2.5.3 Pre-Milestone A Sustainment Requirement Development Timeline

Figure 3-2 provides the pre-Milestone A stakeholder activities in a timeline format. The major sustainment requirement activities shift from analyzing the candidate systems under analysis to focusing on the preferred system concept determined at the Alternative System Review (ASR).

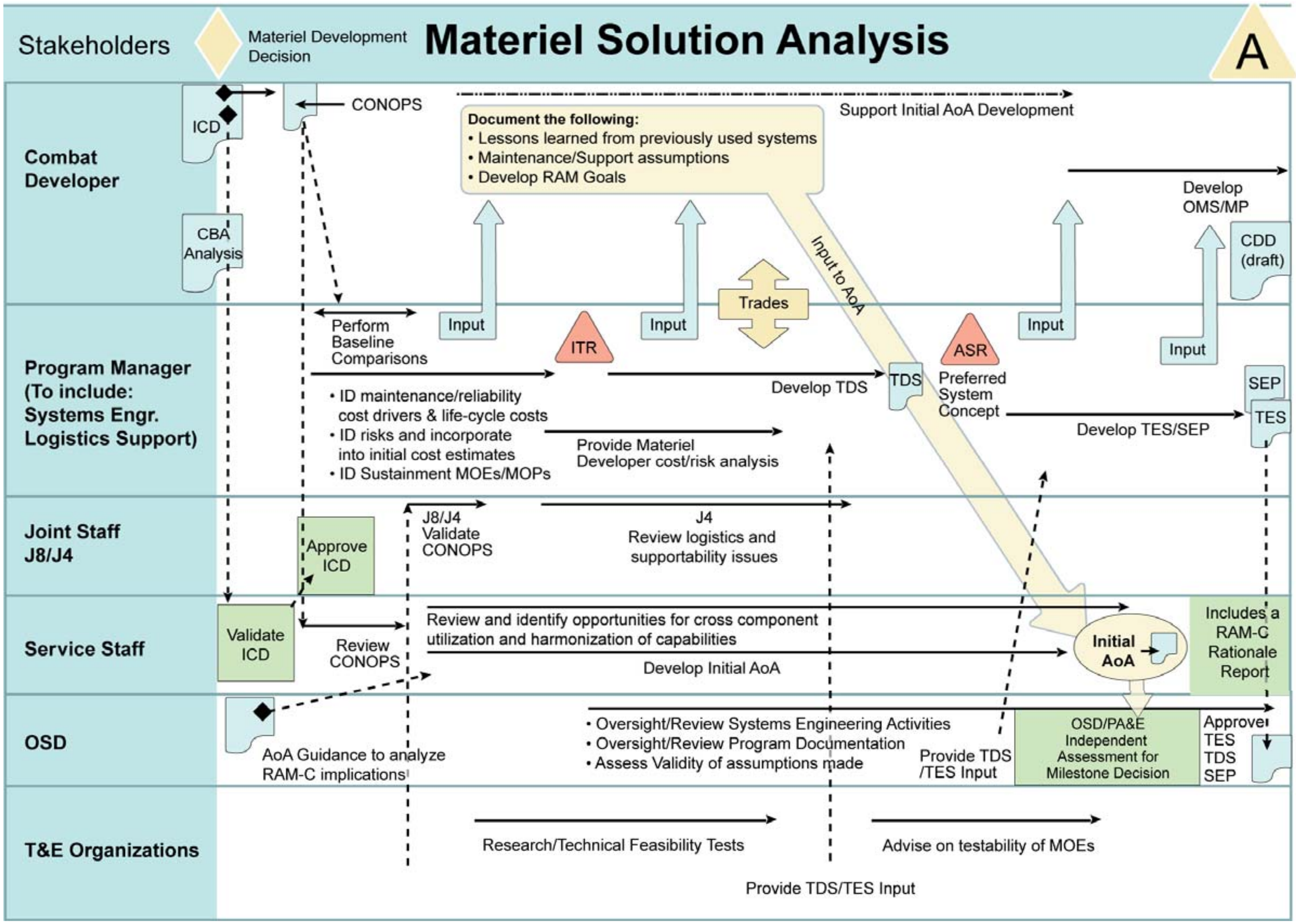

Figure 3-2 Pre-Milestone A Sustainment Requirements Development Process

3.2.5.4 Pre-Milestone B Sustainment Requirement Development Timeline

Figure 3-3 details the pre-Milestone B stakeholder activities throughout the Technology Development Phase. Major sustainment requirement activities during this period focus on establishing threshold and objective values for each of the requirements and performing sustainment requirement tradeoffs between the varied approaches evaluated during the Analysis of Alternatives. The tradeoffs are refined as the design approaches maturity, leading to the final sustainment requirement ranges included in the CDD/CPD and RAM-C Report. These values are included in the CDD prior to the Milestone B decision. Approval of the CDD indicates approval of the sustainment requirement ranges in terms of thresholds and objectives.

3.2.5.5 Pre-Milestone C Sustainment Requirement Development Timeline

Figure 3-4 covers the pre-Milestone C stakeholder activities throughout the EMD phase. Sustainment requirement activities during this phase include demonstrating the measurable values (MTBF, MTTR, A_O, maintenance costs, and so on) necessary for determining the A_M, R_M, and OC achieved. The sustainment requirement tradeoffs are repeated to reflect the effect of the achieved values on the viability of the system. The effects of any un-met threshold values—or thresholds with a high risk of failure—must be considered. If necessary, the sustainment requirements may be updated using approval processes established in the JCIDS Manual. The analysis of the achieved values is incorporated into the RAM-C Report and the CPD prior to Milestone C.

3.2.5.6 Post-Milestone C Sustainment Requirement Development Activities

Post-Milestone C sustainment requirement activities focus on evaluating the actual fielded system element's performance in support of the Full Rate Production decision. The program manager is responsible for updating the RAM-C Report as required to document the achieved sustainment metric values throughout the system life cycle.

3.2.5.7 Need to Determine Overall Number of System Failures Expected by Type

The total number of system failures of $type_i$ expected (N_i) is determined by:

$$N_i = T_i \lambda_i$$

Where:

- T_i is the total time over the system life cycle that $failure\ mode_i$ can occur
- λ_i is the failure rate of $mode_i$
- All potential failures requiring repair actions must be considered
  - N_i must be calculated for all identified critical and non-critical failure modes.

The total number of system failures by type is essential to determining the system's maintenance costs. Section 4.3.5 below discusses how N_i is used to calculate cost.

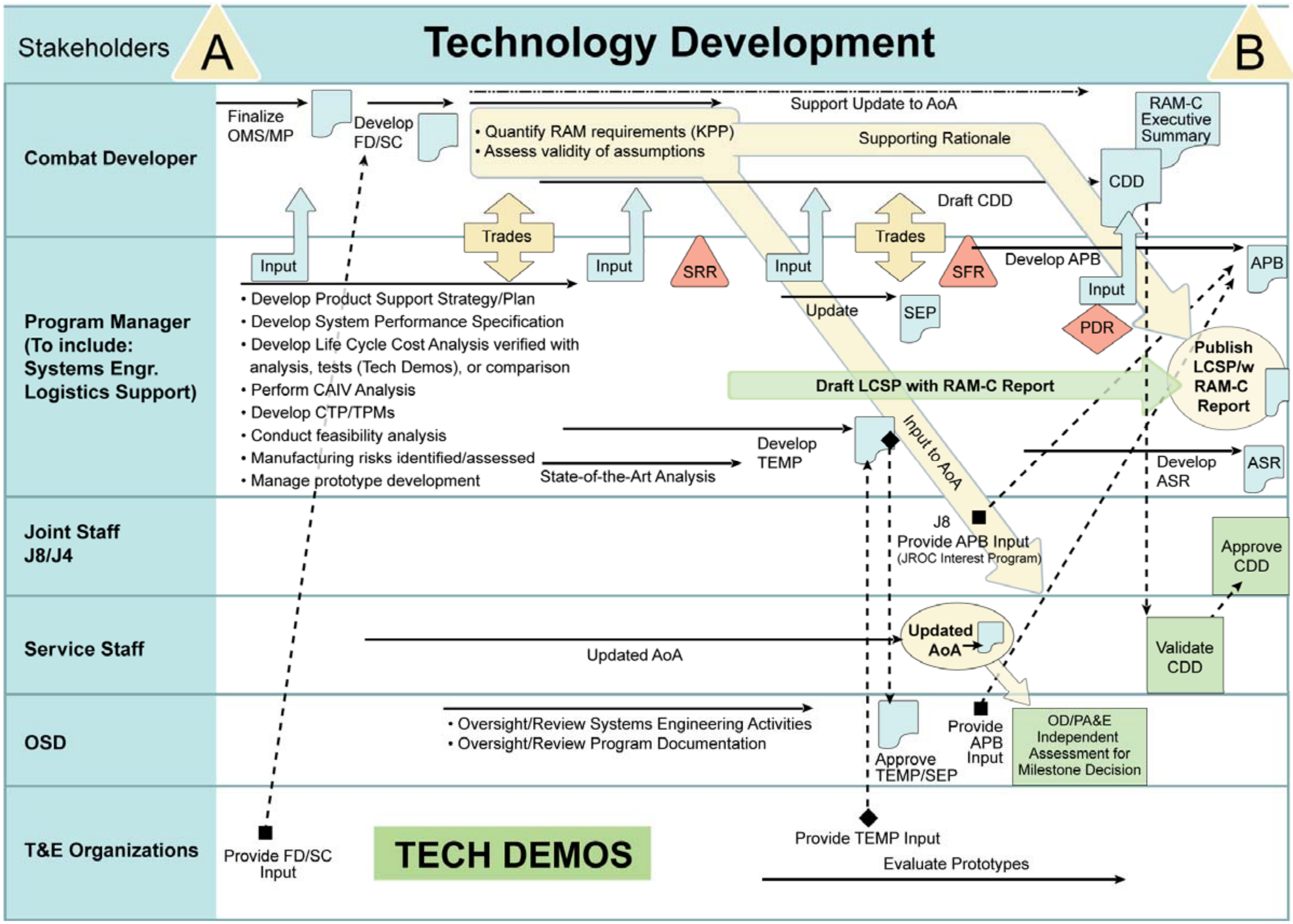

Figure 3-3 Pre-Milestone B Sustainment Requirements Development Process

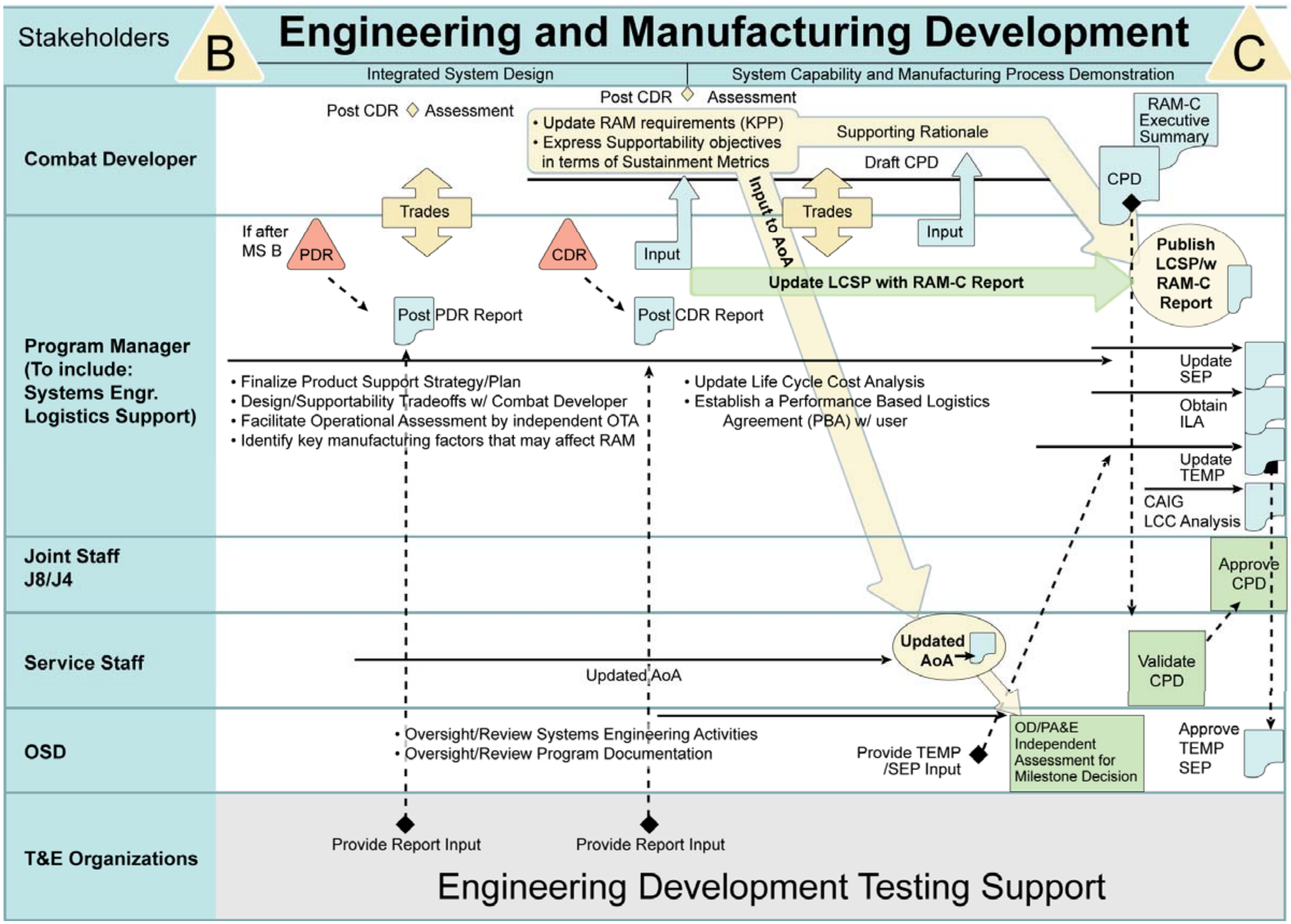

Figure 3-4 Pre-Milestone C Sustainment Requirements Development Process

3.2.5.8 Total Acquisition Quantity Determination and Initial A_M Estimate

For Systems with System Level Float/Spares

The program manager must determine the total number of systems required to fully support warfighter needs, including spares and training units (based on system design, operational concept, support concept, and the failure rates determined above). Consideration of downtime related to planned maintenance or upgrades must be included. The resulting number is the total population value in the definition of Materiel Availability.

The achieved A_M may be determined during testing and fielding as described in Section 3.1.2.1. For this case, the A_M estimate is:

$$\text{Estimated } A_M = \frac{(\text{number of operational end items})}{(\text{total number of end items acquired})}$$

Where "operational" means ready for tasking for the designated mission no matter whether the designated mission is operational in nature (training is a designated mission under this definition).

For Systems without System Level Float/Spares

The program manager must determine the Materiel Availability required to support the warfighter's needs utilizing the defined support system. The program manager's analysis must include consideration of downtime related to planned maintenance, unscheduled maintenance, or upgrades. The achieved A_M may be determined during testing and fielding as described in Section 3.1.2.2. For this case, the A_M estimate is:

$$A_M = \frac{(\text{uptime})}{(\text{uptime}) + (\text{downtime})} = \frac{(\text{MTBM})}{(\text{MTBM} + \text{MDT})}$$

Where MTBM is defined as the mean time between maintenance events that require the system to be taken off-line.

A_M calculations should take degraded operating modes into account if applicable (a two-catapult system may be partially effective even if one is out of service—and the assessed value of achieved A_M should reflect this fact).

Table 3-2 Failure Definition/Scoring Criteria Description

Document	Purpose	Contents

Failure Definitions	To establish the guidelines used to classify the cause and effect of test incidents prior to test start	• Mission Essential Functions must be determined and recorded.
		  ◦ Mission essential functions are the minimum operational tasks that the system must be capable of performing in order to accomplish the assigned mission.
		  ◦ Descriptions of mission essential functions should be in operational terms that relate to mission requirements.
		  ◦ The equipment operator should be able to readily identify the loss of a mission essential function.

Scoring Criteria	Test scoring results are used to determine reliability estimates for the system at the applicable point in time	• Scoring criteria must be applicable to the sustainment requirements.
		• Charging of incidents must be grouped as to the reason for or cause of the incident (i.e., hardware, software, operator error, accident, etc.)
		• Criteria include a classification process that ensures the consistent analysis of all test events including (at the minimum):
		  ◦ No-Test
		  ◦ Correctable Maintenance
		  ◦ Operational Mission Failure
		  ◦ Essential Maintenance Action
		  ◦ Unscheduled Maintenance Action
		  ◦ Identification of the Chargeable Event
		  ◦ Rating of the Hazard/Severity of the failure or incident

Table 3-3 Operational Mode Summary/Mission Profile Description

Document	Purpose	Contents
Operational Mode Summary	To provide a description of the anticipated mix of ways a system will be used in carrying out its operational role	• Documents system usages to be used as fundamental inputs to the design process and as the basis for test and evaluation efforts • Covers all primary missions listed in the mission • Includes relative frequency of the various missions or the percentage of the systems to involved in each mission • Details percentage of time the system will be exposed to each type of environmental condition during the system life
Mission Profile	Provision of a time-phased description of the operational events and environments an item experiences from beginning to end of a specific mission	• Identifies the tasks, events, durations, operating conditions, and environments the system encounters during each phase of the mission • Must include typical mission scenarios • Should identify mission tasks or operational events that must be completed to successfully accomplish the mission • States specific amounts of operation (e.g., hours, rounds, miles, cycles, etc.) for each mission essential functions within the mission • Shall be consistent with doctrine and tactics • May use a timeline or any other appropriate format

3.2.5.9 Determination of Ownership Costs

OC includes four elements: Energy, Maintenance, Sustaining Support, and Continuing System I

Improvements. These elements are described below. The Operating and Support Cost-Estimating Guide (October 2007) contains expanded discussions.

- *Energy.* These costs include cost of POL, propulsion fuel, and fuel additives used by systems in performing their normal peacetime missions. These costs also include the cost of field-generated electricity and commercial electricity necessary to support the operation of a system. Depending on the system, energy can constitute 5–15 percent of a system's OC. The Department is transitioning to the "fully burdened cost of fuel." Until the transition is complete, analysts must be careful to ensure comparisons are done using the same fuel cost-estimating basis.
- *Maintenance.* Maintenance includes the costs of labor (outside of the scope of unit level) and materials at all levels of maintenance in support of the primary system, simulators, training devices, and associated support equipment. This element includes the military and non-military mechanics that maintain these vehicles. Design choices and logistics decisions made early in a program affect this aspect of cost. An example evaluation of maintenance cost is the Maintenance Ratio (MR), a measure of the number of maintenance man-hours required per unit of operation. Where costs cannot be separately identified to distinct levels of maintenance, the category that represents the predominant costs should be used. Any maintenance costs provided through a system support contract should be identified separately within the appropriate cost element. Other support elements, such as cryptographic support costs, should be counted in this cost element. Maintenance costs can make up 60–70 percent of a system's OC.
- *Sustaining Support.* This category includes support services provided by centrally managed support activities external to the units that own the operating systems. Costs included in this category should represent costs that can be identified to a specific system and exclude costs that must be arbitrarily allocated. Where a single cost element includes multiple types of support, or where the support is provided by contractors, each element should be separately identified in the cost estimate. Sustaining Support can constitute 10–20 percent of a system's OC.
- *Continuing System Improvements.* This portion of the cost element structure includes the costs of hardware and software updates that occur after deployment of a system, which improve or sustain a system's safety, reliability, maintainability, or performance characteristics to enable the system to meet its basic operational requirements throughout its life. These costs include government and contract labor, materials, and overhead costs. Costs should be separated into government and contractor costs within each cost element, if possible. The Continuing System Improvements portion of an O&S estimate does not include all changes to a system developed subsequent to the initial delivered configuration. System improvements identified as part of an incremental evolutionary acquisition strategy, or pre-planned product improvement program that are included in the acquisition cost estimate, are not included in this portion of an O&S cost estimate. Any improvement of sufficient dollar value that would qualify it as a distinct Major Defense Acquisition Programs (MDAP) in its own right normally would not be included in this

portion of the O&S cost estimate. Continuing System Improvements can make up 10–20 percent of a system's OC. For example, software and computer equipment need constant upgrade just to keep operating without actually "improving" anything.

The fidelity of OC estimates improves as the definition of the system attains more specificity. Generally, at Milestone A, the system is described in broad terms as required to meet capability gaps. Over time, as the system progresses through Technology Development (TD), Engineering and Manufacturing Development, and production, cost estimator understanding of its salient characteristics improves. The confidence bands of the OC estimates narrow accordingly. Table 3-4 generally describes the minimal level of definition for each of the four major elements of OC at each of the four milestones.

The analyst must ensure that estimates of OC at each milestone appropriately reflect the level of system definition. The following discussion provides guidelines for estimating each of the four elements at each milestone, as described in Table 3-4. Note that if predecessor system data are unavailable, then use of fully documented (assumptions and rationale) engineering estimates will be necessary. If predecessor system data are available, document the assumptions and rationale used to apply the data to the system under development.

Table 3-4 Levels of Ownership Cost Definition at Four Milestones

MS	Energy	Maintenance	Sustaining Support	Continuing System Improvements
A	Alternative concepts identified	Alternative sustainment strategies may be identified	Initial concept developed	Probably not identified
B	Candidate technologies identified; some demonstrated results in TD	Alternative sustainment strategies identified	Implementa-tion plans developed	Probably not identified
C	Defined and demonstrated in EMD	Sustainment strategy chosen	Defined	May be defined
FRP	Underway—some actuals available	Underway to a limited extent—some actuals available	Underway—some actuals available	Defined; however, actuals likely to be many years away

Milestone A

The system is described primarily as a concept at this juncture, with little of the detail needed for preparation of a high-fidelity estimate. While the cost analyst's options are limited, analysis of lower-level details of subsystems that are key Availability, Reliability, or Ownership Cost drivers can be very valuable. In addition, for more than the past 30 years, the introduction of more capable and complex systems has led to significant increases in O&S costs. Therefore, the cost analyst is advised to use OC estimates for predecessor systems as a lower bound for the OC of the new system. In fact, selected elements of the Ownership Cost should be increased, in real terms, to reflect trends in energy costs and the costs of consumables and exchangeables. Suggested rates of increase are shown in Table 3-5.

Table 3-5 Ownership Cost Estimation Techniques at Milestone A

Element of Ownership Cost	Technique
Energy	Assumed inventory times assumed operating tempo (OPTEMPO) times energy consumption rate of predecessor program. Add 4.5% per year through the assumed service life, to account for real cost growth for energy.
Maintenance*	
Organizational level	Assumed inventory times assumed OPTEMPO times cost for organizational maintenance per mile/hour of predecessor program. Adjust for TD experience if appropriate.
Intermediate level	Assumed inventory times cost per predecessor system from VAMOSC. Make appropriate adjustments for complexity.
Depot level	Assumed inventory times cost per predecessor system from VAMOSC. Make appropriate adjustments for complexity.
Sustaining Support	Assumed inventory times cost per predecessor system from VAMOSC. Make appropriate adjustments for complexity.
Continuing System Improvements	Assumed inventory times cost per predecessor system from VAMOSC. Make appropriate adjustments for complexity.

VAMOSC = Visibility and Management of Operating and Support Cost
**Historically, comptrollers have added 3% per year through the assumed service life to account for real cost growth.*

Milestone B

By this time, the program is sufficiently defined that it can be described in detail in a Cost Analysis Requirements Document (CARD). There is probably sufficient detail with which to base the OC. In addition, results from the TD phase may be available. Suggested cost-estimation techniques are described in Table 3-6.

Table 3-6 Ownership Cost Estimation Techniques at Milestone B

Element of Ownership Cost	Technique
Energy	Assumed inventory times assumed OPTEMPO times energy consumption rate of predecessor program or rate of energy consumption during TD/prototyping. Add 4.5% per year through the assumed service life, to account for real cost growth for energy.
Maintenance*	
Organizational level	Assumed inventory times assumed OPTEMPO times cost for organizational maintenance per mile/hour of predecessor system(s). Adjust for TD/prototyping experience if appropriate.
Intermediate level	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Depot level	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Sustaining Support	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Continuing System Improvements	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.

VAMOSC = Visibility and Management of Operating and Support Cost
**Historically, comptrollers have added 3% per year through the assumed service life to account for real cost growth.*

Milestone C

The program is now well defined and described in a CARD. Results of TD/prototyping and EMD operational test and evaluation may be available. Complexity factors used to scale costs from predecessor systems can now be refined. Furthermore, sustainment strategies are defined to the point where their costs based on empirical data available in VAMOSC systems can be applied with more confidence. Suggested cost-estimation techniques are described in Table 3-7.

Table 3-7 Ownership Cost Estimation Techniques at Milestone C

Element of Ownership Cost	Technique
Energy	Assumed inventory times assumed OPTEMPO times energy consumption rate of predecessor system(s) or rate of energy consumption during TD/prototype demonstration and EMD. Add 4.5% per year through the assumed service life, to account for real cost growth for energy.
Maintenance*	
Organizational level	Assumed inventory times assumed OPTEMPO times cost for organizational maintenance per mile/hour of predecessor system(s). Adjust for TD and EMD experience if appropriate.
Intermediate level	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Depot level	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Sustaining Support	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.
Continuing System Improvements	Assumed inventory times cost per predecessor system(s) from VAMOSC. Make appropriate adjustments for complexity.

VAMOSC = Visibility and Management of Operating and Support Cost
**Historically, comptrollers have added 3% per year through the assumed service life to account for real cost growth.*

Full-Rate Production

At this point, IOT&E results are also available. The program has accumulated sufficient empirical content on which to refine estimates of OC with confidence. Suggested cost-estimation techniques are described in Table 3-8.

Table 3-8 Ownership Cost Estimation Techniques at Full-Rate Production

Element of Ownership Cost	Technique
Energy	Assumed inventory times assumed OPTEMPO times energy consumption rate observed in TD, EMD and IOT&E. Add 4.5% per year through the assumed service life, to account for real cost growth for energy.
Maintenance*	
Organizational level	Assumed inventory times assumed OPTEMPO times cost for organizational maintenance per mile/hour observed in TD, EMD and IOT&E.
Intermediate level	Assumed inventory times cost per predecessor system(s) from VAMOSC, adjusted for complexity.
Depot level	Assumed inventory times cost per predecessor system(s) from VAMOSC, adjusted for complexity.
Sustaining Support	Assumed inventory times cost per predecessor system(s) from VAMOSC, adjusted for complexity.
Continuing System Improvements	Assumed inventory times cost per predecessor system(s) from VAMOSC, adjusted for complexity.

VAMOSC = Visibility and Management of Operating and Support Cost
**Historically, comptrollers have added 3% per year through the assumed service life to account for real cost growth.*

3.2.6 Sustainment Metric Tradeoffs

The trade space for the sustainment requirements is determined by the threshold and objective values determined for Materiel Availability, Operational Availability, Reliability, and Ownership Cost. The anticipated acquisition cost—based on total acquisition quantity anticipated—is developed for each proposed acquisition/sustainment approach. The materiel-related LCC for each acquisition/sustainment approach is then determined by adding the acquisition and Ownership Costs.

Internal tradeoffs are made to develop the optimal system for the given acquisition/sustainment approach (for example, increasing or decreasing the Reliability values to reduce the overall LCC).

The final tradeoff is to compare the optimized acquisition/sustainment approaches in order to select the best approach to meet the warfighter's requirements. In a family of systems or system of systems approach, consideration of the end item's contribution to the overall system is essential. Note that the selected approach must meet the overall program constraints (for example, funding, timing) in order to be viable.

4 EXAMPLE PROGRAM APPROACH TO SUSTAINMENT KPP DEVELOPMENT

4.1 Introduction

This section uses a fictitious self-propelled Howitzer program to demonstrate the process of developing values for the sustainment requirements. The discussion details program considerations and decisions made to evaluate related sustainment requirements and is intended to further define the process required to ensure the program efficiently provides a suitable and feasible capability to the warfighter. Process steps required for translation of a stated user need into A_M, R_M, and OC design values for the fictional self-propelled Howitzer are provided. Finally, two tradeoffs are investigated with their resulting effects on expected system parameters.

4.2 Materiel Solution Analysis Phase Considerations

4.2.1 R_M KSA Initial Development

4.2.1.1 Minimum R_M Assessment

Mission profiles analysis establishes minimum requirements for system MTBF. Various system MTBF values are evaluated against selected mission profiles to determine resulting mission reliabilities. The probability of mission success and effectiveness is then assessed based on system reliability. The minimum MTBF required to meet warfighter needs is determined from this analysis and coordinated tradeoffs by the combat developer, the program manager, and the warfighter. Note that for systems with non-critical failure modes, the analysis uses MTBM in place of MTBF.

4.2.1.2 State of the Art and Comparable System Evaluation

The combat developer, with technical support from the program manager (especially in the evaluation of existing technological capabilities), evaluates the achievability of the minimum R_M required by analyzing the ability of mature or developing technologies to provide needed capabilities. This analysis includes historical trending for similar or predecessor systems and extrapolation of trending results to applicable new technologies. The combat developer determines the potential R_M attainable and any associated risks—leading to a range of R_M and risk combinations for system development. The combat developer identifies low-risk approaches resulting in sufficient R_M to meet the warfighter's needs to set the program R_M threshold. Higher values of R_M attainable with acceptable risk or investment are used to set the R_M objective values. Establishment of threshold and objective values provides the necessary sustainment requirement trade space for system development. For situations where the minimum R_M value cannot be met using existing state-of-the-art approaches, the combat developer may establish a block development approach for the system with iterative R_M values for each block leading to achievement of the required reliability.

4.2.2 Maintenance and Product Support Concepts Development

Given the impact of technology on system design, maintenance, and support, the combat developer, with support from the program manager as required, leads the development of a maintenance and product support concept that balances Ownership Cost, logistics footprint, and logistics response times with changes in Materiel Availability and Materiel Reliability while minimizing program technical and schedule risks. This effort produces estimates of the range of sustainment metric values for both the total number of systems to be acquired and the OC.

4.2.3 Determination of OC and A_M Design Values through Tradeoffs

The program manager uses the sustainment metric ranges determined to perform tradeoffs among the materiel approaches considered. The goal of the tradeoffs is to optimize the system LCC as shown in Figure 3-1. Once each materiel approach is optimized, the candidate approaches are evaluated against one another (at the Alternative Systems Review) in order to select the preferred system approach.

4.2.4 Sustainment Requirement Refinement throughout Program Development

The program manager constantly updates the analyses and tradeoffs performed as the program matures and data become available describing reliability, cost, and availability achieved. The combat developer reflects the results of these tradeoffs and analyses in updates to the RAM-C Report throughout the system life cycle.

4.3 Example of Sustainment Requirements Development

The example in this section presents a simplified development scenario for a fictional system, the XYZ Motorized Howitzer.

4.3.1 Preliminary Analysis and Assumptions

For reasons of brevity, the discussion of failures and repairs in this example is limited to the first indenture of the design. In a real design scenario, each subsystem would be broken out into its own reliability block diagram in iterative fashion until all removable or repairable assemblies or components are included.

4.3.1.1 Initial Assumptions

During the preliminary stages of concept development, the combat developer determined the following set of basic assumptions for the XYZ Howitzer:

- The system is made up of two major subsystems:
  - Gun Subsystem
    - Breech Assembly
    - Firing Mechanism
    - Casing Ejection System
    - Barrel

- Motorized Platform

- The breech assembly, firing mechanism, casing ejection system, and barrel are new designs that are I/O level Line Replaceable Units (LRUs). These four subsystems make up the Gun Subsystem described in the example.

- The motorized platform is a Non-Developmental Item (NDI) and will be one of two candidate designs for which the MMBM is well known. Selection of the platform will be made based on the tradeoffs discussed in the example. Ninety percent of platform failures are I/O level repairable, while 10 percent require depot repairs.

- The sustainment strategy calls for two-level maintenance where:
  - All gun component maintenance will be at the I/O level.
  - Motorized gun platform normal maintenance is at the I/O level with major maintenance at depot level.
  - Operational systems will require 72 hours of scheduled maintenance downtime per year (performed at I/O level without placing a spare in service).
  - Operational systems will undergo one depot-level overhaul after 4 years of normal use (a spare is placed in service for this overhaul).
  - All failed operational guns are replaced by spare guns with an average downtime before replacement of 48 hours (for operational availability purposes).

- All failures require taking the system down for repairs (for example, are critical failures affecting the operational status of the system). Failures not affecting the system's operational status are repaired during defined scheduled maintenance periods (note that this is $\mu_{S\text{-}M}$ in the example). The system is down during the scheduled maintenance periods.

- All in-service systems will go through one overhaul at the approximate midpoint of their design life. This scheduled maintenance ($\mu_{S\text{-}O}$ in the example) ensures that the costs of the overhaul, in both support cost and lost uptime, are incorporated into the calculations. The system is down during the overhaul period.

- The number of spare systems required to support the maximum operating tempo (OPTEMPO) is determined using a probabilistic approach as described. Other considerations (forward basing of spares, multiple instances of the maximum OPTEMPO occurring simultaneously, and so on) may require acquisition of larger numbers of spares.

4.3.1.2 Concept of Operations Analysis

A joint analysis by the combat developer and program manager of the concept of operations determined the following:

- Each XYZ Motorized Howitzer will have an 8-year service life.

- Five hundred operational guns are required to meet expected operational needs at Full Operational Capability (FOC).

- Each operational gun will:
  - Fire an average of 400 rounds per year
  - Travel up to 1,000 miles per year under its own power.

- The motorized gun platform will be selected from two existing systems and treated as Government Furnished Equipment (GFE).
- Ten systems will be assigned to training operations—note that these systems are excluded from any analysis of operational availability but are assumed as "up" for materiel availability analysis (because their assigned mission is training).
- Review of the OMS/MP indicated:
  - Maximum OPTEMPO of the system is 50 guns operating continuously for 5 days (120 hours) while firing 300 rounds and traveling 60 total miles under their own power.
  - Up to three maximum OPTEMPO events may occur simultaneously, and the minimum number of spares required will be determined based on supporting all three at a to-be-determined probability of having sufficient spares available.
  - An effective fighting force requires a minimum of 40 guns (80 percent) to be operational at the end of the 5-day mission.
  - Systems that fail during maximum OPTEMPO will not be replaced during the mission.

4.3.2 Step 1: Determine the Minimum R_M Required

To begin the evaluation process, the combat developer created the system block diagram shown in Figure 4-1.

Because both platforms are non-developmental items (NDI) with an available reliability history, the combat developer used existing data to determine that Platform A had an MMBM of 400 miles, while Platform B MMBM was 600 miles. Using the less-reliable Platform A as the limiting factor, the combat developer determined its reliability using the exponential distribution[1]:

$$\text{Platform A} = e^{-\frac{t}{MTBF}} = e^{-\frac{60}{400}} = 0.8607$$

Given that the desired capability is for a minimum of 80 percent of the howitzers to be operating at the end of the 5-day maximum OPTEMPO, the combat developer was able to establish the necessary reliability of the Gun Subsystem with some simple arithmetic:

XYZ Howitzer Reliability = Gun Subsystem Reliability * Platform Reliability →

0.80 = Gun Subsystem Reliability * 0.8607 →

Gun Subsystem Reliability Required = 0.80 / 0.8607 = 0.9295

The $MTBF_{required}$ for the Gun Subsystem is:

$$(\text{Desired Reliability}) = e^{-\frac{t}{MTBF_{required}}}$$

Solving for $MTBF_{required}$ (rounded up):

$$MTBF_{required} = -\frac{t}{\ln(DesiredReliability)}$$

$$= -\frac{300\ Rounds}{\ln(0.9295)} = 4102\ Rounds$$

[1] The exponential distribution is appropriate for the useful life phase of system operation. The scheduled maintenance actions and mid-cycle overhaul keep operational systems in the useful life phase throughout their life cycle by reducing wear-out failure modes to negligible levels.

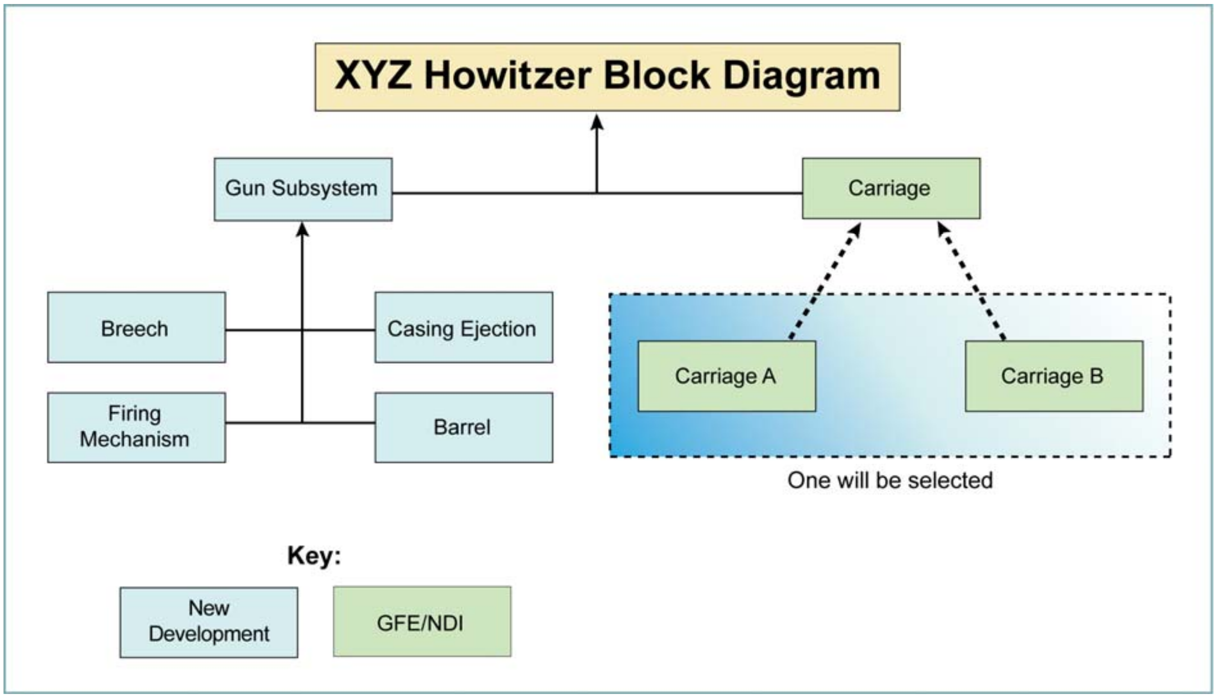

Figure 4-1 Notional Block Diagram for XYZ Howitzer

Note: The system has six failure modes represented in the example by:

- λ_1 = Failure rate of Breech Assembly (in failures per round fired)
- λ_2 = Failure rate of Firing Mechanism (in failures per round fired)
- λ_3 = Failure rate of Casing Ejection System (in failures per round fired)
- λ_4 = Failure rate of Barrel (in failures per round fired)
- λ_5 = Failure rate of Motorized Platform requiring Depot Repair (in failures per mile driven)
- λ_6 = Failure rate of Motorized Platform requiring I/O Repair (in failures per mile driven)

4.3.2.1 Gun Platform Reliability:

As mentioned above, the two motorized gun platforms under consideration have well-known MMBM values of 400 miles for Platform A and 600 miles for Platform B. For either platform, 90 percent of failures will require I/O repair and 10 percent will require depot repair. As these systems are GFE, improvement of these values is not part of the system development program; so the gun platform subsystems are not included in the analysis of Steps 2 and 3.

4.3.3 Step 2: Calculate Gun Subsystem Failure Rate

The Gun Subsystem failure rate, λ_{Gun} (rounded up) is:

$$\lambda_{Gun} = \frac{1}{MTBF_{required}} = 0.000244 \frac{\text{failures}}{\text{round}}$$

4.3.4 Step 3: Allocate Failures to Subsystems

Figure 4-2 shows the reliability block diagram for the Gun Subsystem, which is composed of four major subassemblies that cover all potential failures within the system.

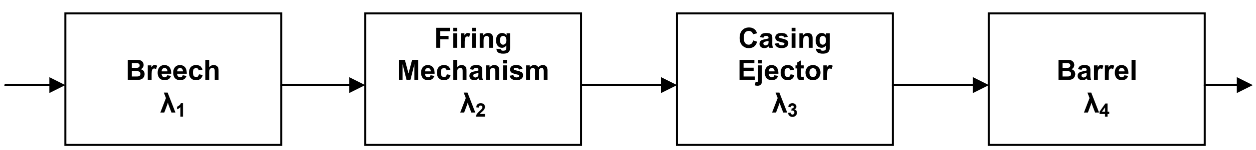

Figure 4-2 XYZ Gun Subsystem Reliability Block Diagram

The Gun Subsystem failure rate is the sum of the subassembly failure rates:

$$\lambda_{Gun\ Subsystem} = \sum_{For\ all\ i} \lambda_i = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4$$

The reliability allocation process distributes the total system failure rate among the assemblies identified in the reliability block diagram. The program manager allocated the $\lambda_{Gun\ Subsystem}$ as follows:

$$\lambda_1 = 0.000078 \frac{\text{failures}}{\text{round}};\ \lambda_2 = 0.000118 \frac{\text{failures}}{\text{round}};$$

$$\lambda_3 = 0.000039 \frac{\text{failures}}{\text{round}};\ \lambda_4 = 0.000008 \frac{\text{failures}}{\text{round}}$$

Note that this gives a slightly lower failure rate overall due to rounding error:

$$\lambda_{subsystem} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = 0.000078 + 0.000118 + 0.000039 + 0.000008 = 0.000243$$

4.3.5 Step 4: Calculate Total Number of Failures of Type "I" Expected

In most cases, specific failures can occur only during certain portions of the system life cycle. For each of the failures in this example, λ_1 through λ_6, the total of all times throughout the system life cycle during which the applicable failure rate can occur is defined as T_i where i = 1, 2, …, 6. The total number of failures of type "i" (N_i) is determined by:

$$N_i = T_i \lambda_i$$

T_i is calculated from the analysis in Section 4.3.1.2 where it was determined there would be an average of 500 guns operational, firing 400 rounds per year, over an 8-year system life cycle. This determination leads to the following translation of rounds per year into total time:

$$T_i = 500 \frac{\text{guns}}{\text{year}} * 400 \frac{\text{rounds}}{\text{gun}} * 8 \text{ years} = 1{,}600{,}000 \text{ rounds}$$

Note: Because the time base consists of rounds fired, and each failure rate is "per round fired," the value of T_i is the same for all four Gun Subsystem failure types.

The resulting N_i values (rounded up) for the Gun Subsystem are:

$$N_1 = 1{,}600{,}000 \text{ rounds} * 0.000078 \frac{\text{failures}}{\text{round}} * 8 \text{ years} = 126 \text{ failures}$$

$$N_2 = 189; N_3 = 63; N_4 = 14; \text{Total} = 392 \text{ failures}$$

The N_i values for the platform subsystems depend on which platform is used (either Platform A or Platform B):

Platform A:

Platform A has an MTBM of 400 miles with an expected use of 8,000 miles per gun throughout its lifetime. Given that 10 percent of the failures result in depot repairs, the values of N_{5A} and N_{6A} are:

$$N_{5A} = 0.1 * \frac{1 \text{ failure}}{400 \text{ miles}} * 8000 \frac{\text{miles}}{\text{gun}} * 500 \text{ guns} = 1{,}000 \text{ failures}$$

$$N_{6A} = 0.9 * \frac{1 \text{ failure}}{400 \text{ miles}} * 8000 \frac{\text{miles}}{\text{gun}} * 500 \text{ guns} = 9{,}000 \text{ failures}$$

Platform B:

Platform B has an MTBF of 600 miles with an expected use of 8,000 miles per gun throughout its lifetime. Because 10 percent of the failures result in depot repairs, the value of N_{5B} and N_{6B} are:

$$N_{5B} = 0.1 * \frac{1 \text{ failure}}{600 \text{ miles}} * 8{,}000 \frac{\text{miles}}{\text{gun}} * 500 \text{ guns} = 667 \text{ failures}$$

$$N_{6B} = 0.9 * \frac{1 \text{ failure}}{600 \text{ miles}} * 8{,}000 \frac{\text{miles}}{\text{gun}} * 500 \text{ guns} = 6{,}000 \text{ failures}$$

4.3.6 Step 5: Calculate Total Operational Downtime

According to the system definition in Section 4.3.1:

- Each failure will result in an average downtime of 48 hours until a spare system is in place.

Note: The 48-hour downtime does not apply to systems being sent for overhaul, as maintenance planning should include having a spare in place before removing the system from operational assignment.

- Each year, scheduled maintenance actions will result in 72 hours of downtime per gun.

Because 500 guns will be operational throughout the 8-year life cycle, the total downtime related to annual scheduled maintenance ($\mu_{S\text{-}M}$) is:

$$\text{Downtime}_{\text{scheduled}} = \frac{72 \text{ hours}}{\text{Gun Year}} * \frac{500 \text{ Gun Year}}{\text{Year Fielded}} * 8 \text{ Years Fielded} = 288{,}000 \text{ hours}$$

Using the number of failures determined in Step 4, the total failure-related operational downtime is:

Platform A:

- Total failures: 10,392
- 48 hours downtime per failure before a spare is in place

- 498,816 hours of failure downtime

Platform B:

- Total failures: 7,059
- 48 hours downtime per failure before a spare is in place
- 338,832 hours of failure downtime

4.3.7 Step 6: Calculate Resulting A_O

System total operational uptime required is:

$$\text{Total Time} = 8\,\text{years} * 365\frac{\text{days}}{\text{year}} * 24\frac{\text{hours}}{\text{gun day}} * 500\,\text{guns} = 35{,}040{,}000\ \text{hours}$$

The system A_O resulting from the reliability and maintainability allocations made to this point is:

Platform A:

$$A_O = \frac{\text{Operational Uptime} - \text{Operational Downtime}}{\text{Operational Uptime}} = \frac{35{,}040{,}000\,\text{hours} - 786{,}816\,\text{hours}}{35{,}040{,}000\,\text{hours}}$$
$$= 0.978$$

Platform B:

$$A_O = \frac{35{,}040{,}000\ \text{hours} - 626{,}832\,\text{hours}}{35{,}040{,}000\,\text{hours}} = 0.982$$

Note: Given that the system is designed to have 500 units operating for the entire 8-year life (leading to the operational uptime value shown), determining A_O requires calculating the total uptime by subtracting the estimated operational downtime from the operational uptime as indicated.

4.3.8 Step 7: Calculate Minimum Number of Spares Required

The method described here is a probabilistic analysis of spares required to support the system for the duration of maximum OPTEMPO after Full Operational Capability (FOC). There are many other ways to determine the number of spares necessary for the system:

- Total repair downtime may be used to calculate the required spares.
- Determining the number of spares based on requirements to pre-position units in order to ensure system effectiveness is an alternative method not covered here.
- Use any other method developed on a case-by-case basis and then fully documented in the RAM-C Report.

Probabilistic Spares Analysis:

The maximum OPTEMPO, defined in Section 4.3.1.2, consists of 50 guns on a continuous 120-hour mission firing 300 rounds and moving 60 miles per gun.

The failure rates per hour (rounded up) during maximum OPTEMPO are:

$$\lambda_1 = \frac{0.000078 \text{ failures}}{\text{round}} * \frac{2.5 \text{ rounds}}{\text{hour}} = 0.000196 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_2 = \frac{0.000118 \text{ failures}}{\text{round}} * \frac{2.5 \text{ rounds}}{\text{hour}} = 0.000294 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_3 = \frac{0.000039 \text{ failures}}{\text{round}} * \frac{2.5 \text{ rounds}}{\text{hour}} = 0.000098 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_4 = \frac{0.000008 \text{ failures}}{\text{round}} * \frac{2.5 \text{ rounds}}{\text{hour}} = 0.000021 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_{5A} = \frac{0.000250 \text{ failures}}{\text{mile}} * \frac{0.5 \text{ miles}}{\text{hour}} = 0.000125 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_{5B} = \frac{0.000017 \text{ failures}}{\text{mile}} * \frac{0.5 \text{ miles}}{\text{hour}} = 0.000083 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_{6A} = \frac{0.00225 \text{ failures}}{\text{mile}} * \frac{0.5 \text{ miles}}{\text{hour}} = 0.001125 \frac{\text{failures}}{\text{hour}}$$

$$\lambda_{6B} = \frac{0.00150 \text{ failures}}{\text{mile}} * \frac{0.5 \text{ miles}}{\text{hour}} = 0.000750 \frac{\text{failures}}{\text{hour}}$$

Summing up the failure rates by platform type:

Platform A:

$$\lambda_{\text{A@Max Optempo}} = \sum_{i=1}^{6} \lambda_i = 0.001859 \frac{\text{failures}}{\text{hour}}$$

Platform B:

$$\lambda_{B@Max\ Optempo} = \sum_{i=1}^{6} \lambda_i = 0.001443 \frac{\text{failures}}{\text{hour}}$$

Calculating the probability of successfully completing the 120-hour mission:

Platform A:

$$pr\{success\ Platform\ A\} = e^{-\lambda t} = e^{-(0.001859*120)} = 0.800007$$

Platform B:

$$pr\{success\ Platform\ B\} = e^{-\lambda t} = e^{-(0.001443*120)} = 0.841024$$

The analyst then uses the hypergeometric distribution to determine the total number of failures expected at the specified maximum OPTEMPO—Explanation: The hypergeometric distribution provides the number of successes (failures) expected in a sample drawn from a finite population with a known number of successes in the population. If all 500 systems were to operate at the maximum OPTEMPO, the expectation would be for 100 failures (500 x 20 percent unreliability) if the gun system used Platform A, and 79 failures (500 x 15.9 percent unreliability) for Platform B-based systems. The 50 guns operating during a maximum OPTEMPO event are a random sample of 50 drawn from the population of 500 (see Table 4-1).

Table 4-1 Single Maximum OPTEMPO Event Failure Analysis

Configuration	Failures	Pr{n ≥ failures occurring}
Platform A Based System	12	82.6%
	13	90.1%
	15	97.6%
	17	99.6%
Platform B Based System	10	85.6%
	11	92.5%
	12	96.5%
	14	99.4%

The requirement to support up to three simultaneous maximum OPTEMPO events results in the adjusted calculation (based on a sample of 150 systems from the population of 500 units) illustrated in Table 4-2:

Table 4-2 Three Simultaneous Maximum OPTEMPO Events Failure Analysis

Configuration	Failures	Pr{n ≥ failures occurring}
Platform A Based System	33	80.4%
	35	90.9%
	37	96.5%
	40	99.4%
Platform B Based System	27	84.5%
	29	93.8%
	30	96.4%
	33	99.5%

Note: Simply multiplying the single maximum OPTEMPO failure rate by three would overstate the expected result.

4.3.9 Step 8: Determine A_M

The total population, based on the system design and OPTEMPO described above, and resulting A_M values are shown in Table 4-3. Note the following when reviewing the table:

- Training units:
  - Ten units are assigned to training use.
  - Training units are assumed to be up throughout the life cycle due to the low utilization rate of the expected training OPTEMPO.
- Maximum OPTEMPO spares set the minimum spares required value:
  - Requirement is to support three maximum OPTEMPO events simultaneously
  - Four different scenarios are included covering minimum probabilities (80 percent, 90 percent, 95 percent, and 99 percent) of having sufficient spares available.

Table 4-3 Determination of A_M

Configuration	Spares Acquired	Probability Sufficient Spares Available	Total Population (Includes training units)	Resulting A_M
Platform A Based System	33	80.4%	543	0.939
	35	90.9%	545	0.936
	37	96.5%	547	0.932
	40	99.4%	550	0.927
Platform B Based System	27	84.5%	537	0.950
	29	93.8%	539	0.946
	30	96.4%	540	0.944
	33	99.5%	543	0.939

4.3.10 Ownership Cost Analysis

Four elements must be considered in determining the OC for this system. One of the elements, Continuing Systems Improvements, while an important element of OC, is not addressed in this simple scenario. The cost analyst must use constant base year dollars in this analysis; all costs in this example are in FY XX constant dollars.

Element 1: Fuel

Historical performance values for Platform A indicated a fuel cost of $240 per mile. Similar analysis of Platform B showed higher consumption resulting in a cost of $320 per mile. (Note: The Under Secretary of Defense (Acquisition, Technology and Logistics) is overseeing a pilot program to investigate the use of fully burdened costs of fuel in tradeoff analyses. After the pilot program is completed, formal policy on the use of fully burdened costs of fuel will be promulgated and its implementation described.)

Element 2: Maintenance Costs

Maintenance costs will contribute to the XYZ Motorized Howitzer OC KSA. Normally, maintenance costs will be incurred at least two, and possibly three, levels: organizational, intermediate, and depot. For this example, a combined intermediate and organizational level (I/O) is assumed. Determination of this contribution begins with estimating costs at the organizational level: consumables, repair parts, and exchangeables.

The cost analyst refers to the department's Visibility and Management of Operating and Support Costs (VAMOSC) system and collects actual cost for similar guns in the department's inventory.

The analyst then compares the complexity of the XYZ Motorized Howitzer with legacy systems and adjusts the values from VAMOSC to estimate costs for XYZ Motorized Howitzer. For the purposes of this example, assume that each legacy Gun Subsystem incurs an expense of $44,533 per year on consumables, repair parts, and depot-level repairables at the organizational level. The cost analyst, consulting with engineers, determines that the new Gun Subsystem will require 50 percent more support. The analyst concludes that the new gun will cost $66,800 per year at the organizational level ($44,533 * 150 percent). The analyst consults the VAMOSC to determine the legacy costs for Platform A and Platform B. After determining that there are no substantial differences between previous applications of the platforms and the XYZ Motorized Howitzer application, the analyst decides to use the historical annual platform maintenance values of $560,000 for Platform A and $280,000 for Platform B.

The cost analyst also consults the VAMOSC system and determines that legacy guns cost $1,000,000 per midlife overhaul. Based on an assumed complexity factor for support, the analyst determines that the cost to overhaul each XYZ Motorized Howitzer will be about $1,500,000.

Element 3: Sustaining Support

The analyst determines that Sustaining Support—Support Equipment Replacement, Operating Equipment Replacement, Sustaining Engineering and Program Management, and Other Sustaining Support—for legacy systems costs about $13,333 per gun per year. The analyst judges that, due to the expected increased support costs, the XYZ Motorized Howitzer will cost approximately 50 percent more than the legacy gun for Sustaining Support. Therefore, the analyst uses $20,000 per XYZ Motorized Howitzer per year for Sustaining Support ($13,333 * 150 percent). The result of the above calculations is shown in Tables 4-4 and 4-5 for a fleet of 500 XYZ Motorized Howitzers over 8 years.

Table 4-4 Repair Costs for the XYZ Motorized Howitzer with Platform A

Cost Element	Cost per Gun per Year (FY xx, $K)	Total Annual Cost for 500 XYZ Guns (FY xx, $M)	Total Cost for 500 XYZ Guns for 8 Years (FY xx, $M)
Fuel for Platform A	240	120	960
Gun Subsystem Maintenance			
Organizational	66.8	15	120
Depot	200	100	800
Platform A Maintenance	560	280	2240
Sustaining Support	20	10	80

Table 4-5 Repair Costs for the XYZ Motorized Howitzer with Platform B

Cost Element	Cost per Gun per Year (FY xx, $K)	Total Annual Cost for 500 XYZ Guns (FY xx, $M)	Total Cost for 500 XYZ Guns for 8 Years (FY xx, $M)
Fuel for Platform B	320	160	1280
Gun Subsystem Maintenance			
Organizational	66.8	15	120
Depot	200	100	800
Platform B Maintenance	280	140	1120
Sustaining Support	20	10	80

The Ownership Costs for this example (taken from the last column of Tables 4-4 and 4-5 as applicable) are as follows:

Platform A:

$$OC_A = 120 + 800 + 2240 + 960 + 80 = \$4.20\,\text{Billion}$$

Platform B:

$$OC_B = 120 + 800 + 1120 + 1280 + 80 = \$3.40\,\text{Billion}$$

4.3.11 Life Cycle Cost Analysis

Life Cycle Cost (LCC) is the sum of acquisition cost and Ownership Cost. Assuming the program has a $4,250,000 average per unit cost (APUC) for acquisition with Platform A and $5,000,000 with Platform B, and that a minimum of 95 percent spares availability for the maximum OPTEMPO is required, then the LCC values would be:

$$LCC_{\text{Platform A}} = 547 * \$4{,}250{,}000 + \$4{,}200{,}000{,}000 = \$6{,}524{,}750{,}000$$

$$LCC_{\text{Platform B}} = 540 * \$5{,}000{,}000 + \$3{,}400{,}000{,}000 = \$6{,}100{,}000{,}000$$

After performing the LCC analysis, the Platform B option was preferred from the complete life cycle perspective as it:

- provides an A_O of 0.982 versus an A_O of 0.978 for the Platform A option
- reduces the program life cycle costs by more than $400 million despite having a significantly higher APUC than Platform A.

4.3.12 Discussion of Additional Analyses Available as the System Design Matures

Two analyses are discussed here to illustrate potential tradeoffs available to the program. Section 4.3.12.1 shows how increasing the fidelity of the cost estimates may affect the final system configuration decision. Section 4.3.12.2 explores the effect of investing in reliability improvement for the chosen configuration. Section 4.3.12.3 discusses some additional analyses that may be useful during system development.

4.3.12.1 Refinement of Repair Costs

As more information regarding the actual cost of repairing the subsystems in the XYZ Motorized Howitzer became available, the program manager improved the fidelity of the LCC analysis in Section 4.3.11. The cost of repair for each individual failure type plus the MTTR, ADT, and LDT values identified by the program manager are shown in Table 4-6, and the results of the analysis appear in Table 4-7. Platform B is still the preferred option.

Table 4-6 Repair Cost and Downtime

=Maintenance Action	Symbol	Cost per Maintenance Action	MTTR	ADT	LDT
Breech Repair	λ_1	$400,000	24	48	144
Firing Mechanism Repair	λ_2	$150,000	72	48	72
Casing Ejection System Repair	λ_3	$250,000	36	48	216
Barrel Repair	λ_4	$800,000	144	48	288
Platform A Depot Repair	λ_{5A}	$500,000	288	48	288
Platform B Depot Repair	λ_{5B}	$500,000	288	48	288
Platform A I/O Repair	λ_{6A}	$100,000	72	48	72
Platform B I/O Repair	λ_{6B}	$100,000	72	48	72
Scheduled Overhaul	μ_{S-O}	$1,500,000	2016	48	288

Table 4-7 Tradeoff 1: Platform A versus Platform B Analysis

Configuration	Total Maintenance Downtime	Total Maintenance Cost	LCC
Platform A	4,404,420 hours	$3,297,300,000	$5,579,550,000
Platform B	3,460,644 hours	$3,150,800,000	$5,800,800,000

4.3.12.2 Investment in Reliability

After the selection of the Platform B-based design, the program manager decided to investigate the effects of spending an extra 10 percent ($500,000 per Howitzer) to increase the MMBM of the legacy Platform B design from 600 miles to 1,000 miles. Table 4-8 details the results of this trade. The analysis suggests that the investment to increase MMBM should be made as it results in more than $140M in program savings and decreased need for acquisition of spare systems while providing increased AO to the warfighter. There also will be ancillary benefits including increased mission reliability, reduced repairs, and fewer required spare parts, resulting in a reduced logistics footprint.

Table 4-8 Tradeoff 2: Improve Platform MMBF from 600 to 1,000

Platform MMBF	Total MDT(hours)	Acquisition Cost($M)	Total Maintenance Cost ($M)	LCC	Spares Required to Support Max OPTEMPO	A_M(Calculated as above)	A_O
600 miles	3,460,644	$2,650	$3,150.8	$5,800.8	30	0.944	0.982
1,000 miles	2,705,220	$2,882	$2,777.3	$5,659.3	24	0.955	0.986

4.3.12.3 Additional Analyses Affecting System Development

While the example above covers many of the steps required to determine which of two systems is preferred from a Sustainment KPP perspective, some additional analyses could also be useful. In the example, the number of spare systems required was determined solely by maximum OPTEMPO event needs. Additional spare systems might be necessary if the strategy included forward deployed (or pre-staged) systems. Analysis of the additional acquisition costs necessary to support a forward deployment strategy might lead to a different preferred system decision since platform A based systems are less expensive to acquire than platform B based systems. Additionally, a sensitivity analysis on key drivers of AM, AO, RM, and/or OC might be useful to ensure the system chosen is optimized for operational use. Section 4.3.12.2 shows a type of sensitivity analysis showing significant improvement in the system's operational characteristics through increasing the reliability of platform B.

APPENDIX: RAM-C REPORT OUTLINE

This section provides a format and a description of the elements of the RAM-C Report including general information as to what will be required in the completed report.

A.1 Executive Summary

Creation of the Executive Summary is the responsibility of the combat developer with assistance from the program manager (includes systems engineering and logistic support). The Executive Summary details the user sustainment requirement elements (Materiel Availability, Operational Availability, Reliability, and Ownership Cost) status along with summaries of the combat developer and program manager analyses. Expected sustainment requirement element maturity varies by program phase. Expected rationale maturity are discussed in the program phase description in Sections 1 and 2 of this manual.

A.1.1 System Description and Summary of RAM Goals and Constraints

A.1.1.1 System Description

A.1.1.2 Mission

A.1.2 Description of Sustainment Requirement Element Values

Threshold and objective values for each metric are to be included. This description should take into account:

- Summary of current OMS/MP (all acquisition phases)
- Summary of top drivers of mission failure rate, manpower, and cost
- Analysis showing demonstrated impact on Materiel Availability, Operational Availability, Reliability, and Ownership Cost (Systems Acquisition Phase and Sustainment Phase only).

A.1.3 One-Page Summary of Program Manager Analysis

The program manager's analysis of the sustainment requirement values are summarized here.

- Summary of decomposition of warfighter requirements to materiel (that is, contract) requirements
- Summary of tradeoff analyses conducted or planned
- List of key assumptions made by program manager, such as inventory objectives.

A.1.4 One-Page Summary of Combat Developer Analysis Including Updated RAM-C Goals as Appropriate

Based on the program manager's engineering analysis, the combat developer must assess how he will modify his RAM-C goals based on what the program manager says is achievable.

- Summary of warfighter requirements and rationale for any changes from previously documented values

- Summary of tradeoff analyses conducted or planned
- List of key assumptions made by the combat developer, such as ADT and LDT assumptions.

A.1.5 One-Page Summary of Sustainment System

The combat developer should state how the system will be sustained, the assumptions that are made regarding the sustainment plan and any trades that are made.

- Summary of sustainment concept and metrics including status of metric evaluation
- Summary of tradeoff analyses conducted or planned
- List of key assumptions made by logisticians.

A.1.6 Information for Obtaining Full RAM-C Report

Provide the office name, address and contact info for the office providing the report.

- Address of office responsible for writing report
- Phone number of office
- Point of contact

A.1.7 Approval Signatures for Mid-Phase Updates to Sustainment Requirements

A.2 Program Summary Introduction

Provide a brief description of the program to date, including a description of reasons for changes to the sustainment requirements from previous RAM-C Reports.

A.3 Predecessor System

Describe any predecessor systems considered during the Material Solution Analysis Phase and the capability improvement expected for the materiel solution under development. Include a discussion of the improvements achieved and demonstrated during the later program development and fielding stages.

A.4 Reliability, Availability, Maintainability, and Cost Goals and Constraints

A.4.1 Materiel Availability

A.4.1.1 A_M Requirement

Provide the current AM requirement and the rationale for the stated value. Include any historic values used if changes occur during program refinement. The stated requirement should be in the form of threshold and objective values as they become available. The RAM-C Report developed for the Milestone A decision may only have a single AM value due to program concept immaturity.

A.4.1.2 A_M Rationale

Include rationale used to determine the AM requirement values, including the effects of any assumptions made.

A.4.1.3 Assumption Rationale

Include a listing of assumptions made and related rationale used in AM requirement development and mentioned in the section above. This rationale should be sufficiently detailed to provide the reader with the ability to evaluate the assumption and its effects on the metric.

A.4.1.4 Relevant Facts Known

List facts used during AM requirement development and provide information establishing their factual basis.

A.4.1.5 Supporting Analysis (Combat Developer and/or Program Manager)

Provide details of analyses conducted by the combat developer and/or the program manager in establishing the AM requirements. Include links to detailed supporting information if available.

A.4.2 Operational Availability

A.4.2.1 A_O Requirement

Provide the current AO requirement and the rationale for the stated value. Include any historic values used if changes occur during program refinement. The stated requirement should be in the form of threshold and objective values as they become available. It is anticipated that the RAM-C Report developed for the Milestone A decision may only have a single AO value due to program concept immaturity.

A.4.2.2 A_O Rationale

Include rationale used to determine the AO requirement values including the effects of any assumptions made.

A.4.2.3 Assumption Rationale

Include a listing of assumptions made and related rationale used in AO requirement development and mentioned in the paragraph above. This rationale should be sufficiently detailed to provide the reader with the ability to evaluate the assumption and its effects on the metric.

A.4.2.4 Relevant Facts Known

List facts used during AO requirement development and provide information establishing their factual basis.

A.4.2.5 Supporting Analysis (Combat Developer and/or Program Manager)

Provide details of analyses conducted by the combat developer and/or the program manager in establishing the AO requirements. Include links to detailed supporting information if available.

A.4.3 Materiel Reliability (R_M)

A.4.3.1 R_M Requirement

Provide the current RM requirement and the rationale for the stated value. Include any historic values used if changes occur during program refinement. The stated requirement should be in the form of threshold and objective values as they become available. The RAM-C Report developed for the Milestone A decision may only have an estimate of the RM value due to program concept immaturity.

A.4.3.2 R_M Rationale

Include rationale used to determine the RM requirement values, including the effects of any assumptions made.

A.4.3.3 Assumption Rationale

Include a listing of assumptions made and related rationale used in RM requirement development and mentioned in the section above. This rationale should be sufficiently detailed to provide the reader with the ability to evaluate the assumption and its effects on the metric.

A.4.3.4 Relevant Facts Known

List facts used during RM requirement development and provide information establishing their factual basis.

A.4.3.5 Supporting Analysis (Combat Developer and/or Program Manager)

Provide details of analyses conducted by the combat developer and/or the program manager in establishing the RM requirements. Include links to detailed supporting information if available.

A.4.4 Ownership Cost

A.4.4.1 OC Requirement

Provide the current OC requirement and the rationale for the stated value. Include any historic values used if changes occur during program refinement. Include a description of any key cost drivers identified. The stated requirement should be in the form of threshold and objective values as they become available. The RAM-C Report developed for the Milestone A decision may only have an order of magnitude estimate for OC due to program concept immaturity.

A.4.4.2 OC Rationale

Include rationale used to determine the OC requirement values, including the effects of any assumptions made.

A.4.4.3 Assumption Rationale

Include a listing of assumptions made and related rationale used in OC requirement development and mentioned in the section above. This rationale should be sufficiently detailed to provide the reader with the ability to evaluate the assumption and its effects on the metric. The rationale should be broken out to address the CAIG elements required to support the KSA.

A.4.4.4 Relevant Facts Known

List facts used during OC requirement development and provide information establishing their factual basis.

A.4.4.5 Supporting Analysis (Combat Developer and/or Program Manager)

Provide details of analyses conducted by the combat developer and/or the program manager in establishing the OC requirements. Include links to detailed supporting information if available.

Acronyms

ACAT	Acquisition Category
ACQ	Acquisition
ADT	Administrative Delay Time
Am	Materiel Availability
A_o	Operational Availability
AoA	Analysis of Alternatives
APUC	Average Per Unit Cost
AOTR	Assessment of Operational Test Readiness
ASR	Acquisition Strategy
ASR	Alternative System Review
AT&L	Acquisition, Technology and Logistics
BIT	Built-In-Test
BLRIP	Beyond Low-Rate Initial Production
CAIG	Cost Analysis Improvement Group
CARD	Cost Analysis Requirements Description
CBA	Capabilities Based Assessment
CDD	Capability Development Document
CDR	Critical Design Review
COI	Critical Operational Issue
COIC	Critical Operational Issue and Criteria
CONOPS	Concept of Operations
CPD	Capability Production Document
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
DOTMLPF	Doctrine, Training, Materiel, Leadership, Personnel, and Facilities
DT/OT	Developmental Test/Operational Test
DT&E	Development Test and Evaluation
EMD	Engineering and Manufacturing Development

EoA	Evaluation of Alternatives
EUT	Early User Test
FCA	Functional Configuration Audit
FD/SC	Failure Definition / Scoring Criteria
FOC	Full Operational Capability
FRP	Full-Rate Production
FSA	Functional Solution Assessment
GFE	Government Furnished Equipment
IBR	Integrated Baseline Review
ICD	Initial Capabilities Document
IETM	Interactive Electronic Technical Manuals
ILA	Integrated Logistics Assessment
IOC	Initial Operating Capability
IOT&E	Initial Operational Test and Evaluation
ISR	In-Service Review
ITR	Initial Technical Review
JCIDS	Joint Capabilities Integration and Development System
JROC	Joint Requirements Oversight Council
KM/DS	Knowledge Management/Decision Support
KPP	Key Performance Parameter
KSA	Key System Attribute
LCC	Life Cycle Costs
LCSP	Life Cycle Sustainment Plan
LDT	Logistics Delay-Time
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
LUT	Limited User Test
M&S	Modeling and Simulation
MCBF	Mean Cycles Between Failure
MDAP	Major Defense Acquisition Program

MDD	Materiel Development Decision
MDT	Maintenance Down Time
MMBF	Mean Miles Between Failure
MOE	Measure of Effectiveness
MOP	Measure of Performance
MR	Maintenance Ratio
MRBF	Mean Rounds Between Failure
MS A	Milestone A
MS B	Milestone B
MS C	Milestone C
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTBMs	Mean Time Between Maintenance, Scheduled
MTBMu	Mean Time Between Maintenance, Unscheduled
MTTR	Mean Time to Repair
NDI	Non-Developmental Item
O&S	Operations and Support
OC	Ownership Cost
OMS/MP	Operational Mode Summary / Mission Profile
OPTEMPO	Operating Tempo
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OT	Operational Test
OTA	Operational Test Activity
OT&E	Operational Test and Evaluation
OTRR	Operational Test Readiness Review
OUSD(AT&L)	Office of the Under Secretary of Defense for Acquisition, Technology and Logistics
OUSD(PA&E)	Office of the Under Secretary of Defense for Program Analysis and Evaluation
PBA	Performance-Based Agreement

PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PM	Program Manager
POL	Petroleum, Oil, and Lubricants
PRR	Production Readiness Review
R&D	Research and Development
R&M	Reliability and Maintainability
RAM	Reliability, Availability, and Maintainability
RAM-C	Reliability, Availability, Maintainability, and Cost
R_M	Materiel Reliability
SEP	Systems Engineering Plan
SFR	System Functional Review
SRR	System Requirements Review
SVR	System Verification Review
T&E	Test and Evaluation
TD	Technology Development
TDS	Technology Development Strategy
TEMP	Test and Evaluation Master Plan\
TES	Test and Evaluation Strategy
TOC	Total Ownership Cost
TRA	Technology Readiness Assessment
VAMOSC	Visibility and Management of Operating and Support Costs

References

CJCSI (Chairman of the Joint Chiefs of Staff Instruction) 3170.01G. "Joint Capabilities Integration and Development System," March 1, 2009.

"Defense Science Board Task Force Report on Developmental Test and Evaluation." Washington, DC: U.S. Department of Defense, 2008.

DoD Guide for Achieving Reliability, Availability, and Maintainability (RAM). Washington, DC: U.S. Department of Defense, 2005.

DoD Instruction (DoDI) 5000.02. "Operation of the Defense Acquisition System," December 8, 2008.

GEIA Standard 0009. "Standards on Reliability—Program Standard for Systems Design, Development, and Manufacturing,"2008.

JCIDS (Joint Capabilities Integration and Development System). *Manual for the Operation of the Joint Capabilities Integration and Development System,* March 2009. www.intelink.sgov.gov/wiki/JCIDS.

"Report of the Reliability Improvement Working Group." Washington, DC: U.S. Department of Defense, 2008.

Young, J.J. USD(AT&L) memorandum, "Reliability, Availability, and Maintainability Policy." Washington, DC: OUSD(AT&L). July 21, 2008.

Department of Defense
Reliability, Availability, Maintainability, and Cost Rationale Report Manual

Office of the Secretary of Defense in Collaboration with The Joint Staff

Office of the Deputy Under Secretary of Defense for
Acquisition and Technology
Systems Engineering
3090 Defense Pentagon
Washington, DC 20301