Optimize power system reliability and maintenance costs through reliability-centered maintenance

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Executive summary
This paper provides an overview of reliability-centered maintenance (RCM), which focuses on power system functionality. RCM addresses the questions:

1) How much maintenance is enough?
2) Is the right maintenance being performed on the right equipment to meet business objectives?
3) Are maintenance dollars being spent efficiently?
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Without a proper maintenance strategy for your electrical distribution equipment, it is a matter of time before breakdowns will occur. Developing the proper strategy can be a complex undertaking, given the different types and manufacturers of equipment with a facility.

Basic considerations for strategy development include:
1) Work scope and frequency
2) Spare parts requirements
3) Resource requirements (including labor and tools)
4) Budget requirements

Maintenance costs can be broken down into two categories: proactive (planned) and reactive (unplanned). Even though reactive maintenance activities typically cost three to four times more, planned maintenance activities are often deferred due to high productivity objectives and tight maintenance budgets.

NFPA 70B: Recommended Practice for Electrical System Maintenance

The 2016 edition of NFPA 70B: Recommended Practice for Electrical Equipment Maintenance, defines electrical preventive maintenance as:

“A managed program of inspecting, testing, analyzing, and servicing electrical systems and equipment with the purpose of maintaining safe operations and production by reducing or eliminating system interruptions and equipment breakdowns.”

Note the use of the word ‘systems’ in the definition. It is important to keep in mind that any individual maintenance on separate pieces of equipment or components does not ensure a completely coordinated and reliable power system.
In general terms, reliability is a property of an electrical power system that describes the likelihood that the system will successfully operate or perform as designed, constructed, and intended. It is determined from the combination of statistical dysfunctional or inoperative rates of individual components and the configuration of the power system to which they are applied.

More exactly, the “notion of reliability” is more of a mathematical probability than an actual physical condition. Electrical reliability is measured by its trouble-free time. For example, if a piece of equipment is designed and intended to continuously operate “X” years and it does, it is 100% reliable to “X” years. After that point in time, if there is an occasional breakdown, the reliability beyond the stated time is less than 100%.

Electrical Equipment Reliability Does Not Equal Electrical System Reliability

An electrical system is as reliable as its weakest link, as illustrated below. The more complex the system, the higher the risk of unplanned downtime.

Facility managers may be unaware of the current reliability state of their electrical power system unless maintenance and test inventory data on all equipment is complete and readily available throughout the equipment’s service life. This information may also be used over time for trending purposes as well as to identify deteriorating or aging equipment.

If documentation is unavailable or outdated, management may consider having a power system assessment performed by a professional engineer. This assessment determines the present state of electrical system, its associated equipment, its functionality, and its reliability relative to the present needs of a facility’s functions and operations.
Reliability Centered Maintenance

The objective of RCM is to provide the optimal blend of maintenance strategies that meet reliability and availability requirements at the lowest cost. A properly designed and executed RCM strategy enables management to make quantifiable maintenance decisions.

- Focuses on electrical system functionality rather than individual components (assets).
- Analyzes each component, i.e., its function, level of criticality to overall operations, and known failure rate.
- Prioritizes maintenance spend on critical vs. non-critical functions.
  - Critical functions must be preserved at all costs.
  - Non-critical functions may be designated as run to failure.
- Selects applicable maintenance activities to control the failure modes.

RCM integrates preventive maintenance, predictive testing and inspection, run-to-fail and proactive maintenance techniques. An ongoing process, RCM gathers performance data to improve equipment design and enable management to make more informed future maintenance decisions.

History of Reliability-Centered Maintenance

The concept of reliability-centered maintenance began in the commercial aviation industry over fifty years ago. Senior executives and engineers at United Airlines used the term in publicly-released papers that proposed a process to define optimal maintenance requirements for aircraft.

The failure rate of first generation jet aircraft was high, even though extensive maintenance programs were in place. In the early 1960s, the Federal Aviation Administration (FAA) approved a series of intensive engineering studies, conducted by the airline, on in-service aircraft to address safety concerns. The studies disproved the fundamental assumption that every major component in a complex, modern jetliner had a specific lifetime of reliable service and upon reaching its useful life, had to be replaced (or overhauled). In fact, the United Airlines report concluded that only 9% of the failures were related to the age of the aircraft.

After ‘taking-off’ in the aviation industry, the discipline of reliability-centered maintenance was adopted by the U.S. military (1970s) and the U.S. commercial nuclear power industry (1980s). In the late 1980s, John Moubray, author of RCM2, adapted the process for wider industrial use.

SAE JA1011, Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes

Today RCM is defined in the standard SAE JA1011, which is intended for use by any organization looking to manage physical assets or systems more responsibly. SAE JA1011 has a set of minimum criteria before a maintenance strategy can be called RCM. There are seven questions that need to be addressed for each asset:

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?
Failure modes exist for every product or process. NFPA 70B (2016 edition) Article 30.1.2.1 (3) states that “the failure characteristics of components or sub-systems must be understood to determine the effectiveness of the preventive maintenance program.”

Identifying critical versus non-critical failures helps focus attention on those maintenance tasks that are essential. A failure can be any of the following:
- any loss that interrupts the continuity of production
- a loss of asset availability
- the unavailability of equipment
- a deviation from the status quo
- not meeting target expectations
- any secondary defect
Optimize power system reliability

**RCM Failure Modes**

The United Airlines report identified six unique failure patterns of equipment, as shown by the graphs below:

- **Bathtub Curve**
  - Approximately 4% of failures
  - High failure probability of new equipment
  - Low level of random failures
  - Sharp increase in failures at end of life

- **Wear Out Curve**
  - Approximately 2% of failures
  - Low level of random failures
  - Sharp increase in failures at end of life

- **Fatigue Curve**
  - Approximately 5% of failures
  - Gradually increasing failure level over equipment life

- **Initial Break-In Curve**
  - Approximately 7% of failures
  - Low failure level followed by sharp rise to constant failure levels

- **Random Pattern**
  - Approximately 14% of failures
  - Consistent level of random failures over equipment life

- **Infant Mortality Curve**
  - Approximately 68% of failures
  - High initial failure rate followed by a random level of failures

**Age related failures = 11%**

**Random failures = 89%**

Random failures increase in proportion as equipment becomes more automated or complex.
Key Elements to Successful Implementation

Implementing RCM is a multi-faceted, multi-functional process, including participation from maintenance, facilities operations, risk management, purchasing and human resources. Of course, any major initiative should have executive sponsorship. Four key elements to RCM success include:

1. Identify the purpose and develop the plan.
2. Execute the core analysis process.
   - Assess failure modes, effects and criticality analysis
   - Select significant functions
   - RCM task evaluation and selection
3. Implement analysis, including recommendations from process.
4. Employ a regimen of monitoring and continuous process improvement to help ensure sustainability.

Updated System Documentation: A Critical Pre-Requisite

As previously noted, facility management may not know the reliability of the power system unless all maintenance and testing records are readily available. An electrical risk assessment determines the power system’s “present state”, including its associated equipment, its functionality, and its reliability relative to the present needs of a facility’s functions and operations.

The assessment should be performed by a registered professional engineer with in-depth experience in the design, operation, maintenance, safety, and reliability of ac and dc power systems and equipment. It employs a systematic method to evaluate the condition of the electrical system as well as the vulnerability of a facility or process to the adverse effects of an unexpected electrical event. A facility’s risk is determined by the combination of four factors:

1. The impact of the occurrence to key process elements.
2. The safety hazard to electrical workers.
3. The probability of an occurrence.
4. The ability to respond quickly to correct the negative effects of the occurrence.

Conclusion

RCM focuses on the operation of the power system as a whole by identifying the functions and failure modes of assets that are most critical. Maintenance tasks are then determined and prioritized to minimize the possibility of failure. RCM enables facility management to make quantifiable decisions on maintenance costs, while increasing power system reliability.

NFPA 70B (Annex N) states that, “RCM is a logical, structured framework for determining the optimum mix of maintenance activities to sustain power system and equipment reliability while ensuring their safe and economical operation.”

Resources:

- NFPA 70B: Recommended Practice For Electrical Equipment Maintenance (2016).