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RCM Gains Renewed Interest in Semiconductor Space:

Reliability-Centered Maintenance Techniques are Being Used to Reduce Life-Cycle Costs and Typical OEM Maintenance Schedules for Existing Systems

Abstract

There is tremendous interest these days to design and develop all types of complex systems, including infrastructure, communication, logistics and distribution systems that are not only reliable and maintainable but are also robust, resilient and sustainable. The field of reliability sometimes has been narrow in its scope and we have not always integrated the methodology with recent emphasis on broader measures of system performance. We need new measures for system performance based on reliability which are realistic and useful. In this presentation, motivation for these new measures and their trends and applications are provided based on systems oriented, integrated and distributed, customer-centered multi-state system reliability and maintainability methodology and their extensions based on fuzzy logic. Some models using Markov and other general stochastic processes are presented. Examples and applications to infrastructure and network applications as well as health systems are developed and presented.

It has long been known that inclusion of reliability and maintainability (R&M) considerations early in the design life cycle will lead to significant cost savings of the final product or system. This concurrent activity is even more important with today's increasingly complex systems.

The benefits of early R&M participation in the design efforts can be extended with derivative approaches like reliability-centered maintainability (RCM). Additionally, RCM may also serve to optimize costs and resource requirements by reducing the typical maintenance schedules recommended by OEMs.

The latest issue of the RSMP Journal includes a basic review of the RCM methodology. This newsletter piece will complement the journal article by providing a quick overview of RCM as applied to a case study from the semiconductor industry.

Reliability-Center Maintainability is part of the larger reliability and maintainability effort that supports a comprehensive and concurrent systems engineering effort. As explained in the journal article, "RCM is a systematic approach to develop a focused, effective, and cost-efficient preventive maintenance (PM) program and control plan for a system or product. This technique is best initiated during the early system design process and evolves as the system is developed, produced, and deployed. However, the technique can also be used to evaluate preventive maintenance programs for existing systems, with the objective of continuous product/process improvement."

The basic methodology of RCM starts by determining equipment or component criticality within a functional system by identifying equipment failure modes and analyzing the effects of failure resulting from each of those modes. Next, the cause of failure for each one of the previously identified failure modes is determined. The final task is to select the appropriate

Russell A. Vacante, Ph.D.

Beyond the Scope of Established RMS, Systems Engineering & Logistics Practices

The recent reported cyber attack on the U.S. elections process along with numerous attacks on our banking systems, power grids and various other economic and defense infrastructures should be a wake-up call, albeit a very late one, to our national leaders regarding national and international threats to our national security. The convenience and awe-inspiring technological wonders of the internet has blinded many of us to the dangers, potential and real, associated with this electronic (internet-satellite) media. Remember, foreign entities captured the secrets of the atomic bomb one year after its development by the U.S. During our current dependency on digital communications it is conceivable that closely guarded U.S. secrets can be in enemies' hands in seconds, if not in nearly real time.

While our communication systems in many spheres of our life are increasingly becoming well deigned and increasingly

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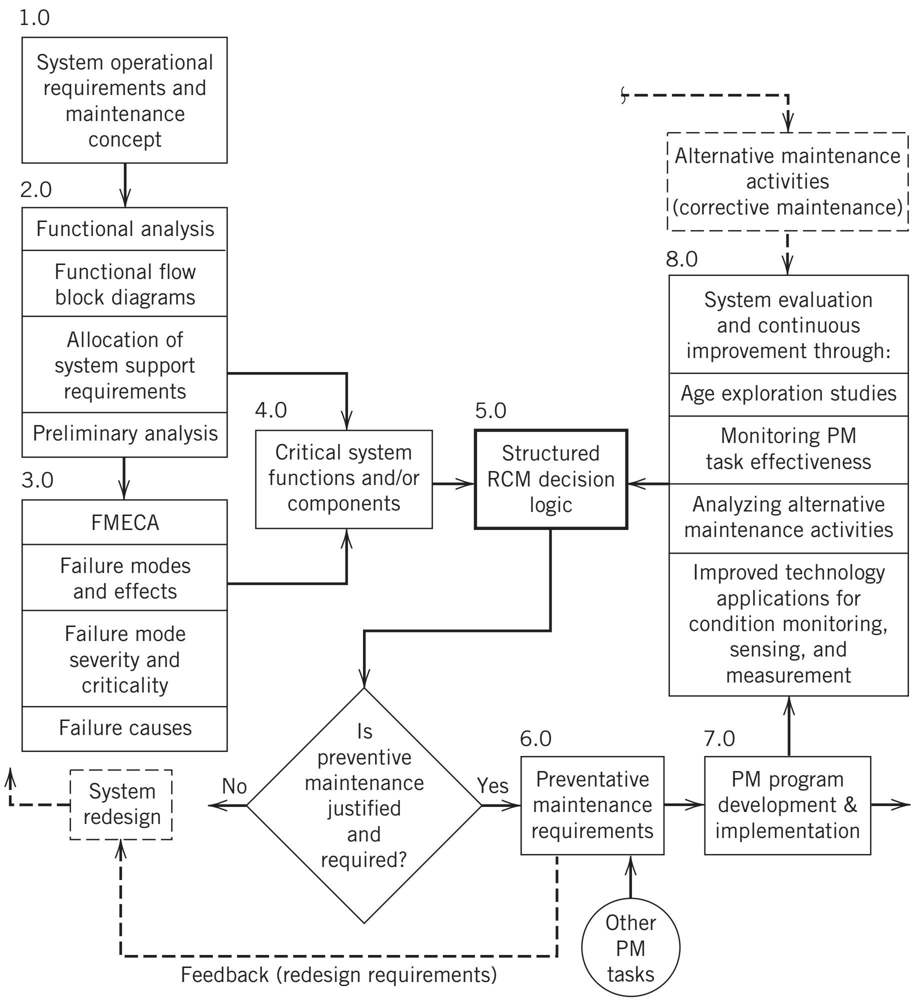

Figure 1: Reliability-centered maintenance analysis process. (Courtesy Blanchard and Blyler)

preventive and predictive maintenance tasks including time-based and renewal tasks that specifically address the identified failure causes (see Figure 1, following page). To learn more about the details for the RCM approach, please refer to the RMSP Journal article on RCM.

RCM Example

Many examples from past RMSP journal articles highlight the techniques of successful RCM activities. For this piece, let's focus on an example from the semiconductor industry developed by Srisawat Supsomboon and Kanthapong Hongthanapach, "A Simulation Model for Machine Efficiency Improvement Using Reliability Centered Maintenance: Case Study of Semiconductor Factory," Modeling and Simulation in Engineering, vol. 2014, Article ID 956182, 9 pages, 2014. doi:10.1155/2014/956182. It is an open access article distributed under the Creative Commons Attribution License (https://www.hindawi.com/journals/mse/2014/956182/). The following are portions from the complete article.

This case study focused on a test machine that caused a lead-related defect

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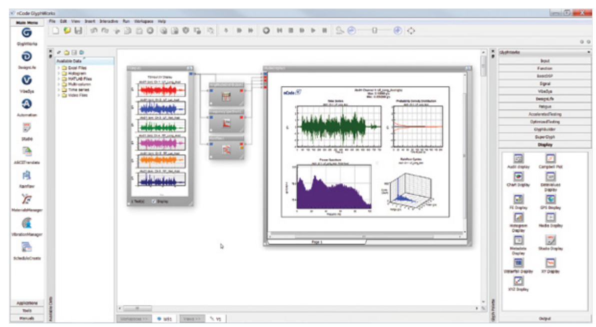

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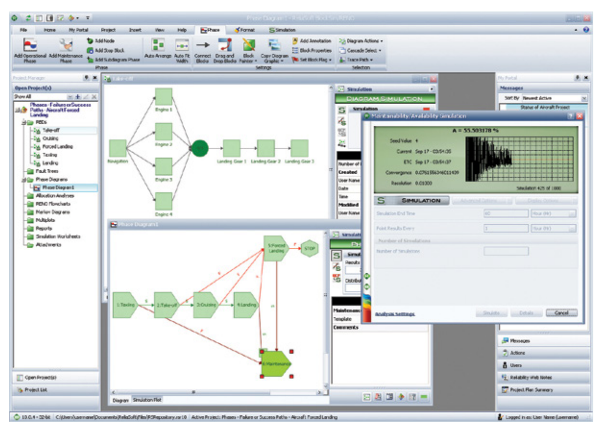

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	Mechanical part list (Impact Lead defect)	Potential of failure mode	Effect	Severity	Occurrence	Directive	RPN
1	Vacuum pad	Wear	Dropped unit	8	4	9	288
2	Ejector filter	Blocking	Dropped unit	8	4	8	256
3	Picker cylinder	Erosion	Unit misplacement	8	4	9	288
4	Solenoid valve	Valve does not open/close	Dropped unit	6	4	8	192
5	Pitch ring	Wear	Unit misplacement	5	3	8	120
6	Pitch bearing	Wear	Unit misplacement	5	2	4	40
7	Timing belt	Damage	Unit misplacement	7	3	9	189
8	Test tray	Damage	Unit misplacement	6	1	4	24
9	Air tubing	Leakage	Unit misplacement	3	1	4	12
10	Motor shaft	Crack/fracture	Dropped unit	6	3	2	36
11	Motor stator	Open/short circuit	Dropped unit	5	2	2	20
12	Inserter	Breakage	Overpress on Lead	8	4	9	288
13	Lead pusher	Breakage	Overpress on Lead	8	4	9	288
14	Test socket	Poga pin stuck	Overpress on Lead	8	5	8	320
15	Loader buffer	Wear	Unit misplacement	3	1	8	24
16	Loader preciser	Misalignment	Unit misplacement	6	1	8	48
17	Unloader preciser	Misalignment	Unit misplacement	7	3	8	168
18	Unloader sortable	Wear	Unit misplacement	4	1	8	32
19	Linear guide	Wear	Unit misplacement	8	4	9	288
20	Ball screw	Crack/fracture	Dropped unit	3	1	2	6

Figure 2: FMEA worksheet for test machine components.

in a semiconductor factory. From the historical data of corrective maintenance, various components in a test machine such as test socket, inserter, and lead pusher deteriorated over time affecting the lead quality of products. In order to stabilize the test machine and reduce defects in process, an effective preventive maintenance (PM) plan was required. This study aimed to establish a preventive maintenance plan based on reliability data of the test machine and applied discrete event simulation to select the preventive maintenance intervals that gave the best performance values.

Failure analysis of the test machine mechanical and change of kit (COK) components revealed the impact of each type of failure on the lead quality. The failure modes and effect analysis (FMEA) were carried out on the test machine components under study to evaluate the various modes of failure of each component. After brainstorming with test machine experts, the FMEA worksheet was obtained (see Figure 2). The worksheet consisted of defining what could fail and the way it could fail (failure mode) and the effect of each failure mode on the components. Severity was ranked according to the seriousness of the failure mode effect on the product quality. Occurrence was scored according to likely failure rate.

A graphical tool known as a Pareto chart was used to rank the causes of problems from the most significant to the least significant. Then system data was collected and analyzed in order to build the RCM model. In order to clarify and analyze the logic of the simulation model, a flowchart describing the logic of the reliability centered maintenance (RCM) model of a test machine was constructed.

After that, time was spent to verify and validate the system model. After analyzing the output of the system, optimization techniques were used to determine the optimal maintenance interval that maximized the total cost, minimized lead parts per million (ppm), and maximized the number of preventive maintenance (PM) intervals.

In order to solve optimization problems, software generated solutions by varying the values of decision variables according to their data type, lower bounds, and upper bounds. After selecting the decision variables, e.g., PM intervals, an objective function was defined to measure the utility of the solutions tested by the optimization software.

In summary, the objective of the study was to create a preventive maintenance plan under the reliability centered maintenance (RCM) method and to reduce the defects of the TS056 IC package occurring during TMP process. The critical components of the test machine were examined as the case study, where the machine behavior and outcomes were obtained by using a ProModel-based simulation model. The simulation optimization approach based on evolutionary algorithms was employed for the preventive maintenance technique selection process to select the

Strategies	Test Machine Components	Multiterm Objective Function
1	Separated	(1) Maximize total cost (2) Minimize Lead PPM
2	Separated	(1) Maximize total cost (2) Minimize Lead PPM (3) Maximize PM plan of the separated component
3	Separated	(1) Maximize total cost (2) Minimize Lead PPM
4	Combined	(1) Maximize total cost (2) Minimize Lead PPM (3) Maximize PM plan of test socket (4) Maximize PM plan of inserter (5) Maximize PM plan of Lead pusher (6) Maximize PM plan of linear guide (7) Maximize PM plan of vacuum pad (8) Maximize PM plan of picker cylinder (9) Maximize PM plan of ejector filter (10) Maximize PM plan of solenoid valve (11) Maximize PM plan of timing belt
5	Combined	(1) Maximize total cost

Figure 3: Overall scenarios of RCM model

PM interval that gave the best total cost and Lead PPM values. Five distinct optimization strategies were identified. The effects on the performance measures were described.

According to the results of the study, optimization strategy 1 provided the highest total cost and the lowest Lead PPM for the case study (see Figure 3). In this study, there were five optimization strategies proposed in order to define test machine components and multiterm objective function (see Figure 3). The reasons for those optimization strategies were to optimize all scenarios that could impact the total cost, Lead PPM, and PM interval of each component. Lead PPM could be reduced from 1,087 ppm to 15 ppm or decreased 98.6 percent. Furthermore, cost of preventive maintenance was decreased.

Some important conclusions from the study are as follows. First, to improve equipment reliability, the critical components required immediate attention to quantitatively evaluate reliability centered maintenance based on essential historical data. The study showed that simulation technique could be used as a computer-aided solving tool in reliability engineering area. It assists in decision making regarding maintenance and Lead defect reduction.

Second, the critical components were selected based on risk priority number (RPN) from failure mode and effect analysis (FMEA). Time-to-failure (TTF) and time-to-repair (TTR) of each critical component were collected from the maintenance reports, failure observations, and daily reports prior to creating simulation model.

Finally, simulation model was used for the entire process to define characteristics of components and to imitate the machine behavior under different preventive maintenance intervals and different reliability constraints. Total cost and Lead ppm were evaluated to obtain the most suitable preventive maintenance schedule for the case study.

In conclusion, there has been renewed interest in RCM techniques to reduce total life cycle costs as well as reducing the typical maintenance schedules recommended by OEMs in existing systems. One example is the semiconductor space utilized simulation models to optimize the preventative maintenance schedules.

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Reliability and cybersecurity ranked as the two most important issues currently confronting the electric industry, according to surveys completed by 672 qualified utility, municipal, commercial, and community stakeholders for Black & Veatch's "2016 Strategic Directions: Electric Industry Report."

It's not particularly surprising to see reliability rank at the top of the list.

"Reliability has always been—I'm sure always will be—a cornerstone of owner-operators," said Ed Walsh, president of Black & Veatch's power business, during an interview with *POWER*. Walsh noted that maintaining 24/7/365 service is paramount to preserving customers' confidence. ●

About the Authors

John Blyler *covers today's latest high-tech, R&D and even science fiction stories in articles, blogs, whitepapers, books and videos. He is an experienced physicist, engineer, journalist, author and professor who continues to speak at major conferences and before the camera. John has 23 years of experience as a systems engineer-manager in the commercial, DOD and DOE hardware-software electronics industries. Another 16 years of experience has gained in the technical trade and professional engineering journal markets. He was the founding advisor and affiliate professor for Portland State University's online graduate program in systems engineering. Also, John has co-authored several books on systems engineering, RF design and automotive hardware-software integration for Wiley, Elsevier, IEEE and SAE.*

Editorial, from page 1

reliable from purely a technical perspective, from a converse perspective, these systems will possibly never be secure enough to prevent outside intrusion and physical attacks. By expanding our concept of systems engineering and reliability to include failures perpetrated by criminal or enemy government actors, it can be stated the U.S. has economically, socially and militarily become dependent upon a technology that is designed inherently unreliable. As so many folks have stated "if communication is taking place in the air, it is available for anyone to latch on to." In other words, all communication and data that are transmitted over the air waves is transparent to the user community and all other interested parties. The technological community of system engineers and RMS and logistics professionals have worked hard to ensure the reliability inherent in internet-digital technology. However, there is next to nothing this community can do regarding long-term protection of our financial and social systems from cyber attacks. There is also little the technology community can do to secure the protection of U.S. satellites from physical destruction at the hands of our adversaries. Few, if any, U.S. digital-satellite communications systems, can be made resilient enough to recover from electronic or physical attack.

We have to ask ourselves at this point of our conversation, what are the folks in charge of our national security thinking? They surely understood that the strategic and tactical advantages of digital-satellite dependent, and open air system, would only provide short-term national security leverage. They could not have been blinded to the fact, that for all practical purposes, that sole dependence on internet-satellite communication systems creates a single point of failure for major systems without a recourse for alternative command and control systems. The vulnerability of internet based communications is, in my opinion, greater than the vulnerability we experienced with hard-wired communication systems.

The systems engineering, reliability and logistics community may have the folks with the needed expertise to help resolve the technological dilemma now facing the U.S. For example, they have the expertise to improve the function and the robustness of existing hard wired systems as a backup communications system for both domestic and defense purposes. Our relatively mothball hard wired systems can be upgraded to expand its flexibility in terms of speed and volume so critical functions and information remain available to the domestic and defense decision makers when cyber attacks occur over the internet or in space. In fact, it may be worth considering that having key components that can absolutely shut down from outside intrusion resident only in hard wired systems. This is not turning technologically back, it is recognizing that there is an alternative way to safeguard U.S. national economic and defense security.

For certain, the intrusions into our voting process reportedly by Russian bad actors has stirred the collective thinking of the American people regarding the vulnerability of U.S. cherished institutions and processes. This editorial is a call for our leaders and the American people, in general, to wean ourselves from sole dependency on internet-satellite based communications and develop and implement communication systems that are secure and ruggedized. We can begin by improving our dormant hard wired communication systems while at the same time using the American ingenuity to invite alternative communication systems. There are many bad actors in the world that seek to do harm to the U.S. As we have seen they are on a daily basis investing time and resources to testing ways to exploit our dependency on internet-satellite communication systems. Before it is too late, the U.S. needs to explore and soon implement communication systems that limit their access to the appropriate user community and no one else. ●

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Dr. Lloyd H. Muller

What PBL Ain't

I'm old enough to remember when the term Performance Based Logistics, otherwise known as PBL, first made its appearance. At that time, it was the darling buzzword of the day that was accepted as being a new form of logistics. "Integrated logistics is out; PBL is in."

Well, folks, PBL is in, but so is integrated logistics. I'm still teaching the concept with this thought in mind. Last night I just completed a distance learning course offered by the RMS Partnership. (By the way, it was a great success. If any readers want to know more about courses presented with this teaching method, please don't hesitate to contact me through the partnership.) In it, during the early part of the course, this fact was emphasized.

The reason for this is simple. PBL is a procurement strategy. Directly speaking, it has nothing to do with logistics itself. Rather, it is a method of holding logisticians responsible for providing support outputs. That is, when maintenance is provided, the measured criterion is whether the system works. If it doesn't, then the job's not done. This may be so even when the services provided were exactly what should be done.

Before PBL, if the job was done exactly as directives indicated, then regardless of the outcome, the job was done. The maintainer could go home. A comparable analogy is the medical term, "Fee for Service." The outcome was not the issue. Did the doctor perform the surgery in a medically correct manner? The answer was often morbid: the operation was a success, but the patient died. The same was true for support. The gas was passed, but the vehicle didn't work, and the worker got paid.

Under PBL rules, the gas will be passed and the vehicle will either work or no pay. This has resulted in large cost savings for industry and government. Let's see why. Facility maintenance contracts, at one time, would say, "Have all the light bulbs shining and you will be paid for each bulb replaced." This meant that the maintainer would use cheap light bulbs. Why? Because they would wear out quickly and generate an expensive replacement. The more replacements, the higher costs and presumably profits. But, when one thinks about the situation, what is really wanted is illumination on a constant basis. How often the bulbs are replaced is not the user's concern; what is wanted is illumination.

Therefore, if one demands just illumination while leaving the "how" to the maintainer, the fewer light bulbs replaced means less work. Less work means fewer bulbs to be purchased and fewer hours of contractor labor to be expended. Profits come from doing less. Meanwhile, illumination is achieved.

This is a simple example, but it is just as true for an F-35 fighter which is obviously more complicated than a light bulb. Engineers go to great length to ensure its reliability and operational availability from a design standpoint. Logisticians test it for maintainability and supportability by using integrated logistics principles to make follow-on support easier. Usually, engineers and logisticians go back and forth many times making improvements until it's just right. At that point, it's ready for the field. It is ready to be flown and maintained on a daily basis. What is different from a light bulb is the seriousness of the result. Pilots want their airplanes ready and able to engage in combat under trying circumstances. The last thing they need is for the maintenance to have been done "according to the book," but the plane still not able to perform its mission. They want performance, and they want it now. PBL creates the mind set and the profit motive to ensure just that: to be ready.

That's it, folks. PBL ain't logistics. It's a procurement strategy designed to get things done right the first time and cost effectively. ●

About the Authors

Dr. Lloyd Muller *is widely versed in the academic elements of logistics. Bringing his wealth of practical experience to education, he has taught at universities located both in the United States and in foreign countries. Among them are the University of Maryland, Emery Riddle Aeronautical University, La Verne University and Middle East Technical University in Ankara Turkey. He has also been a logistics instructor for the United States Navy. Currently, he is an associate professor of logistics for Florida Institute of Technology as well as Vice President for Curriculum Development for the Reliability, Maintainability and Supportability Partnership (RMSP). Prior to his academic career, as an Air Force colonel he implemented the planning of logistical requirements and applications for worldwide contingencies led to the development of an automated real time system that managed all of the logistics resources in the Mediterranean during Operation Desert Storm. This system became a prototype for Air Force application. His last assignment was Deputy Commander of 16th Air Force.*

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