Smithsonian Infrastructure

Responsible for O&M for an infrastructure valued at $4.5 billion consisting of:

- **660 buildings totaling 9.3M square feet with 3.2M square feet of roofing**
- **The utilities infrastructure consists of:**
  - 100 lane miles of roads
  - 9.4 miles of high and medium voltage power cable (and an unknown amount of 220/110V wiring)
  - 22.5 miles of water mains (> 6” internal diameter)
  - 12 miles of sanitary and storm sewers
  - ~ 1 mile of both gas and steam lines
  - ½ mile of chilled water piping
- **Major utility equipment consists of the following:**
  - 62 major chiller plants and their associated support equipment
  - 75 air compressors
  - 178 major air handlers
  - 21 steam stations
  - 20 emergency generators
  - 32 fire pumps
  - 15 boilers
  - > 40,000 Building Automation System (BAS) Sensors
Smithsonian Maintenance Organization

- SI recently moved from a centralized maintenance and minor repair philosophy to centrally supported zones based on Reliability Centered Maintenance (RCM)
  - Office of Facilities Maintenance
  - Office of Facilities Reliability
- Eight zones responsible for daily maintenance and repair
- Systems Engineering provides support for:
  - Life Safety
  - Utilities
  - RCM
  - Root Cause Failure Analysis
  - Condition Monitoring
  - Building Automation
  - Vertical Transportation
  - High Voltage Distribution
  - Roofing Systems
Mission – Maintaining Availability

MTTR = Transition + Admin + Logistics + Repair
“Despite the time-honored belief that reliability was directly related to the intervals between scheduled overhauls, searching studies based on actuarial analysis of failure data suggested that the traditional hard-time policies were, apart from their expense, ineffective in controlling failure rates. This was not because the intervals were not short enough, and surely not because the tear-down inspections were not sufficiently through. Rather, it was because, contrary to expectations, for many items the likelihood of failure did not in fact increase with increasing operation age. Consequently a maintenance policy based exclusively on some maximum operating age would, no matter what the age limit, have little or no effect on the failure rate.”

F. Stanley Nowlan, Director, Maintenance Analysis, and Howard F. Heap, Manager, Maintenance Program Planning, of United Airlines
What Is Reliability Centered Maintenance?

One definition is:

- Reliability Centered Maintenance is a maintenance strategy that logically incorporates the optimum mix of reactive, preventive, condition based and proactive maintenance practices.

But SAE and others may have something else to say…
What Is SAE Reliability Centered Maintenance?

“Reliability-Centered Maintenance (RCM)—Any RCM process shall ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown as follows:

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)?

To answer each of the previous questions ‘satisfactorily,” the following information shall be gathered, and the following decisions shall be made. All information and decisions shall be documented in a way which makes the information and the decisions fully available to and acceptable to the owner or user of the asset…”

JA1011 - Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes
# Reliability Goals and Logic

<table>
<thead>
<tr>
<th><strong>RCM Goals</strong></th>
<th><strong>RCM Logic</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ensure realization of inherent safety and reliability of the equipment</td>
<td>• Determine the function of the system/component</td>
</tr>
<tr>
<td>• Restore equipment to required levels when deterioration occurs</td>
<td>• Define what is a functional failure</td>
</tr>
<tr>
<td>• Obtain the information necessary for design improvements where inherent reliability is insufficient</td>
<td>• Evaluate the consequences of failure</td>
</tr>
<tr>
<td>• Accomplish these goals at a minimum total life cycle cost</td>
<td>• Assign a maintenance task to prevent the failure</td>
</tr>
</tbody>
</table>
RCM History

- 1960 - FAA and airline task force.
- 1965 - United Airline decision diagram.
- 1968 - MSG-1
- 1970’s - Military Interest
- 1980’s - Industry Interest
- 1990’s - NASA Facilities
- 2000 - Accepted as a Best Practice by Federal Facilities Council
Why Perform RCM?

• Financial benefits are derived from the following:
  - Reduced maintenance expenses due to elimination of maintenance tasks
  - Application of Age Exploration techniques to expand time between tasks
  - Reduction in the amount of reactive maintenance performed by:
    • Modifying existing procurement/installation practices and techniques
    • Identifying systems for condition monitoring by using RCM analysis
    • Development of an acceptance criteria and commissioning

• Indirect benefits
  - Reduction in downtime
  - MRO reduction
  - Fewer compliance issues
MRO Effectiveness Business Case Finding

Area: Facilities Maintenance
Manager:

Opportunity: Reduce Technical Warehouse spare parts inventory and inventory carrying cost

Benefit: Eliminating obsolete/idle inventory (spare parts and MRO that has not turned since 1992), valued at ~$0.8MM, will save financing cost (COM), lessen inventory management administrative burden and free-up warehouse space

Financial Impact:

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Average Annual Inventory Value</td>
<td>$5,464,000</td>
<td>$5,464,000</td>
<td>$5,245,440</td>
<td>$5,035,622</td>
<td>$4,834,198</td>
</tr>
<tr>
<td>% Reduction</td>
<td>15%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Reduction in Inventory Value</td>
<td>$819,600</td>
<td>$218,560</td>
<td>$209,818</td>
<td>$201,425</td>
<td>$145,026</td>
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<tr>
<td>Cost of Money</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Annual Savings</td>
<td>$98,352</td>
<td>$26,227</td>
<td>$25,178</td>
<td>$24,171</td>
<td>$17,403</td>
</tr>
</tbody>
</table>

Income from Sale  | $245,880      | $65,568       | $62,945       | $60,427       | $43,508       |
Cost of Removal/Disposal | ($5,000) | ($2,000)      | ($2,000)      | ($2,000)      | ($2,000)      |
One Time Income     | $240,880      | $63,568       | $60,945       | $58,427       | $41,508       |
Inventory Write-off | ($578,720)    | ($154,992)    | ($148,872)    | ($142,997)    | ($103,518)    |

Time to Implement: 6 months

Resources Required: 5 person team w/representatives from maintenance, manufacturing, engineering and purchasing

Owner Validation: ____________________ Finance Validation: ____________________
Maintenance Effectiveness Business Case Finding

Area: Facilities Maintenance
Manager:

Opportunity: Increase efficiency and effectiveness of available craft hours

Benefit: Customizing and prioritizing maintenance tasks to meet required system reliability will increase available craft hours (wrench time) and cut 11% overtime to Industry Benchmark range of 5% to 7%. Downtime caused by PM work will be reduced by 70% to 80% through better planning and scheduling with manufacturing

Financial Impact (Range):
1997 Overtime maintenance hours 3483 (11% of available hours)
   5% Overtime (1583 hrs) to 7% Overtime (2216) @ $12.48/hr
   $19,758 ~ $27,661

   YTD Downtime caused by PMs 248.55 (5.5% of downtime hours)
   70% reduction (174 hrs) to 80% reduction (199hrs) @ $66.42/hr
   $11,556 ~ $13,217

   Total $31314 ~ $40878

Cost (Range): $0

Time to Implement: 4 months

Resources Required: 5 person team w/representatives from maintenance, manufacturing and engineering

Owner Validation: ___________________________ Finance Validation: ___________________________
## Reliability Business Case Finding

**Area:** Facilities Maintenance  
**Manager:**

**Opportunity:** Maximize plant capacity

**Benefit:** Increase equipment reliability through use of Reliability Centered Maintenance practices will result in increased production capacity and a 30% to 50% reduction in downtime due to mechanical failures

**Financial Impact (Range):**  
YTD Downtime attributed to equipment failure 3348 hours (73.4% of downtime hours)  
30% reduction (1004 hrs) to 50% reduction (1674 hrs) @ $66.42/hr  
$66,685 ~ $111,187

**Cost (Range):**  
Investment in predictive testing equipment and training (1st yr)  
$60,000

**Time to Implement:** 4 months

**Resources Required:** 7 person team w/representatives from maintenance, manufacturing and engineering

**Owner Validation:**  
**Finance Validation:**
# Financial Impact of Steam Leaks

## Cost of steam

<table>
<thead>
<tr>
<th>Fuel Oil Cost ($)</th>
<th>Maintenance Supplies</th>
<th>Misc. Operating Expenses</th>
<th>Maintenance Labor ($)</th>
<th>Total Variable Cost ($)</th>
<th>Steam Produced (Lbs.)</th>
<th>Cost/Lb. ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,047,746</td>
<td>64,926</td>
<td>236,864</td>
<td>132,072</td>
<td>1,481,608</td>
<td>166,507,719</td>
<td>0.088985</td>
</tr>
</tbody>
</table>

## Estimated number/cost of steam leaks

<table>
<thead>
<tr>
<th>Number of Steam Traps</th>
<th>Total Leaks (Estimated)</th>
<th>Leak Size (In.)</th>
<th>Steam Loss/Month (Est.) (Lbs)</th>
<th>Steam Cost ($)</th>
<th>Total Cost/Month ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>89</td>
<td>1/16</td>
<td>1,183,700</td>
<td>0.088985</td>
<td>105,331</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/32</td>
<td>295,925</td>
<td></td>
<td>26,332</td>
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<tr>
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<td></td>
<td>1/64</td>
<td>73,981</td>
<td></td>
<td>6,583</td>
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</table>
Effect On Repair Costs

Implementation Bow-wave

Breakeven Point (2-3 years)

Direct Cost of Maintenance

Planned PM (20-70%)

Condition Based (20-50%)

Reactive Maintenance (30-80%)

20-50% Operator Maintenance

Proactive/Planned 50-80%

Strive for Zero Downtime

Time

2-5 Years

DOS Current PM Schedules are Based on Interval and not Condition

The traditional approach to maintenance is based on a misunderstanding of failure distributions. Only a small percentage of equipment follows this curve.
At Times, We are Performing the Wrong PM on the Wrong Equipment Components

Thirty Identical 6309 Deep Groove Ball Bearings Run to Fatigue Failure Under Test Load Conditions

From: Ball and Roller Bearings: Theory, Design, & Application, Eschmann, et al
John Wiley & Sons. 1985

Bearings’ lubrication is one of our more common tasks - Should it be?
**Age Related Failure Curves**

<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>1%</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>4%</td>
<td>3%</td>
</tr>
</tbody>
</table>

- UAL (1968): 4%, 2%, 5%
- BROMBERG (1973): 3%, 1%, 4%
- U.S. NAVY (1982): 3%, 17%, 3%
Random Failure Curves

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7%</td>
<td>11%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>14%</td>
<td>15%</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>68%</td>
<td>66%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Conditional Probability of Failure
Degradation Mechanisms

- Corrosion
- Overload/Overheating
- Fatigue
- Erosion/Fretting Corrosion
- Microbiological Corrosion
- Mechanical Wear
- Oxidation
- Chemical Attack
Failure Definitions:

- A failure is an unsatisfactory condition. It may be catastrophic or merely out-of-tolerance.
- A functional failure is the inability of an item or system to meet a specified performance standard.
- A potential failure is an identifiable and quantifiable physical condition which indicates a functional failure is imminent.

What about hidden failures?
Failure Terms

- **Failure Rate**: Number of failures divided by some interval (time or cycles).
- **Mean Time Between Failures**: The reciprocal of the Failure Rate.
- **Conditional Probability of Failure**: Measure of the probability of failure during a specified age interval.
Consequences Of Functional Failure

- Environmental, Health or Safety/Security
- Production or Mission Impact
  - Quantity
  - Quality
- Life Cycle Cost
- Morale
Resistence to Failure

Resistence to Failure

Stress

Operating Age

Functional Failure Point
Common Cause Failures

• Multiple failures may be considered when there is a common cause for the failure.

• Otherwise:
  - Multiple failures are rare.
  - Be careful not to expend energy trying to minimize the multiple failure.
Multiple Independent Failures

- Independent Failure: One does not influence the other.
  - If a machine has a failure rate of 1 failure every 100 days, the probability of failure on any given day is $1/100$.
  - If a second machine has the same probability of failure, the probability that both machines fail on the same day is $1/(100)^2$ or 1 in 10,000.
Failure Mode

- Failure: A cessation of proper functioning or performance.
- Failure Mode: A specific type or manner of failure.
  - The fan stopped is a failure; a broken drive belt is the failure mode.
- Dominant Failure Mode: A failure mode responsible for significant number of failures.
Complex Machine Failure

• Simple Machines: Failure ages for single failure modes tend to cluster about an average age.

• Complex Machines: Unless there is a dominant failure mode, overall failure ages are usually widely dispersed and unrelated to a specific operating age.
**Failure Avoidance**

- **Increase or Restore Resistance**
- **Decrease Rate of Degradation**

Diagram showing the relationship between stress, resistance, and operating age with points labeled as $f_0$, $f_1$, $f_2$, and $f_3$. The graph illustrates how resistance and stress change over the operating age.
Failure Modes And Effects Analysis (FMEA)

• A failure analysis conducted in the design phase of an equipment or system; also used as a tool for analysis in Reliability Centered Maintenance (RCM).

• The FMEA contains:
  - Description of Failure Modes
  - Cause and Effects of failure
  - Probability of Failure
  - Criticality of Failure
  - Corrective/Preventive Measures
Age Exploration

- The AE process examines the applicability of all maintenance tasks in terms of the following:
  - Technical Content
  - Performance Interval
  - Task Grouping
  - Reliability Growth
Age Exploration

- Used to determine applicability of tasks and effective time intervals.
- Evaluate effectiveness of tasks over time.
- Expand the interval between discard, overhaul, or open & inspect tasks.
Technical Content

• The technical content of the tasks are reviewed to ensure all identified failure modes are addressed and that the existing maintenance tasks produce the desired amount of reliability.
Performance Interval

• During the AE process, the task performance interval is continually adjusted until the rate at which resistance to failure declines is determined. For example, identical motors with significantly different amplitudes of vibration could result in different monitoring intervals.
Task Grouping

- Tasks with similar periodicity are grouped together to improve the amount of time spent on the job site and minimize outages.
Reliability-growth Modeling

• **Reliability growth** refers to positive improvements in reliability parameters related to changes in product design and/or manufacturing processes over a period of time.
Selecting the Maintenance Approach

<table>
<thead>
<tr>
<th>Maintenance Approach</th>
<th>Machine/System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition-Based</td>
<td>Simple Low Cost</td>
</tr>
<tr>
<td>Time-Cycle-Based</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>Run-to-Failure</td>
<td></td>
</tr>
</tbody>
</table>

- Simple Low Cost
- Non-Critical
- Complex High Cost
RTF Applications

Use RTF if Unexpected Failure is Acceptable in Terms of Impact on:

- Safety/Security
- Capacity
- Life Cycle Cost
- Regulatory
- Probability of Failure is Low
PM Tasks

- Strong correlation between area/cycles and probability of failure
- Frictional wear
- Corrosion
- Simple component replacement
- Regulatory
- More than that is like believing in …
Condition Based Maintenance (CBM)

CBM is the use of advanced technology to sense machinery operating characteristics such as vibration, temperature, pressure, etc. and to compare the measured values of these characteristics with historical data or other pre-established criteria to assess machinery condition. CBM permits condition based rather than time based initiation of the maintenance effort to correct any problems identified.

Is it predictive or is it condition based?
Review Intrusive Scheduled Maintenance

- Open and Inspects Should be Replaced with Condition Monitoring
- Review Shutdown Work Packages
- Scheduled Bearing Replacements Should be Eliminated
- Substitute Thermography for Tightening of Connectors
- Clean Instead of Balance
- Vibration Instead of Lubrication
- Measure System Efficiency (Thermal and Electrical)

Performance monitoring is essential if maintenance tasks are to be reduced.
Failure Detection

- Must have Capability to detect failure.
- Must have Standard to define failure.
- Capability and Standard are often obvious in simple machines/systems.

Ideally, the impending failure should be detected in a non-intrusive and nondestructive manner.
Function

- What are system characteristics?
  - Primary (core operation) or support?
- Is function continuous or intermittent?
  - If intermittent, is failure hidden?
- Is function active or passive?
  - Active - motor/pump
  - Passive - pipe/wall/support
Systems

- Input
- Resources
- Constraints
- Plant System
- Machine Component
- Output
The Three Major Classifications of Reliability Block Diagrams Are:

- **Series diagrams.** In a series diagram, all components must operate if the overall equipment system is to function. Overall system reliability is determined by individual-component reliability. This is the most common reliability block diagram and is the easiest to analyze.

- **Parallel diagrams.** In a parallel diagram, components are in parallel, so all components must fail for the equipment system to cease to function. There may be two or more identical components in the system. This redundancy is used to increase system reliability, but it also increases acquisition costs.

- **Combination diagrams.** In a combination diagram, there are both series and parallel systems. This type of reliability block diagram is more complex to analyze since it requires the evaluation of both types of diagrams in one equipment system.
Network Reliability

Series Reliability

\[ R_T = R_A \times R_B = 0.81 \]

Parallel Reliability

\[ R_T = (R_A + R_B) - (R_A \times R_B) = 0.99 \]

Series-Parallel Reliability

\[ R_T = R_A \times R_B \times R_C = 0.891 \]
RCM Approach

- What is the function of the machine?
- What is a functional failure?
- What are the consequences of the failure?
- What can be done to improve the machine’s reliability if required?
Function

• What are system characteristics?
  - Primary (core operation) or support?

• Is function continuous or intermittent?
  - If intermittent, is failure hidden?

• Is function active or passive?
  - Active - motor/pump
  - Passive - pipe/wall/support
How We Set Priorities

- Fire and Life Safety
  - Safety of visitors and staff
  - Detection/suppression/containment
  - Safety deficiencies
- Code or regulatory compliance
  - Vertical transportation
  - OSHA
  - ADA
- Impact on collections and buildings
  - Temperature and Relative Humidity (RH)
  - Indoor Air Quality
  - Vibration
  - Light
  - Façade
- Public image
- Staff morale
RCM Logic Tree

Will the failure have a direct and adverse effect on safety or environment?

No

Yes

Will the failure have a direct and adverse effect on operations (quantity or quality)?

No

Yes

Is there an effective Condition Monitoring technology/approach?

No

Yes

Is there an effective Preventive Maintenance task?

No

Yes

Develop & schedule Condition Monitoring task.

Develop & schedule PM task.

Redesign system or accept risk.

Run-to-Fail

Candidate For -
## Failure Mode & Effects Worksheet

**Area:** Identify Plant Area or Process  
**System:** System Name  
**FMEA Number:** If Used  
**Team Members:** Who prepared this FMEA  

<table>
<thead>
<tr>
<th>Control Number</th>
<th>Name &amp; Function/Performance Requirement</th>
<th>Potential Failure Mode</th>
<th>Potential Failure Effects</th>
<th>C</th>
<th>P</th>
<th>MA Code</th>
<th>Maintenance Approach</th>
<th>Remarks/Continue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**Date FMEA Started:**  
**Date FMEA Completed:**
Task Selection

• Select tasks that are Applicable & Effective.
  - Rework/Overhaul
  - Discard
  - Condition Monitor
  - Inspection

• Effective If:
  - Reduces Probability of Failure
  - Is Cost Effective

Do not monitor just to be monitoring.
Cost Effective

- Include all costs associated with failure
- Operational down time.
  - Product
  - Labor
- Collateral damage
- High failure rates.
Proactive Maintenance

Proactive Maintenance is defined as the application of PdM during the design, procurement, installation, and operation phases of facility construction and/or repair and the use of Root Cause Failure Analysis, Age Exploration, and the application of precision alignment and balancing during the Facility Life Cycle.
Building Construction: Pre-RCM

- In a new office building, 92% of the rotating equipment was found to be improperly installed - primarily balance and alignment.
  - Similar problems were encountered at two other government NOBs
- National Security Agency experienced problems with 100% of the newly installed rotating equipment.
- In all cases:
  - the specifications did not address the current best reliability practices.
  - acceptance testing had not been updated to reflect the changes in system/component testing capabilities

Sources:
Report on RCM Implementation Plan, Phase 3, Johnson Space Center, 1994
Reliability Assessment Report, Goddard Space Flight Center, 1997
Reliability Assessment P.T. Badak, 1996
Life-Cycle Cost Commitment

Source: Blanchard, B.S., Design and Manage to Life Cycle Cost, Forest Grove, OR, MA Press, 1978
RCM and Design Cost

NOB 1

R&M Design Cost 0.11% of Total Project Cost

90% Design-To-Budget
10% A/E Design Fee

R&M Design Cost 0.11% of Total Project Cost

88% Design-To-Budget
12% A/E Design Fee

Specific Reliability and Maintainability Language has been Inserted in the SOW/RFP’s for 9 NOB’s and 2 Major Renovations

Source: CO Negotiation
## AEDG and RCM Process

<table>
<thead>
<tr>
<th>A/FBO/FAC RCM Process</th>
<th>AEDG Reliability and Maintainability</th>
<th>Compliant (Y/N)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>The RCM process seeks to attain the required building and system availability at the lowest Life Cycle Cost (LCC) while meeting all standards for Security, Environmental Health and Safety and Post Mission requirements.</td>
<td>3.1.3 Design Policy “….The concept of whole-building performance shall be incorporated into the design so that a balance between function, security, safety, environmental, energy, and operational factors is achieved. Sensitivity to economic costs of a building’s initial construction and life-cycle operations shall reflect a commitment to providing high standards of comfort, productivity, and quality of life for its occupants.” 4.4.1 Design Scope “..define design, construction, operation, and maintenance requirements for the Project.” 4.4.16.1 O&amp;M Design Guidelines “…It is during the design phase that operations and maintenance (O&amp;M) considerations must be first addressed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The RCM process is to be incorporated into all designs.</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
### Design Process Reviewed for Operational Dependability and Maintainability

<table>
<thead>
<tr>
<th>NOBs</th>
<th>Doha (D/B by Owner)</th>
<th>Dar es Salaam (D/B)</th>
<th>Kampala (D/B)</th>
<th>İstanbul (D/BB)</th>
<th>Luanda (D/B)</th>
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<tr>
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**NOB Inspection Identified...**

- All HVAC pumps were misaligned at installation
- All HVAC pumps had inadequate shims
- 90% of HVAC fans had improper sheaves specified and installed
- 80% of all fans tested had excessive vibration
- All fan vibration problems were traceable to balance and/or sheave problems
- 2 out of 3 Vertical pumps had extreme vibration caused by imbalance

*These findings are consistent with NASA, NSA, and others prior to RCM implementation.*
Pump Vibration, Before & After Balancing

Before (ISO G16)

After (~ISO G2.5)

Pump Vibration

Domestic H₂O Pumps
**Fan Vibration, Before & After Balancing**

Before (ISO G40)

After (ISO G2.5)

Fan Vibration

Fan
Root Cause Failure Analysis

RCFA should be used when any of the following exist:

• Short Equipment Life is Normal
• Correction is Symptomatic, not Systematic
• Failures are not Random

Root Cause Failure Analysis is a key to a successful RCM program.
Repetitive Failures

- Repetitive failures are defined as the recurring inability of a system, subsystem, structure or component to perform the required function, i.e.,
  - Repeated failure of an individual piece of equipment;
  - Repeat failures of various equipment within a system or subsystem; or
  - Failures of the same or similar components in several different systems.
Sources Of Repetitive Failure Data

- Number of maintenance man-hours by system or component
- Number of maintenance work orders by system or component
- Maintenance backlog (by system)
- Control instruments out of service
- Achievement of maintenance performance goals
- Safety system unavailability
- Number of inadvertent safety system actuation
- Number of unplanned facility shutdowns
- Lost mission or production time
- Forced outage rate
- Number of Incident Reports
Data Required

- All Maintenance Actions for a Given Time Interval
- Equipment Number and Name
- System
- Type of Maintenance
- Problem Description
- When and How Discovered
- Work Summary
Cause And Effect Charting
Cluster Analysis

- Identify Clusters (i.e., Repetitive Maintenance Actions)
- Determine if Maintenance Actions are due to Personnel Performance
- Determine Wear-out Pattern
  - Should be Exponential after Initial Period
  - Short Time Failures Should Be Minimal
Fault Diagram
Recurrence Control

- This section provides a systematic approach using technical analysis of hardware and/or material failures for dealing with repetitive failures.
- Events warranting RCFA are an end result or product of implementing the following methodology.
Rigorous or Streamlined

• Identical in principles and approach.
• Differences exist in how process is applied to well understood systems and machines.
  - Streamlined well suited for most industrial applications.
  - Leverage across facility.
Approaches

• Classical RCM (Nowlan & Heap)

• RCM (J. Moubray)
  - Formal FMEA, Limited Actuarial Approach, Good Condition Monitoring.

• RCM (A. Smith)

• Streamlined RCM
## RCM Analysis Time Investment

<table>
<thead>
<tr>
<th>RCM Process</th>
<th>Rigorous</th>
<th>Streamlined</th>
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</thead>
<tbody>
<tr>
<td>System Identification</td>
<td>Moderate</td>
<td>Low</td>
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<tr>
<td>System Boundary</td>
<td>Moderate</td>
<td>Low</td>
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<tr>
<td>Functional Analysis</td>
<td>High</td>
<td>Very Low</td>
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<tr>
<td>Failure Definition</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Failure Modes and Effects</td>
<td>Very High</td>
<td>Very Low</td>
</tr>
<tr>
<td>RCM Logic Tree</td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td>Maintenance Approach</td>
<td>High to Very High</td>
<td>Moderate</td>
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</tbody>
</table>
Implementation Approach

Priority Team

Implementation Team

RCM Steering

RCM Champion

Stakeholder Review & Approval

Implement Work Control

Condition Monitoring Team

Feedback, questions, requests for additional information to the Implementation Team.
Implementation Steps

Step 1. Information collection
The first step in the RCM process is to collect all information that describes equipment—design, configuration, operating parameters, maintenance history or plan, failure history or projections, and operating procedures.

Step 2. Equipment identification and systemization
As preparation for analysis, this step divides plant equipment into systems, subsystems, components, and parts.

Step 3. Requirements analysis
A. Use the RCM decision tree
B. Compile a list of equipment systems, subsystems, or components
C. Conduct a FEMA on all systems, subsystems, or components

Step 4. Maintenance-task analysis

Step 5. Planning
Develop a comprehensive maintenance plan.
Maintenance Approach

• What To Do
  - Time/Cycle Maintenance
  - Inspection
  - Condition Monitoring
  - Run-to-Failure

• How To Do Work - Procedures

• Who Should Do Work
Review & Approval

• System Owners
• Usually Systems Engineers
• Pocket Veto
  - Must Act On Implementation Team Recommendations
  - RCM Champion must have stature with this group to be effective.
Organizational Fit

Maintenance Manager

Existing Organization

Condition Monitoring
## The Benefits Need to Be Measurable

<table>
<thead>
<tr>
<th>Benefit Category (How will improvement be seen?)</th>
<th>Key Performance Indicators (How can benefit be measured?)</th>
<th>Benefit Range (annualized) (What is benefit range for improvement?)</th>
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Source: Jeffrey S. Wilson
Use KPIs As a Management Tool

• Publish “compliance” indicators widely, for example:
  - % of new procedures in place
  - % of areas reporting new KPIs

• Collect KPIs frequently and follow up variances quickly

• Focus Team resources where KPIs indicate underachievement:
  - Avoids project drift

• Use zone employees where leverage is greatest, for example:
  - Train the trainers
  - Manage pilots
  - Conduct open/regular team reviews

Keeping to the implementation timeline is a KPI.
Process Metrics Correlate Performance

Process Metrics Correlate to Area Metrics Which Correlate to Performance
Global Metrics

- Required Availability = Hours Available divided by the Hours Required.
  - If Hours Required = 40
  - And Hours Available = 38
  - Then Required Availability = .95
Global Metrics

- Absolute Availability Cost = Total cost associated with providing availability.
- Includes all elements of Maintenance and Repair.
- Provides little useful information on its own.
Event Metrics (KPIs)

• Maintenance Actions Performed (total and by building, area, or equipment).

• Total Items Maintained and % That:
  - Have had RCM analysis completed.
  - Functionally Failed (i.e., not available).
  - Required Emergency Work.
  - In Condition Monitoring program.

• Deferred Maintenance (Condition Monitoring).
Condition-Based Maintenance

Factors:
- Random Failure Process
- Unknown Time to Onset of Wear
- Re-initiation of Infant Mortality

Leads To:
- Condition-Based Maintenance
Distribution Between Planned and Unplanned Maintenance

Planned Maintenance Cost as a % of Total Maintenance Cost

*Due to installation of Facility 8i, February data not available*
HVAC Control: % Time Temperature in Band of 70±4°F
HVAC Control: % Time Relative Humidity in Normal Band 45±8%

- MSC: 34
- CRC: 62
- RENWICK: 86
- NMAH: 94
- NMNH: 42
- FREER: 89
- QUAD: 92
- HMSG: 66
- NASM: 50
HVAC Sensor Points Out of Service

![Bar Chart showing data for Alarms, Failed Points, and Operator Override by month from April to March. Each month is represented by a different color, and the chart shows the number of points out of service for each category.]
**Mean Time Between Callbacks for SI Vertical Transportation**

- National Average = 60 days
- Mean Time Between Callbacks (MTBC) = # of Units X Days/Calls
- Five year, $8.5M modernization plan underway, approximately $1M obligated in FY03 & FY04
- Discussion: The lower the MTBCs, the lower the reliability. Data is from Schindler website dated 4/11/05 and is based on 149 units.
- Major upgrades of 4 Quad elevators awarded and underway, #1 completed 2/22/05, 3 and 4 postponed until 12/05 at tenants request. Contributing to worsened MTBC performance during construction.

- New contract award date – in OCON
Comparing Maintenance Budgets

Maintenance & Repair Project Funds Committed

Data based on requisitions processed through Facility Center – Does not reflect People Soft obligations
Facilities Maintenance Funding Compared to FFC and NAPPA Recommendations: FY03 – FY06

FFC recommended funding @ 4% CRV

FFC recommended funding @ 2% CRV

NAPPA minimum recommended funding

FFC – Federal Facilities Council
CRV – Current Replacement Value ($4.5B)
NAPPA – National Association of Physical Plant Administrators
Condition Monitoring

Continuous or periodic monitoring and diagnosis of equipment and components in order to forecast equipment failures. Know in industry as Predictive Maintenance (PdM).
Why Use Condition Monitoring?

• Better Planning
  - Equipment Condition is Quantifiable
• Reduced Collateral Damage
  - Catastrophic Failures Reduced
• Increased Availability
  - Equipment Downtime Minimized
• Confirm Corrective Repairs
Typical Condition Monitoring Technologies

- Vibration Analysis
- Lubricant and Wear Particle Analysis
- Thermography
- Motor Circuit/Current Analysis
- Thermodynamic Process (Operational) Parameters
- Airborne Ultrasonics
- Thickness Measurement & Imaging
Vibration Analysis

- Over 30 years of development in technology and techniques; over 78% of all manufacturing or process plants use vibration analysis.
- Uses Trend Analysis, Pattern Recognition, and Correlation
- Provides data on rotating equipment and structures
- Can be performed by craft, technician, and engineering personnel
- Specialized equipment and training required
Vibration analysis *assumes two basic facts*:

1. All failure modes have vibration frequencies that can be isolated and identified.
2. The amplitude of each vibration component remains constant unless there is a change in the operating condition of the equipment.
Types of Vibration Analysis

- Broadband trending typically monitors the total vibration of a machine at a specific data collection point. Broadband trending does not provide any information regarding the condition of individual components that make up the frequency measured.

- Narrow band trending uses a vibration frequency that represents specific machine components or failure modes.

- Signature analysis provides visual representation of each frequency component generated by a piece of equipment.
Sources of Vibration

- Imbalance
- Misalignment
- Impeller/Vanes
- Gears/Bearings
- Electrical (Rotor and Stator)
- Mechanical Looseness
- Belts and Sheaves
Typical Vibration Spectra
SI Vibration Analysis Program

Average Vibration Levels of Smithsonian Facilities, 3/04
Infrared Thermography

- Measures Temperature: Differential or Absolute
- Quick, Safe (Non-contact), and Accurate
- Used on Mechanical, Electrical, and Structures
- Uses Comparison, Pattern Recognition, and Alarm Levels
Just How Versatile?
Types of Infrared Devices

• *Infrared thermometers* provide the actual surface temperature of a component at a single, relatively small point on the component.

• *Line scanners* provide single dimensional scans of comparative radiation.

• *Infrared imaging*, commonly called thermographic imaging, provides the means to scan the temperature of complete machines, systems, or equipment items in a very short time.
Electrical

- Estimated 95% of electrical problems are loose or corroded connections.
- Unbalanced load.
- Inductive heating (eddy current).
- Spiral heating in multi-strand wire.
- Slip rings, commutators, brush riggings.
Thermography and UPS Testing

Spot 1
92.5

Spot 2
87.6

* > 93.0°F

83.0
84.0
85.0
86.0
87.0
88.0
89.0
90.0
91.0
92.0
93.0

* < 83.0°F

GSFC UPS test results 7/20/99
Mechanical

- Ventilation
- Machine casings, couplings, and bearing housings.
- Steam Traps (limited use).
- Underground Fluid Lines
- Tank Levels
- Insulation
- Passive thermography - inspects using energy already present.
- Active thermography - you add heat to create temperature change.
  - Boiler tubes (prior to startup)
  - Structure Defects
  - Debonding in laminates, cracks in plastics.
Many companies have effectively used thermography to measure misalignment.
Roofs

- Most leaks occur at flashing.
- Thermal pattern dependent on insulation type.
  - Closed Cell Insulation: Window Pane
  - Absorbent Panels: Straight Lines/Angles
  - Absorbent Tight Fit: Free Form
Environmental

- **Ambient Temperature**
  - Little effect on T inspections.

- **Solar Energy**
  - Little effect on T inspections.

- **Wind**
  - Effect on T inspections increases with wind speed.
  - 15 ml/hr max. on windward side.
SI Thermography Program

<table>
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<tr>
<th>SYSTEMS</th>
<th>PROBLEMS FOUND</th>
<th>SYSTEMS INSPECTED</th>
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<td>MSC</td>
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</table>
ADDITIONAL INFORMATION

• American Society for Nondestructive Testing (800) 222 - 2768
• Infraspection Institute (802) 985 - 2500
• John Snell & Associates (800) 636 - 9820
Airborne Ultrasonics

• Detects Noise in the 20-100,000 Hertz Range
• Hearing Limited to 20-16,000 HZ
• Ultrasonic Noise Caused BY:
  - Gas/Vacuum Leaks
  - Impacts (Bearings/Gears)
  - Electrical Arcing
Basic Applications

1. Mechanical inspection
2. Leak detection
3. Electrical inspection
Applicability of Fluid Analysis

- Gearboxes
- Chillers
- Transformers
- Hydraulic Systems
- Diesel Engines
- Bearings
Some Common Tests

1. **Viscosity tests** determine whether a lubricant is thinning or thickening in service.
2. **Contamination tests** check for lubricant contamination by water or other substances.
3. **Oxidation tests**, as their name indicates, test for oxidation of the oil itself.
4. **Particle count** examines the machine lubricant for abnormal wear particles.
Lubricant & Wear Particle Analysis

- Lubrication Analysis is performed for:
  - Lubricant/Fluid Condition
  - Contamination
  - Mechanical Wear
- Uses Trending, Pattern Recognition, and Alarm Values
- Requires Highly Specialized Equipment
Lack of Hydraulic Oil Testing is Destroying Machine Life

Equipment examples:
- Automated Guided Vehicles
- Forklifts
- Hydraulic elevators
- Hydraulic motors (i.e., for centrifuge)

Our current oil tests do not check for particles

Effect of Water on Bearing Life

One PPM is one milligram per kilogram.
Wear Particles

- **Rubbing wear** is the result of *normal* sliding wear in a machine. During the normal start-up of a wearing surface, a boundary layer is formed at the contact point of the surface.

- **Cutting wear** is generated when one contact surface penetrates another. Particles from cutting wear indicate something is misaligned, that there is a mismatch of the surfaces, or that the lubricant for the components is carrying an abrasive contaminant.

- **Rolling wear** is associated primarily with roller bearings and produces wear particles different from those produced by rubbing or cutting wear. When rolling fatigue occurs, it is a sign that the life of the component is nearing its end.

- **Rolling and sliding wear** results from the moving contact of gear surfaces. This type of wear is generally caused by loads or speeds that are too high.

- **Severe sliding wear** is caused by excessive loads or heat in a gear system. High loads or temperatures accelerate the breakdown of a lubricant. Severe sliding wear is an accelerated form of rolling and sliding wear.
**Electrical Tests**

- Insulation Resistance/Polarization Index IEEE Std 43
- High Potential Tests IEEE Std 95
- Motor Surge Testing (EPRI Identified as a Go/No Go Test)
- Motor Circuit Analysis
- Motor Current Signature Analysis
## Electrical Tests

<table>
<thead>
<tr>
<th>Electrical Equipment</th>
<th>Power Factor Tests</th>
<th>Excitation Tests</th>
<th>Insulation Resistance</th>
<th>Infrared</th>
<th>Ultrasonic</th>
<th>Battery Impedance</th>
<th>Breaker timing</th>
<th>Insulating Oil Condition</th>
<th>Partial Discharge</th>
<th>Contact Resistance</th>
<th>High Voltage Testing</th>
<th>Motor Circuit Analysis</th>
<th>Turn Ratio Tests</th>
<th>Dissolved Gas Analysis</th>
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Evaluations: ● - Evaluated; ○ - Not Evaluated
Rationale for Electrical Testing

• Causes of Motor Failures
  - Bearing Related - 41%
  - Stator Related - 37%
  - Rotor Related - 10%
  - Other (Balance/alignment, etc..) - 12%

Source: 1985 GE Study for EPRI: 6,000 motors.
Typical Variation of Insulation Resistance with Time for Class B Insulated Alternating-Current Armature Windings
Source: IEEE Std 43-1974
Trending Data

Polarization Index by Month

Alert 2.2
Alarm 2.0
Impact of Voltage Imbalance


• “A 3.5% voltage imbalance can produce as much as a 25% increase in temperature rise of at least part of the winding.” Handbook to Assess the Insulation Condition of Large Rotating Machines, EPRI, 1991

• “Excess heat generation in a motor running on a 2% unbalance can reduce insulation by a factor of 8.” Energy Efficient Electric Motors: Selection and Application, 1982
Motor Circuit Analysis

• Measures insulation resistance and capacitance
• Calculates complex phase impedance
• Test uses low voltage
• Uses trend analysis, alarm limits, and correlation
Motor Current Signature Analysis

- Potential to be the next major PT&I technology
- Utilizes an FFT of the current to determine condition of motor rotor
- Developed to test Motor Operated Valves
- In the laboratory:
  - Uses motor as transducer to determine imbalance, misalignment, bearing, and impeller problems.
Airborne Ultrasonics

- Detects Noise in the 20-100,000 Hertz Range
- Hearing Limited to 20-16,000 HZ
- Ultrasonic Noise Caused BY:
  - Gas/Vacuum Leaks
  - Impacts (Bearings/Gears)
  - Electrical Arcing
NDT Techniques

• Radiography
• Ultrasonic
• Magnetic Particle Testing
• Dye-Penetrant
• Hydrostatic Testing
• Eddy Current testing
Selection Of NDT Technique

Define System Boundaries

Establish Equipment Criticality

Conduct Failure Modes & Effects Analysis

Evaluate Regulatory Requirements

Establish Failure Modes To Be Addressed By NDT

Define Information Required From NDT Technique

Evaluate Safety & Access Constraints

Evaluate Cost Per Point

Determine Skills Required

Select NDT Based on Information, Access, Cost & Skills Required

Establish Sampling Locations

Refer To Establish Sampling Intervals

Document & Formalize Program
Process Parameters

- Utilizes EMCS/UCS Data Combined with Portable Measurements of:
  - Temperature
  - Pressure
  - Flow
  - Power Consumption
  - Run Times
  - Cycle Time
Data Correlation
**Statistical Process Analysis**

A normal distribution can be used to determine which machines are in an abnormal condition.

![Diagram showing a normal distribution with parameters: Mean, Mean - 2 Sigma, Mean + 2 Sigma, and 2.25% of Machine Population.]
How SI Defines Work — Adapted from FFC 1996

- **Preventive maintenance**: The planned, scheduled, periodic inspection, adjustment, cleaning, lubrication, parts replacement, and minor repair of equipment and systems for which a specific operator is not assigned.

- **Predictive testing and inspection**: Testing and inspection activities that involve the use of sophisticated means to identify maintenance requirements.

- **Repair**: The restoration of a facility or component thereof to such condition that it may be effectively utilized for its designated purposes by overhaul, reprocessing, or replacement of constituent parts or materials that have deteriorated by action of the elements or usage and have not been corrected through maintenance.

- **Operational Activities**: Include custodial work (i.e., services and cleaning); snow removal, pest control, refuse collection and disposal; grounds care, landscaping; environmental operations and recordkeeping; security services; fire protection services. Operational activities may involve some routine maintenance and minor repair work that is incidental to operations but they do not include any significant amount of maintenance or repair work that would be included as a separate budget item.

- **Service requests**: Service requests are not maintenance items, but are so often performed by facilities maintenance organizations they become a part of the baseline. Service requests are requests for facilities-related work that is new in nature and as such should be funded by the requesting organization. (NASA Facilities Maintenance Management NPG 8831.2D, 6/25/2001)
SI Processes for Work Identification

- Facility Condition Assessment – triennial
- METR Inspections – Annual
- **Predictive Testing & Inspection**
  - Vibration
  - Thermography
  - Tribology
  - Motor/electrical testing
  - Nondestructive testing (NDT)
  - Airborne ultrasonics
- Preventive Maintenance Tasks
- Energy Audits
- Replacement of Obsolete Items
- Customer Requested
- Emergency Repairs

ASCO NMAH (Before & After)
How We Set Priorities

• Fire and Life Safety
  - Safety of visitors and staff
  - Detection/suppression/containment
  - Safety deficiencies

• Code or regulatory compliance
  - Vertical transportation
  - OSHA
  - ADA

• Impact on collections and buildings
  - Temperature and Relative Humidity (RH)
  - Indoor Air Quality
  - Vibration
  - Light
  - Façade

• Public image

• Staff morale

Painting damaged by improper temperature and RH control
**Determining Funding Priorities**

### Sources of Maintenance & Minor Repair (M&MR)
- Annual Safety, Health & Environmental Inspections
- Code and regulatory requirements
- Physical/chemical impact on collections storage & display
- Public perspective (Public relations)
- Employee perspective (Morale & working conditions)

---

**Rank** | **Effect**
--- | ---
1 | Potential Safety, Health, or Environment issue. Failure imminent.
2 | Potential Safety, Health, or Environment issue. Failure will occur with warning.
3 | High disruption to facility function. All Operations is lost. Significant delay in restoring function.
4 | High disruption to facility function. Significant delay in restoring function.
5 | Moderate disruption to facility function. Moderate delay in restoring function.
6 | Moderate disruption to facility function. 100% of Operations delayed and/or interrupted.
7 | Moderate disruption to facility function. Some portion of Operations delayed or interrupted.
8 | Minor disruption to facility function. Repair to failure may be longer than trouble call.
9 | Minor disruption to facility function. Repair to failure can be accomplished during trouble call.
10 | No reason to expect failure to have any effect on Safety, Health, Environment or Operations.
Process Map – Work Management

Work Management Process

1. Receive Work Request
   - Emergency?
     - Life Safety?
       - Notify OPS/OSEM
       - Notify Zone Manager & Liaison
     - Use Call in List/Contact Supervisor
   - Call in Required?
2. Service Request?
3. Operational Support?
4. Repair?
5. Planned?
   - Identify Funding Source
   - Write Work Order
6. OFM?
   - Forward to Zone
   - Forward to Zone Liaison
7. Within OFR Contracting Scope?
   - Forward to PM & Notify Requestor
8. Identify Funding
9. Develop SOW
10. Award Contract
11. Perform Work
12. Update Work Order
13. Return to Work Control Management

Go to Page 2
Process Map – Work Management (cont.)
Planning & Tracking Execution

- Zone Liaisons interface with Zone Managers
- Project Management support from Office of Project Management
- Accurate project scope and cost estimates
- Weekly planning/status meetings
- Work and Expenses tracked in:
  - Facility Center (CMMS)
  - PeopleSoft (ERP)
  - PFITS – Project Facilities Information and Tracking System
  - Excel
- All contracted work must be approved by Associate Director or higher
- Once approved, committed dollars tracked against plan
### Planning & Tracking Execution – Repair Projects

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Unit</th>
<th>Plant</th>
<th>Project</th>
<th>IPR Start</th>
<th>IPR End</th>
<th>Lead</th>
<th>Pack</th>
<th>MIR</th>
<th>MIR Start</th>
<th>MIR End</th>
<th>Lead</th>
<th>Pack</th>
<th>MIR</th>
<th>Completed</th>
<th>Estimated</th>
<th>Overseen</th>
<th>Deficiency</th>
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<th>Notes</th>
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</tbody>
</table>

**Table Notes:**
- **Task Name:** Describes the specific task or project.
- **Unit:** Identifies the unit responsible for the task.
- **Plant:** Specifies the plant or location where the task is performed.
- **Project:** Provides additional context or details about the project.
- **IPR Start/End:** Indicates the start and end dates for the initial planning record.
- **Lead/Pack/MIR:** Represents different phases or levels of planning.
- **Completed:** Marks when the task/phase is completed.
- **Estimated:** Shows expected completion dates.
- **Overseen:** Highlights tasks overseen or managed by specific individuals.
- **Deficiency:** Indicates any deficiencies or issues identified.

---

**Planning & Tracking Execution:**
- **OFR:** Overview and Planning Phase.
- **FY04 Total:** Total costs or resources allocated for FY04.
- **OFEO:** Operational and Execution Phase.
- **Campus Project Review:** Summarizes project reviews.
- **Tool:** Tools or systems used for planning.
- **OPM:** Operational and Maintenance Phase.
- **Start to Ocon Antic.:** Start dates for operations.
- **Museum Support Center:** Details for support center activities.
- **Baseline Testing and Contract:** Baseline testing and contract completion.
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.
- **Baseline Testing and Contract Maintenance:** Baseline testing and contract maintenance.
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.

---

**Example Task Details:**
- **New York, NY:** Locations.
- **Contracted:** Contractors involved.
- **General Maintenance & Repairs:** Types of maintenance and repairs.
- **Slivko Slivko Hansen:** Responsibilities.
- **NOA:** Notes or observations.
- **OFR y 1/26/04:** Specific start and end dates.
- **by 7/04 var var var:** Completion status.
- **Baseline Testing and Contract Maintenance:** Baseline testing and contract maintenance.
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.

---

**Additional Notes:**
- **Baseline Testing and Contract Maintenance & Obligation:** Baseline testing and contract maintenance.
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.

---

**Challenges:**
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.
- **Baseline Testing and Contract Maintenance:** Baseline testing and contract maintenance.
- **Obli gated:** Obligated funds or resources.
- **Facilities Maintenance:** Includes maintenance and repair activities.
- **Price verified from USACE:** Ensures costs are verified.
- **Subtotal:** Cumulative costs or resources.

---

**Summary:**
- The table provides a comprehensive overview of various planning and tracking execution tasks, including details on units, plants, projects, and estimated completion dates. It highlights the importance of detailed planning and tracking to ensure efficient execution of repair projects.

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**For Further Information:**
- Review the table for specific sections or tasks of interest.
- Contact relevant parties for more details on specific projects or tasks.

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**Contact Information:**
- Smithsonian Institution
- MFPT 2005

---

**Notes:**
- Ensure all necessary information is included in the table.
- Regular updates are crucial for maintaining effective planning and tracking.
- Collaboration among teams is vital for successful project execution.

---

**References:**
- Internal project documentation.
- External resources or guidelines.
- Relevant industry standards.

---

**Acknowledgments:**
- Recognize contributions from key stakeholders.
- Thank all involved parties for their efforts in planning and tracking execution.

---

**Conclusion:**
- Summary of key findings or recommendations.
- Future action items.
- Contingency plans.

---

**Appendix:**
- Additional data or supporting materials.
- Detailed project timelines.
- Contact information for further assistance.
Facilities Maintenance Planning – Facilities Assessment
### Backlog of Repairs – Facilities Assessment

![Pie Chart: Backlog of System Repairs](chart.png)

**Total Facilities Condition Assessment Backlog $329.4 M**

**Building Systems**
- Accessibility
- Architectural
- Asbestos
- Conveyances
- Electrical
- Exterior Façade
- HVAC
- Interior Finish
- Life Safety Electrical
- Life Safety Mechanical
- Plumbing
- Renovation
- Roofing
- Site General Construction
- Structural
- Utility

---

**Backlog of Repairs**

- Facilities Assessment

**Backlog**

- Accessibility: $6
- Architectural: $15
- Asbestos: $7
- Conveyances: $9
- Electrical: $15
- Exterior Façade: $2
- HVAC: $17
- Interior Finish: $71
- Life Safety Electrical: $20
- Life Safety Mechanical: $6
- Plumbing: $34
- Renovation: $59
- Roofing: $26
- Site General Construction: $6
- Structural: $14
- Utility: $23

**Total Backlog: $329.4 M**
Managing the Backlog – Allocating Shortage

- Balance demand and planned to fully resource critical breakdown tasks
- Continuous assessment of project priorities
- Continuous communications among OFM/OFR and supported units
- Reliance on Facilities Assessment
- Control of funding commitments
- Minimize duplication
- Maximize buying power

<table>
<thead>
<tr>
<th>Available</th>
<th>Required</th>
</tr>
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Maintenance Budget Scale
Summary – More Focus on Stewardship

The key is more museums

Planning

We’ll be there tomorrow morning

Museum

We can’t do PM until the museum is closed

Maintenance

We can’t do PM until the museum is closed
Additional Information

RCM


Condition Monitoring

• P/PM Technology, (800-848-8324). Free for year if you attend the Predictive Maintenance Technology National Conference

• Reliability, Industrial Communications, Inc. info@reliability-mag.com (423-531-2193)

• Maintenance Technology, Applied Technology Publications, (800-554-7470)