UNIVERSITI PUTRA MALAYSIA

ESTIMATION METHOD OF MINIMUM PREVENTIVE MAINTENANCE INTERVAL FOR AVIONICS SYSTEM

AISYAH RAZANA BINTI MAHAYUDIN

FK 2014 156

ESTIMATION METHOD OF MINIMUM PREVENTIVE MAINTENANCE INTERVAL FOR AVIONICS SYSTEM

By

AISYAH RAZANA BINTI MAHAYUDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

February and 2014

© COPYRIGHT UPM

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia

© COPYRIGHT UPM

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science.

ESTIMATION METHOD OF MINIMUM PREVENTIVE MAINTENANCE INTERVAL FOR AVIONICS SYSTEM

By

AISYAH RAZANA BINTI MAHAYUDIN

February and 2014

Chair: Assoc. Prof. Lt. Col. (R)Mohamed Tarmizi Ahmad
Faculty: Engineering

Maintenance simulation is important to foresee the impact on the availability percentage and maintenance cost before actual maintenance is done. Therefore, it is important to simulate a maintenance activity as close as possible to real life. The maintenance simulation requires a preset preventive maintenance interval (PMI). The thesis analyzes simulation for many PMIs at various maintenance types which are perfect, imperfect and minimal maintenance. Since the most realistic maintenance simulation is the main focus, imperfect maintenance is the best routine to simulate the maintenance activity. However, previous data of the maintenance activity are needed in order to simulate imperfect maintenance. Thus, in the thesis also proposes a way to simulate imperfect maintenance without having previous data of the maintenance activity. In order to prove the simulation procedure, the same maintenance activity is simulated with different types of maintenance degree which are perfect maintenance and minimal maintenance. Then, the simulation of imperfect maintenance is then compared with simulations of perfect and minimal maintenance. The simulation methodologies used are Monte Carlo simulation and Discrete Event simulation. For a case study of the simulation, two subsystems of avionics system are used. The subsystems are Flight Instruments and Engine Indication System. The avionics systems used is from Cirrus SR20 with Perspective Avionics. From the simulation, perfect maintenance has the highest availability percentage and minimal maintenance always has the lowest availability percentage. Meanwhile imperfect maintenance's availability percentage are in between perfect and imperfect maintenance. As for maintenance cost, minimal maintenance has the highest maintenance cost and perfect maintenance has the lowest maintenance cost. Meanwhile imperfect maintenance has a maintenance cost in between perfect and minimal maintenance. Based on these findings, it can be concluded that the methodology to simulate imperfect maintenance is relevant. Then, the relationship between maintenance cost and availability percentage is discussed

© COPYRIGHT UPM

for each maintenance type. From the discussion, the minimum PMI is proposed based on preset criteria.

© COPYRIGHT UPM

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master of Sains

KAEDAH ANGGARAN SELANG MASA PENYELENGGARAAN MINIMA UNTUK SISTEM AVIONIK

Oleh

AISYAH RAZANA BINTI MAHAYUDIN

Februari dan 2014

Pengerusi: Assoc. Prof. Lt. Col. (R)Mohamed Tarmizi Ahmad
Fakulti: Kejuruteraan

Simulasi penyelenggaraan penting untuk meramal impak ke atas peratusan kesediaan dan kos penyelenggaraan sebelum penyelenggaraan sebenar dilakukan. Oleh itu, amat penting untuk melakukan simulasi aktiviti penyelenggaraan yang paling hampir dengan kehidupan sebenar. Simulasi penyelenggaraan memerlukan satu pratetap selang masa pencegahan penyelenggaraan (SPP). Tesis ini menganalisa simulasi untuk banyak SPP pada bermacam jenis penyelenggaraan iaitu kesempurnaan penyelenggaraan, ketidaksempurnaan penyelenggaraan dan minima penyelenggaraan. Oleh kerana fokus utama adalah simulasi penyelenggaraan yang paling realistic, ketidaksempurnaan penyelenggaraan adalah rutin terbaik untuk melakukan simulasi aktiviti penyelenggaraan. Walaubagaimanapun, maklumat aktiviti penyelenggaraan terdahulu diperlukan untuk melakukan simulasi ketidaksempurnaan penyelenggaraan. Disebabkan itu, tesis ini turut menawarkan kaedah untuk melakukan simulasi ketidaksempurnaan penyelenggaraan tanpa memperolehi maklumat aktiviti penyelenggaraan terdahulu. Untuk membuktikan prosedur simulasi ini, aktiviti penyelenggaraan yang sama disimulasikan dengan jenis-jenis penyelenggaraan yang berlainan. Jenis-jenis penyelenggaraan yang berlainan adalah kesempurnaan penyelenggaraan dan minima penyelenggaraan. Kemudian, simulasi ketidaksempurnaan penyelenggaraan dibandingkan dengan simulasi kesempurnaan penyelenggaraan dan minima penyelenggaraan. Kaedah simulasi digunakan adalah mengikut kaedah simulasi Monte Carlo dan simulasi Discrete Event. Dua sub-sistem daripada system avionik digunakan sebagai kajian kes bagi simulasi ini. Dua sub-sistem berikut adalah Flight Instruments dan Engine Indication System. Sistem avionik ini adalah dari Cirrus SR20 dengan Perspective Avionik. Daripada simulasi tersebut, kesempurnaan penyelenggaraan mempunyai peratusan kesediaan tertinggin manakala minima penyelenggaraan mempunyai peratusan kesediaan terendah. Manakala peratusan kesediaan bagi ketidaksempurnaan penyelenggaraan terletak di

© COPYRIGHT UPM

antara peratusan kesediaan kesempurnaan penyelenggaraan dan peratusan kesediaan minima penyelenggaraan. Bagi kos penyelenggaraan, minimal penyelenggaraan mempunyai kos yang tertinggi dan kesempurnaan penyelenggaraan mempunyai kos yang terendah. Manakala ketidaksempurnaan penyelenggaraan mempunyai kos di antara kos kesempurnaan penyelenggaraan dan kos minimum penyelenggaraan. Daripada keputusan tersebut, konklusi dapat dibuat bahawa kaedah untuk membuat simulasi ketidaksempurnaan penyelenggaraan adalah relevan. Kemudiam, hubung kait antara kos penyelenggaraan dan peratusan kesediaan dibincangkan untuk setiap jenis penyelenggaraan. Daripada perbincangan tersebut, SPP yang paling minima diutarakan berdasarkan kriteria yg ditetapkan.

© COPYRIGHT UPM

ACKNOWLEDGEMENT

I would like to thank my husband and my family for believing in me to pursue my master's degree in engineering. Their unconditional love, unlimited support and trust always make me not to give up on this. I also want to mention my beloved two sons for always making my day whenever I feel down or stressful. Their presence is a blessing. Not to forget my supervisor and co-supervisor who are always help me out whenever I have doubts or questions regarding this thesis. Thank you so much.

From;
Aisyah Razana binti Mahayudin

© COPYRIGHT UPM

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master Of Science. The members of Supervisory Committee were as follows:

Mohamed Tarmizi bin Ahmad,
Associate Professor Lt. Col. (R)
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Fairuz Izzuddin bin Romli, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

© COPYRIGHT UPM

DECLARATION

I hereby confirm that:

- this thesis is my original work;
- quatations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of the thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature:________________________ Date: ________________________

Name and Matric No.: Aisyah Razana binti Mahayudin and GS26154

© COPYRIGHT UPM

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	____________________	Signature:	____________________
Name of Chairman of Supervisory Committee:	____________________	Name of Member of Supervisory Committee:	____________________

© COPYRIGHT UPM

TABLE OF CONTENTS

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF TABLES

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF FIGURES

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

Glossary of Terms

Definitions of Terms for Reliability and Maintainability as per MIL-STD-721C [61]:

- Achieved: Obtained as a result of measurement.
- Alignment: Performing the adjustments that are necessary to return an item to specified operation.
- Availability: A measure of degree to which an item is in an operable and committable state at the start of the mission when the mission is called for at an unknown (random) time. (Item state at start of mission includes the combine effects of the readiness-related system reliability and maintainability parameters, but excludes mission time; *see* Dependability.
- Criticality: A relative measure of the consequence of a failure mode and its frequency of occurrences.
- Degradation: A gradual impairment in ability to perform.
- Demonstrated: That which has been measured by the use of objective evidence gathered under specified conditions.
- Dormant: *see* Not Operating.
- Environment: The aggregate of all external and internal conditions (such as temperature, humidity, radiation, magnetic and electric fields, shock vibration, etc.) either natural or man made, or self-induced, that influences the form, performance, reliability or survival of an item.
- Failure: The event, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.
- Failure, Random: Failure whose occurrence is predictable only in probabilistic or statistical sense. This applies to all distributions.
- Failure Rate: The total number of failures within an item population, divided by the total number of life units expended by that population, during a particular measurement interval under stated conditions.
- Fault: Immediate cause of failure (e.g. , maladjustment, misalignment, defect, etc.)
- Inherent Reliability and Maintainability Value: A measure of reliability and maintainability that include only the effects of an item design and its application, and assumes an ideal operation and support environment.

© COPYRIGHT UPM

- Interchange: Removing the item that is to be replaced, and installing the replacement item.
- Item: A non-specific term used to denote any product, including systems, material parts, subassemblies, sets, accessories, etc.
- Maintainability: The measure of the ability of an item to be retained in or restored to specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.
- Maintainability, Mission: The measure of the ability of an item to be retained in or restored to specified condition when maintenance is performed during a course of a specified mission profile. (The mission-related system maintainability parameter.)
- Maintenance: All actions necessary for retaining an item in or restoring it to a specified condition.
- Maintenance Action: An element of maintenance event. One or more tasks (i.e. fault localization, fault isolation, servicing and inspection) necessary to retain an item in or restore it to a specified condition.
- Maintenance, Corrective (CM): All actions performed as a result of failure, to restore an item to a specified condition. Corrective maintenance can include any of all following steps: Localization, Isolation, Disassembly, Interchange, Reassembly, Alignment and Checkout.
- Maintenance, Event: One or more maintenance actions required to effect corrective or preventive maintenance due to any type of failure or malfunction, false alarm or scheduled maintenance plan.
- Maintenance, Preventive (PM): All action performed in an attempt to retain an item in specified condition by providing systematic inspection, detection, and prevention of incipient failures.
- Maintenance, Scheduled: Preventive maintenance performed at prescribed points in the item's life.
- Maintenance Time: An element of down time which excludes modification and delay time.
- Maintenance, Unscheduled: Corrective maintenance required by item conditions.
- Malfunction: *see* Failure.

© COPYRIGHT UPM

- Mean-Maintenance-Time: The measure of item maintainability taking into account maintenance policy. The sum of preventive and corrective maintenance times, divided by the sum of scheduled and unscheduled maintenance events, during a state of period of time.

- Mean-Time-Between-Failure (MTBF): A basic measure of reliability for repairable items: The mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions.

- Mean-Time-Between-Maintenance (MTBM): The measure of reliability taking into account maintenance policy. The total number of life units expanded by a given time, divided by the total number of maintenance events (scheduled and unscheduled) due to that time.

- Mean-Time-To-Failure (MTTF): A basic measure of reliability for non-repairable items: The total number of life units of an item divided by the total number of failures within that population, during a particular measurement interval under stated conditions.

- Mean-Time-To-Repair (MTTR): A basic measurement of maintainability: The sum of corrective maintenance times at any specific level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

- Mission Profile: A time-phased description of the events and environments an item experiences from initiation to completion of a specified mission, to include the criteria of mission success or critical failures.

- Not Operating (Dormant): The state wherein an item is able to function but is not required to function. Not to be confused with Down-Time.

- Operable: The state of being able to perform the intended function.

- Predicted: That which is expected at some future time, postulated on analysis of past experience and tests.

- Reassembly: Assembling the items that were removed during the disassembly and closing the reassembled items.

- Redundancy: The existence of more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical.

- Reliability:

  (1) The duration of probability of failure-free performance under stated conditions.

© COPYRIGHT UPM

(2) The probability that an item can perform its intended function for a specified interval under stated conditions. (For non-redundant items, this is equivalent to definition (1). For redundant item, this is equivalent to definition of Mission Reliability.)

- Reliability Mission: The ability of an item to perform its required functions for the duration of specified "mission profile."

- Repair: *See* Maintenance, Corrective.

- Repairable Item: An item which can be restored to perform all of its required functions by corrective maintenance.

- Screening: A process for inspecting items to remove those that are unsatisfactory or those likely to exhibit early failure. Inspection includes visual examination, physical dimension measurement and functional performance measurement under specified environmental conditions.

- Servicing: The performance of any act needed to keep an item in operating condition, (i.e. lubricating, fueling, oiling, cleaning, etc.), but not including preventive maintenance of parts or corrective maintenance tasks.

- Subsystem: A combination of sets, groups, etc. which performs an operational function within a system and is a major subdivision of the system.

- System: General – A composite of equipment and skills, and techniques capable of performing or supporting an operational role, or both. A complete system includes all equipment, related facilities, material, software, services, and personnel required for its operation and support to the degree that it can be considered self-sufficient in its intended operational environment.

- System Reliability and Maintainability parameter: A measure of reliability and maintainability in which the units of measurement are directly related to operational readiness, mission success, maintenance manpower cost, or logistic support cost.

- Time: The universal measure of duration. The general word 'Time' will be modified by an additional term when used in reference to operating time, mission time, test time, etc. In general expression such as "Mean-Time-Between-Failure (MTBF)," time stands for "life units" which must be more specifically defined whenever the general term refers to particular time.

- Time, Active: That time during which an item is in an operational inventory.

© COPYRIGHT UPM

- Time, Administrative: That element of delay time, not included in the supply delay time.

- Time, Checkout: That element of Maintenance Time during which performance of an item is verified to be a specified condition.

- Time, Delay: That element of down time during which no maintenance is being accomplished on the item because of either supply or administrative delay.

- Time, Down (Downtime): That element of active time during which an item is not in condition to perform its required function. (Reduces Availability and Dependability)

- Time, Inactive: That time during which an item is in reserve. (In the Inactive Inventory)

- Time, Mission: That element of up time required to perform a stated mission profile.

- Time, Modification: The time necessary to introduce any specific change(s) to an item to improve its characteristics or to add new ones.

- Time, Not Operating: That element of up time during which the item is not required to operate.

- Time, Supply Delay: That element of Delay Time during which a needed replacement item is being obtained.

- Time, Turn Around: The element of Maintenance Time needed to replenish consumables and check out an item for recommitment.

- Time, Up (Uptime): That element of Active Time during which an item is in condition to perform its required functions. (Increase Availability and Dependability).

- Uptime Ratio: A composite measure of operational availability and dependability that includes the combined effects of item design, installation, quality, environment, operation, maintenance, repair and logistic support: The quotient of uptime divided by uptime plus downtime.

- Useful Life: The number of life units from manufacture to when the item has an unrepairable failure or unacceptable failure rate.

- Wearout: The process which results in an increase of the failure rate or probability of failure with increasing number of life units.

© COPYRIGHT UPM

Other Definitions of Terms for Reliability and Maintainability:

- Cumulative Distribution Function (CDF): It provides a cumulative probability for discrete and continuous distributions. [48]
- Imperfect Maintenance: Restores the system operating state to somewhere between as good as new and as bad as at an older age [69].
- Inherent Availability: it is based solely on the failure distribution and repair-time distribution. It can therefore be viewed as an equipment design parameter, and reliability-maintainability trade-offs can be based on this interpretation. [48]
- Line Replaceable Unit (LRU): It refers to the highest level of modularization, in which a unit may be removed and replaced from its higher assembly. [48]
- Minimal Maintenance: Restores the system to failure rate it has when it failed [69].
- Mission Duration: Total time for a system under a mission. The time duration may include total uptime and total downtime.
- Mission Time (TM): Total of predicted or required time for a system to be in full operating condition. Mission time does not include the downtime of the system.
- Perfect Maintenance: Restores the system operating condition to as good as new. [69].
- Probability Density Function (PDF): It assigns a probability to an interval of values of a continuous random variable. [48]
- PMI: Preventive Maintenance Interval. It also means scheduled maintenance time.
- Reliability Block Diagram (RBD): Reliability block diagram (RBD) is a way of showing how the components connected with each other. [36]
- Restoration Factor (RF): A factor to determine the age of the component after imperfect maintenance / inspection. RF is defined between 0 to 1.
- TTF: Time to Failure

© COPYRIGHT UPM

CHAPTER 1

INTRODUCTION

1.1 Background

Maintenance activity is necessary in order for a system to keep running without failure. However, maintenance activity is a cost for the owner of the system. For airline industry, aircraft maintenance is important not only for the availability of the aircraft, but also to adhere to the regulations set up by the aviation authority and flight safety.

The maintenance activity could be either to prevent the failure before it happens or to amend the failure after it happens. The preventive action is called Preventive Maintenance (PM) whereas amending action is called Corrective Maintenance (CM). There are also a few assumptions of maintenance actions. One could assume that the maintenance is perfect, minimal or imperfect. Perfect maintenance means after the maintenance, the aircraft or the system is assumed to perform as brand new (i.e. as good as new) whereas minimal maintenance means after the maintenance, the aircraft or the system is assumed to perform no better than before failure (i.e. as bad as old). Imperfect maintenance means the aircraft or the system is assumed to perform not as a brand new but better than before failure. In reality, maintenance effect is in between as bad as old and as good as new. The maintenance is called imperfect maintenance [34, 71].

1.2 Problem Statement

Understanding maintenance activities for any aircraft is important. The importance is not merely on the technical aspect of the maintenance activities and adherence to regulatory, but also how to relate the maintenance activities with availability and maintenance cost. Preventive maintenance interval (PMI) can affect the availability and maintenance cost. For the purpose of this studies, an Avionic system is chosen. It is because avionics is important equipment in aircraft for flight crew to fly the aircraft. Moreover, the avionics equipment cost is about 30% of the aircraft total cost [30]. Almost all of components in avionics system are electronic components. Although electronic component's useful life can be very long, the complexity of the overall avionics system could shorten the useful life of whole system due to interactions of every component in the system [33]. Thus for the thesis, the most realistic Avionics maintenance simulation is needed and imperfect simulation is assumed. Restoration factor (RF) is required to be known to simulate imperfect maintenance. Previous researchers either retrieved RF from historical data mining or assumed it to any constant value between 0 to 1 [15, 21, 41, 54, 59, 67]. Recent published article in 2013 has assumed the restoration factor to be constant and did not explain in details how the assumption was done [41]. This thesis proposes method for system's end user to calculate RF for imperfect maintenance simulation with

© COPYRIGHT UPM

assumption that the system's historical data is insufficient. The simulation is also run for both perfect and minimal maintenance for comparison. From these simulations run in Matlab, minimum PMI for avionics system can be estimated.

1.3 Objective of the Research

Based from the problem statement, the followings are the objectives of the thesis:

1. To comprehend the practice of perfect maintenance, imperfect maintenance and minimal maintenance.
2. To simulate maintenance activities of the system as realistic as possible at different Preventive Maintenance Interval (PMI).
3. To estimate optimum value of PMI.

1.4 Scope of the Thesis and Limitations

The data and analysis for the research are specific to Cirrus SR-20 aircraft with Perspective Avionics. The research is only focus on two sub-systems of avionics system which are Engine Indication System and Flight Instruments.

1.5 Organization of the Thesis

The thesis will be divided into five main chapters. Chapter 1 is an introductory of the research. In this chapter, background of reliability, maintainability and availability of a system are discussed. Also, problem statement, objectives and scope and limitations of the research are mentioned and explained in this chapter. On the other hand, Chapter 2 mentions about previous researches and findings related to this study. In the next chapter which is Chapter 3, materials, steps and methods required for the research are explained in detail. Then, the result of the research is presented and discussed in the upcoming chapter which is Chapter 4. Lastly, the work of this research is summarized and concluded in Chapter 5.

© COPYRIGHT UPM

REFERENCES

"Air Data Computer (ADC): 9004 TAS/Plus ". 2012. (http://www.teledynecontrols.com/productsolution/adc/overview.asp). Retrieved 17 Apr 2012.

"Cirrus Parts by API. 11657-001 ". (https://www.cirruspartsbyapi.com/products/1105-11657-001.aspx). 2012. Retrieved 18 Apr 2012.

"Cirrus Parts by API. 12744-004-OH-E ". (https://www.cirruspartsbyapi.com/products/4501-12744-004-oh-e.aspx). 2012. Retreived 18 Apr 2012.

"Cirrus Parts by API. 20919-001 ". (https://www.cirruspartsbyapi.com/products/6597-20919-001.aspx). 2012. Retrieved 18 Apr 2012.

"Garmin | Out of Warranty ". (http://www8.garmin.com/support/outofwarranty.html). 2012. Retrieved 18 Apr 2012.

"MSRPList.Pdf (application/pdf Object) ". (http://www.cirruslink.com/mycirrus/downloads/MSRPList.pdf). 2012. Retrieved 18 Apr 2012.

Agnes, Michael. *Webster's New World College Dictionary*. New York: Macmillan, 2000.

Aircraft Maintenance Manual for the Cirrus Design SR20. Cirrus Design Incorporated, 2012.

Airplane Information Manual for the Cirrus Design SR20 Aircraft Serials 2016 and Subsequent with Perspective Avionics System. September 2011 (http://servicecenters.cirrusdesign.com/TechPubs/pdf/POH/SR20-004/pdf/13999-004InfoManual.pdf). Retrieved 18 April 2012.

Al-Najjar, Basim and Imad Alsyouf. Selecting the Most Efficient Maintenance Approach Using Fuzzy Multiple Criteria Decision Making, *International Journal of Production Economics*, Vol. 84, pp. 85-100. 2003.

Ambani, Saumil, Semyon M. Meerkov, and Liang Zhang. "Feasibility and optimization of preventive maintenance in exponential machines and serial lines." *IIE Transactions* 42.10 (2010): 766-777.

© COPYRIGHT UPM

An69705 Aerospace Optimize Fuelflow. 2012. (http://www.ftimeters.com/pdfs/application_notes/an69705_aerospace_optimize_fuelflow.pdf). Retrieved 28 Mar 2012.

Aspinwall, Tom and Dowd, Tim. "Design Project 2005/2006 Technical Report Group 5 - the Strut Braced Wing Aircraft
." 27 Feb 2006. (http://s3.amazonaws.com/zanran_storage/www.bristol.ac.uk/ContentPages/83376580.pdf) Retrieved 17 Apr 2012.

Aven, T. and Uwe Jensen . *Stochastic Models in Reliability*. New York: Springer, 1999.

Ben-Daya, Mohamed. "The economic production lot-sizing problem with imperfect production processes and imperfect maintenance." *International Journal of Production Economics* 76.3 (2002): 257-264.

Berrichi, A., F. Yalaoui, L. Amodeo and M. Mezghiche. Bi-Objective Ant Colony Optimization Approach to Optimize Production and Maintenance Scheduling, *Computers and Operations Research*, No. 37, pp. 1584-1596. 2010.

Bris, R., E. Chatelet and F. Yalaoui. New Method to Minimize the Preventive Maintenance Cost of Series-Parallel Systems, *Reliability Engineering and System Safety*, No. 82, pp. 247-255. 2003.

Byington, Carl S., et al. "Advanced diagnostic/prognostic reasoning and evidence transformation techniques for improved avionics maintenance. "*Aerospace Conference, 2004. Proceedings. 2004 IEEE*. Vol. 5. IEEE, 2004.

Byington, Carl S., et al. "Embedded diagnostic/prognostic reasoning and information continuity for improved avionics maintenance." *AUTOTESTCON 2003. IEEE Systems Readiness Technology Conference. Proceedings*. IEEE, 2003.

Byington, Carl S., Patrick W. Kalgren, and Bryan P. Donovan. "Portable diagnostic reasoning for improved avionics maintenance and information capture & continuity." *AUTOTESTCON 2004. Proceedings*. IEEE, 2004.

Cassady, C. Richard, et al. "A generic model of equipment availability under imperfect maintenance." *Reliability, IEEE Transactions on* 54.4 (2005): 564-571.

Chan, P. K. W. and T. Downs. Two Criteria for Preventive Maintenance, *IEEE Transactions on Reliability*, Vol. R-27, No. 4, pp. 272-273. 1978.

Chelbi, Anis and Daoud Ait-Kadi. Analysis of a Production/Inventory System with Randomly Failing Production Unit Submitted to Regular Preventive Maintenance, *European Journal of Operational Research*, Vol. 156, pp. 712-718. 2004.

Chelbi, Anis and Nidhal Rezg. Analysis of a Production/Inventory System with Randomly Failing Production Unit Subjected to a Minimum Required Availability Level, *International Journal of Production Economics*, Vol. 99, pp. 131-143. 2006.

Chien, Yu-Hung. A Number-Dependent Replacement Policy for a System with Continuous Preventive Maintenance and Random Lead Times, *Applied Mathematical Modelling*, Vol. 33, pp. 1708-1718. 2009.

Chismant, James A. "Using discrete simulation modeling to study large-scale system reliability/availability." *Computers & operations research* 25.3 (1998): 169-174.

Cirrus Perspective™ by Garmin – Pilot's Guide for the SR20/SR22/SR22T. USA: Garmin Ltd or Its Subsidaries, 2008-2010.

CMA9000CT Advanced Flight Management and Control Display Unit. 2012. (http://www.esterline.com/Portals/17/Documents/en-us/cma9000.pdf). Retrieved 17 April 2012.

Coit, David W. and Jiachen Liu. System Reliability Optimization with k-out-of-n Subsystems, *International Journal of Reliability, Quality and Safety Engineering*, Vol. 7, No 2, pp. 129-142. 2000.

Collinson, Richard PG. *Introduction to avionics systems*. Springer, 2011.

Crespo Marquez, Adolfo, Antonio Sánchez Heguedas, and Benoit Iung. "Monte Carlo-based assessment of system availability. A case study for cogeneration plants." *Reliability Engineering & System Safety* 88.3 (2005): 273-289.

Cui, Lirong. Maintenance Models and Optimization. In *Handbook of performability engineering*. Ed. Krishna B. Misra. Springer, 2008.

Ding, Can, Jiuping Xu, and Lei Xu. "Ishm-based intelligent fusion prognostics for space avionics." *Aerospace Science and Technology* 29.1 (2013): 200-205.

Doyen, Laurent. "A generalized Brown-Proschan model for preventive and corrective maintenance." *International Symposium on Business and Industrial Statistics, ISBIS 2010*. 2010.

Ebeling,Charles E. *An Introduction to Reliability and Maintainability Engineering*. Long Grove, Ill: Waveland Press, 2010.

Elsayed, Elsayed A. *Reliability engineering*. Addison Wesley Longman, 1996.

Faulin, Javier, et al. "Predicting availability functions in time-dependent complex systems with SAEDES simulation algorithms." *Reliability Engineering & System Safety* 93.11 (2008): 1761-1771.

Fishman, George S. *Discrete-event simulation: modeling, programming, and analysis*. Springer, 2001.

Floscan Instrument Co. Inc. 2012. (http://www.floscan.com/html/blue/aviation.php). Retrieved 28 Mar 2012.

Ge, Haifeng, Curtis L. Tomasevicz and Sohrab Asgarpoor. Optimum Maintenance Policy with Inspection by Semi-Markov Decision Processes. *Power Symposium, 2007. NAPS'07. 39th North American*, Las Cruces, New Mexico, USA. 2007.

Hou, Wenrui, and Zuhua Jiang. "An Opportunistic Maintenance Policy of Multi-unit Series Production System with Consideration of Imperfect Maintenance."*Appl. Math* 7.1L (2013): 283-290.
Illustrated Part Catalog for the Cirrus Design SR20. Cirrus Design Incorporated, 2012.

Imperfect Repairs. In *Repairable Sytems Analysis Through Simulation*. September 2012 (http://reliawiki.com/index.php/Repairable_Systems_Analysis_Through_Simulation#Imperfect_Repairs). Retrieved 20 April 2012.

Ito, Kodo. "Chapter 9: Maintenance Models of Miscellaneous Systems." Ed. Nakamura, Syouji and Toshio Nakagawa. *Stochastic reliability modeling, optimization and applications.* Singapore; Hackensack, NJ: World Scientific, 2010.

Jones, J., L. Warrington, and Neil Davis. "The use of a discrete event simulation to model the achievement of maintenance free operating time for aerospace systems." *Reliability and Maintainability Symposium, 2001. Proceedings. Annual*. IEEE, 2001.

Juan, Angel A., et al. "Applications of discrete-event simulation to reliability and availability assessment in civil engineering structures." *Simulation Conference (WSC), Proceedings of the 2009 Winter*. IEEE, 2009.

Khatab, Abdelhakim, Daoud Ait-Kadi, and Nidhal Rezg. "A Condition-Based Maintenance Model For Availability Optimization For Stochastic Degrading Systems." *9th International Conference on Modeling, Optimization & SIMulation*. 2012.

Kijima, Masaaki and Ushio Sumita. A Useful Generalization of Renewal Theory: Counting Processes Governed by Non-Negative Markovian Increments, *Journal of Applied Probability,* Vol. 23, No. 1, pp. 71-88. March, 1986.

Kijima, Masaaki. Some Results for Repairable Systems with General Repair, *Journal of Applied Probability,* Vol. 26, No.1, pp. 89-102. March, 1989.

Knezevic, Jezdimir,. *Reliability, Maintainability, and Supportability: A Probabilistic Approach.* London; New York: McGraw-Hill, 1993.

Kuntz, Fabien, et al. "Model-based diagnosis for avionics systems using minimal cuts." *DX 2011 22nd International Workshop on Principles of Diagnosis*. 2011.

Leung, Kit-Nam Francis and Kin-Keung Lai. A Preventive Maintenance and Replacement Policy of a Series System with Failure Interaction, *Optimization*, pp. 1-15. 2012.

Li, Zhaojun, Haitao Liao and David W. Coit. A Two-Stage Approach for Multi-Objective Decision Making with Applications to System Reliability Optimization, *Reliability Engineering and System Safety*, No. 94, pp. 1585-1592. 2009.

Liao, Gwo-Liang, Yen Hung Chen, and Shey-Huei Sheu. "Optimal economic production quantity policy for imperfect process with imperfect repair and maintenance." *European Journal of Operational Research* 195.2 (2009): 348-357.

Márquez, Adolfo Crespo. *The maintenance management framework: models and methods for complex systems maintenance*. Springer, 2007.

Marseguerra, M., and E. Zio. "Optimizing maintenance and repair policies via a combination of genetic algorithms and Monte Carlo simulation." *Reliability Engineering & System Safety* 68.1 (2000): 69-83.

Meggitt Avionics Magnetometer Heading Sensor (MHS). 2012. (http://www.meggitt-avionics.co.uk/pdf/MHS.PDF). Retrieved 17 Apr 2012.

Mesgarzadeh, Behzad, I. Soderquist, and Atila Alvandpour. "Reliability challenges in avionics due to silicon aging." *Design and Diagnostics of Electronic Circuits & Systems (DDECS), 2012 IEEE 15th International Symposium on*. IEEE, 2012.

Mettas, Adamantios and Wenbiao Zhao. Modeling and Analysis of Repairable Systems with General Repair. *2005 Proceedings Annual Reliability and Maintainability Symposium*, Alexandria, Virginia, USA. IEEE, 2005.

MIL-HDBK-217F: Military Handbook Reliability Prediction of Electronic Equipment. USA: Department of Defense, 1991.

MIL-STD-721C: Military Standard Definitions of Terms for Reliability and Maintainability. USA: Department of Defense, 1981.

Misra, K. B. and J. Sharma. Reliability Optimization of a System by Zero-One Programming, *Microelectronics and Reliability*, Vol. 12, pp. 229-233. 1973.

© COPYRIGHT UPM

Naga Srinivasa Rao, P and V. N. Achutha Naikan. An Algorithm for Simultaneous Optimization of Parameters of Condition-Based Preventive Maintenance, *Structural Health Monitoring*, Vol. 8, No. 1, pp. 83-94. 2009.

Nakagawa, Toshio and Kazumi Yasui. Optimum Policies for a System with Imperfect Maintenance, *IEEE Transactions on Reliability*, Vol. R-36, No. 5, pp. 631-633. 1987.

Niu, Gang and Michael Pecht. A Framework for Cost-Effective and Accurate Maintenance Combining CBM RCM and Data Fusion. *Reliability, Maintainability and Safety, 2009. ICRMS 2009. 8th International Conference on*, Chingdu, China. 2009.

Nosoohi, Iman and Seyed Reza Hejazi. "A Multi-Objective Approach to Simultaneous Determination of Spare Part Numbers and Preventive Replacement Times, *Applied Mathematical Modelling*, Vol. 35, pp. 1157-1166. 2011.

Pascual, R., and J. H. Ortega. "Optimal replacement and overhaul decisions with imperfect maintenance and warranty contracts." *Reliability Engineering & System Safety* 91.2 (2006): 241-248.

Pettit, Duane and Andrew Turnbull. *NASA/CR-2001-210647 General Aviation Aircraft Reliability Study.* 2001. (http://dl.acm.org/citation.cfm?id=887467). Retrieved 8 Jun 2012.

Pham, Hoang, and Hongzhou Wang. "Imperfect maintenance." *European journal of operational research* 94.3 (1996): 425-438.

Pilot's Operating Handbook and FAA Approved Airplane Flight Manual for the Cirrus Design SR20 Aircraft Serial 2016 and Subsequent with the Cirrus Perspective Avionics System. Duluth, Minnesota: Cirrus Design Corporation, 2008.

Samet, S., A. Chelbi, and F. Ben Hmida. "Repairable systems availability optimization under imperfect maintenance." *Bulletin of the Polish Academy of Sciences: Technical Sciences* 57.3 (2009): 249-256.

Samrout, M., F. Yalaoui, E. Chatelet and N. Chebbo. New Methods to Minimize the Preventive Maintenance Cost of Series-Parallel Systems Using Ant Colony Optimization, *Reliability Engineering and System Safety*, No. 89, pp. 346-354. 2005.

Scanff, E., K. L. Feldman, S. Ghelam, P. Sandborn, M. Glade and B. Foucher. Life Cycle Cost Impact of Using Prognostic Health Management (PHM) for Helicopter Avionics, *Microelectronics Reliability*, Vol. 47, pp. 1857-1864. 2007.

Schryver, J., J. Nutaro, and Marvin Jonathan Haire. "Metrics for availability analysis using a discrete event simulation method." *Simulation Modelling Practice and Theory* 21.1 (2012): 114-122.

Service Bulletin SB643B. 2012. (http://www.tcmlink.com/pdf2/SB643B.pdf). Retrieved 31 May 2012.

Sheikh, Anwar K.. Strategies in Spare Parts Management Using a Reliability Engineering Approach, *Engineering Cost and Production Economics*, Vol. 21, pp. 51-57. 1991.

Sheu, Shey-Huei, Suh-Huey Li, and Chin-Chih Chang. "A generalised maintenance policy with age-dependent minimal repair cost for a system subject to shocks under periodic overhaul." *International Journal of Systems Science* 43.6 (2012): 1007-1013.

Song, Fuchao, Wenkui Hou, and Long Shi. "The information-enhanced fault diagnosis system design of avionics power supply module." *Quality, Reliability, Risk, Maintenance, and Safety Engineering (QR2MSE), 2013 International Conference on*. IEEE, 2013.

Sony, Michael, V. Mariappan, and Vivek Kamat. "Stochastic modelling of failure interaction: Markov model versus discrete event simulation." *International Journal of Advanced Operations Management* 3.1 (2011): 1-18.

Testing the Aircraft Magneto Coil. 2012. (http://www.sacskyranch.com/eng174.htm). Retrieved 31 May 2012.

Upadhya, K. Sadananda, and N. K. Srinivasan. "Availability estimation using simulation for military systems." *International Journal of Quality & Reliability Management* 29.8 (2012): 937-952.

Upadhya, K. Sadananda, and N. K. Srinivasan. "Availability of weapon systems with multiple failures and logistic delays." *International Journal of Quality & Reliability Management* 20.7 (2003): 836-846.

Vaurio, J. K. Availability and Cost Functions for Periodically Inspected Preventively Maintained Units, *Reliability Engineering and System Safety*, Vol. 63, pp. 133-140. 1999.

Zhang, Y. L., R. C. M. Yam and M. J. Zuo. Optimal Replacement Policy for a Multistate Repairable System, *The Journal of the Operational Research Society, Part Special Issue: Performance Management*, Vol. 53, No. 3, pp. 336-341. Mar. 2002.

© COPYRIGHT UPM

Zhou, Xiaojun, Lifeng Xi, and Jay Lee. "Reliability-centered predictive maintenance scheduling for a continuously monitored system subject to degradation." *Reliability Engineering & System Safety* 92.4 (2007): 530-534.

Zorita, A. L., O. Duque, M. A. Fernandez and L. A. Garcia-Escudero. Determination and Optimization of the Maintenance Frequencies in the Overhead Contact Line System, *Journal of Transportation Engineering*, pp. 964-972. Nov. 2010.

© COPYRIGHT UPM