Fundamentals of Asset Management

Step 7. Optimize Operations & Maintenance (O&M) Investment

A Hands-On Approach
Tom’s bad day…
Fourth of 5 core questions

4. What are my best O&M and CIP investment strategies?
   - What alternative management options exist?
   - Which are the most feasible for my organization?
AM plan 10-step process

1. Develop Asset Registry
2. Assess Performance, Failure Modes
3. Determine Residual Life
4. Determine Life Cycle & Replacement Costs
5. Set Target Levels of Service (LOS)
6. Optimize O&M Investment
7. Optimize Capital Investment
8. Determine Funding Strategy
9. Build AM Plan

4. What are my best O&M and CIP investment strategies?

Root Cause; RCM; PdM; ORDM
Recall view 4: Management framework

- Asset Management Business Processes
- Asset Management Plans
- Strategic Initiatives
- Annual Budgets

- Operating Budget
- Capital Budget
Definition

**Maintenance** - normal support, periodic and minor in nature, required to sustain performance, reliability, and functionality of an asset consistent with design, manufacturer, and operational requirements
What triggers a work order?

Computerized Maintenance Management System (CMMS)

- **Input**
  - Citizen complaints
  - Supervisor “drive-bys”
  - Field crew observations
  - PdM/condition-based maintenance

- **Output**
  - Work order generation
  - Crew scheduling
  - Crew outfitting
  - Crew performance
  - Job costing
  - Materials management

- **Throughput**
  - System architecture & integration
  - Database architecture
  - Field interface
  - Spatial interface
Importance Of The Work Order: Asset Level

**WORK ORDER**

Type: PM or UM

- Estimated bill of quantities
- Actual
  - Labor
  - Plant
  - Materials
- Procedure followed
- Failure mode noted
- Primary cause of failure

**Memos**

- Impact on customers
- Unproductive time
- Other issues

- Tells us planned (PM) or unplanned (UM) maintenance costs
- Builds life cycle cost history; ties to warehouse management
- Tells us actual direct costs of activity
- Tells us the procedures to be applied
- Useful in *failure mode analysis*
- Necessary for *causal analysis*
- Indirect costs on business; impact on customers (*consequence analysis*)
- Used in *efficiency analysis*

Data feedback enables substantive analysis

Fundamentals of Asset Management
X–29 Chemical Feeder

Application:

This guide card applies to tank type water chemical feeders with pumps and agitators.

Frequency

Semi–annual

Special Instructions:

1. Review the Standard Operating Procedure for "Selection, Care, and Use of Respiratory Protection".

Check Points:

1. Drain chemical from feeder into storage containers.
2. Flush and clean feeder tank.
3. Flush piping with water.
4. Remove agitator and clean shaft and propeller; lubricate as required.
5. Check oil in pump reservoir.
7. Check operation of pressure relief valve.
8. Lubricate motors.
9. Replace chemicals into feeder storage tank.

Tools and Materials:

1. Standard tools – basic
2. Rubber gloves and apron
3. Filter air mask
4. Goggles
5. Grease gun and oiler
6. Cleaning materials. Consult the Material Safety Data Sheets (MSDS) for hazardous ingredients and proper personal protective equipment (PPE).
# Bottom-line maintenance “KPIs” from an AM perspective

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<th>Metric</th>
<th>Definition</th>
<th>Target</th>
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<td>Availability</td>
<td>The portion of time that a plant or major system is available for producing output of the required quality and quantity</td>
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<td>% Failure analysis</td>
<td>The portion of equipment downtime events that undergo a thorough analysis of failure modes, effects, and root causes</td>
<td>85 – 100%</td>
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<td>% Planned work</td>
<td>The portion of corrective maintenance work hours that are planned and scheduled in advance (not unplanned breakdowns)</td>
<td>85 – 95%</td>
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<td>% Overtime</td>
<td>The portion of maintenance work hours that are performed at an overtime rate</td>
<td>5 – 8%</td>
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<td>Relative maintenance cost</td>
<td>Annual maintenance spending as a percentage of asset replacement value of the plant being maintained</td>
<td>1.5 – 2.5%</td>
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<td>Technician productivity</td>
<td>The percent of work hours spent on productive activities versus nonproductive (rework, waiting for parts, etc)</td>
<td>70 – 85%</td>
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<td>% Rework</td>
<td>The portion of maintenance work that has to be redone due to poor installation, shoddy workmanship or incorrect diagnosis</td>
<td>2 - 5%</td>
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Importance of the work order: *the asset perspective*

**WORK ORDER**

Asset details
- Type
- Category
- Size
- Condition
- Performance history
- Failure modes

Asset-linked costs enable significant analysis...

1. What type of sewer suffers the greatest number of blockages caused by tree roots?
2. How many failures are experienced by water mains of different ages in different ground conditions?
What Distinguishes EAMS from CMMS?

CMMS

- Work Order 1
- Work Order 2
- Work Order N

Focus is on the maintenance work order and maintenance performance for a defined period

Asset Registry

- Asset 1
- Asset 2
- Asset N

Focus is on an asset’s performance over its life cycle and on aggregate performance of asset groups

EAMS is Enterprise Asset Management System; CMMS is Computer-based Maintenance Management System
The Cost of Maintenance

*Rule of thumb*

Roughly speaking, planned maintenance costs *one-third less* than unplanned maintenance for the same task.
Transition to Planned Maintenance

Mapping total cost—the practical side

Unplanned costs

Planned costs

Total cost

Time/Usage

$
Evolution of maintenance techniques

Unplanned (reactive) maintenance

Proactive strategies

Preventive maintenance

Predictive maintenance

Condition-based

Usage-based

Run to failure

(Redesign)
Fitting maintenance strategies to failure curve

1 Preventive maintenance time- and usage-based strategies

2 Predictive maintenance condition-based strategies

3 Corrective maintenance reactive-based strategies

Performance

Time

X Vibration
X Oil
X Noise
X Heat
The new “maintenance-theory” toolbox

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<th>Core strategies</th>
<th>Operational tactics</th>
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<td>Total productive maintenance</td>
<td>Design reliability analysis</td>
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<td>Asset condition assessment</td>
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<td>Zero breakdown maintenance</td>
<td>Early equipment management</td>
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<td>Predictive (condition-based) maintenance</td>
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<td>Design reliability analysis</td>
<td>Accelerated deterioration elimination</td>
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<td>Asset condition assessment</td>
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<td>Location failure analysis</td>
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<td>Standardized failure codes</td>
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Reliability-centered maintenance—the seven fundamental questions

1. What are the functions and associated performance standards of the asset in its present operating context?
2. In what ways does it fail to fulfill its functions?
3. What causes each functional failure?
4. What happens *mechanically* when each failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure?
7. What should be done if a suitable proactive task cannot be found?

Techniques

- Function and performance standards
- Functional failures
- Failure modes
- Failure effects
- Failure consequences
- Proactive tasks
**Example: RCM analysis on headworks screen**

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>FUNCTIONAL FAILURE</th>
<th>FAILURE MODE (Cause of failure)</th>
<th>FAILURE EFFECT (What happens when it fails)</th>
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</table>
| 1        | To remove all sedimentary and floating foreign matter greater than 1 inch from the effluent | Cannot remove foreign matter from the effluent | Bull screen shovel control cable worn  
Over time the control cable wears and thins, strands start to break and eventually the cable loses enough tensile strength that it can no longer support the shovel’s weight when open. The cable breaks and the shovel closes and cannot be opened. During its descent the shovel catches on the scraper and breaks it off. The shovel continues its cycle but does not open and cannot gather foreign matter. The excess material in front of the screen accumulates and the water level differential across the screen rises. The shovel tries to clean the screen more often and eventually the water level in front of the screen rises enough that the “high level” alarm sounds in the control room. With time the channel overflows. Repair time: 4 hours, Downtime: 5 hours. Special tools: mobile scaffolding and security bar. Spare parts: Wire rope in stock. |

**RCM II INFORMATION WORKSHEET**

© 1984 Alcadon Ltd
Example: RCM analysis on headworks screen

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<tr>
<th>Information reference</th>
<th>Consequence evaluation</th>
<th>Sub-system</th>
<th>RCM II Decision Worksheet</th>
<th>Bull Screens</th>
<th>System</th>
<th>Bull Screens</th>
<th>Task Details</th>
<th>Initial Interval</th>
<th>Can be done by</th>
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<td>Visual inspection of the shovel control cable for broken strands and reduced cable diameter. Standards to be established. Replace cable as needed.</td>
<td>5000 cycles</td>
<td>Mechanic</td>
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<td>Replace the bull screen shovel control cable extension</td>
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<td>Shorten the bull screen shovel lift cable to eliminate the worn section, from the connector to the curvature. Ensure that both lift cables are the same length. The cable can be shortened twice before a new cable must be installed.</td>
<td>3500 cycles</td>
<td>Mechanic</td>
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<td>Visual inspection of the bull screen shovel lift cables for broken strands and reduced cable diameter. Standards to be established. Replace cable as needed. When replacing the cable, ensure that both lift cables are the same length.</td>
<td>5000 cycles</td>
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<td>No scheduled maintenance</td>
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<td>Visual inspection of the bull screen shovel's lift wrench's drums for accumulation of foreign matter. Have the drum's surface cleaned when the accumulation affects cable seating.</td>
<td>Mensuel</td>
<td>Operator</td>
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<td>Visual inspection of the bull screen shovel's control wrench's drum for accumulation of foreign matter. Have the drum's surface cleaned when the accumulation affects cable seating.</td>
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<td>Lubricate the bull screen shovel wrench's bearings. Norms to be established.</td>
<td>Annuel</td>
<td>Mechanic</td>
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Alignment of O&M and capital activities with organizational Level of Service strategies

Organizational strategies

- LOS performance targets: strategic (customer) and tactical (asset unit) levels
- Agency-wide asset performance targets

Drives work planning through work order priority code

Routine O&M and capital activity cycle

Plan → Schedule → Control → Eval. → Execute

2. Set minimum levels of performance at asset level

Drives work planning through work order priority code
Work Management Process Overview

**Contents**

- Work Required (Engineering Projects, Equipment Maintenance, Improvements)
- Work Identification
- Emergency?
- Work Planning
- Work Scheduling
- Work Assignment
- Work Execution
- Work Completion
- Work Analysis
- Feedback for Continuous Improvement

**Legend**

- Decision
- Process Step
- Predefined Process
- Digital Data
- Committee
- Work

**Maintenance Best Practice Work Processes**

**Unplanned Work**

- Corrective Maintenance (Emergency and Non-emergency breakdown)

**Planned Work**

- Preventative Maintenance
- PDM Detected Corrections
- Corrective Maintenance

- Work Order Planning
- Work Scheduling
- Work Assignment
- Work Execution
- Work Completion
- Work Analysis
- Feedback for Continuous Improvement

**Work Processes Fundamentals of Asset Management**

Page 22
Using failure modes to determine maintenance strategies

Decision Issues

Start

- Is capacity an issue?
  - Yes → Likely before other modes?
  - No → Has LOS changed from design?
    - Yes → Likely before other modes?
    - No → Is physical reliability an issue?
      - Yes → Likely before other modes?
      - No → Is cost to operate an issue?
        - Yes → Likely before other modes?
        - No → Redo—it has to fail somehow

Remaining Life
- Capacity: 18 months
- LOS: 3 years
- Mortality: 10 years
- Efficiency: 5 years
Mortality Maintenance Tactics Selection Logic

CBM - Condition Based Maintenance

Is the deviation in condition detectable?

UBM - Usage Based Maintenance

Is there reliable age determination?

RTF - Run-to-Failure

Feasible by default

DIM - Design Improvement

Is there an alternative design solution

Are the S&E aspects addressed?

Are the S&E aspects addressed?

Are the S&E aspects addressed?

Are the S&E aspects addressed?

Calculate the Tactical investment for each applicable Tactic and compare the Cost-effectiveness of these Tactics or combination of Tactics and Select

Yes/No
Predictive maintenance and the monitoring interval

Can the progression of the failure be detected? Is there typically enough time to respond? Does consequence exceed cost of cure?
Cause and effect diagram—what to monitor

Effect
- Main breaker thrown
- Breaker failure

Effect-Cause
- Breaker overload
- Motor overload
- Bearing dry
- Pump overload
- Not fully seated
- Defective

Root Cause
- Grease cap failed
- Bearing stressed
- Misaligned
- Impeller jammed
- Defective breaker case
- Defective
Condition-based maintenance: Vibration analysis
Power evaluation

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<th>Equipment Number</th>
<th>Phase</th>
<th>Voltage to Line</th>
<th>Current Amperage</th>
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Most condition indicators are not visible to the unaided eye

Visual inspection

Infrared view
Alignment of inspection and correction data

Coupling & bearing failure

Inspection
Baseline machine performance tests

Baseline at handover sets life cycle benchmark. Conforms to factory test curves?
Status sheet (summary)

Overall condition

Picture of machine

Description

All nameplate data

Electrical data

Vibration data

Alignment data
### Multiple factors - equipment status list

#### Severity color code

![Severity color code]

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<th>Site Number</th>
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<th>Thermography</th>
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Failure codes

- Use cause-effect diagrams to create codes
- Define codes by class of asset
- Use “drop-down” list

Failure Code
- Coupling failure
- Lube fault
- Misaligned
- Operator error
- Overloaded
- Water damage
- Worn
Condition-based maintenance

“Nameplate” Data

- Vibration Signature
- Sonic Signature
- Thermal Signature
- Electrical Signature
- Performance Signature
- Oil Residue Signature
- Electromagnetic Signature

1. Preventive Maintenance
   - Time and Usage Based Strategies
   - Performance
   - Vibration
   - Oil
   - Audible Noise
   - Tactical Heat

2. Predictive Maintenance
   - Condition Based Strategies
   - Performance
   - Oil

3. Corrective Maintenance
   - Reactive Based Strategies
   - Repair Initiated
   - Service Restored
   - Repair Scheduled
   - Parts, Manuals & Tools Located
   - Failure Reported
   - Failure Occurs

Graph: Modal Consolidation Decay Curve

Curve Description: ModCons
Graph: Details

Update Reason: Update
Update
Cancel

Fundamentals of Asset Management 35
Store the maintenance strategy!

Used to *create an asset ID*...

- Physical attributes
- Geo-reference
- O&M manuals
- Drawings and photos
- Life cycle costs
- Knowledge and strategy
Linking maintenance and design

- **Development design**
  - Evaluate development options

- **Design & construction**
  - Prepare operational specifications and procedures, develop maintenance and inspection strategies, prepare input to asset reference plan, develop facility data

- **Plan**
  - Review and update maintenance strategies, performance, estimates, reference plan, FEMCA
  - Prepare and consolidate plans and budgets

- **Schedule**
  - Schedule asset related work
  - Identify and define unforeseen work

- **Execute**
  - ORDM Analysis of asset performance and maintenance system effectiveness
  - Improve

- **Analyze**
  - Abandonment
  - Decide on remedy or improvement (or abandonment)

- **Maintainability checks RCM**
Key points from this session

Given my system, what are my best O&M strategies?

Key Points:
- Reactive emergency maintenance can be the most expensive type of maintenance and should typically make up no more than 20% to 25% of total maintenance effort.
- Preventive and predictive-based pro-active strategies should comprise the bulk of the effort.
- Assets, especially dynamic assets, leave discernable clues as to their capacity to perform.
- The most cost effective maintenance strategy for a given asset is determined by the likelihood of failure and the consequence of failure.
- “Run to failure” may well be the most cost-effective maintenance strategy for a given asset, but only when coupled with a carefully developed failure response plan.

Associated Techniques:
- Condition-based monitoring plans and deployment
- Reliability Centered Management
- Root cause analysis
- Asset maintenance strategies (zero breakdown, total productivity, reliability centered maintenance)
- Failure response plans
Tom’s spreadsheet

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**Investment Center**

**Disposal System**

**Collection Systems**

**People**

**Incoming Power**

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| Cook              | 1983 | 10 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Access Road        | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Lighting           | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Security           | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Substructure       | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Cast Iron          | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Sign Board        | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Signage           | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Fences            | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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| Gates (other)     | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
|-------------------|------|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| Gates (other)     | 1983 | 1 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
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