The Fundamentals of Asset Management

Step 6. Determine Business Risk ("Criticality")

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

3. Which assets are critical to sustained performance?
   - How *does* it fail? How *can* it fail?
   - What is the *likelihood* of failure?
   - What does it *cost* to repair?
   - What are the *consequences* of failure?
AM plan 10-step process

3. Which assets are critical to sustain performance?

FMECA; Business Risk Exp.; Delphi Techniques
Risk is the heart of AM
Definition of *risk*

- *Risk* in AM-speak is the *consequence of failure multiplied by the probability of failure*
- Often used as a measure of "*criticality*"
- Preferred term is "*business risk exposure (BRE)*"
Variables in *business risk exposure*

- *Probability* or likelihood of failure (PoF)
- *Consequence* or impact of failure (CoF)
- “*Risk mitigation*” or risk reduction and avoidance
Let’s clarify terms

Ambiguous:
- “Risk”
- “Criticality”

Preferred:
- Probability of failure
- Consequence of failure
- “Business risk exposure”
All assets have a probability of failure

Two key questions…
1. Is the failure reasonably *predictable*?
2. Is it cost-effectively *preventable*?
Most common patterns of failures

Two key failure patterns

1. *Bathtub curve*—typically applicable for mechanical and electrical assets
Most common patterns of failures

Two key failure patterns

1. *Bathtub curve*—typically applicable for mechanical and electrical assets
2. *Age-based curve*—typically applicable for civil passive assets

*Reliability*—the probability that a component or system will perform its specified function for the specified period under specified operation conditions
Recall the four major *failure modes*

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Definition</th>
<th>Tactical Aspects</th>
<th>Management Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>Volume of demand exceeds design capacity</td>
<td>Growth, system expansion</td>
<td>Redesign</td>
</tr>
<tr>
<td><strong>LOS</strong></td>
<td>Functional requirements exceed design capacity</td>
<td>Codes &amp; permits: NPDES, CSOs, OSHA, noise, odor, life safety; service, etc.</td>
<td>O&amp;M optimization, renewal</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>Consumption of asset reduces performance below acceptable level</td>
<td>Physical deterioration due to age, usage (including operator error), acts of nature</td>
<td>O&amp;M optimization, renewal</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Operations costs exceed that of feasible alternatives</td>
<td>Pay-back period</td>
<td>Replace</td>
</tr>
</tbody>
</table>

NPDES is National Pollutant Discharge Elimination System, CSOs are combined sewer overflows, and OSHA is Occupational Safety and Health Administration.
The role of primary failure modes in determining the probability of failure

1. The probability of failure is different for each primary failure mode!
2. Look for imminent primary failure mode!

1. The probability of failure is different for each primary failure mode!
2. Look for imminent primary failure mode!
Failure analysis

- Performance parameters
  - What to monitor

- Failure cause
- Failure behavior
- Failure mode

- Failure end state
- Failure consequences

Function
(It works)

Function
Defined by performance standards

Functional Failure
End state or potential end state; Evidence—what you see

Failure Cause
 Contributing & root causes; reasons why failure occurred

Failure Mode
Mechanism of failure

Failure Behavior
Evident, hidden, random, P-F interval

Failure Consequences
Cost, safety, environmental

Function
(It doesn’t work)
Cause and effect diagram

Effect

- Electric motor burned out
  - Internal contact
  - Worn bearing
  - Physical damage
  - Forklift bashed motor
  - No lubrication
  - No schedule
  - No protective crash barrier
  - No assembly procedure

Effect-Cause

- Cause
- Effect
- Incorrectly assembled

Root Cause

- Cause
- Effect
- Burned out contactor
Probability of failure (PoF)

- PoF is directly related to the *failure mode*
- We *cannot* absolutely determine PoF
- Sometimes we have good data, sometimes we do not
- We can estimate a *range of failure*—how early (pessimistic) and how late (optimistic)
What are sources of Probability of Failure?

- CMMS—*mean time between failures* (MTBF)
- Vendor and industry information
- Other *failure records* (hard copies)
- Our brilliant *memories* (staff)
- Our *SCADA system* (if we have one and if it keeps records on this asset)

PoF is probability of failure, CMMS is computerized maintenance management system, SCADA is supervisory control and data acquisition
Finding a proxy for measuring failure

Can *age*, *usage*, or *condition* be substituted?...

![Diagram showing data distribution of asset performance, showing a decay curve, mean asset condition, minimal asset standard, and assets performing below standard.](image-url)
Linking probability of failure to age of asset ("% effective life consumed")

<table>
<thead>
<tr>
<th>% of Effective Life Consumed</th>
<th>PoF Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>70</td>
<td>7</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>Failed</td>
<td>10</td>
</tr>
</tbody>
</table>

PoF is probability of failure
### Linking probability of failure to direct observation tables

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Probability Weighting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost certain</td>
<td>100</td>
<td>Expected to occur within a year</td>
</tr>
<tr>
<td>Very high</td>
<td>75</td>
<td>Likely to occur within a year</td>
</tr>
<tr>
<td>High</td>
<td>50</td>
<td>Estimated 50% chance of occurring in any year</td>
</tr>
<tr>
<td>Quite likely</td>
<td>20</td>
<td>Expected to occur within 5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimated 20% chance of occurring in any year</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>Expected to occur within 10 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimated 10% chance of occurring in any year</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
<td>Expected to occur within 50 years</td>
</tr>
<tr>
<td>Very low</td>
<td>1</td>
<td>Expected to occur within 100 years</td>
</tr>
</tbody>
</table>

* Likelihood of occurrence within a year
Recall alternative: tying condition score to asset failure – how?

![Data distribution of asset condition]

- Decay or failure curve
- Percent of Effective Life Consumed
- Condition
- Performance
- Minimum
- Physical Failure
Relating condition to Probability of Failure through % Physical Life Consumed

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCORE</td>
<td>1</td>
</tr>
<tr>
<td>Technical Performance</td>
<td>Substantially exceeds current requirements</td>
</tr>
<tr>
<td>Operational Performance</td>
<td>Negligible attention required</td>
</tr>
<tr>
<td>Reliability</td>
<td>As specified by manufacturer</td>
</tr>
<tr>
<td>Availability</td>
<td>Virtually always operational</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Easily maintained; OEM maintenance is straightforward</td>
</tr>
<tr>
<td>% Physical life consumed</td>
<td>Almost new: up to 10% physical life consumed</td>
</tr>
<tr>
<td>CONDITION SCORE</td>
<td>1</td>
</tr>
<tr>
<td>Prob of Failure</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Fundamentals of Asset Management
Relating condition to Probability of Failure through \% Physical Life Consumed

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Condition Score</th>
<th>Prob of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Performance</td>
<td>Substantially exceeds current requirements</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Exceeds current requirements</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Meets current requirements but with room for improvement</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>Operational Performance</td>
<td>Negligible attention required</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Exceeds current requirements</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Meets current requirements but with room for improvement</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>Reliability</td>
<td>As specified by manufacturer</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Infrequent breakdown</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Occasional breakdown</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>Availability</td>
<td>Virtually always operational</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Out of service for short periods</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Out of service for moderate period; increasingly difficult to return to service</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Easily maintained; OEM maintenance is straightforward</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Largely prevent maintenance w corrective main beginning to shift baseline monitoring</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Increasing minor maintenance required; periodic corrective maintenance including some repair shortening of monitoring intervals</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>% Physical life consumed</td>
<td>Almost new: up to 10% physical life consumed</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Up to 30% physical life consumed</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Up to 50% physical life consumed</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>CONDITION SCORE</td>
<td>1</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>Prob of Failure</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- **5**: Meets current requirements but with room for improvement
- **7**: Obvious concerns: cost/benefit questions
- **10**: Failing, not capable of sustaining required performance

- **0.1**: Almost new; up to 10\% physical life consumed
- **0.3**: Up to 30\% physical life consumed
- **0.5**: Virtually consumed; imminent failure

- **0.99**: Maintenance is frequent with recurrent patterns of failure; asset must be virtually constantly monitored to sustain performance
## Scoring the Consequence of Failure

<table>
<thead>
<tr>
<th>Social/community/organizational</th>
<th>Loss of Service</th>
<th>Safety</th>
<th>Agency's Image</th>
<th>Financial impact</th>
<th>Economic impact</th>
<th>Environmental</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Can be out of service indefinitely</td>
<td>Cannot be down a month</td>
<td>Cannot be down a week</td>
<td>Cannot be down a day</td>
<td>Cannot be down 8 hours</td>
<td>Cannot be down one hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No impact</td>
<td>Minor inconvenience</td>
<td>Minor injury</td>
<td>Moderate injury and some sickness</td>
<td>Major injury, sickness, some death</td>
<td>Substantial death, widespread injury and sickness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No media or no consequence</td>
<td>Neutral coverage</td>
<td>Adverse media</td>
<td>Widely adverse media</td>
<td>Continual; political opposition</td>
<td>Nationally adverse media</td>
<td></td>
</tr>
<tr>
<td>Loss of Service</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td></td>
</tr>
<tr>
<td>Agency's Image</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td></td>
</tr>
<tr>
<td>Financial impact</td>
<td>Low cost</td>
<td>Moderate cost</td>
<td>High cost</td>
<td>High cost; diverts $</td>
<td>Painful change of priorities</td>
<td>Likely to trigger rate Increase, staff changes</td>
<td></td>
</tr>
<tr>
<td>Economic impact</td>
<td>Insignificant</td>
<td>&lt;$100k</td>
<td>&lt;$500k</td>
<td>&lt;$2 million</td>
<td>&lt;$10 million</td>
<td>&gt;$10 million</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>Short duration, small quantity onsite</td>
<td>Some basement backups</td>
<td>Moderate basement backups, some offsite spillage</td>
<td>Many inconvenienced; moderate health and habitat issues</td>
<td>Severe health and habitat issues; some mandatory vacation of premises</td>
<td>Large areas vacated and closed to public access; extensive specialized containment cleanup required</td>
<td></td>
</tr>
<tr>
<td>Odor</td>
<td>No complaints</td>
<td>A few complaints adjacent to station</td>
<td>Moderate complaints adjacent to station</td>
<td>Extensive complaints adjacent to station; lingering area odor</td>
<td>Extensive area-wide complaints</td>
<td>Odor at dangerous levels at spill site; evacuation of premises required</td>
<td></td>
</tr>
<tr>
<td>Permit compliance</td>
<td>No consequence</td>
<td>Minor violation - reporting only</td>
<td>Regulatory sanction possible</td>
<td>Regulatory sanction likely; Damage reversible less than one year</td>
<td>Extensive regulatory sanction virtually assured; damage reversible in one to five years</td>
<td>Severe sanctions; damage reversible in five years or more</td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td>1 3 5 7 9</td>
<td></td>
</tr>
</tbody>
</table>
Quantifying \textit{consequence of failure}

Sophisticated

- **Direct Costs to the Local Government**
  - Repair and return to service costs
  - Service outage mitigation costs
  - Utility emergency response costs
  - Public safety costs
  - Admin & legal costs of damage settlements
  - (Lost product costs)

- **Direct Customer Costs**
  - Property damage costs (including restoration of business)
  - Service outage costs
  - Service outage mitigation and substitution costs
  - Access impairment and travel delay costs
  - Health damages

- **Community Costs**
  - Emotional strain/welfare
  - Environmental Pollution, erosion, sedimentation
  - Destruction of/damage to habitat
  - “Attractability” (tourist, economic)
## Alternative view of “criticality”—impact on core processes

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mandated by law or corporate policy</td>
</tr>
<tr>
<td>2</td>
<td>Impacts multiple processes, runs continuous without an on-line spare</td>
</tr>
<tr>
<td>3</td>
<td>Impacts multiple processes, runs intermittently without an on-line spare, and/or causes lost production in fewer than 4 hours</td>
</tr>
<tr>
<td>4</td>
<td>Impacts a single process, runs intermittently without an on-line spare, and/or causes lost production between 4-24 hours</td>
</tr>
<tr>
<td>5</td>
<td>Impacts a single process, runs intermittently without an on-line spare, and/or causes lost production in fewer than 24 hours</td>
</tr>
<tr>
<td>6</td>
<td>Impacts multiple processes, runs continuous with an on-line spare, and causes no lost production</td>
</tr>
<tr>
<td>7</td>
<td>Impacts multiple processes, runs intermittently with an on-line spare, and causes no lost production</td>
</tr>
<tr>
<td>8</td>
<td>Impacts a single process, runs intermittently or continuous with an on-line spare, and causes no lost production</td>
</tr>
<tr>
<td>9</td>
<td>Minor or no impact on safety, product, or cost</td>
</tr>
</tbody>
</table>
Alternative view of “criticality”—impact on revenue

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Assets required for conducting <em>value stream</em> functions that produce the core <em>unit of value</em></td>
</tr>
<tr>
<td>2</td>
<td>Assets required to ensure that <em>revenue producing</em> assets are powered or controlled</td>
</tr>
<tr>
<td>3</td>
<td>Assets required for order fulfillment functions such as sales orders, production planning, shipping, and accounting</td>
</tr>
<tr>
<td>4</td>
<td>Assets required for other core production or service functions such as material handling or warehousing</td>
</tr>
<tr>
<td>5</td>
<td>Non-revenue producing assets required for protecting revenue-producing assets from inoperable conditions</td>
</tr>
<tr>
<td>6</td>
<td>Non-revenue producing assets required for conducting supporting business functions</td>
</tr>
<tr>
<td>7</td>
<td>Non-revenue producing assets that impact quality of life</td>
</tr>
</tbody>
</table>
Determining significant failures

The business risk exposure trade-off...

- **B**: High probability - low consequence
- **D**: High probability - high consequence
- **C**: Low probability - high consequence
- **A**: Low probability - low consequence
Business risk exposure drives work program

Worst first? **No**

![Probability vs. Consequence matrix]

- **A**: Good (Low Probability - Low Consequence)
- **B**: Poor (High Probability - High Consequence)
- **C**: Good (Low Probability - High Consequence)
- **D**: Fair (High Probability - Low Consequence)
Business risk exposure drives work program

Work program response

<table>
<thead>
<tr>
<th>Consequence</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>Aggressive monitoring</td>
<td>Sample monitoring</td>
</tr>
</tbody>
</table>

- **High High**: Immediate work
- **High Low**: Aggressive monitoring
- **Low High**: Sample monitoring
- **Low Low**: Aggressive monitoring
Relating Business Risk Exposure to management action

1. Set strategic levels of service & tolerable risk limits

- **High Risk Zone**: Strategy: Plan for asset renewal and/or risk mitigation
  - Probability of Asset Failure (e.g., 0 to 1)
  - Consequences of Asset Failure (e.g., Dollars)
  - Strategy: Mix of reactive and proactive strategies - dependent on owner preferences and site specific issues

- **Medium Risk Zone**: Strategy: Proactive condition and/or performance monitoring

- **Low Risk Zone**: Strategy: Reactive strategies (operate to failure)
Simple risk (criticality) metric

\[ \text{PoF} \times \text{CoF} = \text{BRE} \]
BRE 1—simple approach

Business risk exposure (BRE) increases (higher numbers) as probability of failure (PoF) and consequence of failure (CoF) increase.

![BRE Matrix Diagram](image-url)
Introducing “risk mitigation” into the risk metric

- **Risk mitigation** significantly reduces the risk metric
- BRE = PoF x CoF x R
- Where
  - PoF is probability of failure
  - CoF is consequence of failure
  - R is a risk mitigation factor (≤1.0)
Determining risk mitigation factor

Start

Does any other system/asset/approach **fully** fulfill the function if the asset fails?

- No
  - Does any other system/asset/approach **partially** fulfill the function if the asset fails?
    - Yes
      - Full Mitigation
    - No
      - Partial Mitigation
  - No
    - No Mitigation
Example of assigning weight to risk mitigation – in this case, redundancy

<table>
<thead>
<tr>
<th>Type Redundancy</th>
<th>Percent Redundancy</th>
<th>Percent PoF Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Full</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Double</td>
<td>200</td>
<td>98</td>
</tr>
</tbody>
</table>

Set weights considering operating circumstances, where possible

- True redundancy (peak vs. average)
- Age and condition of equipment
- Nature of operating environment
- Nature of failure modes (evident, hidden, random)
Step-by-step BRE methodology

Levels of filtering and sophistication

BRE 1
- Basic
- 1-10 matrix of CoF & PoF, 1-100 Score

BRE 2
- Intermediate
- 1-1,000 CoF, 0-100% PoF, 0-1000 Score

BRE 3
- Advanced
- Full Economic Cost Model, Probability = MTBF, 0-$millions

BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures.
# Level 1—simple

BRE rating = probability x consequence

<table>
<thead>
<tr>
<th>Asset No.</th>
<th>% Probability</th>
<th>Consequence</th>
<th>Risk Mitigation Factor</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.60</td>
<td>4</td>
<td>0.50</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>0.70</td>
<td>2</td>
<td>1.00</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>0.40</td>
<td>5</td>
<td>1.00</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>0.66</td>
<td>10</td>
<td>1.00</td>
<td>6.6*</td>
</tr>
<tr>
<td>5</td>
<td>0.95</td>
<td>7</td>
<td>1.00</td>
<td>6.7*</td>
</tr>
<tr>
<td>6</td>
<td>0.10</td>
<td>10</td>
<td>0.90</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* Requires further investigation
Level 2—intermediate

Multiple elements, enhanced FMECA analysis techniques

<table>
<thead>
<tr>
<th>Element</th>
<th>Rating</th>
<th>Weighting</th>
<th>Max. Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1-5</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Environment</td>
<td>1-5</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Functionality</td>
<td>1-5</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Cost</td>
<td>1-5</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>145</strong></td>
</tr>
</tbody>
</table>

FMECA is failure mode effect critical analysis
Example of risk table

Matrix of probability and consequence of failure

<table>
<thead>
<tr>
<th>Probability of Failure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>Moderate</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Quite likely</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>H</td>
</tr>
<tr>
<td>High</td>
<td>M</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Very high</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Almost certain</td>
<td>S</td>
<td>S</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

L is low risk, M is moderate risk, S is substantial risk, H is high risk
What is “tolerable risk”?

- As you think of Business Risk Exposure, consider following questions for each asset or asset group:
  - What is a tolerable Consequence of Failure that can happen repeatedly and why?
  - What is a Consequence of Failure that cannot happen even once and why?
  - What do you want to avoid the most and why?
  - What risk score could be acceptable at times and why?

- Categories
  - Tolerable with reactive/PM focused management strategy (“run to failure”)
  - Tolerable with proactive/PdM/monitoring management strategy
  - Not tolerable – “cannot fail”
Tolerable risk mapping

Tolerable Risk Graph (BRE = 50)

Zone 1: Intolerable Risk
Zone 2: Tolerable and Manageable Risk - Assets with a consequence of failure score that are similar to Zone 1 in terms of the environmental and operational impacts that would be experienced on failure; however failure of these assets is not highly likely at this time; aggressive monitoring is called for.

Zone 3: Tolerable and Manageable Risk - Assets in this zone have a consequence of failure and probability of failure that warrant aggressive monitoring and management.

Zone 4: Tolerable and Manageable Risk - Assets in Zone 4 experience failure consequences that are tolerable because they are managed through designed redundancy and operational mitigations such as spares and condition monitoring.

Zone 5: Repeatable Risk - Minor consequences are experienced due to failure of assets in Zone 5. Repeated failures are acceptable in terms of consequence.
Risk Mapping

Operational Failure

Structural Failure

Least likely → Most likely
Modifying the 10-step process

1. Establish Risk Ratings (Criticality)
2. Develop Asset Registry
3. Assess Performance, Failure Modes
4. Determine Residual Life
5. Determine Life Cycle & Replacement Costs
6. Set Target LOS
7. Develop O&M Plans
8. Develop CIP Program
9. Determine Funding Strategy
10. Build AMP
Modifying the 10-step process

1. Develop Asset Registry
2. Assess Performance, Failure Modes
3. Determine Residual Life
4. Set Target LOS
5. Establish Risk Ratings (Criticality)
6. Develop O&M Plans
7. Develop CIP Program
8. Determine Life Cycle & Replacement Costs
9. Determine Funding Strategy
10. Build AMP
Putting it all together—calculating business risk

Core Risk

- Probability of Failure
- Consequence of Failure
- Risk Mitigation Factor

Business Risk Score = \[ \text{Probability of Failure} \times \text{Consequence of Failure} \times \text{Risk Mitigation Factor} \]

Use design or standard life table

Adjust for...
- Design standard
- Construction quality
- Material quality
- Operational history
- Maintenance history
- Operating environ.
- External stresses

Consider...
- Safety, health, and welfare
- Environmental impact
- Process criticality
- Repair costs
- Revenue and aggravation impact on customers and agency

Consider...
- Redundancy
- Diversion/Pipe around
- Spares on site
- SCADA
- Etc.

Here's the point of the analysis – to identify and deploy risk mitigation strategies!
Managing risk—reduction options

Management Treatment Options

- Reduce Probability
  - Add Redundancy
  - Refocus O&M
  - Refurbish/Replace

- Reduce Consequence
  - Manage Post-Failure Impacts
  - Insure
  - Influence Customer Expectations
What caused the Jones Street power station to fail?

- Truck hits pole and causes power failure
- June’s incident report
Let’s apply failure analysis techniques with Tom

- Performance parameters
- What to monitor
- Failure cause
- Failure behavior
- Failure mode
- Failure end state
- Failure consequences

**Function (It works)**

**Functional Failure (It doesn’t work)**

- Function Defined by performance standards
- Functional Failure End state or potential end state; Evidence—what you see
- Failure Cause Contributing & root causes; reasons why failure occurred
- Failure Mode Mechanism of failure
- Failure Behavior Evident, hidden, random, P-F interval
- Failure Consequences Cost, safety, environmental
Recall the cause and effect diagram
### June’s incident report notes

<table>
<thead>
<tr>
<th>Hour</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>19:35</td>
<td>Entered superstructure to shut off power breakers before power-up. The main breaker had been thrown. No immediate clue as to what caused it to trigger. No sign of arcing or flash explosion around the box. That means neither Motor-pump 1 or Motor-pump 2 could run. No wonder the overflow. Why both down?</td>
</tr>
<tr>
<td>20:25</td>
<td>Power temporarily restored by Costly Electric &amp; Illumination. Will return in am to install permanent pole. (Shouldn’t we ask them to move it back from the road?)</td>
</tr>
<tr>
<td>20:30</td>
<td>Mac and I turned on main breaker to Motor 1. Immediately heard loud screeching. Seems to be from Motor 1. Immediately shut main down. Turned off breaker to Motor 1. Turned on main. Good news—Motor 2 ran fine. No unusual noise. Nice to have lights. Wonder if coffee pot works!</td>
</tr>
<tr>
<td>20:40</td>
<td>Noted that motor mounts on Motor 1 appear loose—black skid marks up to half inch from front feet. Back shows movement, but not as bad.</td>
</tr>
</tbody>
</table>
June’s incident report notes, continued

<table>
<thead>
<tr>
<th>Hour</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>20:45</td>
<td>I entered wet well and dry well with Motor 2 running. Mac stayed top. Noted that the two shaft guides on the wall for Motor-pump 1 was completely loose, one side pulled off wall. Bolts pulled clear from wall too. Noticed substantial play in pump shaft at the coupler to the shaft. Way too much play here. See photos.</td>
</tr>
<tr>
<td>05:15</td>
<td>My guess at this point—looks like vibration worked the shaft guides loose, increasing strain on the motor, working the motor loose, which strained bearings to point of break down.</td>
</tr>
</tbody>
</table>
Tom’s cause and effect diagram

- **Effect**: Main breaker thrown
  - Cause: Breaker overload
    - Cause: Motor overload
      - Effect: Bearing dry
        - Cause: Bearing stressed
          - Root Cause: Grease cap failed
        - Cause: Misaligned
          - Root Cause: Impeller jammed
        - Cause: Pump overload
          - Cause: Not fully seated
            - Root Cause: Defective breaker case
          - Cause: Defective
            - Root Cause: Defective
Which major failure modes are at work?

Start

**Decision Issues**
- Is capacity an issue? Yes -> Likely before other modes? Yes -> Capacity
  - No
    - Has LOS changed from design? Yes -> Likely before other modes? Yes -> LOS
      - No
        - Is physical reliability an issue? Yes -> Likely before other modes? Yes -> Mortality
          - No
            - Is cost to operate an issue? Yes -> Likely before other modes? Yes -> Efficiency
              - No

*Redo—it has to fail somehow*

Likely before other modes? ~
Risk mitigation: does Tom have redundancy? If so, how much?
Tom’s risk mitigation tactical options

- Store key spares on site
- Modify piping to accommodate bypass pumping
- Provide proper electrical interface for generator
- Upgrade alarm system to real time SCADA
- Bury power line
- Build berm containment
- Increase redundancy (full)
- Other
Applying business risk to the organization

A *business risk* is the threat that an event—*action or inaction*—will adversely affect an organization’s ability to achieve its business objectives and execute its strategies successfully.

Management of these risks has the twofold advantage of both *avoiding* and *minimizing* the risk itself, and *enabling informed business decision-making* based on an understanding of where the business vulnerabilities lie.
Mapping organizational risk: List risk elements

1. Terrorist attack on OCSD asset (e.g. treatment plant)
2. Regional power outage (up to 24 hours)
3. Safety incident on OCSD project
4. Internal security breach of IT systems
5. Increase in regulatory requirements
6. Finding places to put our biosolids
7. Potential loss of property tax revenue
8. Internal labor unrest at OCSD
9. Consultants ability to meet stakeholders expectations
10. Level of service change for environmental stewardship (constituents of concern)
11. Loss of public confidence in OCSD ability to perform core services
12. Exceedance of pollutants of concerns in groundwater related to GWRS
13. Internal business fraud (e.g. malfeasance)
14. Non compliance by OCSD that result in fines by regulators and legal activities by NGO’s
15. Lack of incentives for early retirement of ageing staff that perform physical activities
16. Poor two way communications across OCSD levels
17. Lack of a leadership model in EMT and management level
18. Changing technology vs. CIP decisions
19. Board not supporting the funding required to support CIP/O&M (Full Cost Pricing)
20. Ability to accurately forecast growth of county
21. Loss of Board institutional knowledge
22. Not sustaining effective plant operations during construction
23. Disasters that destroy collection system or plant
24. Inability to appropriately fund staff at required technical strength
25. Inability to balance strategic initiatives that support GWRS (Groundwater Replenishment System) with plant operations
26. Emergency (operations level) communication among response teams and management for emergencies
27. Lack of alignment of organizational structure with requirements for strategic initiatives
28. Unable to put into effect funding agreement for SARI (Santa Ana River Interceptor)
29. Unable to negotiate new operating agreement with SAWPA (Santa Ana Watershed Project Authority)
30. Public ceases support for GWRS after investment is in place
31. Inability to meet new air emission standards for generating facility
32. Inability to balance impacts on neighbors with desire by public to reduce cost
33. Cost to meet odor and air emissions standards from facilities
34. Privatization of OCSD
35. Recruiting and retention of staff in face of local cost of living
36. Lack of succession planning at OCSD
Sanitation Utility Risk Profile

**Critical Risks:** None categorized as Critical

**High Risks:**
- 2 Regional power outage (up to 24 hours)
- 5 Increase in regulatory requirements
- 6 Finding places to put our biosolids
- 8 Internal labor unrest
- 9 Consultants ability to meet stakeholders expectations
- 19 Board not supporting the funding required to support CIP/O&M (Full Cost Pricing)
- 21 Loss of Board institutional knowledge
- 23 Disasters that destroy collection system or plant
- 26 Unable to put into effective funding agreement with key customer
- 30 Public ceases support for potable water after investment is in place

**Medium Risks:**
- 1 Terrorist attack on assets (e.g. treatment plant)
- 3 Safety incident on major projects
- 7 Potential loss of property tax revenue
- 10 Level of service change for environmental stewardship (constituents of concern)
- 12 Exceedance of pollutants of concerns in groundwater
- 13 Internal business fraud (e.g. malfeasance)
- 14 Non compliance that result in fines by regulators and legal activities by NGO’s
- 16 Poor two way communications across department levels
- 17 Lack of a leadership model in EMT and management level
- 18 Changing technology vs. CIP decisions
- 20 Ability to accurately forecast growth of county
- 22 Not sustaining effective plant operations during construction
- 24 Inability to appropriately fund staff at required technical strength
- 25 Inability to balance strategic initiatives that support groundwater replenishment with plant operations
- 26 Emergency (operations level) communication among response teams and management for emergencies
- 27 Lack of alignment of organizational structure with requirements for strategic initiatives
- 29 Unable to negotiate new operating agreement with key customers
- 31 Inability to meet new air emission standards
- 32 Inability to balance impacts on neighbors with desire by public to reduce cost
- 33 Cost to meet odor and air emissions standards from facilities
- 34 Privatization of organisation
- 35 Recruiting and retention of staff in face of local cost of living
- 36 Lack of succession planning

**Low Risks:**
- 4 Internal security breach of IT systems
- 11 Loss of public confidence in organisation to perform core services
- 15 Lack of incentives for early retirement of ageing staff that perform physical activities

Schematic represents allocation of risk rather than absolute values.
### The risk register – building an action plan

<table>
<thead>
<tr>
<th>#</th>
<th>Risk Issue</th>
<th>Causes and Notes</th>
<th>Potential Impact / Consequence</th>
<th>Current Mitigation Measures</th>
<th>Initial Risk</th>
<th>Proposed Mitigation Measures</th>
<th>By Whom</th>
<th>By When</th>
<th>Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Public ceases support for SWRS after investment is in place</td>
<td>Public perception, rate resistance</td>
<td>Loss of $200m, political tension</td>
<td>Active public relations outreach program, lobbying, public relations plan, Blue Ribbon Panel (academic, regulatory and environmentalists), enhanced source control (pollution concerns)</td>
<td>Major</td>
<td>Unlikely</td>
<td>High</td>
<td>Increase source control to non-industrial users, design more flexibility into design process, second outfall design as backup (need to confirm maximum capacity of outfall)</td>
<td>Human Resources – Public Relations</td>
</tr>
<tr>
<td>31</td>
<td>Inability to meet new air emission standards for generating facility</td>
<td>Regulations</td>
<td>Unable to run cogeneration plant, power cost increase, what to do with gas</td>
<td></td>
<td>Moderate</td>
<td>Possible</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Inability to balance impacts on neighbors with desire by public to reduce cost</td>
<td>Competing interests, takeover of board</td>
<td>Political tension, replacement of board, unhappy consequences</td>
<td></td>
<td>Minor</td>
<td>Possible</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Cost to meet odor and air emissions standards from facilities</td>
<td>Increasing regulation, rate resistance, high public expectations, growth, increasing cost of inputs</td>
<td>Political tension, existing LOS, increasing failures</td>
<td></td>
<td>Moderate</td>
<td>Possible</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Privatization of OCCD</td>
<td>Rate resistance</td>
<td>Political tension, organizational tension</td>
<td></td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Recruiting and retention of staff in face of local cost of living</td>
<td>High cost of living, especially housing, decreasing pool of resources available</td>
<td>Increased cost</td>
<td></td>
<td>Moderate</td>
<td>Possible</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Fundamentals of Asset Management 60
Key points from this session

*Given my system, which assets are critical to sustained performance?*

Key Points:
- Not all assets fail the same way
- Not all assets have the same likelihood of failure
- Not all assets have the same consequence of failure
- Understanding failure drives acquisition, maintenance and renewal management decisions.

Associated Techniques:
- Failure analysis (“root cause” analysis; failure mode, effects and criticality analysis; reliability-centered analysis)
- Failure codes
- Probability of failure
- Consequence of failure
- Business risk exposure
- Asset list by business risk exposure level
- Asset functionality statements
Tom’s spreadsheet

<table>
<thead>
<tr>
<th>Asset Register and Hierarchy</th>
<th>Required Loss</th>
<th>Which Are Most &quot;Critical&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Date</td>
<td>Asset Class</td>
<td>Original Cost</td>
</tr>
<tr>
<td>Year</td>
<td>Years</td>
<td>$</td>
</tr>
<tr>
<td>2008</td>
<td>3</td>
<td>$1,200</td>
</tr>
<tr>
<td>2009</td>
<td>4</td>
<td>$1,300</td>
</tr>
<tr>
<td>2010</td>
<td>5</td>
<td>$1,400</td>
</tr>
<tr>
<td>2011</td>
<td>6</td>
<td>$1,500</td>
</tr>
<tr>
<td>2012</td>
<td>7</td>
<td>$1,600</td>
</tr>
</tbody>
</table>

Fundamentals of Asset Management