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)
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
Using failure modes to determine probability of failure

**Decision Issues**

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

**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
Cause and effect diagram

Effect
- Electric motor burned out
  - Cause
    - Water inside motor
      - Cause
        - Burned out contactor
  - Effect
    - Internal contact
      - Cause
        - Worn bearing
          - Effect
            - Physical damage
              - Cause
                - Forklift bashed motor
    - Effect
      - Incorrectly assembled
        - Cause
          - No lubrication
            - Root Cause
              - No schedule
                - No protective crash barrier
          - No schedule
            - No assembly procedure
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?...

Data distribution of asset performance

- Decay curve
- Mean asset condition
- Minimal asset standard
- Assets performing below standard

Percent of Effective Life Consumed
Linking probability of failure to age of asset

<table>
<thead>
<tr>
<th>% of Effective Life Consumed</th>
<th>PoF Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>60</td>
<td>7</td>
</tr>
<tr>
<td>70</td>
<td>8</td>
</tr>
<tr>
<td>80</td>
<td>9</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
</tr>
</tbody>
</table>

PoF is probability of failure
## Linking probability of failure to condition

<table>
<thead>
<tr>
<th>Asset Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Pressure pipework</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Sewers</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Pumps</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Valves</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Motors</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Electrical</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Controls</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Building assets</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Land</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
### 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
### Scoring Probability of Failure

#### Performance:
- **Capacity, Efficiency, LOS/Regulation**
  - Exceeds Current & Future Expectations
  - Meets Current Expectations
  - Room for Improvement
  - Obvious Concerns; Cost/Benefit Questions
  - Bottleneck; Inefficient; Obsolete
  - Failing; Not Up To Industry Standards or Technology

#### Mortality:
- **Repair History**
  - No Reason to Suspect Problems
  - Some Repairs Rqd As Expected
  - Suspect Above Ave Problems
  - Reputation As Lemon
  - Repair is Excessive or Not Worth It
  - Resource Intensive Other Work Neglected

- **Equipment Life**
  - Asset is Almost New
  - 30% Consumed
  - 45% Consumed
  - 60% Consumed
  - 85% Consumed
  - End of Life or in Failure

- **Maint. Practice:**
  - Above Normal Intervention Not Beneficial
  - Maint & Monitoring is Adequate
  - Some Done But Need More
  - Needs Not Met Most of the Time
  - Substantial Care Rqd But Not Done
  - Imminent Failure; No Action; Dereliction of Duty

- **Asset Alignment to Mission & General Outlook**
  - Failure is Rare (>20yrs)
  - Failure Unlikely (10-20yrs)
  - Failure Possible (6-10yrs)
  - Moderate Chance (3-5yrs)
  - Failure Likely (2yrs)
  - Failure Almost Certain (1yr)

#### Score A
- 1
- 3
- 5
- 7
- 9
- 10

---

*Fundamentals of Asset Management*
Quantifying consequence of failure

<table>
<thead>
<tr>
<th>Consequence of Failure</th>
<th>CoF Rating</th>
<th>Description</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Component Failure</td>
<td>1</td>
<td>Minor Component Failure</td>
<td></td>
</tr>
<tr>
<td>Major Component Failure</td>
<td>2</td>
<td>Major Component Failure</td>
<td></td>
</tr>
<tr>
<td>Major Asset</td>
<td>3</td>
<td>Major Asset</td>
<td></td>
</tr>
<tr>
<td>Multiple Asset Failure</td>
<td>4</td>
<td>Multiple Asset Failure</td>
<td></td>
</tr>
<tr>
<td>Major Facility Failure</td>
<td>5</td>
<td>Major Facility Failure</td>
<td></td>
</tr>
<tr>
<td>Minor Sanitary System Failure</td>
<td>6</td>
<td>Minor Sanitary System Failure</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>7</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>8</td>
<td>Intermediate</td>
<td></td>
</tr>
<tr>
<td>Significant</td>
<td>9</td>
<td>Significant</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

Simple

- **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)

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)
## Scoring the Consequence of Failure

<table>
<thead>
<tr>
<th>Consequence of Failure</th>
<th>Spill, Flood, Odor</th>
<th>Process &amp; Effluent Quality</th>
<th>Environmental and Permit</th>
<th>ECDEP Image</th>
<th>Hassle Factor &amp; Economics</th>
<th>Loss of Service Impacts</th>
<th>Equipment &amp; Safety</th>
<th>Score B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short Duration Sm. Qty. Onsite: No complaints</td>
<td>No impact: SS; BOD; MPN; Cake</td>
<td>No Consequence</td>
<td>No Media or No Consequence</td>
<td>Low Cost &amp; low Hassle</td>
<td>Can be out of service indefinitely</td>
<td>No impact</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Backups; Small No. of Complaints</td>
<td>Routine Adjustment</td>
<td>Violated Daily Standard</td>
<td>Neutral Coverage</td>
<td>Low Cost &amp; High Hassle</td>
<td>Cannot be down a month</td>
<td>Part Level; Routine</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Aggressive complaints and liability</td>
<td>Significant Corrective Action</td>
<td>Violated Weekly Standard</td>
<td>Adverse Media</td>
<td>High Cost; Low Hassle</td>
<td>Cannot be down a week</td>
<td>Asset Level; Minor</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Substantial Liability Many Impacted</td>
<td>Significant Adj. With Uncertainty</td>
<td>Violated Monthly Standard</td>
<td>Widely Adverse Media</td>
<td>High Cost &amp; High Hassle &amp; Diverts $</td>
<td>Cannot be down 1 day</td>
<td>Function Level; Major</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Has not Happened at this Scale Before</td>
<td>Major Process Recovery with Lag Time and Uncertainty</td>
<td>Damage Reversible in Six Months</td>
<td>Continual; Political Opposition</td>
<td>Painful Change of Priorities</td>
<td>Cannot be down 8 hours</td>
<td>System Level; Sever</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Sustained, Lg. Qty. Offsite Many Complaints</td>
<td>Loss of Process Control</td>
<td>Permit Jeopardized; Damage Reversible in 5 yrs</td>
<td>National Adverse Media</td>
<td>May Prompt Rate Increase; Staff Changes</td>
<td>Cannot be down 1 hour</td>
<td>Plant Level; Catastrophic</td>
<td>10</td>
</tr>
</tbody>
</table>
## Alternative view of “criticality”—impact on process

<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…

- **A**: Low probability—low consequence
- **B**: High probability—low consequence
- **C**: Low probability—high consequence
- **D**: High probability—high consequence

---

Fundamentals of Asset Management
Business risk exposure drives work program

Worst first? No

<table>
<thead>
<tr>
<th>Probability</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Good</td>
</tr>
<tr>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Low</td>
<td>Poor</td>
</tr>
<tr>
<td>High</td>
<td>Fair</td>
</tr>
</tbody>
</table>

Fundamentals of Asset Management
Business risk exposure drives work program

Work program response

- **High Risk, High Consequence (D)**: Immediate work
- **High Risk, Low Consequence (B)**: Aggressive monitoring
- **Low Risk, Low Consequence (A)**: Sample monitoring
- **Low Risk, High Consequence (C)**: Aggressive monitoring
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.

<table>
<thead>
<tr>
<th>Probability of Failure</th>
<th>Consequence of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (1)</td>
<td>Low (1)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>High (3)</td>
<td>High (3)</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

Fundamentals of Asset Management
Impact of redundancy on the risk metric

- **Redundancy** significantly reduces the risk metric
- Risk = PoF x CoF x $R$
- Where
  - PoF is probability of failure
  - CoF is consequence of failure
  - $R$ is redundancy factor
Determining redundancy

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

No Redundancy

Yes

Partial Redundancy

Yes

Full Redundancy
Example of assigning weight to 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)
Does Tom have redundancy? If so, how much?
Step-by-step BRE methodology

Levels of filtering and sophistication

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

Risk rating = probability x consequence

<table>
<thead>
<tr>
<th>Asset No.</th>
<th>% Probability</th>
<th>Consequence</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>4</td>
<td>2.4</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>2</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>68</td>
<td>10</td>
<td>6.8*</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
<td>7</td>
<td>6.7*</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>10</td>
<td>1.0</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>
</tbody>
</table>

145

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 satisfactory risk, H is high risk
### Example of BRE level 1

#### Business Risk Exposure Tool Calculator - BRE 1.0 Model (5 x 5 Matrix) Version 4.0
Licensed Client **: Orange County Sanitation District
2005 CIP Validation Program

<table>
<thead>
<tr>
<th>Consequence of Failure</th>
<th>Percentage Affected</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Component Failure</td>
<td>25-50%</td>
<td>Asset</td>
</tr>
</tbody>
</table>

#### Probability of Failure

<table>
<thead>
<tr>
<th>Years to 100% Probability of Failure</th>
<th>&gt; 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redundancy</td>
<td>With Backup</td>
</tr>
<tr>
<td>Probability</td>
<td>0.50</td>
</tr>
</tbody>
</table>

#### Business Risk Exposure

| Total BRE | 1.00 |

---

This workbook forms part of GHD’s Approach to Advanced Life Cycle Asset Management of Infrastructure & other assets. It uses the TEAMOF™ Quality Framework and Confidence Level Rating (CLR) & Business Risk Exposure (BRE) Techniques.
Example of BRE level 2
Example of BRE level 3
Modifying the 10-step process

1. Establish Risk Ratings (Criticality)
2. Develop Asset Registry
3. Assess Failure Modes [Capacity, Mortality, LOS, Efficiency]
4. Determine Residual Life
5. Develop O&M Plans
6. Assess Failure Modes [Capacity, Mortality, LOS, Efficiency] → Determine Residual Life → Develop CIP Program
7. Determine Replacement Cost & Date
8. Develop CIP Program
9. Determine Funding Strategy
10. Set Target LOS

Build AMP
Modifying the 10-step process

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

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

- **Probability of Failure**
  - Use design or standard life table
  - Adjust for:
    - Design standard
    - Construction quality
    - Material quality
    - Operational history
    - Maintenance history
    - Operating environ.
    - External stresses

- **Consequence of Failure**
  - Consider:
    - Safety, health, and welfare
    - Environmental impact
    - Process criticality
    - Repair costs
    - Revenue and aggravation impact on customers and agency

- **Redundancy**
  - Consider:
    - Peak vs. average
    - Age and condition
    - Operating environ.
    - Failure mode
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
Risk Mapping

Operational failure  Structural failure

Least likely  Most likely

Fundamentals of Asset Management
What caused the Jones Street power station to fail?

- Truck hits pole and causes power failure
- Don’t really know
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* )

- 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

Functional Failure
( *It doesn’t work* )
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

Breaker overload

Motor overload

Bearing dry

Grease cap failed

Root Cause

Effect-Cause

Breaker failure

Cause

Effect

Effect

Cause

Effect

Bearing stressed

Misaligned

Impeller jammed

Defective breaker case

Defective

Defective

Not fully seated

Pump overload

Defective
Which major failure modes are at work?

Start

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?

No

Redo—it has to fail somehow

Yes

Likely before other modes?

Yes

Efficiency

~
Strategic business risk

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 population
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
Mapping organizational risk: BRE map

Sanitation Utility Risk Profile

Catastrophic

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
- 28 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 organization
- 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 organization to perform core services
- 15 Lack of incentives for early retirement of ageing staff that perform physical activities

Likelihood

Schematic represents allocation of risk rather than absolute values
### Risk register

<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>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Finding places to put out biosolids</td>
<td>Potential ordinance against OCGS disposal of biosolids. Lack of availability of suitable disposal sites. Lack of on-site disposal. Natural closure of transport routes. Excess available in waste treatment processes.</td>
<td>Public health implications. Increased costs to source landfill sites. Limitations for onsite storage of OCGS. Violation of permit.</td>
<td>OCGS/OCGS legislation which covers on and offsite actions. Specific section addressing monitoring the situation including regulations, policies etc.</td>
<td>Moderate Possible Medium</td>
</tr>
<tr>
<td>7</td>
<td>Potential loss of property tax revenue</td>
<td>Political decision regarding funding made at all levels. State budget issues. Perception of self sufficiency at OCGS. Current revenue 4% 10bn per year from property tax.</td>
<td>Need to increase rates. Reduction in capital investment. Operating budget reduction.</td>
<td>New state legislation structure that makes changes (reductions) more difficult.</td>
<td>Major Possible High</td>
</tr>
<tr>
<td>8</td>
<td>Internal labor unrest at OCGS</td>
<td>Link to risk 4. Union demands. Completion of contract.</td>
<td>Work to rule. Staff shortages. Level of service impacted. Vandalism. Morale. Negative impact on recruitment. Interruption to supply of chemicals (storage under a week).</td>
<td>Labor contracts are negotiated and OCGS offers a couple above salary and benefits program.</td>
<td>Moderate Unlikely Medium</td>
</tr>
</tbody>
</table>
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>Installed Date</th>
<th>Asset Class</th>
<th>Original Cost</th>
<th>Estimated Eff Life</th>
<th>Condition Rating</th>
<th>Annual Dep</th>
<th>Asses Dep</th>
<th>Current LOSS</th>
<th>Minimum Condition</th>
<th>Backstop (Throughput Reduction)</th>
<th>Probability of Failure</th>
<th>Consequence of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanitation System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental Health</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Janitorial Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asbestos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>asbestos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>