RELIABILITY AND MAINTAINABILITY (R&M)

1. Introduction.

a. R&M is a part of the logistics engineering discipline which:

(1) Establishes logistics design requirements based upon analyses of the system's projected operational missions.

(2) Provides essential operational and logistic requirements which are included in developmental contracts.

(3) Develops operational and logistic criteria for evaluating the system during and after testing.

b. Because materiel acquisition is such a complex and expensive process, functional characteristics of a system compete with one another for resources. During this competition, tradeoffs among cost, schedule, and performance are made. That is, functional characteristics of the system are weighed and decisions are made. For example, we can make the system go faster if we make it lighter. If we make it lighter, it may be less rugged. If the system is less rugged, it may fail more often and not be mission capable when needed. This example illustrates a few of the numerous functional interrelationships. A good R&M program will enable us to:

(1) Develop intelligent requirements by analyzing operational scenarios and deriving quantitative logistics requirements.

(2) Develop a test plan which will incorporate these quantitative measures of effectiveness.

(3) Evaluate the test results and provide defensible recommendations for the disposition of the system. This evaluation will compass:

(a) Determining the amount of technical risk from a supportability view.

(b) Determining the logistics support cost of ownership of the system.

2. Objectives. At the conclusion of this unit of instruction, you should be able to:

a. Provide definitions of reliability, reliability growth, maintainability, availability, operational availability, operational mode summary/mission profile (OMS/MP), operating time (OT), total corrective maintenance (TCM), total preventative maintenance (TPM), total administrative and logistics down time (TALDT), standby time (ST), failure definitions and scoring criteria, four categories of failure, and test-analyze-fix-test (TAFT).

b. Recite at least five qualitative reliability design factors and at least five qualitative maintainability design factors. Describe how qualitative reliability and maintainability factors are used in system design.

c. Integrate R&M related events into a system's materiel acquisition process.

d. Describe the Training and Doctrine Command (TRADOC), Army Materiel Command (AMC), Operational Test and Evaluation Command (ATEC), and the program manager's roles regarding R&M.

3. Operational Mode Summary/Mission Profile (OMS/MP).

a. The purpose of an OMS/MP is to describe how a system or training device will be used in wartime and peacetime at the time it is fielded with focus on the future. Information in an OMS/MP presents a structured, quantitative picture of annual equipment usage. The OMS/MP is a source document for many elements of the materiel acquisition community. They include people working in logistics, test and evaluation, materiel requirements generation, organizational structuring, training, operational planning, and manpower analysis.

b. The OMS/MP is the genesis of the future usage profiles which are used to develop the force structure in the total Army Analysis (TAA) process. It is a source document used to build the Congressionally mandated Manpower Estimate Report (MER).

c. An OMS/MP has been required by the Army as part of a materiel requirements document for many years. The Operational Requirements Document (ORD) contains an overview of the OMS/MP data. The details of the OMS/MP are contained in an annex to the ORD.

d. An OMS/MP describes the anticipated mix of ways units, by unit or mission task mix, will use equipment during a year. It provides the basis for the essential characteristics described in the ORD. As such, the rationale for those characteristics must be supported by the OMS/MP. It covers all missions and profiles for each mission.

(1) The operational mode summary (OMS) shows the relative frequency of the various missions. It also includes the percentage of time the materiel will be exposed to each type of environmental condition during the life of the system. The OMS will not specify unscheduled downtime. The OMS must address special conditions of use, such as wartime usage surge rates, stability and support missions, or high-intensity peacetime usage, when appropriate.

(2) A mission profile (MP) is a time-phased description of the operational events (equipment usage) and environments (natural and man-made) an item experiences from beginning to end of a specific mission. It identifies sequentially the tasks, events, durations, and operating conditions of the system for each phase of a mission. The operational events or tasks may be classified as:

(a) Multifunctional. An item performing several tasks such as a tank shooting, moving, and communicating.

(b) Single function continuous. An item continuously performing one task such as a surveillance radar.

(c) Single function cyclic. An item performing the same task repeatedly such as a missile launcher or artillery piece.

(d) Single function, one time. An item performing a one time task such as a missile or round of ammunition.

Mission Profile Calculations

Operational events or tasks	Number of occurrences	Operating time per task	Total time
Total	XX		XXX

e. The TRADOC proponent that writes an ORD also writes the OMS-MP. Information in an OMS/MP is normally based on an derived from approved TRADOC standard scenarios (and other official sources). Normally, multiple scenarios are used to capture the full range of mission profiles the equipment must accomplish in each unit type. Profiles for each mission quantitatively states specific amounts of operation; e.g., hours, rounds, miles, or cycles, for functions within each mission. Various models are used to develop specific amounts. The information can be provided in a table supported by a narrative summarization.

f. The OMS/MP shows the expected range of environmental conditions into which the entire fleet of systems can be expected to be deployed and operated. Environmental conditions are natural environmental factors such as climate and terrain, as well as man made factors such as nuclear, biological, chemical contamination, electronic counter measures, urban terrain, and smoke. See Appendix A.

OMS Numerical Values

Mission Profiles	OT	OT+AT	CT	# Msns	Total OT	Total OT+AT	Total CT
Total Scenario							

g. There is no standard format or length for an OMS/MP that will fit all types of equipment. Each OMS/MP is unique. Source: ATCD-RM Memorandum, Subject: Operational Mode Summary/Mission Profile (OMS/MP) Development Procedures, dated 15 March 1994.

4. Concept Based Requirements System (CBRS).

a. Within the Army, the Training and Doctrine Command (TRADOC) is the agency responsible for preparing the Army for both present and future battles. TRADOC, the Army's primary combat developer, uses the Concept Based Requirement System (CBRS) as its principal tool. CBRS provides the focus for development of doctrine, force design, training programs, or materiel. Its focus is based on operational concepts to determine the need for new materiel systems.

b. Completing the CBRS analyses is the starting point for TRADOC to initiate the Mission Need Statement (MNS) and later the Operational Requirements Document (ORD). CBRS is driven by the operational concepts and doctrine for how we will fight on the next battlefield. These concepts are periodically analyzed through a process which examines the tasks that must be performed on the battlefield and uncovers deficiencies in the Army's capability to execute the areas of doctrine, training, force structure, or materiel. An integral part of the analysis is the determination of the frequency of task performance, the conditions under which they are performed, and the standards which constitute acceptable performance. This description of tasks, frequency, conditions, and standards forms the basis for the OMS/MP needed to support the requirements documents for new materiel. CBRS attempts to define equipment that will allow the Army to execute its wartime missions effectively to meet established standards.

c. From these studies, the combat developer (concepts and studies experts) determines the major missions for the system, the expected length or calendar time (CT) for each mission, the percentage of total time (frequency) each mission will consume, and the conditions under which the tasks must be performed. This latter requirement (conditions) helps the design engineers develop equipment that will operate in the full range of environmental conditions the system is expected to encounter.

d. There is no standard set of mission templates that can be applied to developing an OMS/MP for any piece of equipment. Each must be tailored to the specific operational requirements, the scenario, and the expected environmental conditions.

5. Reliability.

a. Reliability is defined as the probability that an item will perform in its intended function for a specified interval under stated conditions. This definition does not specifically consider the effect of the age of the system. The following adaptation is useful for systems that are repairable. Reliability, for repairable systems, is the probability that an item will perform its intended function for a specified interval, under stated conditions, at a given age, if both corrective and preventive maintenance are performed in a specified manner. If a system is capable of performing multiple missions, or if it can perform one or more of its missions while operating in a degraded condition or if the mission test profiles represent only typical usage, then the concept of a unique mission reliability becomes difficult to define. In such cases, it is preferable to use a reliability measure that is not based solely on the length of a specified time interval but rather on the definition of a specific mission profile or set of profiles. The meaning of the terms “stated conditions” and “specified interval” are important to the understanding of reliability. The term “stated conditions” refers to the complete definition of the scenario in which the system will operate. For a ground combat vehicle, these conditions include climatic conditions, road surfaces, and loads that would be experienced during a selected mission profile. These conditions should reflect operational usage. The term “specified interval” refers to the length of the mission described in a mission profile. This interval may include multiple factors. For example, an air defense system mission profile will define an interval containing X rounds fired, Y hours of electronics on-time, and Z miles of travel. For a simpler system, say an air-burst artillery round, the interval may include a single event; i.e., round detonation.

b. Qualitative R&M requirements are used when quantitative R&M characteristics are not essential or useful. Qualitative R&M design factors are:

Qualitative Reliability Design Factors

+ Simplicity
+ Use of proven components
+ Improvement of stress-strength relationship
+ Redundancy
+ Protective techniques
+ Local environmental control
+ Elimination of critical failure modes
+ Self- healing
+ Detection of impending failure
+ Use of preventive maintenance
+ Tolerance of evaluation

c. Mean time between failures (MTBF) is defined as the total functioning life of a population of an item during a specific measurement interval, divided by the total number of failures within the population during that interval. MTBF can be interpreted as the expected length of time a system will be operational between failures. The definition is true for time, cycles, miles, events, or other measure-of-life units. These various measure-of-life units permit the MTBF term to be tailored to the reliability requirements of a specific system.

d. Failure rate is the number of failures during a given operating period. The term “failure rate” is often expressed as (λ) (the Greek letter, lambda); e.g., during one million hours of operation, an electronic part might fail 50 times. This would be expressed as:

$$\lambda = 50/1{,}000{,}000 = 0.00005.$$

This measure is more difficult to visualize than the MTBF measure. However, it is a useful mathematical term which frequently appears in engineering and statistical calculations. Also, failure rates are used in determining how many parts to buy for the new system. Failure rate is the reciprocal of the MTBF measure or

$$\text{Failure Rate}\,(\lambda) = \frac{1}{\text{MTBF}}$$

6. Maintainability. Maintainability and reliability are the two major system characteristics that combine to form the commonly used effectiveness index availability. While maintainability is important as a factor of availability, it also merits substantial consideration as an individual system characteristic. The importance of this parameter in the national defense posture becomes even more obvious when we consider that each branch of the armed services spends one third of its budget on system maintenance activities. Several aspects of system maintainability must be addressed before an accurate assessment can be undertaken. First, the difference between maintainability and maintenance must be understood. Maintainability is a design consideration, whereas maintenance is the consequence of design. After a system is fielded, the maintenance activity must live with whatever maintainability is inherent in the design. That is, it must preserve the existing level of maintainability and can do nothing to improve that level. The second consideration is that maintainability requirements can be specified, measured, and demonstrated. Unlike reliability, a detailed and quantitative study of maintainability was not initiated until the early 1950s. Until recently, maintainability often was viewed as a "common sense" ingredient of design. It is now seen as a factor of the design process and a inherent design characteristic that is quantitative in nature and therefore lends itself to specification, demonstration, and trade-off analysis with such characteristics as reliability and logistics support.

a. Maintainability is defined as the probability that an item will be retained in, or restored to, a specified condition within a given period if prescribed procedures and resources are used. A commonly used working definition states that maintainability is a design consideration. It is the inherent characteristic of a finished design that determines the type and amount of maintenance required to retain that design in, or restore it to, a specified condition.

b. Maintenance is defined as, all actions required to retain an item in, or restore it to, a specified condition. This includes diagnosis, repair, and inspection.

(1) Preventive maintenance is defined as systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects. Adjustment, lubrication, and scheduled checks are included in the definition of preventive maintenance.

(2) Corrective maintenance is defined as that maintenance performed on a non-scheduled basis to restore equipment to a satisfactory condition by correcting a malfunction.

c. Some physical design features affect the speed and ease with which maintenance can be performed. These features are qualitative maintainability design factors:

Qualitative Maintainability Design Factors

+ Accessibility
+ Labeling and identification
+ Interchangeability
+ Safety
+ Simplicity
+ Modularization
+ Fasteners and connectors
+ Diagnostics
+ Repair policy
+ Standardization

d. Personnel and human factor considerations are of prime importance. These considerations include the experience of the technician, training, skill level, supervision required, supervision available, techniques used, physical coordination and strength, number of technicians, and teamwork requirements.

e. Support considerations cover the logistics system and maintenance organization required to support the weapon system. They include availability of supplies, spare parts, technical manuals, test equipment, tools (standard or special), and servicing equipment.

f. While some elements of maintainability can be assessed individually, it should be obvious that a true assessment of system maintainability must be developed at the system level under operation conditions and using production configuration hardware.

g. Quantitative Maintainability Indices. The following paragraphs describe mathematical indices used to quantify maintainability.

(1) Mean-Time-To-Repair (MTTR). MTTR is the total corrective maintenance down time accumulated during a specific period divided by the total number of corrective maintenance actions completed during the same period. MTTR commonly is used as an on-equipment measure, but can be applied to each maintenance level. The MTTR considers active corrective maintenance actions and the total number of man-hours expended are not considered (clock hours are used). This index does not provide a good measure of the maintenance burden.

(2) Maintenance Ratio (MR). MR is the cumulative number of man-hours of maintenance expended in direct labor during a given period of time, divided by the cumulative number of end item operating hours (or rounds or miles) during the same time. The MR is expressed at each level of maintenance and summarized for all levels of maintenance. Both corrective and preventive maintenance are included. The MR is a useful measure of the relative maintenance burden associated with a system. It provides a means of comparing systems and is useful in determining the compatibility of a system with the size of the maintenance organization.

h. Diagnostic Systems. One aspect of maintainability that has received significant attention in system design is automatic diagnostic systems. These systems include both internal or integrated diagnostic systems referred to as built-in-test (BIT) or built-in-test-equipment (BITE), and external diagnostic systems, referred to as automatic test equipment (ATE), test sets, or off-line test equipment. As technology advances continue to increase the capability and complexity of modern weapon systems, we are relying more on the use of automatic diagnostics as a means of attaining the required level of failure detection capability. Our need for BIT is driven by operational availability requirements which do not permit lengthy repair actions of detecting and isolating failure modes in microcircuit technology equipment. A well designed BIT system can substantially reduce the need for highly trained field level maintenance technicians by permitting less skilled personnel to locate failures and channel suspect hardware to centralized intermediate repair facilities which are equipped to diagnose or repair defective hardware. BIT is not a comprehensive solution to all system maintenance problems, but rather a tool required to deal with the complexity of modern electronic systems.

7. Availability. Availability translates system reliability and maintainability characteristics into an index of effectiveness. It is based on the question, “Is the equipment available in working condition when it is needed?” The ability to answer this question for a specific system represents a powerful concept in itself, and there are additional side benefits that result. An important benefit is the ability to use the availability analysis as a platform to support both the establishment of reliability and maintainability parameters and trade-offs between these parameters.

a. Availability is defined as a measure of the degree to which an item is in an operable and commitable state at the start of a mission when the mission is called for at a random point in time.

b. Elements of Availability. As evident by its very nature, approaches to availability are time-related. The following chart illustrates the breakdown of total equipment time into those time-based elements on which the analysis of availability is based. Note that the time designated as “off time” does not apply to availability analyses because during this time system operation is not required. Storage and transportation periods are examples of "off time."

<table>
<tr><td colspan="6">Breakdown of Total Equipment Time</td></tr>
<tr><td colspan="5">Total Time</td><td>Off Time</td></tr>
<tr><td colspan="2">Up Time</td><td colspan="3">Down Time</td><td rowspan="2"></td></tr>
<tr><td>OT</td><td>ST</td><td>TCM</td><td>TPM</td><td>TALDT</td></tr>
</table>

c. Definition of Terms.

TCM = Total corrective maintenance (unscheduled maintenance).

TPM = Total preventive maintenance (scheduled maintenance).

ALDT = Administrative and logistics delay or down time. (Time spent waiting for parts, maintenance personnel, or transportation.

CT = Calendar time. Total clock time. From the start of the mission to the end of the mission.

OT = Operating time (equipment in use).

ST = Standby time (not operating but assumed operable).

d. Mathematical Expressions of Availability. Operational Availability (A_o) is the most desirable form of availability to be used in assessing a system's combat potential. A_o is an important measure of system effectiveness because it relates system hardware, support, and environmental characteristics into one parameter. Because it is an effectiveness-related index, availability is used as a starting point for nearly all effectiveness and force sizing analyses. An Operational Availability formula is:

$$A_o = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}$$

This relationship is intended to provide a realistic measure of equipment availability when the equipment is deployed and functioning in a combat environment. Operational availability is used to support operational testing assessments, life cycle costing, and force development exercises. One significant problem associated with determining A_o is that it becomes costly and time consuming to define the various parameters. Defining TALDT and TPM under combat conditions is not feasible in most instances. Nevertheless, the operational availability expression does provide an acceptable technique of relating standard reliability and maintainability elements into an effectiveness-oriented parameter. As such, it is a useful assessment tool. In order to derive A_o, the following formula will be used:

$$A_o = \frac{OT + AT}{CT}$$

Since A_o is the user's statement of the availability requirements of the system to operate on the battlefield, a strong defensible argument for the desired values must be prepared. There should be an audit trail from the concept based requirements system (CBRS) to the operational mode summary/mission profile to the performance requirements and operational characteristics.

8. Failure Definition and Scoring Criteria.

a. If each activity involved in a materiel acquisition program developed their own unique definition of failure, you may find yourself in an unenviable position of having to defend multiple failure rates. (See the M60A2 Tank Test Results.) Obviously, with a range dispersion from 35 miles to 341 miles between failures, opponents of the program will use the 35 MMBF, proponents will use the 341 MMBF, and the Army will lose credibility. For this reason, the Army must develop one definition of failure and use it throughout the life of the materiel acquisition program.

M60A2 Tank Test Results		
Test Activity	MMBF	Logic Used
CDC	232	Unknown
TECOM	089	Nondeferrable incidents
TECOM	122	Parts with mission reliability factors
TECOM	035	All unscheduled actions
TACOM	341	Inability to move or fire

b. Failure Definition. A failure is a degraded and unacceptable performance of a system evidenced by a component or subsystem malfunction. The first part of a failure definition contains a listing of a system's essential functions. The essential functions are generic statements of the system characteristics. They are itemized in the failure definition in order to use qualitative and quantitative descriptions to state the amount of degradation acceptable (if any) before the system is considered to have "failed."

c. According to guidelines developed by TRADOC, the combat developer is responsible for developing and documenting the failure definition for a system throughout the acquisition process. As a system progress through its acquisition program and becomes better defined, it is often necessary to refine and add detail to the failure definition. The materiel developer provides input to this process. Additionally, testers and evaluators will join the materiel and combat developers in coordinating overall definitions of failure and scoring criteria.

d. Mission essential functions are the minimum operational tasks which the system must be capable of performing to successfully complete its mission. These tasks should be taken from the mission profiles. The loss of any mission essential function, regardless of when it occurs, will be scored as an operational mission failure. The purpose of clearly describing the mission essential functions is to allow application of the failure definition which references the mission essential functions to the test data. Categories of failure are:

(1) Category 1 - Catastrophic. May cause death or system loss.

(2) Category 2 - Critical. May cause severe injury, severe occupational illness, major system damage, or mission abort.

(3) Category 3 - Marginal. May cause minor injury, minor occupational illness, minor system damage, or mission delay.

(4) Category 4 - Negligible (Minor). May cause unscheduled maintenance, but will not have any impact upon mission.

A catastrophic or critical failure would be scored as an operational mission failure.

e. Scoring criteria is a term associated with allocating all failures observed during testing. Scoring criteria will provide the procedures for classifying test incident reports into proper failure categories and for charging failures to appropriate causes. Primary classification categories in test incident reports are:

(1) No test. Examples are pre-test inspections, system modifications, test-peculiar events, test-directed abuse, or unrelated damage.

(2) Non essential function failure. Events that result in a system's loss of non-essential functions.

(3) Essential function failure. A failure or malfunction causing degradation below an established level or causing complete loss of an essential function. A frequency or time constraint for determining when an essential function failure becomes a system abort may be specified.

(4) System abort. An event resulting in loss or degradation of an essential function which renders the system unable to enter service or causes immediate removal from service. A system abort prevents the system from being mission capable.

The failure definition and scoring criteria process is used to provide data for system evaluation.

9. Reliability Growth. Initial prototype models of complex weapon systems will invariably have inherent reliability and performance deficiencies that could not have been foreseen and eliminated in early design stages. To uncover and eliminate these deficiencies, we subject these early prototypes and later more mature models to a series of developmental and operational tests. These tests have been specifically planned to stress the system components to predetermined realistic levels at which inadequate design features will surface as system failures. These features are analyzed, design modifications incorporated, and the modified system is tested to verify the validity of the design change. This testing philosophy utilizes the test-analyze-fix-test (TAFT) procedure as the basic catalyst in achieving system reliability growth. The ultimate goal of a reliability growth program is to increase system reliability to stated requirement levels by eliminating a sufficient number of inherent system failure modes.

10. R&M Policies.

a. The Operational Requirements Document (ORD) will state initial operational capability (IOC) requirements for R&M that are based on mission need and operating and support cost reduction. Wartime and peacetime system readiness objectives will be included in the ORD.

b. Issues and risks associated with R&M thresholds will be quantitatively stated in the Test and Evaluation Master Plan (TEMP).

c. Achieving R&M thresholds will be a criterion for transitioning to the next acquisition phase.

d. All R&M requirements will be developed in coordination with the materiel developer, combat developer, and independent development and operational test evaluators.

11. Summary. R&M requirements should be used to influence the system's design. The benefits will be more realistic requirements and lower operating and support costs.

Appendix A (Environmental Conditions)

1. Climatic criteria. AR 70-38 has divided the world into four climatic design types. This is an important contribution to the design of military equipment because it provides boundaries which will help define design parameters. The four types are:

a. Hot. The world's highest air temperatures occur in the areas identified with the hot climatic design type. These are low latitude deserts which also have very low relative humidity and intense solar radiation. Examples are the deserts of northern Africa, the Middle East, Pakistan, India, southwestern United States and northern Mexico.

b. Basic. The humid tropics and the mid latitudes are characterized by moderate temperature. This zone covers more land mass than all others combined. Included are the most densely populated and highly industrialized sectors of the world. All general purpose Army materiel is expected to operate in this zone. Also, since microbial deterioration is a function of humidity and is an inseparable condition of hot, humid tropics and the mid latitudes, it must be considered in the design of all standard general purpose equipment.

c. Cold. The cold climatic design type areas are confined to the northern hemisphere. This area includes parts of Canada, Alaska, Greenland, northern Scandinavia, northern Asia, Tibet, and small areas of the Alps, Himalayas, and Andes mountains.

d. Severe cold. These regions are found in the interiors of Alaska and Canada, northern islands of Canada, the Greenland Ice cap, and in northern Asia.

2. Movement terrain. Unless the system is a stationary item such as a permanent radar site, communications site, or fortification, it must be capable of being moved from one location to another. If the system is being moved over the surface, the Army identifies three types of terrain. They are:

Primary Road
Secondary Road
Cross-Country

Should the system move through the air, minimum and maximum altitudes must be considered. It is very important that each condition be described in detail so specifications and tests can be accurately developed and conducted.

3. Other environmental considerations. Limited visibility; electronic countermeasures; and nuclear, biological, and chemical (NBC) must also be addressed for Army systems.

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