Asset Management Council
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TECHNICAL FAQ1: How is Maintenance Related to Reliability?

Question

How is maintenance related to reliability?

How do reliability concepts/theory/tools help in maintenance activities such as

- Criticality assessment
- Consequences assessment
- Spare parts analysis

Question from Eric and John at the Reliability for Asset Management training intensive (Melbourne).

Answer

Definition of Maintenance

Current definitions of maintenance include:

- "All actions necessary for retaining an item in or restoring it to a specified condition" from US Military Standard 338B; and
- "Combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function" from IEC 60300.3.14 2005 Dependability Management.

Without a common understanding of what maintenance is, the paths taken to achieve the objective may differ, especially if they are built on folklore rather than on well established concepts of risk/maintenance engineering.

The AM Council uses the following definition:

"Maintenance is the set of actions taken to assure that systems, equipments and components provide their intended functions, when required".

There are a few points that require emphasizing in this definition.

First, the primary focus of this definition is on assuring the intended function of an item rather than its manufacturer's (OEM) nameplate design performance. Many designs provide excess performance capacity or endurance as an inherent characteristic of the design - e.g. the commercial off the shelf (COTS) pump selected for a system may be rated at 100 lpm for purchasing convenience when the system design requirement is only 75 lpm. Maintenance that is oriented to sustaining excess capability not needed for operations expends resources without benefit. This is not good maintenance practice.

Secondly, this definition focuses on the level of assurance of the function. In this respect, from a technical perspective, assurance is taken to mean reliability. Remember, that uncertainty is a key aspect of asset management and one that can significantly influence the maintenance analysts's response to the development of appropriate maintenance tasks. Change the required level of assurance, and a significant change in maintenance tasks might result!

Next, this definition requires the function being maintained to be available when it is required to operate. The failure of continuous functions are evident to the system operator and hence availability readily assessed. However, certain functions, such as overpressure relief, may not be required continuously and there may be a need to verify their availability which is not immediately evident.

Finally, the terms "systems, equipments and components" as used in this definition, apply to plant at the particular level where the analysis is being performed. This may be a system, a subsystem, equipment, or a component, depending on the specific preventive maintenance task being examined.

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Maintenance Basics

Figure 1 illustrates the nature and purpose of a maintenance task, in Reliability and Usage terms.

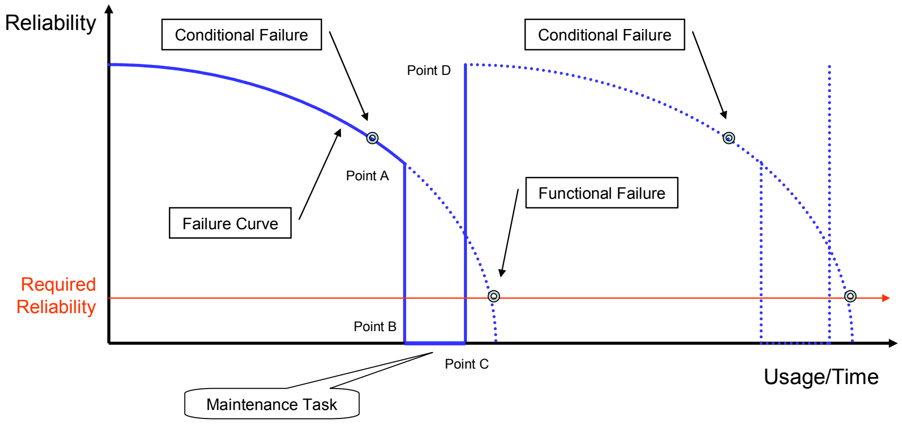

Figure 1 Maintenance Fundamentals

Based upon the design characteristics, the reliability of the item progresses down the failure curve slope with use until a maintenance task is undertaken at Point A, resulting in the change in the curve down (maintenance is usually undertaken when the item is not working and not available i.e. shut down). The time taken to complete the task (between Point B and C) is shown by the horizontal line on the y axis. After the completion of the maintenance task, the reliability is restored to the original value, at Point D – and the process continues.

During the design process the curves used are those that the designer and the maintenance analyst believe is appropriate. The curves are validated during “in service” and replace the original.

To plan effectively, the maintenance planner’s task is to determine where on the curve the failure mode is - at any time. As a result, much maintenance activity (namely, condition directed tasks) is directed at finding information that either individually and/or collectively provides the planner with that information.

Two very important terms used in Figure 1 should be examined carefully at this point. The first term is “Functional Failure” and the second is “Conditional Failure”.

At Functional Failure, the item can no longer perform one or more of its required functions. Operating standards including reliability determine satisfactory in service operation and should be used to define failure - rather than the as designed standard which is used to define the acceptability of a new item – refer to Figure 1.

Thus the definition of functional failure is:

Functional Failure is an unsatisfactory condition in which intended functions are not provided.

The manner in which functional failure is detected is dependent on what type of function is involved. There are several classifications of function necessary to the determination of maintenance programs:

- Active functions require activity of an item; e.g. a pump provides liquid flow.
- Passive functions are not related to activity; e.g. a pump contains the working fluid.
- On-line functions are continuously provided during normal operations; e.g. distribution of electrical power.

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- Off-line functions are not continuously provided e.g. inflation of a life jacket or firing a missile. Usually, they are activated by some infrequent action or event.
- Evident functions are those whose loss is observable (and usually measurable) during their normal operating routine; e.g. loss of refrigerant flow causes an increase in refrigerated space temperature.

Hidden functions are not observable during normal operations. They are provided by an item for which there is no immediate indication of malfunction or failure; e.g. failure of a relief valve to lift.

The second term needing definition is the point of "Conditional Failure":

An identifiable physical condition, which indicates that the future likelihood of Functional Failure is unacceptable.

The matter of whether or not an item is at the point of Conditional Failure depends on how the conditional failure is defined. It is the result of measuring material condition or performance against a standard that determines whether the item is satisfactory, marginal, or unsatisfactory for service. One or more such measurements can be performed.

Whenever a functional or conditional failure is defined in terms of performance, condition or dimension, the appropriate standards must be documented to provide the basis for determining when the item is at that point on the curve.

Based upon Figure 1, two important considerations are evident, namely reliability changes with age/usage and that maintenance can only restore the item's inherent reliability.

Reliability Change with Age/Usage

As can be seen from Figure 1, the in service reliability decreases with age/usage – remember that reliability is a function of both failure rate and age/time. There is no good reason to invest maintenance resources on an item whose operating reliability does not or will not change with age.

Hardware reliability must change with age/usage for maintenance to be considered as an option. Everything changes with age/usage, however degradation does not always cause a problem with reliability. Some items degrade so slowly with age that they will be discarded or replaced for some other reason before degraded reliability becomes a problem. It is the rate of age degradation during the life of the item that is the key issue here. The rate of age degradation must be sufficient to create concern for maintenance managers – that is, create a risk that needs to be mitigated.

It's important to note that 'age' may not always be measured in terms of calendar time. Age may be measured in such terms as equipment cycles, miles travelled, rounds fired, operating hours, or calendar time. Additionally, complex repairable equipment may go through a number of repair processes that progressively replace elements of the whole creating a mix of lives that do not represent the nameplate life and hence is not purely equipment age related.

Applicable Maintenance

From the perspective of risk and noting that risk is the product of consequence and likelihood - risk reduction options resulting from a failure mode are limited to a "consequence reduction", a "likelihood reduction" or both. The consequences of a failure mode are characteristics of the equipment design/configuration and the environment in which the equipment operates, and as a result, maintenance can never change these characteristics.

Further, maintenance is generally about changing the low reliability current part for a higher reliability new/refurbished part. Therefore RCM, as a tool for determining maintenance requirements, can only be effective in risk reduction through a "likelihood reduction".

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As can be seen from Figure 1, maintenance can at most, only restore or preserve the hardware's inherent design reliability and performance characteristics. Put simply:

Maintenance can only influence the probability or likelihood of failure

That is, good maintenance changes the reliability from Point A to Point D in Figure 1. As a result, if the design's inherent reliability or performance is poor, doing more maintenance will not help. To improve poor reliability or performance attributable to inadequate design, one must change the design.

An "applicable task" therefore is one that addresses the failure mode in question, that is, is technically relevant – the task solves the problem.

Some tasks, however, either have no effect as they cannot discover the existence of the failure mode or have an adverse effect on reliability as they might introduce human error (infant mortality in reworked items) without a commensurate reduction in risk. These tasks are not applicable to a well designed maintenance program because they fail to have the desired result.

RCM Logic Process

The RCM Logic Process methodology includes rules for determining whether the three types of preventive maintenance tasks (condition monitoring, time directed and failure finding tasks) are applicable. Further details on the different types of maintenance task can be provided separately.

The two other types of preventive maintenance tasks (servicing and lubrication) do not require formal rules since:

- Servicing tasks are self evident and do not require special analysis: operating consumables must obviously be replaced before they reach levels that cause functional failures. The only real issue is how fast they are consumed under differing operating regimes.
- The requirement for lubrication is evident for situations that involve rolling or sliding friction. The requirement for grease should be evident for situations where exterior corrosion may present a problem.

There are three Task Rules for determining the applicability or relevance of condition monitoring tasks, age directed tasks, and failure finding tasks.

Condition Monitoring Task Rules

1. The conditional probability of failure does not change with age/usage;
2. At least one characteristic corresponding to the specific failure mode can be identified;
3. That each characteristic can be measured with some consistency (the more accurate the better) even though this may be visual; and
4. Sufficient time exists between the identification of potential failure and actual failure to take corrective action to prevent failure.

Time Directed Task Rules

1. The conditional probability of failure increases at a specific age (evidence of "wear out");
2. A large proportion of the population must survive to the point of "wear out"; and
3. There must be no condition that predicts failure.

Failure Finding Task Rules

1. The functional failure must not be evident (usually to at least the operating crew) during routine operations;
2. The failure finding task determines whether or not the intended function is available; and

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3. No appropriate Condition Directed or Time Directed task can be devised to prevent failure.

All of the applicability Task Rules associated with a given type of task must be satisfied for each task being analysed, for the task to be applicable. If the task fails to satisfy any of its rules, it is not applicable, and should not be used as is and an amendment may be necessary.

Failure of a proposed task to satisfy one or more of the appropriate rules does not necessarily mean the task has no inherent value. Rather, failure to satisfy a rule may mean that some change is required to the task as currently presented that will make it applicable. These rules do more than simply serve as a "go - no-go gauge" for task evaluation. They also serve as diagnostics to improve currently formulated tasks.

General Issues

Systems and equipment do not always have to "look like new" or meet design specifications to deliver the required functionality. There is no need to invest maintenance resources to attain greater performance than needed. The design engineer typically incorporates various margins in the design specifications. These margins normally provide protection from such conditions as corrosion and erosion in the operating environment and abnormal levels of stress from performance outside prescribed operating ranges.

They also take into account dimensional variations from manufacturing processes, differences in the material composition of constituent parts that comprise the complete item, and other factors. In addition, functional performance parameters, such as pump pressure and throughput, required by procurement specifications or available in commercial off the shelf (COTS) equipment may be greater than required for adequate system performance. There is nearly always a difference between construction standards and maintenance standards to allow for deterioration over time.

The required result is for each task to restore or maintain the inherent reliability of the item. That is a basic reason for maintenance. It is not, however, a sufficient reason. Each proposed task must also be worth doing.

Effective Maintenance

"Applicable" preventive maintenance tasks reduce functional failures, but not all such failures are worth preventing. Expressed differently, how is it determined whether the maintenance tasks being performed are effective, i.e. have value?

The term "value" implies worth: a measure of outcome (usually risk reduction) that exceeds a given cost. Since all maintenance actions have an associated cost, it is not unreasonable to expect the worth of the maintenance to exceed its cost.

Effective tasks have value and, therefore, may be worth doing. This worth is usually a trade off between the cost of a task at a certain period and its risk reduction effectiveness at that period.

The determination of whether a task is "effective" requires examining the failure consequences as not all failures have the same consequences:

- Some failures can result in injury or death. Tasks that prevent failures that seriously injure or kill someone are often statutorily required.
- Some failures may violate federal, state, or local regulations such as those related to protection of the environment. Tasks that prevent these failures also have great value.
- Other failures can substantially impair an assets ability to carry out its assigned outputs. Tasks that prevent failures causing the loss of a production capability are very valuable.
- All other failures are evaluated on the basis of economics.

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Maintenance is an investment. The issue is one of measuring the Return On Investment (ROI) for the maintenance performed. The following criteria are used to determine priorities for maintenance task accomplishment as well as for determining whether they are at all worth doing. In very simple terms, to be effective:

- Tasks for failures that affect personnel safety or the environment must reduce the risk to an acceptable level – usually through using the definitions in the organisation's risk matrices.
- Tasks for failures that affect production/mission must reduce the production/mission impact of failure to an acceptable level – again using the organisation's risk matrices.
- Tasks for all other failures must cost less to accomplish than the cost of repairing the failure plus the cost of the lost capability where that can be quantified.

Maintenance programs must change and adapt to take advantage of experience that is gained in operational service as well as advances in technology while meeting new requirements that may be imposed on the plant. A maintenance program that is developed, installed and never changed during the normal life of the plant/asset is almost certain to be ineffective in a number of different areas.

As a result, a good maintenance programs will require re-analysis of the assumptions from which the original task was developed. This type of review usually centres on the following:

- Continued relevance of the original failure modes;
- Variance to the original failure characteristic for each failure mode; and
- Changes in technology that would allow a different and more cost effective maintenance task to be implemented.

The frequency of any such review should be linked to the risk profile for each failure mode and the perceived adequacy of current controls.

Maintenance and Corporate Values

A maintenance task is a risk reduction activity. Most organisations these days have published risk matrices and the acceptable risk levels - representing the corporate values of the organisation. As such, those values must also be used by the maintenance system – if that maintenance is to represent the values of the organisation, that is, be a good maintenance system.

While much maintenance analysis demands the use of both qualitative and quantitative techniques, when used in a quantitative manner, the analysis process might need to be tailored to include:

- Likelihood values expressed in quantitative terms – usually in failures per 10^6 operating hours; and
- The use of Weibull curves (or similar) to determine probability of failure.

Task Packaging

Task Packaging transforms all the maintenance task requirements into an optimal set of tasks that are fit for release. The format and overall content of these tasks may, depending on the organisation, conform to certain data and format requirements.

Packaging is one of two major activities in this process - combining individual requirements into do-able activities. Packaging takes into account many practical issues, including:

- Efficiency - combining requirements that involve the same activities to minimise duplicated effort.
- Skill availability - activities may be grouped/changed to accord with ship workcentre manning levels.

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- Skill capability - activities may be grouped/changed to accord with available technical personnel competencies.
- Contracts - resources might only be available at certain times of the year.
- Location - resources might only be available at certain locations (e.g. drydock for a ship).
- Level of Repair Analysis (LORA).

Packaging is the area where the most significant cost savings can be achieved.

The second major activity specifies the maintenance tasks/schedules in detail, providing supporting information, guidelines, cautions, etc. Supporting this specification is the Job Safety Analysis for maintenance and operating activities. Job Safety Analysis (JSA) is another application of risk analysis, applied to activities to be carried out by people.

More information on the fundaments of maintenance engineering is available from the AM Council, by request.