OPTIMIZING PROACTIVE MAINTENANCE USING RCM
THE CRITICALITY ISSUE

A major challenge currently confronting plant staff and management is how to deliver cost-effective and sustainable business practices based on plant performance requirements over the lifecycle of the assets. This can be especially challenging when it comes to recruiting and retaining skilled technicians who can operate and maintain an industrial complex. While it is recognized that a primary cause for this challenge is a shrinking pool of newly qualified technicians to replace the retiring workforce, a second and substantial cause is the inefficient allocation of resources that are here TODAY. What can be done to address this inefficiency? This article suggests a ready solution exists when you stop to recognize that not everything in your plants is of equal importance to achieving your objectives. Think return on investment (ROI). How can you identify those systems and equipment that are most responsible (think **critical**) for the loss of ROI? In the operations and maintenance (O&M) world, the selective application of reliability-centered maintenance (RCM) to your plants can optimize the use of available resources. This article describes a real-world application of RCM to focus the optimal use of your available resources.

"How can you identify those systems and equipment that are most responsible (think **critical**) for the loss of ROI?"

PLANT BACKGROUND

Since 1946, Central Contra Costa Sanitary District (Central San) has been providing safe and reliable wastewater collection and treatment for residents in central Contra Costa County, California. Today, Central San serves over 481,600 residents and 3,000 businesses in 147 square miles. Its services include a complex treatment plant, 19 pump stations, recycled water for parks and golf courses, operation of a household hazardous waste collection facility and running a sophisticated water quality laboratory.

During 2017, Central San piloted an RCM approach on two systems as part of an overarching asset management implementation plan. The plan is part of the strategic goals, with clear line of sight objectives from vision and mission to success measures.

The objective of this pilot is to establish a framework for Central San to improve maintenance efficiency and functional reliability of assets. The project aligns with its strategic plan, specifically to:

“Be a fiscally sound and effective water sector utility, to develop and retain a highly trained and innovative workforce, and to maintain a reliable infrastructure.”

RCM ORIGIN

Historically, RCM was invented in the 1960s by a United Airlines (UA) team headed by then Vice President, Maintenance Planning Tom Matteson. It was in response to a serious concern about operating maintenance costs for the new 747 “jumbo jet” airplane. The team’s creative approach first addressed defining the airplane’s systems, then called functionally significant items (FSIs), and then mandating that the functions of flight critical FSIs be preserved. Only then did the team turn to determining which specific component failure modes could defeat those functions. This new step in the maintenance decision world provided a logical focus on where to specify maintenance actions that could prevent or mitigate the loss of flight critical FSIs (and, by the way, also revealed that many of the then maintenance actions on the operating jet fleets were totally unnecessary or ineffective). The obvious outcome of this logic also identified the equipment in noncritical FSIs, thus introducing the potential for cost-effective run to failure (RTF) decisions.

The team’s solution was so successful that it became the standard for defining the preventive maintenance (PM) program for virtually all new commercial airplanes. The details of that solution were first recorded publicly in the 1978 U.S. Department of Defense sponsored book titled, “Reliability-Centered Maintenance,” coauthored by two members of the original UA team, Stanley Nowlan and Howard Heap. In the 1980s, the RCM process was widely introduced to industry and several RCM books were written, most notably by Anthony (Mac) Smith and John Moubray. (See References for these publications.)

In summary, the RCM methodology is basically these four features:

1. Preserve Function;
2. How Are Functions Defeated (failure modes)?
3. What Are the Failure Mode Priorities?
4. For the High Priority Failure Modes:

- Define applicable task candidates,

- Select the most effective (i.e., least costly) one.

THE CLASSICAL RCM PROCESS

Today, virtually all RCM practitioners incorporate the four features in their analysis work. The “classical” descriptor was bestowed by the Electric Power Research Institute for the specific form of analysis used by Mac Smith in his facilitation work because it follows as closely as possible to the original UA creation (see Reference #1).

Classical RCM has a 7-step system analysis protocol as shown in Table 1. This was formulated years ago via a trial and error process to assure it captured all the salient features used by the UA creators. These seven steps also form the basis for the RCM WorkSaver software that was introduced in the late 1990s. Today, it is the only known software devoted completely to the 7-step system analysis. These seven steps also were the basis for the project reported in this article.

Table 1 - 7-STEP SYSTEM ANALYSIS PROCESS
Step 1: System Selection – agreement on system priorities
Step 2: System Boundary Definition
Step 3: System Description and Functional Block Diagram – what is in the box
Step 4: System Functions and Functional Failures – agreement on functions
Step 5: Failure Mode and Effects Analysis (FMEA) – hope to strategy, predictable day
Step 6: Logic (Decision) Tree Analysis (LTA) – what is important as opposed to everything is important
Step 7: Task Selection – select the best appropriate practice

Step 1 in Table 1 is used to select the 80/20 “bad actor” systems in a plant or facility and is the industrial equivalent of the FSI used by the UA team. (More details on the “Selecting System Criticality” process follows in a separate section.) Steps 2 and 3 assure the classical process clearly identified and recorded in the software the boundaries for the critical 80/20 systems, then the components inside and finally the functional block diagram and description for the selected system.

The four features of the RCM process are captured in the analyses performed in Steps 4, 5, 6 and 7. Step 4 is crucial to a successful project as it is the step that captures what the selected system does and must preserve so it will not experience a functional failure. Step 5 combines information from Steps 2 and 3 and with Step 4, specifically pinpoints the failure modes that should be prevented or mitigated. Step 6 takes the criticality issues to the failure mode level and characterizes whether it is the source of a safety or environmental, outage, or hidden failure, with the default issue being an insignificant failure. (The upcoming section on “Selecting Component Failure Mode Criticality” describes this assignment process in detail.) Step 7 then addresses the failure modes with a critical label as the culprits needing a realistic PM task.

THE TEAM

A successful RCM project requires two organizational considerations. First, since the RCM process is relatively new to most organizations, an RCM project requires leadership and facilitation by someone who is well versed in the basic RCM methodology. This person must be a good teacher who can explain the details of the 7-step system analysis and all the ground rules associated with its application.

Second, it requires the commitment of a dedicated team of highly qualified technicians who know the equipment and plant systems and how they operate together to produce the product. The team must share their personal expertise as they are almost always the exclusive source of the data to “fill in” the questions and the format of the analyses’ steps. This team also needs a leader who is respected by the team members and can assume the role of the RCM champion for this and subsequent RCM projects. Figure 1 shows the A-Team organization that produced the results discussed in this article.

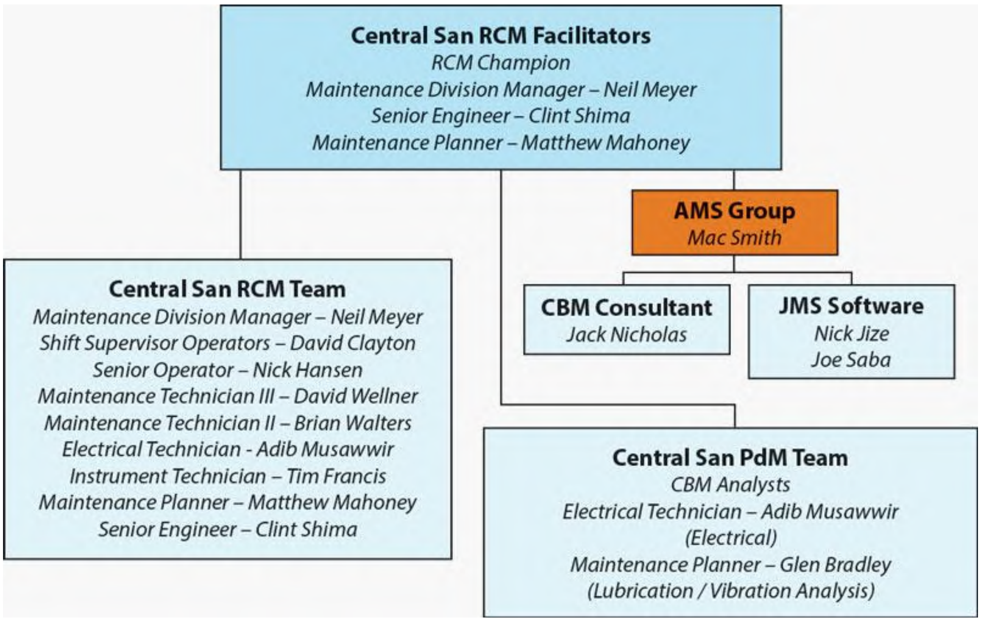

Figure 1: Organizational structure for the team

SELECTING SYSTEM CRITICALITY

As previously suggested, a major issue today is how to best utilize the limited plant resources that are usually available. One could further suggest that not all plant assets are equally important in achieving the plant's mission and goals. So, how can you identify those assets most critical to those goals? In the O&M world, criticality is most commonly associated with costs and system availability. So, what parameters can be used to best measure this?

Step 1 in the Classical RCM process directly addresses this question by illustrating a factual approach that will identify the bad actor systems in the plant. It does this by employing the Pareto diagram technique to rank, from worst to least, the individual plant system contributors to one of these rather easily measured parameters: corrective maintenance work order (WO) counts, corrective maintenance costs (labor plus materials), or unplanned downtimes. All three are usually assessed over a previous 24-month period. In the study for the Central Contra Costa Sanitation District treatment plant, the prior 24-month WO counts history was used for each of the 33 systems that comprise the treatment plant. The resulting Pareto diagram is shown in Figure 2. Looking back over some 60 Classical RCM projects, the pattern shown in Figure 2 ALWAYS existed. One can rather easily determine by visual inspection just which systems are doing the least good to the plant. Also, as a rule, it had been common to see the diagram reflect either an 80/20 or 70/30 pattern (80% of WOs occur in 20% of the systems, etc.). In this study, the top two bad actor systems, dewatering and steam generation, were initially selected for the two pilot studies. Within those system boundaries, several subsystems existed, so the same data was used to select the worst subsystems in each for the details conducted in Steps 2 to 7 of the 7-step system analysis process.

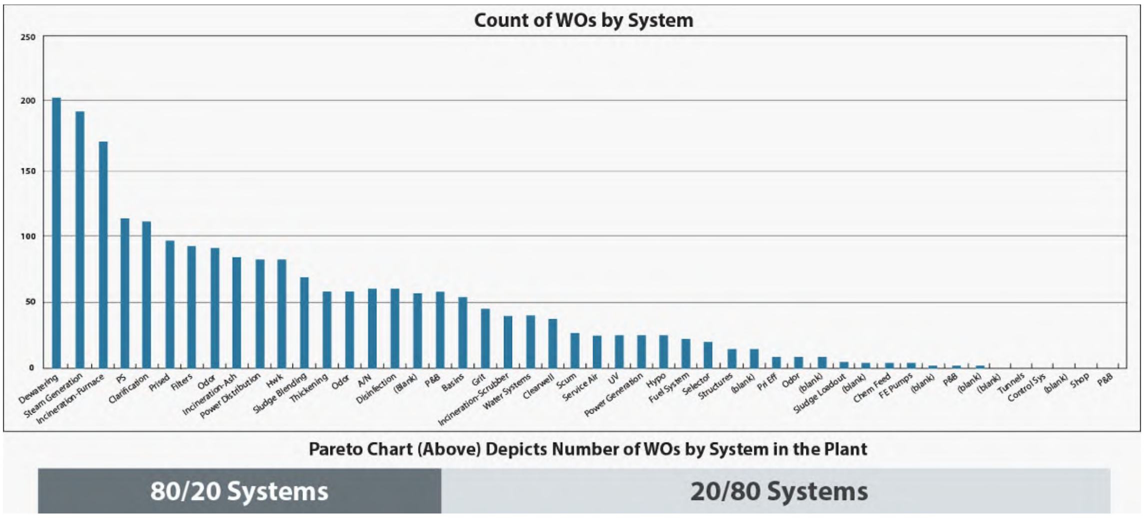

Figure 2: Pareto diagram

SELECTING COMPONENT FAILURE MODE CRITICALITY

Steps 4 and 5 in the 7-Step Classical RCM system analysis process provide the details for how the selected system or subsystem can develop component failures that may degrade or eliminate the system's functions. Step 5 is one of the most detailed steps in the analysis process as it systematically addresses each component inside the system and lists specific failure modes that could do this (some of which may have already occurred in the plant's WO records).

The next step in the criticality discovery chain takes place in Step 6, shown in Figure 3. The decision logic tree passes each failure mode listed in Step 5, one by one, through this three question "Yes or No tree," which pinpoints the nature of the failure mode consequence. A "Yes" answer serves to identify the role of the failure mode in creating a safety, outage and/or hidden failure condition (coded with the letter A, B and/or D), with the default condition being a failure mode that has little to no impact on system performance or criticality (coded with the letter C). The A, B and D failure modes pass to Step 7 for assignment of a PM task that will hopefully eliminate or mitigate their occurrence. The C failure modes become candidates for a run to failure (RTF) decision that delays any expenditure of resources until it is convenient and cost-effective to do so. However, such RTF decisions are subjected to a sanity checklist in Step 7 that first must be considered. For example, redundancy is lost, so this would be a risk that should not be taken. The results of Step 6 and 7 then become the recommended PM tasks for the system or subsystem. The final analysis in Step 7 is to then compare for each failure mode in Step 5 the current PM action versus the RCM recommended PM action. This comparison is shown in the upcoming section, "Analysis Results – Task Comparisons."

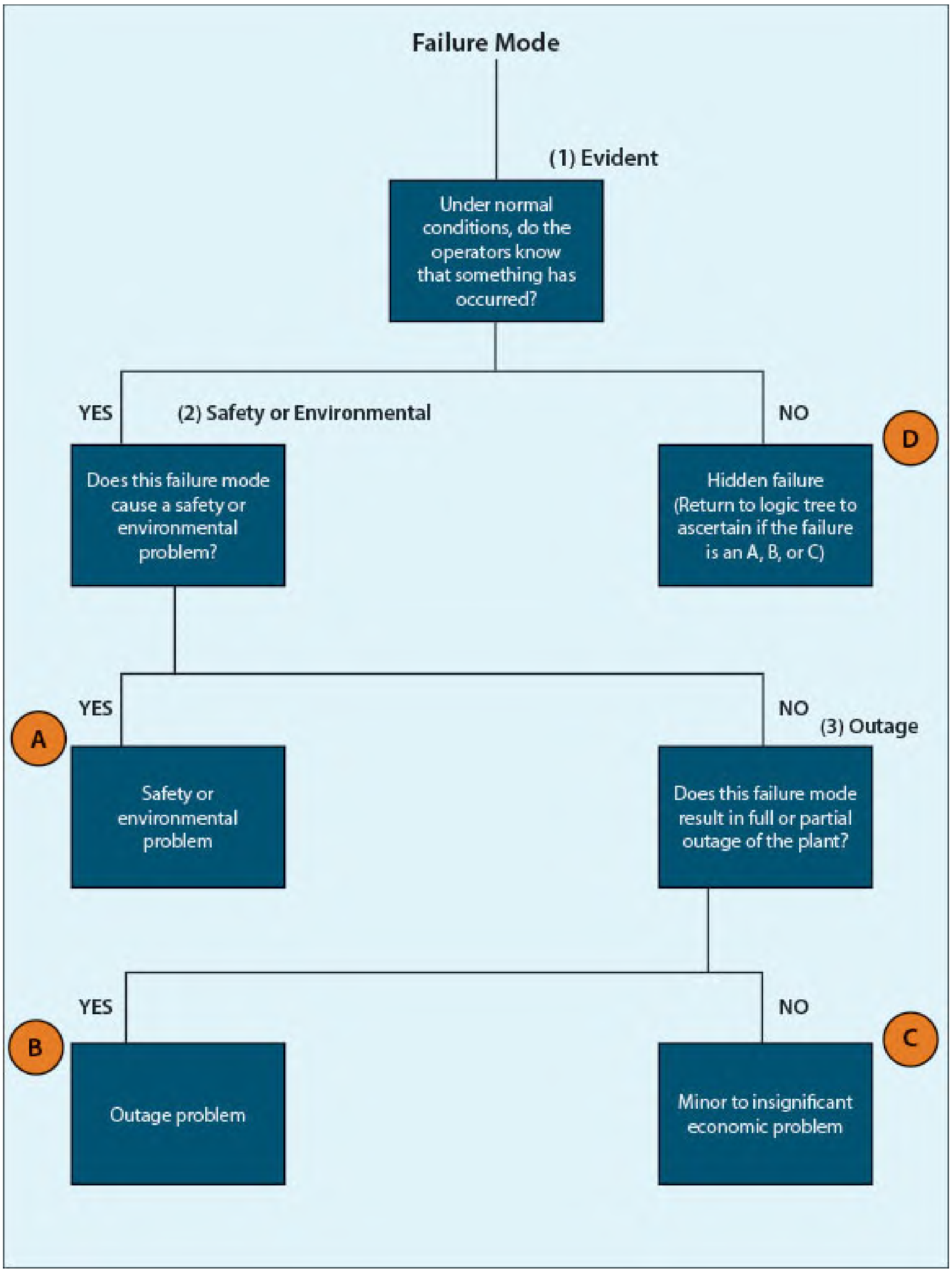

Figure 3: Decision logic tree

Notice that this process between the Step 1 and Step 6 analyses has defined *two* levels of criticality decisions: system and component failure mode. This provides a detailed road map for where the maintenance resource can be effectively applied – no more guessing at it!

ANALYSIS RESULTS – SUBSYSTEM PROFILES

After the final step in the RCM 7-step system analysis process for each subsystem, typically 50 to 60 pages of detailed information have been recorded in the RCM software as the final report. The team's action at the end of Step 7 is to summarize a group of statistics that provide an overview of both the content of this report and the highlights of the findings. Table 2 presents the statistics for this RCM system analysis profile. This profile contains information that is very descriptive with the details the team has examined and discussed. Here are some observations.

Table 2 – Statistics from RCM System Analysis Profile		
RCM Systems Analysis Profile	**Centrifuge Subsystem**	**Waste Heat Boiler Subsystems**
Subsystem Functions	6	7
Subsystem Functional Failures	9	11
Components in Subsystem Boundary	16	25
Failure Modes Analyzed Critical Non-Critical Hidden	46 29 (63%) 17 (37%) 13 (28%)	63 28 (44%) 35 (56%) 7 (11%)
PM Tasks Specified (includes Run to Failure)	62	70
Active PM Tasks	53	58
Items of Interest	30	16

- **From Step 4** – System/Subsystem (S/S) Functions and Functional Failures: Each S/S is commonly thought to have one, maybe two, functions. They usually have more than two to fully perform their intended role. Such is the case here. Also, notice there are more functional failures than functions; this is because a S/S may have more than one way *not* to do its complete job (e.g., it would not stop altogether, but is in a degraded mode).
- **From Steps 2 and 3** – S/S Components: The numbers here are about average, but many S/Ss do have numbers that are two times or larger.
- **From Steps 5 and 6** – Failure Modes Analyzed: This is the heart of the analysis' findings because a) it is the failure mode that causes all the trouble, and b) it is the failure mode that needs to be addressed via preventive maintenance or other corrective actions. Notice that on average, every component had about three failure modes per component and the clear majority of them (63% and 44%) are critical, that is "A" and/or "B" categories from Step 6. It is those failure modes that made these S/Ss critical in the first place. Also, notice that some of them are hidden from the operators (23% and 11%). In comparison to many other studies, these percentages are low.
- **From Step 7** – Active PM Tasks Specified: Notice that some failure modes have more than one active PM task specified. The introduction of predictive maintenance (PdM) technology and tasks specific to the hidden characteristic may be the reason.

All this information represents input from the team's technicians. It involved collective team agreement, with frequent discussions and additional research to accumulate all the data over about a staggered 20 day, seven hours per day, period.

ANALYSIS RESULTS – TASK COMPARISONS

In Table 3, another very important part of the analysis shows a comparison between the current PM task program and the PM task program recommended by the Classical RCM study. There are six different comparison categories shown. The 62 PM tasks for the centrifuge subsystem and the 70 PM tasks for the waste heat boiler subsystem have been assigned to the appropriate category descriptors shown in Table 3. The final analysis in Step 7 also assigned current PM tasks to each appropriate failure mode in the study to obtain the comparison statistics.

Table 3 – Current and Recommended PM Task Program Comparison			
PM Task Comparison(By Failure Mode)		**Centrifuge Subsystem**	**Waste Heat Boiler Subsystems**
I	RCM Task = Current Task	0 (0%)	11 (16%)
II	RCM Task = Modified Current Task	21 (34%)	24 (34%)
III	RCM Specifies Task, No Current Task Exists	29 (47%)	24 (34%)
IV	RCM Specifies Task, Current Specifies Different Task	3 (5%)	0 (0%)
V	RCM Specifies RTF, Current Task Exists	1 (1%)	0 (0%)
VI	RCM Specifies RTF, No Current Task Exists	8 (13%)	11 (16%)

Category I: Referring back to the Pareto diagram in Figure 2, the two subsystems in the study came from the #1 and #2 bad actor systems, dewatering and steam, respectively. Thus, before the study was done, it was known that these two subsystems would likely need some major overhaul in their PM programs. The data in Category I reflects that expectation. In the centrifuge subsystem, not one current PM task was recommended to stay completely "as is," and in the waste heat boiler subsystem, only 16 percent were recommended for retention.

Category II and III: Given the results for Category I, it is not surprising to see the results in these two categories!

Category II: The results for both subsystems are larger at 34 percent each than the average numbers most frequently seen in many other studies and provide a very valuable lesson learned for the team. What these statistics made visible is that while a current PM task is generally the right thing to do, it is not clearly stated or written just what specific actions need to be done. For example, the task may be, inspect the widget quarterly, but no details are provided on just what to inspect, measure, clean, tighten, etc., or record for the file. The term for these missing details in such a task is "tribal knowledge." In other words, to assure the PM is properly accomplished, an organization relies only on the knowledge and thoroughness of an individual technician to do a complete job without spelling out what that is. The problems with using tribal knowledge are: a) the tribe is retiring and all the details of the task procedure are walking out the door with them; b) the tribe takes vacations, sick leave, etc.; or c) the tribe has a new member who is not totally familiar with the widget. This tribal knowledge problem is common and without RCM, tends to go unnoticed.

Category III: This is often called the "ho-hum crasher" category! In the centrifuge subsystem, nearly half (47%) of the failure modes currently receive **no** PM and in the waste heat boiler subsystem, one third of the failure modes receive **no** PM. Basically, this situation is why these two systems are at the top of the bad actor list and generate a large amount of corrective maintenance activity. They also are the culprits behind unintended large resource expenditures, since corrective maintenance can be ten times the cost of a PM task that could have prevented them. The knowledge obtained from the Category III data, if acted upon, can easily reduce your reactive costs by 50 percent or more.

Category IV and V: No special meaning or value in this study. However, in other studies, Category V has seen data in the 10 percent to 20 percent range, which signifies that PM resources are being wasted on failure modes that are of little consequence.

Category VI: This category indicates that without any formal RCM decision process, the current PM program is **not** wasting resources on some small percentage of the failure modes. In other words, you lucked out, but did not realize it until you did this RCM study.

SUMMARY OF SIGNIFICANT FINDINGS

Both subsystems in Pilots #1 and #2 reflect the need for four very important, beneficial actions:

- Upgrade the selected PM tasks in the existing program to eliminate tribal knowledge as the basic procedure or modus operandi;
- Add PM tasks to many components that currently have no coverage to prevent possible failure modes;
- Better knowledge of the assets and how they can fail;
- Need to progressively replace the large percentage of time-directed intrusive (TDI) PM tasks with nonintrusive PM technology available with predictive maintenance (PdM) methodology.

Other significant findings include:

- Several items of interest (IOIs) were identified;
- Emphasis on the importance to integrate with a computerized maintenance management system (CMMS);
- New and updated standard operating procedures (SOPs);
- Fault, cause, action codes;
- Update asset attributes;
- Review spares and warehouse inventory;
- Metrics.

OTHER STRATEGIC CONSIDERATIONS

Figure 2 suggests a broader issue that the 20/80 systems also may be harboring a few failure modes that could be serious (i.e., “showstopper”) disruptions to the plant. Three additional methods were examined to address such a possibility. The following three methods typically take 4 to 8 hours per system to flush them out.

Risk Threshold Identification (RTI)

While not 100 percent bulletproof, the idea here is to have special brainstorming sessions with your subject matter experts (SMEs) who must list the functions of a selected system and then list their experiences on where specific components could manifest a problem that may cause one or more serious consequences to the plant. To date, there have been some previously unknown “finds” that needed immediate corrective actions.

Defect Elimination (DE)

The methodology and rationale for including DE in addition to root cause analysis (RCA) is to eliminate known defects caused by aging, wear and tear, careless or poorly executed work habits, changed operating conditions requiring more robust components, or inadequate replacement parts that don’t meet current stress levels present in an asset. DE analysis meetings typically can be completed in a day because they deal with known defects.

Root Cause Analysis (RCA)

An in-depth investigation of why a specific failure occurred is more the result of an actual failure that had very large consequences (e.g., shutdowns, safety, regulatory violations, etc.) and less about a clear understanding of the “why” question not being satisfactorily ascertained. In a way, RCA may be considered a special form of DE coupled with the large consequence situation.

These three methods are the subject of a future *Uptime* article.

REFERENCES

1. Nowlan, F. Stanley and Heap, Howard F. “Reliability-Centered Maintenance.” Alexandria: National Technical Information Services. Report No. AD/A066-579, December 29, 1978.
2. Smith, Anthony M. “Reliability-Centered Maintenance.” Dallas: McGraw Hill, 1992.
3. Smith, Anthony M. and Hinchcliffe, Glenn. “RCM – Gateway to World Class Maintenance.” Waltham: Butterworth-Heinemann, 2003.
4. Moubray, John. “Reliability-Centered Maintenance, RCM II,” Second Edition. Norwalk: Industrial Press, 1997.

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