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Using a System Reliability Model to Optimize Maintenance Costs A Best Practices Guide

RATIONALE

Complex repairable systems that consist of many individual components can be designed to be quite reliable, at least when they're still new. However, as such a system continues to be used and repairs are made to address failures that occur, the interval between failures gets shorter and shorter. Eventually, that complex system becomes a collection of parts, each with a different amount of operating time and differing reliabilities. Maintenance intervals that may have aligned with one another when the system was new will eventually become misaligned, making maintenance more complicated, or at least sub-optimal and more expensive. It is not uncommon to have a repaired system returned to service only to be shut down shortly thereafter because of another failure.

The classical Reliability Centered Maintenance (RCM) process does a good job of focusing attention on the actual reliability and failure modes that is (or will be) exhibited by a particular system, and helps a system designer, implementer, or operator develop an effective maintenance strategy for that system. However, the RCM decision logic only looks at the individual components and doesn't address how to reconcile different maintenance intervals for each component across the entire system. Furthermore, RCM focuses more on preventive maintenance (lubrication and failure finding tasks) and doesn't really address corrective maintenance. So when a complex system is taken out service for maintenance, there is no guidance as to what other optional maintenance should be performed to increase the time until the next failure and/or reduce long-term operating costs.

This "Best Practices Guide" describes a proven approach for objectively determining what other maintenance should be performed when a system is being repaired to improve system reliability and reduce long-term operating costs.

FOREWORD

The classical RCM analysis process is designed to look at each individual component of a complex system (such as an aircraft, military tank, ship, radar system, factory, etc.), determine how each component can fail, identify the consequences of each failure mode, and decide which maintenance strategy best meets the needs of each component in order to maximize the reliability of the system. The RCM maintenance strategy options are: impose a scheduled discard event, running a component to failure, initiating failure-finding tasks, implementing a preventive maintenance program, or a one-time change (redesigning a part if its failure would pose a safety or environmental risk and such a failure cannot be mitigated through other means, operational change, etc.). At the end of this process, the analyst will have a structured, thorough, maintenance plan that will account for all parts of the system being evaluated.

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However, classical RCM (as defined in the current RCM Standards) doesn't take into account situations where maintenance on one piece of equipment may disturb or drive maintenance on one or more other pieces of equipment. It also doesn't tell the analyst, when the RCM analysis specifies maintenance intervals for various portions of the system that are all different from each other, how to reconcile those differences in such a way that will keep maintenance costs, down-time, or any other system-wide maintenance optimization, to a minimum. Furthermore, it will not address how to best perform **corrective** maintenance – i.e., how to decide what other optional tasks should be performed while the system is down for maintenance.

Undoubtedly, there will be differences between different types of systems, users, operating locations, etc., and they all would have some kind of criteria to measure the cost-effectiveness of any maintenance decisions that are contemplated. The real issue is how to calculate the cost effectiveness in all those various situations. The costs themselves may be easy enough to compile, but the “effectiveness” part of the equation is usually a bit more difficult to determine.

This guide is an attempt to document and explain one general method for determining the cost-effectiveness of various maintenance options that are possible when a complex, heavily integrated system is taken off-line for maintenance. The techniques described herein have been developed for, and successfully applied to, aircraft and aircraft engines. They allow a comparison of a wide variety of considerations to be made whereby the cost and the “effectiveness” are determined computationally (vice notionally), and gives system maintainers a more unambiguous recommendation for the maintenance that should be performed that will result in the lowest practical long-term maintenance cost.

Since the techniques described herein have been successfully applied to aircraft and aircraft engines, the examples below will frequently refer to these applications. However, in the course of the following discussion, this guide will try to provide enough explanation of the issues involved so that the reader will be able to identify and apply the same techniques to their own situations and address any similar requirements and constraints that pertain to them.

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1. SCOPE

SAE JA6097 (“Using a System Reliability Model to Optimize Maintenance”) shows how to determine which maintenance to perform on a system when that system requires corrective maintenance to achieve the lowest long-term operating cost. While this document may focus on applications to Jet Engines and Aircraft, this methodology could be applied to nearly any type of system. However, it would be most effective for systems that are tightly integrated, where a failure in any part of the system causes the entire system to go off-line, and the process of accessing a failed component can require additional maintenance on other unrelated components.

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

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

2.2 Related Publications

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

F. Stanley Nowlan and Howard F. Heap, “Reliability-Centered Maintenance”, Department of Defense, Washington, D.C., 1978, OASD Report Number AD-A066-579

2.2.1 US Government Publications

Condition Based Maintenance Plus DoD Guidebook, May 2008

Condition Based Maintenance Plus (CBM+) for Materiel Maintenance, DoDI 4151.22, December 2, 2007 (http://www.acq.osd.mil/log/mpp/cbm+/CBM_DoD_Guidebook_May08.pdf)

Guidelines for the Naval Aviation Reliability-Centered Maintenance Process, NAVAIR 00-25-403, U.S. Naval Air Systems Command

Planned Maintenance System: Development of Maintenance Requirement Cards, Maintenance Index Pages, and Associated Documentation, MIL-P-24534 (U.S. Naval Sea Systems Command)

Procedures for Performing a Failure Mode, Effects and Criticality Analysis, MIL-STD-1629A, Notice 2, 1984, Department of Defense, Washington, D.C. (NOTE: canceled without replacement, August 1998.)

Reliability Centered Maintenance for Aircraft, Engines and Equipment, MIL-STD-1843, United States Air Force (NOTE: canceled without replacement, August 1995.)

Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment, MIL-HDBK-2173(AS), U.S. Naval Air Systems Command (NOTE: canceled without replacement, August 2001.)

2.2.2 Books

Anderson, Ronald T. and Neri, Lewis, "Reliability-Centered Maintenance: Management and Engineering Methods," Elsevier Applied Science, London and New York, 1990

Andrews, J.D. and Moss, T.R., "Reliability and Risk Assessment," Longman, Harlow, Essex (UK), 1993

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

Cox, S.J. and Tait, N.R.S., "Reliability, Safety and Risk Management," Butterworth Heinemann, Oxford, 1991

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

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

Rausand, Marvin and Høyland, Arnljot, "System Reliability Theory, Models, Statistical Methods, and Applications", 2004

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

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

2.3 Other Publications

"Dependability Management - Part 3-11: Application guide - Reliability centred maintenance," International Electrotechnical Commission, Geneva, Doc. No. 56/651/FDIS

MSG-3, "Maintenance Program Development Document," Air Transport Association, Washington, D.C. Revision 2, 1993

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)

3. DEFINITIONS

3.1 PROBABILISTIC

Of, based on, or affected by probability, randomness, or chance (American Heritage Dictionary). For the purposes of this document, a probabilistic failure is an event where the system (or a component thereof) becomes unserviceable, and the underlying probability of that type of failure mechanism occurring at a given point in time can be represented by a mathematical function, such as an Exponential, Weibull or LogNormal distribution. See also Stochastic (below).

3.2 STOCHASTIC

Of or pertaining to a process involving a randomly determined sequence of observations each of which is considered as a sample of one element from a probability distribution (Random House Dictionary).

3.3 SUNSHINE COSTS

Costs incurred to correct conditions discovered only when a part is exposed and a fault with that part becomes visible to, and detected by, the technician.

3.4 WORKSCOPE

The scope (amount or extent) of work you plan to do during a maintenance event.

4. ACRONYMS

4.1 ATOW

Average Time On-Wing. This is the historical time between aircraft engine removals.

4.2 CBM

Condition-Based Maintenance. CBM is an approach to maintenance whereby maintenance is only performed on evidence of need identified through direct or indirect monitoring. CBM requires specific knowledge of an asset's condition at any given time in its operating life such that the maintenance action can be planned with sufficient lead time to minimize the cost and operational impact of the occurrence of a failure. CBM differs from "on-condition" maintenance in that under CBM, knowledge of asset condition at any given time provides an understanding of how much time is available before the required maintenance must be performed.

4.3 CPFH/CPEFH

Cost Per (Engine) Flying Hour. The cost of maintenance (parts and labor, not fuel) divided by time the system operates from the time it is repaired until it fails again, or the estimated amount of time it could be expected to operate given a certain level of repair.

4.4 ETOW

Estimated Time On-Wing. This is a future projection (estimate) of aircraft engine life expectancy (time between engine removals). It is the "expected value" (E(t)) term derived by integrating the overall system reliability function (R(t)).

4.5 LCF

Low Cycle Fatigue.

4.6 LLP

Life-Limited Part. Engine parts that have a limited allowable service life.

4.7 OCM

On-Condition Maintenance. Scheduled maintenance performed to detect potential failures. This usually consists of inspections, tests, or measurements to determine if an item is or is expected to remain in serviceable condition until the next scheduled maintenance event.

4.8 PM

Preventive Maintenance. Maintenance tasks such as inspections, adjustments, tests, as well as lubrication and other servicing actions performed to extend the life of a component or system.

4.9 RBD

Reliability Block Diagram. RBD models are a way of graphically representing the reliability relationships of various components in a system, including the potential for single point failures as well as redundancies.

4.10 RCM

Reliability-Centered Maintenance. 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 operational context. (See SAE JA1011).

4.11 TSO/TSN

Time Since Overhaul or Time Since New. Different measures of service life accumulation.

5. BACKGROUND

As we have all been reminded many times over the last few years, aircraft operators (specifically, commercial airlines and cargo delivery service providers) are under intense pressure to reduce operating costs. Rising fuel prices, increased competition spurred by de-regulation, and aging aircraft fleets requiring increased levels of maintenance are all cutting into the airlines' profit margins. Several airlines have even been driven into bankruptcy as a result.

The single largest controllable expense for aircraft fleet owners or operators is maintenance. In fact, the aircraft engines alone typically account for about 50% of all aviation fleet maintenance costs. Since other costs, such as fuel, are driven by external market conditions and are not really controllable, those aircraft fleet owners have typically looked at how they perform maintenance as a means to reduce costs.

Historically, maintenance decisions have been made based only on short-term needs, not based on the long-term financial impact. One of the reasons is that the maintainers have had no objective method for determining what maintenance is the most cost-effective whenever something breaks; it's all based on 'experience' or 'gut instinct', neither of which is very accurate and can sometimes be totally wrong. In addition, aircraft engine maintenance is complicated by an abundance of rules, regulations, technical manual requirements, the complex design of the engines, a wide variety of configurations, high asset value, high cost impact when it's unavailable, all of the possible decisions to be made when engines are brought in for repair, and whether it is a scheduled or unscheduled maintenance event. Any method that could objectively determine what maintenance to perform, with the goal of lowering the long-term operating cost and increasing system availability, needs to address all of these issues.

6. LIMITATIONS OF 'CLASSICAL' RELIABILITY-CENTERED MAINTENANCE

Recall the steps of the traditional Reliability-Centered Maintenance (RCM) system analysis process (shown below). Basically, an analyst looks at all of the components of a system, identifies all the ways that each component can fail, determines the consequences of each failure, then decides (using the RCM decision logic) what maintenance strategy will best address that failure mode.