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A Guide to the Reliability-Centered Maintenance (RCM) Standard		

RATIONALE

The document was updated as a result of the normal 5 year review cycle and to maintain consistency with the most recent revisions to SAE JA1011 – Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes. Changes were made to clarify the origin of the Reliability Centered Maintenance process and purpose of that document. Additionally, terminology was updated to reflect current usage in the user community and to remove items that might have been considered biased to individual commercial processes. The overall technical process remains unchanged.

FOREWORD

Reliability-Centered Maintenance (RCM) was first documented in a report written by F.S. Nowlan and H.F. Heap of United Airlines and published by the U.S. Department of Defense in 1978. It described the then-current state-of-the-art processes used to develop maintenance programs for commercial aircraft. Since then, the RCM process has been widely used by other industries, and has been extensively refined and developed. These refinements have been incorporated into numerous application documents, published by a variety of organizations around the world. Many of these documents remain faithful to the basic principles of RCM as expounded by Nowlan and Heap.

However in the development of some of these documents, key elements of the RCM process have been omitted or misinterpreted. Due to the growing popularity of RCM, other processes have emerged that have been given the name “RCM” by their proponents, but that are not based on Nowlan and Heap at all. While most of these processes may achieve some of the goals of RCM, a few are actively counterproductive, and some are even dangerous.

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.” SAE JA1011 meets that need. However SAE JA1011 presupposes a high degree of familiarity with the concepts and terminology of RCM. This Guide amplifies, and where necessary clarifies, those key concepts and terms, especially those that are unique to RCM.

Note that this Guide is not intended to be a manual or a procedural guide for performing RCM. Those who wish to apply RCM are strongly encouraged to study the subject in greater detail, and to develop their competency under the guidance of experienced RCM practitioners.

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TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Organization of the Guide	4
2.	REFERENCES.....	4
2.1	Applicable Publications	4
2.2	Related Publications	4
2.3	Other Publications.....	5
3.	DEFINITIONS	6
4.	ACRONYMS	9
5.	ASSET DEFINITION	9
6.	FUNCTIONS	9
6.1	Operating Context	10
6.2	List of Functions	11
6.3	Describing Functions.....	13
6.4	Performance Standards	14
7.	FUNCTIONAL FAILURES.....	15
7.1	Partial and Total Failure	16
7.2	Upper and Lower Limits	16
8.	FAILURE MODES.....	16
8.1	Identifying Failure Modes	17
8.2	Establishing What Is Meant By "Reasonably Likely"	18
8.3	Levels of Causation.....	18
8.4	Sources of Information about Failure Modes.....	20
8.5	Types of Failure Modes.....	21
9.	FAILURE EFFECTS.....	21
9.1	Basic Assumptions	22
9.2	Information Needed.....	22
10.	FAILURE CONSEQUENCE CATEGORIES.....	24
10.1	Consequence Categories	24
10.2	Assessing Failure Consequences.....	28
11.	FAILURE MANAGEMENT POLICY SELECTION	28
11.1	The Relationship Between Age and Failure	28
11.2	Technically Feasible and Worth Doing	29
11.3	Cost Effectiveness	29
11.4	Failure Management Policy Selection.....	30
12.	FAILURE CONSEQUENCE MANAGEMENT	30
12.1	Evident Failure Modes with Safety or Environmental Consequences	30
12.2	Hidden Failure Modes with Safety or Environmental Consequences.....	32
12.3	Evident Failure Modes with Economic Consequences.....	33
12.4	Hidden Failure Modes with Economic Consequences	34
13.	FAILURE MANAGEMENT POLICIES—SCHEDULED TASKS.....	34
13.1	On-Condition Tasks	34
13.2	Scheduled Restoration and Scheduled Discard Tasks.....	40
13.3	Failure-finding Tasks.....	41
13.4	Combination of Tasks	46

14.	FAILURE MANAGEMENT POLICIES—ONE-TIME CHANGES AND RUN-TO-FAILURE	46
14.1	One-Time Changes	46
14.2	Run To Failure	49
15.	FAILURE MANAGEMENT POLICY SELECTION	49
15.1	Two Approaches	49
15.2	The Rigorous Approach	50
15.3	Decision Diagram Approaches	51
16.	A LIVING PROGRAM	56
17.	MATHEMATICAL AND STATISTICAL FORMULAE	57
17.1	Logically Robust	57
17.2	Available to Owner or User	57
18.	IMPORTANT ADDITIONAL CONSIDERATIONS	58
18.1	Prioritizing assets and establishing objectives	58
18.2	Planning	59
18.3	Level of Analysis And Asset Boundaries	59
18.4	Technical Documentation	60
18.5	Organization	60
18.6	Training	61
18.7	Role of computer software	61
18.8	Data gathering	61
18.9	Implementation	62
19.	NOTES	62
FIGURE 1	FUNCTION OF A PUMP	13
FIGURE 2	ALLOWING FOR DETERIORATION	14
FIGURE 3	FAILURE MODES OF A PUMP	17
FIGURE 4	FAILURE MODES AT DIFFERENT LEVELS OF DETAIL	19
FIGURE 5	EVIDENT FAILURE OF A PROTECTIVE FUNCTION	25
FIGURE 6	HIDDEN FAILURE OF A PROTECTIVE FUNCTION	26
FIGURE 7	SIX PATTERNS OF FAILURE	29
FIGURE 8	THE P-F CURVE	35
FIGURE 9	THE P-F INTERVAL	35
FIGURE 10	NET P-F INTERVAL	36
FIGURE 11	RANDOM FAILURES AND THE P-F INTERVAL	37
FIGURE 12	A LIINEAR P-F CURVE	38
FIGURE 13	INCONSISTENT P-F INTERVALS	39
FIGURE 14	SAFE LIFE LIMITS	41
FIGURE 15	FAILURE-FINDING INTERVAL, AVAILABILITY, AND RELIABILITY	44
FIGURE 16	FIRST DECISION DIAGRAM EXAMPLE	54
FIGURE 17	SECOND DECISION DIAGRAM EXAMPLE	55

1. SCOPE

SAE JA1012 ("A Guide to the Reliability-Centered Maintenance (RCM) Standard") amplifies and clarifies each of the key criteria listed in SAE JA1011 ("Evaluation Criteria for RCM Processes"), and summarizes additional issues that must be addressed in order to apply RCM successfully.

1.1 Organization of the Guide

Sections 5 to 14, 16, and 17 of this Guide reflect the major sections of SAE JA1011. Section 15 explains in more detail how key elements of the RCM process can be combined to select appropriate policies for managing individual failure modes and their consequences. Section 18 addresses management and resourcing issues essential to the successful performance of RCM.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE JA1011 Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 U.S. Department of Commerce Publication

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

2.2.2 U.S. Department of Defense Publications

Available from DODSSP, Subscription Services Desk, Building 4/Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5098. MIL standards and handbooks may also be obtained from <https://assist.daps.dla.mil/quicksearch/>.

MIL-HDBK 2173(AS)	"Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment," (U.S. Naval Air Systems Command) (NOTE: canceled without replacement, August 2001.)
NAVAIR 00-25-403	"Guidelines for the Naval Aviation Reliability-Centered Maintenance Process," (U.S. Naval Air Systems Command)
MIL-P-24534	"Planned Maintenance System: Development of Maintenance Requirement Cards, Maintenance Index Pages, and Associated Documentation," (U.S. Naval Sea Systems Command)
MIL-STD-1629	"Procedures for Performing a Failure Mode, Effects and Criticality Analysis," Department of Defense, Washington, DC, 1984 (NOTE: Cancelled without replacement, August 1998)
MIL-STD-1843	"Reliability Centered Maintenance for Aircraft, Engines, and Equipment," United States Air Force (NOTE: Cancelled without Replacement, August 1995)
S9081-AB-GIB-010/MAINT	"Reliability-Centered Maintenance Handbook" (U.S. Naval Sea Systems Command)

2.2.3 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)
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2.3 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., D. Verma 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, Doc. No. 56/651/FDIS

Jones, Richard B., "Risk-Based Management: A Reliability-Centered Approach," Gulf Publishing Co., Houston, TX, 1995

MSG-3, Maintenance Program Development Document," Air Transport Association, Washington, D.C. Revision 2007.1

Moubry, John, "Reliability Centered Maintenance," Industrial Press. Inc. New York City, 1997.

Smith, Anthony M., "Reliability Centered Maintenance," McGraw-Hill, New York. 1993

Zwinglestein, G., "Reliability Centered Maintenance, a practical guide for implementation," Hermès, Paris, 1996

3. DEFINITIONS

3.1 AGE

A measure of exposure to stress computed from the moment an item enters service or first begins to degrade, either from new or re-entering service after a task designed to restore its initial capability. Age 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 capable of preventing or mitigating the consequences of failure based on the technical characteristics of that failure

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 classification assigned to failure modes, or multiple failures in the case of hidden failure modes, that could result in a breach of any industry or government environmental standard or regulation.

3.6 EVIDENT FAILURE

A failure mode whose effects become apparent to the operator(s) 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 operator(s) under normal circumstances.

3.8 FAILURE CONSEQUENCES

A classification of the failure effects of failure modes into categories based on evidence of failure, impact on safety, the environment, operational capability, and cost.

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 operator(s) 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 operator(s) 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 NET P-F INTERVAL

The minimum interval likely to elapse between the discovery of a potential failure and the occurrence of the functional failure.

3.20 NON-OPERATIONAL CONSEQUENCES

A classification assigned to failure modes

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.

3.21 ON-CONDITION TASK

A periodic or continuous task used to detect a potential failure.

3.22 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 operational context of the system, or to change the capability of an operator or maintainer (training).

3.23 OPERATING CONTEXT

The circumstances in which a physical asset or system is expected to operate.

3.24 OPERATIONAL CONSEQUENCES

A classification assigned to failure modes 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).

3.25 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.

3.26 P-F INTERVAL

The period between the point at which a potential failure becomes detectable and the point at which it degrades into a functional failure.

3.27 POTENTIAL FAILURE

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

3.28 PROACTIVE MAINTENANCE

Maintenance undertaken before a failure occurs, in order to prevent the item from getting into a failed state (scheduled restoration, scheduled discard, and on-condition maintenance).

3.29 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.

3.30 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.

3.31 RUN-TO-FAILURE

A failure management policy that permits a specific failure mode to occur without any attempt to anticipate or prevent it.

3.32 SAFETY CONSEQUENCES

A classification of failure modes that could injure or kill a human being.

3.33 SCHEDULED DISCARD

A scheduled task that entails replacing an item at or before a specified age limit regardless of its condition at the time.

3.34 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 acceptable probability of survival to the end of another specified interval.

3.35 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.

3.36 USER

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

4. ACRONYMS

BITE	Built-In Test Equipment
FFI	Failure-finding (task) interval
FMEA	Failure Mode and Effects Analysis
mm	Millimeters
MMF	Mean Time Between Multiple Failures
MTBF	Mean Time Between Failures
MTED	MTBF of the Protected Function
MTIVE	MTBF of the Protective Function
psi	Pounds per Square Inch
RCM	Reliability-Centered Maintenance
RPM	Revolutions Per Minute
UTIVE	Allowed Unavailability of the Protective Function

5. ASSET DEFINITION

“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.” (SAE JA1011, 1.1)

In order to identify appropriate failure management policies for any physical asset or system, the asset or system must be defined. This entails selecting the asset/system, defining its boundaries, and identifying the most appropriate level of detail at which to carry out the analysis.

SAE JA1011 refers to the processes used to select suitable failure management policies, under the assumption that the asset/system concerned has already been selected and defined. It does not provide criteria for processes to be used for selecting and defining the assets or systems themselves, because such processes tend to be highly dependent on the type of asset/system and where, for what, and by whom it is being (or to be) used. However some general guidance on this topic is provided in Section 18 of this Guide.

6. FUNCTIONS

An RCM process that conforms to SAE JA1011 begins by asking the question, “What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?” This section discusses the following four key concepts concerning functions that are listed in 5.1 of SAE JA1011:

- a. Operating context
- b. Primary and secondary functions
- c. Function statements
- d. Performance standards

6.1 Operating Context

“The operating context of the asset shall be defined.” (SAE JA1011, 5.1.1)

The functions, failure modes, failure consequences, and failure management policies that will be applied to any asset will depend not only on what the asset is, but also on the exact circumstances under which it is to be used. As a result, these circumstances need to be clearly defined before attempting to answer the question quoted above.

An operating context statement for a physical asset typically includes a brief overall description of how it is to be used, where it is to be used, overall performance criteria governing issues such as output, throughput, safety, environmental integrity, and so on. Specific issues that should be documented in the operating context statement include:

- a. Batch versus flow processes: whether the asset is operating in a batch (or intermittent) process or a flow (or continuous) process.
- b. Quality standards: overall quality or customer service expectations, in terms of issues such as overall scrap rates, customer satisfaction measurements (such as on-time performance expectations in transportation systems, or rates of warranty claims for manufactured goods), or military preparedness.
- c. Environmental standards: what organizational, regional, national, and international environmental standards (if any) apply to the asset.
- d. Safety standards: whether any predetermined safety expectations (in terms of overall injury and/or fatality rates) apply to the asset.
- e. Theater of operations: characteristics of the location in which equipment is to be operated (arctic versus tropical, desert versus jungle, onshore versus offshore, proximity to sources of supply of parts and/or labor, etc.).
- f. Intensity of operations: in the case of manufacturing and mining, whether the process of which the equipment forms a part is to operate 24 hours per day, seven days per week, or at lower intensity. In the case of utilities, whether the equipment operates under peak load or base load conditions. In the case of military equipment, whether the failure management policies are designed for peacetime or wartime operations.
- g. Redundancy: whether any redundant or standby capability exists, and if so what form it takes.
- h. Work-in-process: the extent to which work-in-process stocks (if any) allow the equipment to stop without affecting total output or throughput.
- i. Spares: whether any decisions have been made about the stocking of key spares that might impinge on the subsequent selection of failure management policies.
- j. Market demand/raw material supply: whether cyclic fluctuations in market demand and/or the supply of raw materials are likely to impinge on the subsequent selection of failure management policies. (Such fluctuations may occur over the course of a day in the case of an urban transport business, or over the course of a year in the case of a power station, an amusement park, or a food processing business.)

In the case of very large or very complex systems, it might be sensible to structure the operating context in a hierarchical fashion, if necessary starting with the mission statement of the entire organization that is using the asset.

6.2 List of Functions

“All the functions of the asset/system shall be identified (all primary and secondary functions, including the functions of all protective devices).” (SAE JA1011, 5.1.2)

The objective of the RCM process is to develop a set of policies that preserve the functions of the asset or system under consideration to standards of performance that are acceptable to its owner/user. As a result, the RCM process starts by identifying all the functions of the asset in its operating context.

Functions can be divided into two categories: primary and secondary functions.

6.2.1 Primary Functions

The reason why any organization acquires any asset or system is to fulfill a specific function or functions. These are known as primary functions of the asset. For instance, the main reason why someone acquires a car may be “to transport up to five people at speeds up to 90 km an hour along suitable roads.”

6.2.2 Secondary Functions

Most assets are expected to perform other functions, in addition to the primary functions. These are known as their secondary functions. Secondary functions are usually less obvious than primary functions. But the loss of a secondary function can still have serious consequences, sometimes more serious than the loss of a primary function. As a result, secondary functions often need as much if not more attention than primary functions, so they too must be clearly identified.

When identifying secondary functions, care should be taken not to overlook the following:

- a. Environmental integrity
- b. Safety/structural integrity
- c. Control/containment/comfort
- d. Appearance
- e. Protective devices and systems
- f. Economy/efficiency
- g. Superfluous

These issues are discussed in more detail as follows.

6.2.2.1 Environmental Integrity

These functions define the extent to which the asset must comply with the corporate, municipal, regional, national, and international environmental standards or regulations that apply to that asset. These standards govern such things as the release of hazardous materials into the environment, and noise.

6.2.2.2 Safety

It is sometimes necessary to write function statements that deal with specific threats to safety that are inherent in the design or operation of the process (as opposed to safety threats that are a result of a functional failure). For example, the function of electrical insulation on a domestic appliance is “to prevent users from touching electrically live components.”

6.2.2.3 Structural Integrity

Many assets have a secondary function of providing support for or a secure mount for another item. For example, while the primary function of a wall may be to protect people and equipment from the weather, it might also be expected to support the roof, or to bear the weight of shelves and pictures.

6.2.2.4 Control

In many cases, users not only want assets to fulfill functions to a given standard of performance, but they also want to be able to regulate the performance. This expectation is summarized in separate function statements. For example, a function of a cooling system may be to regulate temperature at will between one specific temperature and another. Indication and feedback form an important subset of the control category of functions.

6.2.2.5 Containment

Systems whose primary function is to store materials must also contain them. Similarly, systems that transfer materials—especially fluids—also have a containment function. These functions must be specified as well.

6.2.2.6 Comfort

Owners and users generally expect that their assets or systems will not cause pain or anxiety to operators or maintainers. These problems should of course be dealt with at the design stage. However deterioration or changing expectations can lead to unacceptable levels of pain or anxiety. The best way to ensure that this does not happen is ensure that the associated function statements are described precisely and that they fully reflect current standards.

6.2.2.7 Appearance

Appearance often constitutes an important secondary function. For example, the primary reason for painting most industrial equipment is to protect it from corrosion. However a bright color may be chosen to enhance its visibility for safety's sake, and this function should also be documented.

6.2.2.8 Protection

Protective functions avoid, eliminate, or minimize the consequences of the failure of some other function. These functions are associated with devices or systems that:

- a. Warn operators of abnormal conditions (warning lights or alarms)
- b. Shut down equipment in the event of a functional failure (shutdown mechanisms)
- c. Eliminate or relieve abnormal conditions caused by a functional failure (relief mechanisms, fire suppression systems, life preservers)
- d. Take over from a function that has failed (redundant structural components, stand-by plant)
- e. Prevent dangerous situations from arising in the first place (warning signs, protective covers)

A protective function ensures that the failure of the function being protected is much less serious than it would be without the protection. The associated devices are incorporated into systems to reduce risk, so their functions should be documented with special care.

6.2.2.9 Economy/Efficiency

In most organizations, overall cost expectations are expressed in the form of expenditure budgets. However for specific assets, cost expectations can be addressed directly by secondary function statements concerning such things as energy consumption rates and the rate of attrition of process materials.

6.2.2.10 Superfluous Functions

Some systems incorporate items or components that are found to be completely superfluous. This usually happens when equipment or the way in which it is used has been modified over a period of years, or when new equipment has been overspecified.

Although such items have no positive function and are often costly to remove, they can in fact fail and thus reduce overall system reliability. To avoid this, some may require maintenance and so consume resources.

If they are removed, the associated failure modes and costs will also be removed. However, before their removal can be recommended with confidence, their functions need to be clearly identified and understood.

6.2.2.11 "Reliability" Functions

There is often a temptation to write "reliability" function statements such as "to operate seven days a week, 24 hours per day." In fact, reliability is not a function in its own right. It is a performance expectation that pervades all the other functions. Overall reliability/availability goals can be documented in the context statement. The reliability of a specific asset is in fact managed by dealing appropriately with each of the failure modes that could cause each loss of function.

6.3 Describing Functions

"All function statements shall contain a verb, an object, and a performance standard (quantified in every case where this can be done)." (SAE JA1011, 5.1.3)

For example, Figure 1 shows a pump pumping water from one tank into another. The nominal capacity of the pump is 1000 liters per minute, and water is withdrawn from the tank at a maximum rate of 800 liters per minute. The primary function of this pump would be described as: "to pump water from tank X to tank Y at not less than 800 liters per minute." Here the verb is "to pump," the object is "water," and the performance standard is "from tank X to tank Y at not less than 800 liters per minute."

Protective function statements need special handling. These functions act by exception—in other words, when something else goes wrong—so the function statement should reflect this fact. This is usually done by incorporating the words "if" or "in the event of," followed by a very brief summary of the circumstances or event that would activate the protection. For example, the function of a pressure safety valve may be described as follows: "To be capable of relieving the pressure in the boiler if it exceeds 250 psi."

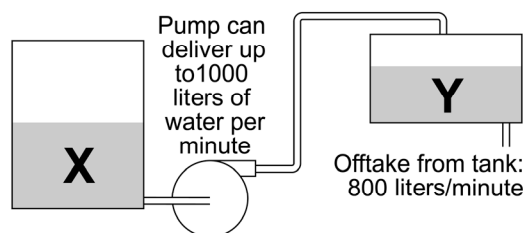


FIGURE 1 - FUNCTION OF A PUMP

6.4 Performance Standards

“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.” (SAE JA1011, 5.1.4)

Any organized system exposed to the real world will deteriorate—to total disorganization (also known as “chaos” or “entropy”)—unless steps are taken to deal with whatever process is causing the system to deteriorate.

For example, centrifugal pumps are subject to impeller wear. This happens whether a pump moves acid or lubricating oil, and whether the impeller is made of titanium or mild steel. The only question is how fast the impeller will wear to the point that it can no longer pump fluid at the minimum required flow rate.

Once the performance of an asset drops below the minimum that is acceptable to the user, that asset has failed. Conversely, if the performance of the asset is maintained above this minimum, it continues to function to a level that is satisfactory to the user. As used in this Guide, “users” include the owners of the assets, the users of the assets—usually the operators—and society as a whole. Owners are satisfied if their assets generate a satisfactory return on the investment made to acquire them (usually financial return for commercial operations, or other measures for non-commercial operations). Users are satisfied if each asset continues to do whatever they want it to do to a standard of performance that they—the users—consider satisfactory. Finally, society as a whole is satisfied if assets do not fail in ways that threaten public safety and the environment.

In essence, this means that if we are seeking to cause an asset to continue to function to a level that is satisfactory to the user, then the objective of maintenance is to ensure that assets continue to perform above the minimum level that is acceptable to those users. If it were possible to build an asset that could deliver the minimum performance without deteriorating in any way, then it would be able to run continuously, with no need for maintenance.

However, deterioration is inevitable, so it must be allowed for. This means that when any asset is put into service, it must be able to deliver more than the minimum standard of performance desired by the user. What the asset is able to deliver at this point in time is known as its initial capability. Figure 2 shows the correct relationship between this capability and desired performance.

This means that performance can be defined in two ways:

- a. Desired performance (what the user wants the asset to do)
- b. Built-in capability (what it can do)

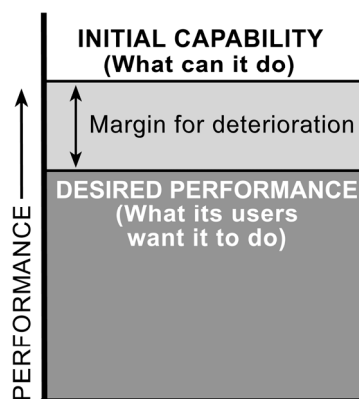


FIGURE 2 - ALLOWING FOR DETERIORATION

The margin for deterioration must be large enough to allow for a reasonable amount of use before the component degrades to functional failure, but not so large that the system is “over-designed” and hence too expensive. In practice, the margin is adequate in the case of most components, so it is usually possible to develop maintenance programs accordingly.

However if the desired performance is higher than built-in capability, no amount of maintenance can deliver the desired performance, in which case the asset is not maintainable.

All this means that, in order to ascertain whether an asset can be maintained, we need to know both kinds of performance: the built-in capability of the asset, and the minimum performance that the user is prepared to accept in the context in which the asset is being used. This minimum performance is the performance standard that must be incorporated in the function statement.

For example, the initial capability of the pump in Figure 1 is 1000 liters per minute, and the rate at which the water is being withdrawn from the tank (offtake) is 800 liters per minute. In this context, the pump is fulfilling the expectations of its users as long as it continues to pump water into the tank faster than the water is being withdrawn. As a result, the primary function of the pump was described as being “to pump water from tank X to tank Y at not less than 800 liters per minute,” and not “to pump at 1000 liters per minute.”

Note that if the same pump were to be used in a situation where the offtake from the tank was (say) 900 liters per minute, then the primary function would read, “to pump water from tank X to tank Y at not less than 900 liters per minute,” and the maintenance program would be changed to reflect this new performance expectation.

Note that users and maintainers often have significantly different views about what constitutes acceptable performance. As a result, in order to avoid misunderstandings about what constitutes “functional failure,” the minimum standards of acceptable performance must be clearly understood and accepted by the users and maintainers of the asset, together with anyone else who has a legitimate interest in the behavior of the asset.

Performance standards must be quantified where possible, because quantitative standards are clearer and more precise than qualitative standards. Occasionally it is only possible to use qualitative standards, for example when dealing with functions relating to appearance. In such cases, special care must be taken to ensure that the qualitative standard is understood and accepted by users and maintainers of the asset.

7. FUNCTIONAL FAILURES

An RCM process that conforms to SAE JA1011 then asks the question, “In what ways can it fail to fulfill its functions (functional failures)?” In order to answer this question satisfactorily, SAE JA1011, 5.2 states that “all the failed states associated with each function shall be identified.”

Section 6 explained that an asset is failed if it is incapable of doing what its users want it to do. It also explained that what the asset must do is defined as a function, and that every asset has more than one (and often several) different functions. Since it is possible for each one of these functions to fail, it follows that any asset can suffer from a variety of failed states.

For example, the primary function of the pump in Figure 1 was “to pump water from tank X to tank Y at not less than 800 liters per minute,” while a secondary function is “to contain the water in the pump.” It is possible for such a pump to be capable of pumping the required amount of water (not failed in terms of its primary function) while leaking excessively (failed in terms of its secondary function). Conversely, it is equally possible for the pump to deteriorate to the point where it cannot pump the required amount (failed in terms of its primary function) while it still contains the required liquid (not failed in terms of its secondary function).

For this reason, it is more accurate to define failure in terms of the loss of specific functions, rather than failure of an asset as a whole. The previous example also shows why the RCM process uses the term “functional failure” to describe failed states, rather than “failure” on its own. (Note that RCM distinguishes between a functional failure, or failed state, and a “failure mode,” which is an event that causes a failed state.)

Two further points that need to be considered when defining functional failures are: partial and total failure, and upper and lower limits.

7.1 Partial and Total Failure

Functional failures that represent total failure of the function are relatively easy to identify. For example, it is clear that the pump mentioned in 6.3, will have suffered a functional failure if it fails to pump any water at all (“total failure”). However the pump will also have suffered a functional failure if it can pump water but the rate at which it does so is less than 800 liters per minute.

The second failed state in this example is known as a “partial failure.” Partial failures need to be identified separately because they are nearly always caused by different failure modes from total failures, and because the consequences are also nearly always different.

Bear in mind that partial failure is not the same as deterioration below initial capability. Everything deteriorates below initial capability after some use, and such deterioration can be tolerated as long as it does not reach the point that is unacceptable to the user of the asset, as shown in Figure 2. Deterioration only becomes functional failure (partial or total) when the performance drops below the minimum level required by the user.

7.2 Upper and Lower Limits

The performance standards associated with some functions incorporate upper and lower limits. These limits mean that the asset has failed if it performs above the upper limit or below the lower limit. In these cases, the breach of the upper limit needs to be documented separately from the breach of the lower limit. This is because the failure modes and/or consequences associated with exceeding the upper limit are usually different from those associated with going below the lower limit.

For example, the primary function of a grinding machine may be listed as: “To grind bearing journals in a cycle time of 3.00 min $\pm$ 0.03 min, to a diameter of 75 mm $\pm$ 0.1 mm, with a surface finish of no greater than Ra 0.2.” This machine has failed if:

- a. It stops altogether
- b. It grinds workpiece in a cycle time longer than 3.03 min
- c. It grinds workpiece in a cycle time less than 2.97 min
- d. Diameter exceeds 75.1 mm
- e. Diameter is below 74.9 mm
- f. Surface finish too rough (exceeds Ra 0.2)

8. FAILURE MODES

An RCM process that conforms to SAE JA1011 then asks the question, “What causes each functional failure (failure modes)?” This section discusses the following five key concepts concerning failure modes that are listed in 5.3 of SAE JA1011:

- a. Identifying failure modes
- b. Establishing what is meant by “reasonably likely”
- c. Levels of causation
- d. Sources of information
- e. Types of failure modes

8.1 Identifying Failure Modes

“All failure modes reasonably likely to cause each functional failure shall be identified.” (SAE JA1011, 5.3.1)

Section 7 of this Guide mentioned that RCM distinguishes between the failed state of the asset (functional failure) and the events that cause the failed states (failure modes). Because it is impossible to define causes of failure until we have established exactly what we mean by “failed,” the RCM process identifies functional failures before failure modes. The way in which this is usually documented is shown in Figure 3, for the primary function of the pump illustrated in Figure 1. Figure 3, which lists an asset’s functions, functional failures, and failure modes, shows nearly all elements of a Failure Mode and Effects Analysis (FMEA). The “effects” of each failure mode are listed in a subsequent step (see Section 9 of this Guide).

Figure 3 also shows that at the very least, a description of a failure mode should consist of a noun and a verb. The description should contain enough detail for it to be possible to select an appropriate failure management policy, but not so much detail that excessive amounts of time are wasted on the analysis process itself.

In particular, the verbs used to describe failure modes should be chosen with care, because they strongly influence the subsequent failure management policy selection process. For instance, verbs such as “fails” or “breaks” or “malfunctions” should be used sparingly, because they give little or no indication as to what might be an appropriate way of managing the failure mode. The use of more specific verbs makes it possible to select from the full range of failure management options.

For example, failure mode 1A4 in Figure 3 might have been phrased, “coupling fails.” However such a phrase would provide no clue as to what might be done to anticipate or prevent the failure mode. If we say “coupling bolts come loose” or “coupling hub shears due to fatigue,” then it becomes much easier to identify a possible proactive task.

ASSET: Pumping System					
FUNCTION		FUNCTIONAL FAILURE (Loss of Function)		FAILURE MODE (Cause of Failure)	
1	Transfer water from tank X to tank Y at not less than 800 liters/minute	A	Unable to transfer any water at all	1	Bearing seizes
				2	Motor burns out
				3	Impeller comes adrift
				4	Coupling hub shears due to fatigue
				5	Inlet valve jams closed
				6	Impeller jammed by foreign object ... etc
		B	Transfers less than 800 liters/minute	1	Impeller worn
				2	Partially blocked suction line ... etc

FIGURE 3 - FAILURE MODES OF A PUMP

For valves, switches, and similar devices, the failure mode description should indicate whether the loss of function is caused by the item failing in the open or closed position. “Valve jams closed” says more than “valve jams.” Furthermore, the purpose of identifying failure modes is to identify the cause of the functional failure so that a way may be found to anticipate or prevent it. As a result, it may sometimes be necessary to take this one step further, such as: “valve jams closed due to rust on lead screw.” In this context, the use of the word “rust” suggests that it may be appropriate to focus failure management efforts on detecting or controlling rust.

8.2 Establishing What Is Meant By "Reasonably Likely"

"The method used to decide what constitutes a 'reasonably likely' failure mode shall be acceptable to the owner or user of the asset." (SAE JA1011, 5.3.2)

Section 8.1 mentioned that all failure modes reasonably likely to cause each functional failure shall be identified. "Reasonable likelihood" means just that: a likelihood that meets the test of reasonableness, when applied by trained and knowledgeable people. (A term often used instead of "reasonable" in this context is the term "credible.") If people who are trained to use RCM, and who are knowledgeable about the asset in its operating context, agree that the probability that a specific failure mode could occur is sufficiently high to warrant further analysis, then that failure mode should be listed.

In practice, it is sometimes very difficult to decide whether a failure mode should or should not be listed. This issue is related to both probability of occurrence and the level of detail used to describe failure modes. Too few failure modes, and/or too little detail, leads to superficial and sometimes dangerous analysis. Too many failure modes, and/or too much detail, causes the entire RCM process to take much longer than it needs to. In extreme cases, this can cause the process to take two or even three times longer than necessary (a phenomenon known as "analysis paralysis"), and can also lead to excessively cumbersome maintenance programs.

In situations where there may be doubt or disagreement as to what constitutes the threshold of "reasonableness," the final decision must be taken by the organization that owns or uses the asset, because that organization will ultimately be held accountable for the consequences if the failure mode does occur.

Note that the decision to list a failure mode should be tempered by a consideration of its consequences. If the consequences are likely to be very severe indeed, then less likely failure modes should be listed and subjected to further analysis.

For example, if the pump described in Figure 3 was installed in a food factory or a vehicle assembly plant, the failure mode "casing smashed by an object falling from the sky" would be dismissed immediately as being laughably unlikely. However if the same pump were a primary coolant pump in a nuclear reactor at a commercial power plant, this failure mode is more likely to be taken seriously—even though it is still highly improbable. (Appropriate failure management policies might be either to ban aircraft from flying over the facility, or to design a roof that can withstand a crashing aircraft. This is not simply speculation, of course—both policies are routinely considered at nuclear power stations.)

8.3 Levels of Causation

"Failure modes shall be identified at a level of causation that makes it possible to identify an appropriate failure management policy." (SAE JA1011, 5.3.3)

Previous sections of this Guide stated that failure modes should be described in enough detail for it to be possible to select an appropriate failure management policy, but not in so much detail that excessive amounts of time are wasted on the analysis process itself.

The extent to which failure modes can be described at different levels of detail is illustrated in Figure 4, which is based on the pump whose functions and functional failures were described in Figure 3. Figure 4 lists some of the failure modes that might cause the functional failure "unable to transfer any water at all." In this example, these failure modes are considered in seven levels of detail, beginning with the failure of the pump set as a whole.

The first point to emerge from this example is the connection between the level of detail and the number of failure modes listed. The example shows that the further one "drills down" in an FMEA, the larger the number of failure modes that can be listed. For example, there are 3 failure modes listed for the pump at level 3 in Figure 4, but 20 at level 6.

One other point that arises from Figure 4 is "root causes." It is discussed as follows.

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Pump set fails	Pump fails	Impeller fails	Impeller comes adrift	Mounting nut undone	Nut not tightened correctly	Assembly error
				Mounting nut worn away	Nut eroded/corroded away	
				Impeller nut cracked	Nut made of wrong material	Wrong material specified
					Impeller nut overtightened	Wrong material supplied
				Impeller key sheared	Nut made of wrong material	Assembly error
					Wrong material specified	Wrong material supplied
				Part in system after maintenance	Wrong key steel specified	Design error
					Wrong key steel supplied	Procurement error
				Foreign object enters system		Storekeeping error
						Requisitioning error
				Object smashes impeller	Assembly error	See (human error)
					Suction strainer not installed	Assembly error
				Casing bolts come loose	Strainer holed by corrosion	
					Assembly error	See (human error)
				Bolts loosened by vibration		
				Casing bolts corroded away		
				Bolts fail due to fatigue		
				Joints incorrectly fitted		
				Joint fails due to fretting		
				Casing smashed by vehicle		
				Smashed by object from sky		
				Seal abraded		
				See "water supply fails" below		
				Assembly error		
				See (human error)		
				Wrong seal supplied		
				Wrong seal specified		
				Design error		
				Pump seal dropped in stores		
				Storekeeping error		
				Procurement error		
				See (human error)		
				See (human error)		
				Motor fails		
				Driveline fails		
				Valve closed		
				Power fails		
				Etc		

FIGURE 4 - FAILURE MODES AT DIFFERENT LEVELS OF DETAIL