Risk-modeling in Asset Management
Maintenance Strategies

Rui Jorge Almeida
BISS Institute
Towards Future Proof Asset Management Systems
Asset Management

- Asset management is a systematic approach of developing, **operating, maintaining, upgrading**, and disposing of assets
  - Objective of providing the best value level of service for the costs involved;
  - Optimization of **costs, risks, service/performance** and sustainability.
Asset Management

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  • Objective of providing the best value level of service for the costs involved;
  • Optimization of costs, risks, service/performance and sustainability.

• In Finance, models are backbone of asset management:
  • models are used in investment, portfolio management, risk management, and finance functions.
Maintenance

• Maintenance is defined as a set of activities or tasks used to restore an item to a state in which it can perform its designated functions.
Maintenance

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- Downtime reduces production, increases operating costs and interferes with customer services.
  - Nowadays, effects of downtime are being aggravated by the move towards just-in-time systems.
**Maintenance**

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- Downtime reduces production, increases operating costs and interferes with customer services.
  - Nowadays, effects of downtime are being aggravated by the move towards just-in-time systems.

- Small, unmanaged breakdowns, can potentially stop a whole plant.
Maintenance Strategies

First Generation
- Fix it when it broke
- Basic and Routine maintenance
- Corrective maintenance

Second Generation
- Planned preventive maintenance
- Time based maintenance
- Systems for planning and controlling work

Third Generation
- Condition based maintenance
- Reliability centered maintenance
- Workforce multi-skilling and teamworking
- Proactive and strategic

Recent Generation
- Risk based inspection
- Risk based maintenance
- Reliability centered maintenance
- Condition based monitoring
- Computer aided maintenance management and information system

Source: [Cooke, 2003, Arunraj and Maiti, 2007]
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# Maintenance Strategies

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<td>Corrective maintenance</td>
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<td>Workforce multi-skilling and teamworking</td>
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<td></td>
<td></td>
<td>Proactive and strategic</td>
<td>Condition based monitoring</td>
</tr>
<tr>
<td>1940</td>
<td>1950</td>
<td>1960</td>
<td>1970</td>
</tr>
<tr>
<td>1980</td>
<td>1990</td>
<td>2000</td>
<td>Present</td>
</tr>
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Source: [Cooke, 2003, Arunraj and Maiti, 2007]
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Source: [Cooke, 2003, Arunraj and Maiti, 2007]
Risk - Definition

- The risk for an asset $i$ at time $t$, combines the failure probability $\mathbb{P}_i$ in any instant $t_f \leq t$ and consequence losses $L_i$

$$R_i(t) = \mathbb{P}_i(t_f \leq t)L_i$$
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$$R_i(t) = \mathbb{P}_i(t_f \leq t)L_i$$

- The probability of failure is related to the age of the asset:
Risk - Definition

- The risk for an asset $i$ at time $t$, combines the failure probability $\mathbb{P}_i$ in any instant $t_f \leq t$ and consequence losses $L_i$

$$R_i(t) = \mathbb{P}_i(t_f \leq t)L_i$$

- The consequence losses should take into account different factors:
  - Repair costs;
  - Downtime costs and slowdown costs (production loss);
  - Safety hazards and possible accidents.
Risk-Based Maintenance

- Risk-based maintenance (RBM) is used for determining the priority of maintenance using risk which integrates both safety and failure,
  - find the critical/problem assets and dedicate your maintenance resources to them while diverting resources from noncritical assets.

[Lei et al., 2015]
Risk-Based Maintenance

• Risk-based maintenance (RBM) is used for determining the priority of maintenance using risk which integrates both safety and failure,
  • find the critical/problem assets and dedicate your maintenance resources to them while diverting resources from noncritical assets.

• In offshore steel structures, the application of RBM translated in savings over 80% on total repair costs! [Lei et al., 2015]
Risk-Based Approach

Source: [Arunraj and Maiti, 2010]
Risk-Assessment

Start

Divide the system into manageable units

Consider a unit

Hazard analysis

Likelihood estimation

Consequence estimation

Risk evaluation

YES

Maintenance planning
Risk Maintenance Planning

1. Identify high, medium, and low risk units
2. Is risk acceptable?
   - YES
   - NO
     - Is there any other unit?
       - YES
       - NO
         - Stop
       - NO
         - Stop
Choosing the Correct Maintenance

GOAL
Maintenance policy selection

OCCURRENCE
Corrective maintenance

SEVERITY
Preventive maintenance

DETECTABILITY
Predictive maintenance

Source: [Bertolini and Bevilacqua, 2006]
Application: Power-generating unit

- Focus in a power-generating unit in an operating steam power plant [Krishnasamy et al., 2005].

- A steam power plant is a means for converting the potential chemical energy of fuel into electrical energy.
  - In its simplest form, it consists of a boiler and a turbine driving an electrical generator.
Application: Methodology

Identification of the Scope
- Identifying subsystem and components
- Defining relationship among components, subsystem and the main system
- Collection of failure data and defining failure model

Risk Assessment
- Hazard identification
- Probabilistic failure analysis
- Consequence assessment
- Risk quantification

Risk Evaluation
- Selecting risk acceptance criteria
- Comparison of assessed risk against acceptable criteria

Maintenance Planning
- Development of maintenance plan to reduce the unacceptable risk to acceptable level
Application: Unit 3 scope

- **System**: Power plant (Unit 3)
  - **SubSystems**:
    - Steam generator
      - Furnace
      - Economizer
      - Steam drum
      - Super heater
      - Re-heater
      - Blow down system
      - Chemical supply system
      - Forced draft fan east & west
      - Steam air heater east & west
      - Air preheater east & west
      - Air flow control system east & west
      - Flue gas system
    - Air and flue gas system
      - Heavy oil system
      - Light oil system
      - Fuel additive system
      - Turbine
        - Turbine- steam supply system
        - Turbine- rotating system
      - Generator
        - Rotating system
        - Hydrogen supply system
        - Seal oil supply system
        - Vacuum system
        - Cooling water supply system
        - Screen washing system
        - Condenser back wash
      - Condenser
        - Water extraction pumps
        - Gland seal condenser
        - LP feed water heaters
        - Reserve feed water system
        - Water de-mineralization system
        - Chemical supply system
      - Low Pressure (LP) feed water system
      - High Pressure (HP) feed water system
        - De-aerator
        - HP feed water heaters
        - Feed water auxiliaries
        - HP feed water pumps
        - Compressors
        - Air supply system
Application: Risk assessment

- Fault tree analysis

```
Failed to generate and supply power

Failed to generate steam
  - Steam generator failed 1
  - Instrument and service air system failed 3

Failed to supply water
  - Condenser failed 5
  - LP water system failed 7

Failed to generate power
  - Turbine steam supply failed

Failed to start boiler
  - Generator failed 10
  - No fuel supply 11
  - No water supply 13
```

- Air and flue gas system failed 2
  - Fuel oil system failed 4
  - HP water system failed 6
  - Turbine failed 9
  - No air supply 12
Application: Risk and rank analysis

- The risk index is the actual risk divided by the acceptable risk (historically $2,000,000).

<table>
<thead>
<tr>
<th>Rank</th>
<th>Major system</th>
<th>Consequence in millions</th>
<th>Probability of failure over 20 years</th>
<th>Risk ($) over 20 years</th>
<th>Risk index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steam generator</td>
<td>3,678,481</td>
<td>0.9989</td>
<td>3,674,435</td>
<td>1.837</td>
</tr>
<tr>
<td>2</td>
<td>High pressure feed water system</td>
<td>2,478,842</td>
<td>0.9999</td>
<td>2,478,594</td>
<td>1.239</td>
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<td>3</td>
<td>Air and flue gas system</td>
<td>2,102,023</td>
<td>0.9914</td>
<td>2,083,946</td>
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<td>4</td>
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<td>1,598,111</td>
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<td>10</td>
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<td>0.012</td>
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### Application: Risk analysis subsystems

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<tr>
<th>Rank</th>
<th>Subsystems</th>
<th>Risk value $</th>
<th>Risk index</th>
<th>Level of concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air preheater east</td>
<td>2,045,058</td>
<td>1.0225</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Forced draft fan east</td>
<td>1,444,656</td>
<td>0.7278</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Forced draft fan west</td>
<td>1,333,840</td>
<td>0.6669</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Heavy oil system</td>
<td>1,109,352</td>
<td>0.5547</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Re-heater</td>
<td>1,107,242</td>
<td>0.5536</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Super heater</td>
<td>1,102,245</td>
<td>0.5511</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Furnace</td>
<td>918,590</td>
<td>0.4593</td>
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</tr>
<tr>
<td>8</td>
<td>Air preheater west</td>
<td>270,734</td>
<td>0.1354</td>
<td>Low</td>
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<tr>
<td>9</td>
<td>Flue gas system</td>
<td>123,272</td>
<td>0.0616</td>
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</tr>
<tr>
<td>10</td>
<td>Air flow control system west and east</td>
<td>108,783</td>
<td>0.0544</td>
<td></td>
</tr>
<tr>
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<td>Air flow control system east</td>
<td>108,783</td>
<td>0.0544</td>
<td></td>
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<tr>
<td>12</td>
<td>Steam air heater west and east</td>
<td>108,658</td>
<td>0.0543</td>
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<td>Steam air heater west and east</td>
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<td>Reserve feed water system</td>
<td>7192</td>
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<td>26</td>
<td>Gland seal condenser</td>
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<td>0.0036</td>
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<td>Water demineralization system</td>
<td>6894</td>
<td>0.0034</td>
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<td>28</td>
<td>Condenser back wash</td>
<td>2982</td>
<td>0.0015</td>
<td></td>
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<tr>
<td>29</td>
<td>Chemical supply system</td>
<td>2338</td>
<td>0.0016</td>
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</table>
Application: Risk reduction results

- Preventive maintenance: Model based approach to reduce risk.

<table>
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<tr>
<th>No</th>
<th>Subsystem</th>
<th>Initial risk factor ($)</th>
<th>Target probability</th>
<th>Risk reduction in dollars</th>
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<td>0.54</td>
<td>1,984,194</td>
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<td>2</td>
<td>Air and flue gas system</td>
<td>2,083,945</td>
<td>0.85</td>
<td>1,771,353</td>
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<td>3</td>
<td>HP feed water system</td>
<td>2,478,594</td>
<td>0.80</td>
<td>1,982,875</td>
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Risk-modeling in asset management

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Risk-modeling in asset management

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Looking forward to discuss this topic on

11 June
References I


