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Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes

Foreword—Reliability-Centered Maintenance (RCM) was initially developed by the commercial aviation industry to improve the safety and reliability of their equipment. It was first documented in a report written by F.S. Nowlan and H.F. Heap and published by the U.S. Department of Defense in 1978. Since then, RCM has been used to help formulate physical asset management strategies in almost every area of organized human endeavor, and in almost every industrialized country in the world. The process defined by Nowlan and Heap served as the basis of various application documents in which the RCM process has been developed and refined over the ensuing years. Most of these documents retain the key elements of the original process. However the widespread use of the term "RCM" has led to the emergence of a number of processes that differ significantly from the original, but that their proponents also call "RCM." Many of these other processes fail to achieve the goals of Nowlan and Heap, and some are actively counterproductive.

As a result, there has been a growing international demand for a standard that sets out the criteria that any process must comply with in order to be called "RCM." This document meets that need.

The criteria in this SAE Standard are based upon the RCM processes and concepts in three RCM documents: (1) Nowlan and Heap's 1978 book, "Reliability-Centered Maintenance," (2) US naval aviation's MIL-STD-2173(AS) (Reliability-Centered Maintenance Requirements of Naval Aircraft, Weapons Systems and Support Equipment) and its successor, U.S. Naval Air Systems Command Management Manual 00-25-403 (Guidelines for the Naval Aviation Reliability-Centered Maintenance Process), and (3) "Reliability-Centered Maintenance (RCM 2)," by John Moubray. These documents are judged to be the most widely-accepted and widely-used RCM documents available.

This document describes the minimum criteria that any process must comply with to be called "RCM." It does not attempt to define a specific RCM process.

This document is intended for anyone who wishes to ascertain whether any process that purports to be RCM is in fact RCM. It is especially useful to people who wish to purchase RCM services (training, analysis, facilitation, consulting, or any combination thereof).

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1. ***Scope—***This SAE Standard for Reliability Centered Maintenance (RCM) is intended for use by any organization that has or makes use of physical assets or systems that it wishes to manage responsibly.

1.1 **Purpose—**RCM is a specific process used to identify the policies which must be implemented to manage the failure modes which could cause the functional failure of any physical asset in a given operating context. This document is intended to be used to evaluate any process that purports to be an RCM process, in order to determine whether it is a true RCM process. This document supports such an evaluation by specifying the minimum criteria that a process must have in order to be an RCM process.

2. ***References***

2.1 **Related Publications—**The following publications are provided for information purposes only and are not a required part of this document.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE JA1012—A Guide to Reliability-Centered Maintenance (RCM)

2.1.2 U.S. DEPARTMENT OF COMMERCE PUBLICATIONS—Available from NTIS, Port Royal Road, Springfield, VA 22161

Nowlan, F. Stanley, and Howard F. Heap, "Reliability-Centered Maintenance," Department of Defense, Washington, D.C. 1978. Report Number AD-A066579.

2.1.3 U.S. DEPARTMENT OF DEFENSE PUBLICATIONS—Available from DODSSP, Subscription Services Desk, Building 4/Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5098

MIL-STD 2173(AS)—"Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment" (U.S. Naval Air Systems Command)
NAVAIR 00-25-403—"Guidelines for the Naval Aviation Reliability Centered Maintenance Process" (U.S. Naval Air System Command)
MIL-P-24534—"Planned Maintenance System: Development of Maintenance Requirement Cards, Maintenance Index Pages, and Associated Documentation" (U.S. Naval Sea Systems Command)
S9081-AB-GIB-010/MAINT—"Reliability-Centered Maintenance Handbook" (U.S. Naval Sea Systems Command)

2.1.4 INDUSTRIAL PRESS PUBLICATION—Available from Industrial Press, Inc., 200 Madison Avenue, New York City, New York, 10016 (also available from Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford, Great Britain OX2 8DP).

Moubray, John, "Reliability-Centered Maintenance," 1997

2.1.5 U.K. MINISTRY OF DEFENCE PUBLICATION—Available from Reliability-centred Maintenance Implementation Team, Ships Support Agency, Ministry of Defence (Navy), Room 22, Block K, Foxhill, Bath, BA1 5AB United Kingdom.

NES 45—Naval Engineering Standard 45, "Requirements for the Application of Reliability-Centred Maintenance Techniques to HM Ships, Royal Fleet Auxiliaries and other Naval Auxiliary Vessels" (Restricted-Commercial)

2.2 Other Publications—The following publications were consulted in the course of developing this SAE Technical Report and are not a required part of this document.

Anderson, Ronald T. and Neri, Lewis, "Reliability-Centered Maintenance: Management and Engineering Methods," Elsevier Applied Science, London and New York, 1990
Blanchard, B.S., Verma, D., and Peterson, E.L., "Maintainability: A Key to Effective Serviceability and Maintenance Management," John Wiley and Sons, New York, 1995
"Dependability Management—Part 3-11: Application Guide—Reliability Centred Maintenance," International Electrotechnical Commission, Geneva, Document No. 56/651/FDIS.
Jones, Richard B., "Risk-Based Management: A Reliability-Centered Approach," Gulf Publishing Company, Houston, TX, 1995
MSG-3, "Maintenance Program Development Document," Air transport Association, Washington DC, Revision 2 1993
"Procedures for Performing a Failure Mode, Effects and Criticality Analysis," Department of Defense, Washington, DC, Military Standard MIL-DTD. 1629A, Notice 2, 1984
"Reliability Centered Maintenance for Aircraft, Engines, and Equipment," United States Air Force, MIL-STD-1843 (NOTE: Cancelled without Replacement, August 1995)
Smith, Anthony M., "Reliability Centered Maintenance," McGraw-Hill, New York, 1993
Zwingelstein, G., "Reliability Centered Maintenance, A Practical Guide for Implementation," Hermés, Paris, 1996

3. *Definitions*

3.1 **Age—**A measure of exposure to stress computed from the moment an item or component enters service when new or re-enters service after a task designed to restore its initial capability, and can be measured in terms of calendar time, running time, distance traveled, duty cycles, or units of output or throughput.

3.2 **Appropriate Task—**A task that is both technically feasible and worth doing (applicable and effective).

3.3 **Conditional Probability of Failure—**The probability that a failure will occur in a specific period provided that the item concerned has survived to the beginning of that period.

3.4 **Desired Performance—**The level of performance desired by the owner or user of a physical asset or system.

3.5 **Environmental Consequences—**A failure mode or multiple failure has environmental consequences if it could breach any corporate, municipal, regional, national, or international environmental standard or regulation which applies to the physical asset or system under consideration.

3.6 **Evident Failure—**A failure mode whose effects become apparent to the operating crew under normal circumstances if the failure mode occurs on its own.

3.7 **Evident Function—**A function whose failure on its own becomes apparent to the operating crew under normal circumstances.

3.8 **Failure Consequences—**The way(s) in which the effects of a failure mode or a multiple failure matter (evidence of failure, impact on safety, the environment, operational capability, direct, and indirect repair costs).

3.9 **Failure Effect—**What happens when a failure mode occurs.

3.10 **Failure-Finding Task—**A scheduled task used to determine whether a specific hidden failure has occurred.

3.11 **Failure Management Policy—**A generic term that encompasses on-condition tasks, scheduled restoration, scheduled discard, failure-finding, run-to-failure, and one-time changes.

3.12 **Failure Mode—**A single event, which causes a functional failure.

3.13 **Function—**What the owner or user of a physical asset or system wants it to do.

3.14 **Functional Failure—**A state in which a physical asset or system is unable to perform a specific function to a desired level of performance.

3.15 **Hidden Failure—**A failure mode whose effects do not become apparent to the operating crew under normal circumstances if the failure mode occurs on its own.

3.16 **Hidden Function—**A function whose failure on its own does not become apparent to the operating crew under normal circumstances.

3.17 **Initial Capability—**The level of performance that a physical asset or system is capable of achieving at the moment it enters service.

3.18 **Multiple Failure—**An event that occurs if a protected function fails while its protective device or protective system is in a failed state.

3.19 Non-Operational Consequences—A category of failure consequences that do not adversely affect safety, the environment, or operations, but only require repair or replacement of any item(s) that may be affected by the failure.

3.20 On-Condition Task—A scheduled task used to detect a potential failure.

3.21 One-Time Change—Any action taken to change the physical configuration of an asset or system (redesign or modification), to change the method used by an operator or maintainer to perform a specific task, to change the operating context of the system, or to change the capability of an operator or maintainer (training)

3.22 Operating Context—The circumstances in which a physical asset or system is expected to operate.

3.23 Operational Consequences—A category of failure consequences that adversely affect the operational capability of a physical asset or system (output, product quality, customer service, military capability, or operating costs in addition to the cost of repair).

3.24 Owner—A person or organization that may either suffer or be held accountable for the consequences of a failure mode by virtue of ownership of the asset or system.

3.25 P-F Interval—The interval between the point at which a potential failure becomes detectable and the point at which it degrades into a functional failure (also known as “failure development period” and “lead time to failure”)

3.26 Potential Failure—An identifiable condition that indicates that a functional failure is either about to occur or is in the process of occurring.

3.27 Protective Device or Protective System—A device or system which is intended to avoid, eliminate, or minimize the consequences of failure of some other system.

3.28 Primary Function(s)—The function(s) which constitute the main reason(s) why a physical asset or system is acquired by its owner or user.

3.29 Run-to-Failure—A failure management policy that permits a specific failure mode to occur without any attempt to anticipate or prevent it.

3.30 Safety Consequences—A failure mode or multiple failure has safety consequences if it could injure or kill a human being.

3.31 Scheduled—Performed at fixed, predetermined intervals, including “continuous monitoring” (where the interval is effectively zero).

3.32 Scheduled Discard—A scheduled task that entails discarding an item at or before a specified age limit regardless of its condition at the time.

3.33 Scheduled Restoration—A scheduled task that restores the capability of an item at or before a specified interval (age limit), regardless of its condition at the time, to a level that provides a tolerable probability of survival to the end of another specified interval.

3.34 Secondary Functions—Functions which a physical asset or system has to fulfill apart from its primary function(s), such as those needed to fulfill regulatory requirements and those which concern issues such as protection, control, containment, comfort, appearance, energy efficiency, and structural integrity.

3.35 User—A person or organization that operates an asset or system and may either suffer or be held accountable for the consequences of a failure mode of that system.

4. Acronyms

4.1 RCM—Reliability-Centered Maintenance

5. Reliability-Centered Maintenance (RCM)—Any RCM process shall ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown as follows:

a. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
b. In what ways can it fail to fulfil its functions (functional failures)?
c. What causes each functional failure (failure modes)?
d. What happens when each failure occurs (failure effects)?
e. In what way does each failure matter (failure consequences)?
f. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
g. What should be done if a suitable proactive task cannot be found (default actions)?

To answer each of the previous questions "satisfactorily," the following information shall be gathered, and the following decisions shall be made. All information and decisions shall be documented in a way which makes the information and the decisions fully available to and acceptable to the owner or user of the asset.

5.1 Functions

5.1.1 The operating context of the asset shall be defined.

5.1.2 All the functions of the asset/system shall be identified (all primary and secondary functions, including the functions of all protective devices).

5.1.3 All function statements shall contain a verb, an object, and a performance standard (quantified in every case where this can be done).

5.1.4 Performance standards incorporated in function statements shall be the level of performance desired by the owner or user of the asset/system in its operating context.

5.2 Functional failures—All the failed states associated with each function shall be identified.

5.3 Failure modes

5.3.1 All failure modes reasonably likely to cause each functional failure shall be identified.

5.3.2 The method used to decide what constitutes a "reasonably likely" failure mode shall be acceptable to the owner or user of the asset.

5.3.3 Failure modes shall be identified at a level of causation that makes it possible to identify an appropriate failure management policy.

5.3.4 Lists of failure modes shall include failure modes that have happened before, failure modes that are currently being prevented by existing maintenance programs and failure modes that have not yet happened but that are thought to be reasonably likely (credible) in the operating context.

5.3.5 Lists of failure modes should include any event or process that is likely to cause a functional failure, including deterioration, design defects, and human error whether caused by operators or maintainers (unless human error is being actively addressed by analytical processes apart from RCM).

5.4 Failure Effects

5.4.1 Failure effects shall describe what would happen if no specific task is done to anticipate, prevent, or detect the failure.

5.4.2 Failure effects shall include all the information needed to support the evaluation of the consequences of the failure, such as:

a. What evidence (if any) that the failure has occurred (in the case of hidden functions, what would happen if a multiple failure occurred)
b. What it does (if anything) to kill or injure someone, or to have an adverse effect on the environment
c. What it does (if anything) to have an adverse effect on production or operations
d. What physical damage (if any) is caused by the failure
e. What (if anything) must be done to restore the function of the system after the failure

5.5 Failure Consequence Categories

5.5.1 The consequences of every failure mode shall be formally categorized as follows:

5.5.1.1 The consequence categorization process shall separate hidden failure modes from evident failure modes.

5.5.1.2 The consequence categorization process shall clearly distinguish events (failure modes and multiple failures) that have safety and/or environmental consequences from those that only have economic consequences (operational and non-operational consequences).

5.5.2 The assessment of failure consequences shall be carried out as if no specific task is currently being done to anticipate, prevent, or detect the failure.

5.6 Failure Management Policy Selection

5.6.1 The failure management selection process shall take account of the fact that the conditional probability of some failure modes will increase with age (or exposure to stress), that the conditional probability of others will not change with age, and the conditional probability of yet others will decrease with age.

5.6.2 All scheduled tasks shall be technically feasible and worth doing (applicable and effective), and the means by which this requirement will be satisfied are set out in 5.7.

5.6.3 If two or more proposed failure management policies are technically feasible and worth doing (applicable and effective), the policy that is most cost-effective shall be selected.

5.6.4 The selection of failure management policies shall be carried out as if no specific task is currently being done to anticipate, prevent or detect the failure.

5.7 Failure Management Policies—Scheduled Tasks

5.7.1 All scheduled tasks shall comply with the following criteria:

5.7.1.1 In the case of an evident failure mode that has safety or environmental consequences, the task shall reduce the probability of the failure mode to a level that is tolerable to the owner or user of the asset.

5.7.1.2 In the case of a hidden failure mode where the associated multiple failure has safety or environmental consequences, the task shall reduce the probability of the hidden failure mode to an extent which reduces the probability of the associated multiple failure to a level that is tolerable to the owner or user of the asset.

5.7.1.3 In the case of an evident failure mode that does not have safety or environmental consequences, the direct and indirect costs of doing the task shall be less than the direct and indirect costs of the failure mode when measured over comparable periods of time.

5.7.1.4 In the case of a hidden failure mode where the associated multiple failure does not have safety or environmental consequences, the direct and indirect costs of doing the task shall be less than the direct and indirect costs of the multiple failure plus the cost of repairing the hidden failure mode when measured over comparable periods of time.

5.7.2 ON-CONDITION TASKS—Any on-condition task (or predictive or condition-based or condition monitoring task) that is selected shall satisfy the following additional criteria:

5.7.2.1 There shall exist a clearly defined potential failure.

5.7.2.2 There shall exist an identifiable P-F interval (or failure development period).

5.7.2.3 The task interval shall be less than the shortest likely P-F interval.

5.7.2.4 It shall be physically possible to do the task at intervals less than the P-F interval.

5.7.2.5 The shortest time between the discovery of a potential failure and the occurrence of the functional failure (the P-F interval minus the task interval) shall be long enough for predetermined action to be taken to avoid, eliminate, or minimize the consequences of the failure mode.

5.7.3 SCHEDULED DISCARD TASKS—Any scheduled discard task that is selected shall satisfy the following additional criteria:

5.7.3.1 There shall be a clearly defined (preferably a demonstrable) age at which there is an increase in the conditional probability of the failure mode under consideration.

5.7.3.2 A sufficiently large proportion of the occurrences of this failure mode shall occur after this age to reduce the probability of premature failure to a level that is tolerable to the owner or user of the asset.

5.7.4 SCHEDULED RESTORATION TASKS—Any scheduled restoration task that is selected shall satisfy the following additional criteria:

5.7.4.1 There shall be a clearly defined (preferably a demonstrable) age at which there is an increase in the conditional probability of the failure mode under consideration.

5.7.4.2 A sufficiently large proportion of the occurrences of this failure mode shall occur after this age to reduce the probability of premature failure to a level that is tolerable to the owner or user of the asset.

5.7.4.3 The task shall restore the resistance to failure (condition) of the component to a level that is tolerable to the owner or user of the asset.

5.7.5 FAILURE-FINDING TASKS—Any failure-finding task that is selected shall satisfy the following additional criteria (failure-finding does not apply to evident failure modes):

5.7.5.1 The basis upon which the task interval is selected shall take into account the need to reduce the probability of the multiple failure of the associated protected system to a level that is tolerable to the owner or user of the asset.

5.7.5.2 The task shall confirm that all components covered by the failure mode description are functional.

5.7.5.3 The failure-finding task and associated interval selection process should take into account any probability that the task itself might leave the hidden function in a failed state.

5.7.5.4 It shall be physically possible to do the task at the specified intervals.

5.8 Failure Management Policies—One-Time Changes and Run-to-Failure

5.8.1 ONE-TIME CHANGES

5.8.1.1 The RCM process shall endeavor to extract the desired performance of the system as it is currently configured and operated by applying appropriate scheduled tasks.

5.8.1.2 In cases where such tasks cannot be found, one-time changes to the asset or system may be necessary, subject to the following criteria.

5.8.1.2.1 In cases where the failure is hidden, and the associated multiple failure has safety or environmental consequences, a one-time change that reduces the probability of the multiple failure to a level tolerable to the owner or user of the asset is compulsory.

5.8.1.2.2 In cases where the failure mode is evident and has safety or environmental consequences, a one-time change that reduces the probability of the failure mode to a level tolerable to the owner or user of the asset is compulsory.

5.8.1.2.3 In cases where the failure mode is hidden, and the associated multiple failure does not have safety or environmental consequences, any one-time change must be cost-effective in the opinion of the owner or user of the asset.

5.8.1.2.4 In cases where the failure mode is evident and does not have safety or environmental consequences, any one-time change must be cost-effective in the opinion of the owner or user of the asset.

5.8.2 RUN-TO-FAILURE—Any run-to-failure policy that is selected shall satisfy the appropriate criterion as follows:

5.8.2.1 In cases where the failure is hidden and there is no appropriate scheduled task, the associated multiple failure shall not have safety or environmental consequences.

5.8.2.2 In cases where the failure is evident and there is no appropriate scheduled task, the associated failure mode shall not have safety or environmental consequences.

5.9 A Living Program

5.9.1 This document recognizes that (a) much of the data used in the initial analysis are inherently imprecise, and that more precise data will become available in time, (b) the way in which the asset is used, together with associated performance expectations, will also change with time, and (c) maintenance technology continues to evolve. Thus a periodic review is necessary if the RCM-derived asset management program is to ensure that the assets continue to fulfill the current functional expectations of their owners and users.