Cost-Benefit Analysis of Fire Risk Reduction Alternatives

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• The term “fire risk reduction” is defined as the application of technological and administrative measures to reduce fire or explosion risk to a tolerable level. Reduced fire risk means fewer fire losses, less production downtime, better employee morale, better public relations, and greater profit potential. However it is not obtained without cost.
## Risk-Informed, Performance Based Fire Protection Steps

<table>
<thead>
<tr>
<th>Appraisal</th>
<th>Analysis</th>
<th>Performance</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Program Objectives</td>
<td>3 Loss Scenario Development</td>
<td>Fire Protection</td>
<td>7 Risk Estimation &amp; Comparison With Risk Tolerance</td>
</tr>
<tr>
<td>2 Risk Tolerance Criteria</td>
<td>4 Initiating Event Likelihood</td>
<td>Systems Performance Success Probability</td>
<td>Cost/Benefit</td>
</tr>
<tr>
<td></td>
<td>5 Exposure Profile Modeling</td>
<td></td>
<td>8 Analysis of Risk Reduction Alternatives</td>
</tr>
</tbody>
</table>

**Steps:**

1. Program Objectives
2. Risk Tolerance Criteria
3. Loss Scenario Development
4. Initiating Event Likelihood
5. Exposure Profile Modeling
6. Fire Protection Systems Performance Success Probability
7. Risk Estimation & Comparison With Risk Tolerance
8. Cost/Benefit Analysis of Risk Reduction Alternatives
Risk Reduction Evaluation Process

Is Risk Tolerable?  

- Yes: Perform Cost-Benefit Analysis
  - Recalculate Risk and Compare with Risk Tolerance Criteria
  - Tolerable

- No: Evaluate Risk Reduction Alternatives
  - Reduce Likelihood
  - Improve Fire Protection System Performance
  - Modify Consequences

Not Tolerable
Example Depiction of Existing Annualized Risk Versus Risk Tolerance Criteria

- **Annualize Risk ($/Year)**
  - $113,898
  - $20,000

- **Estimated Existing Total Annualized Risk**

- **Risk Tolerance Criteria $/Year**

- **Amount of Risk Reduction Needed**: $93,898

- **Flammable Liquid Fire Exposure – Process XYZ**
To clearly communicate the risk, values are converted to Aggregate Equivalent Monetary Value. To do this, all the consequence levels must be related to an equivalent monetary value:

- Building Damage Level
- Equipment Damage Level
- Stock Damage Level
- Production Downtime Level
- Life Safety Exposure Level
- ‘Other’ Exposure Levels

**Equivalent Monetary ($) Value at Risk**
Example – Life Safety Exposure Levels

<table>
<thead>
<tr>
<th>LIFE SAFETY EXPOSURE LEVELS</th>
<th>LS, EQUIVALENT MONETARY VALUE, EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injuries</td>
<td></td>
</tr>
<tr>
<td>1 First Aid – One Person (primarily smoke related)</td>
<td>* $1,000</td>
</tr>
<tr>
<td>2 Moderate Burn Injury – One person</td>
<td>$10,000</td>
</tr>
<tr>
<td>(may require hospital treatment)</td>
<td></td>
</tr>
<tr>
<td>3 Severe Burn Injuries – Hospital Treatment 1-3 people</td>
<td>$100,000 - $500,000</td>
</tr>
<tr>
<td>Fatalities</td>
<td></td>
</tr>
<tr>
<td>4 Employee/On-Site Contractor – Single Fatality</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>5 On-Site – 1-3 Fatalities</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>6 Off-Site Fatality</td>
<td>$20,000,000</td>
</tr>
</tbody>
</table>

EMV = Equivalent Monetary Value

* NOTE: The $ values in this column are for example purposes only. LS = Life Safety
Example — Existing Life Safety Risk Versus Life Safety Risk Tolerance

![Graph showing life safety risk and risk tolerance over exposure levels.](image-url)
### Example Format For The Initial Listing and Screening of Risk Reduction Alternatives

<table>
<thead>
<tr>
<th>EVENTS</th>
<th>EVENT FACTORS</th>
<th>LIST OF RISK REDUCTION ALTERNATIVES</th>
<th>FEASIBLE RISK REDUCTION ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiating Fire Events</td>
<td><strong>Likelihood Modification:</strong> • Modify abnormal failure situation which provide fuel available for combustion (i.e., equipment failure, human error, external failures) • Reduce oxygen availability • Minimize ignition potential</td>
<td>[IDENTIFICATION]</td>
<td>[SCREENING]</td>
</tr>
<tr>
<td>Fire Protection Systems</td>
<td><strong>Improved Fire Protection Systems:</strong> • Detection Systems • Emergency Control Systems • Automatic Suppression Systems • Propagation Limiting Measures (i.e., Fire Barriers) • Manual Loss Control Intervention.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consequences. Exposure at the Target</td>
<td><strong>Consequence Modification:</strong> • Modify source fire heat release rate • Modify life safety exposure levels • Modify production downtime exposure levels</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Risk Reduction Approaches

The diagram illustrates the relationship between frequency or likelihood and severity or consequences, with the existing risk level represented by point X. The optimum risk tolerance quadrant is shown, with options for risk reduction:

1. Reduce Severity (Option 1)
2. Reduce Likelihood (Option 2)
3. Reduce Both (Option 3)
Fire Protection System Performance Improvement

Fire protection systems of primary interest in fire risk-based evaluations include:

• Detection Systems
• Emergency Control Systems
• Automatic Suppression Systems
• Propagation Limiting Measures (i.e., Fire Barriers)
• Manual Loss Control Intervention
Example of Primary FPS Success Measures

<table>
<thead>
<tr>
<th>FAULTS</th>
<th>SUCCESS MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Not Responsive to a Specific Scenario</td>
<td>Response Effectiveness [RE]</td>
</tr>
<tr>
<td>- time delay in system activation</td>
<td></td>
</tr>
<tr>
<td>- application problems;</td>
<td></td>
</tr>
<tr>
<td>- inappropriate design basis</td>
<td></td>
</tr>
<tr>
<td>- system capacity, duration insufficient</td>
<td></td>
</tr>
<tr>
<td>- system does not respond in time prior to critical conditions</td>
<td></td>
</tr>
<tr>
<td>System Not On-Line at the time of Emergency</td>
<td></td>
</tr>
<tr>
<td>- down for inspection, maintenance, testing</td>
<td></td>
</tr>
<tr>
<td>- down because of false trips or unscheduled repairs</td>
<td></td>
</tr>
<tr>
<td>- down because of Common Cause (i.e., freezing).</td>
<td></td>
</tr>
<tr>
<td>System Did Not Function Properly at the Time of Emergency (i.e., failure on demand)</td>
<td></td>
</tr>
<tr>
<td>- Subsystem ‘Hidden’ Failure Occurs</td>
<td></td>
</tr>
<tr>
<td>- Design &amp; Operational Common Cause Failure (mechanical damage, earthquake, etc.)</td>
<td></td>
</tr>
<tr>
<td>On-Line Availability [OLA]</td>
<td></td>
</tr>
<tr>
<td>Operational Reliability [OPR]</td>
<td></td>
</tr>
<tr>
<td>Primary Performance Measure</td>
<td>RE: Response Effectiveness</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------</td>
</tr>
</tbody>
</table>

**FPS Performance Success Probability (P<sub>s</sub>)**

\[ P_s = P_{RE} \times P_{OLA} \times P_{OPR} \]
FPS Performance Success Tree Framework — Highlighting Time-Related Performance Factors

Performance Requirements

\[ P = P_{\text{RE}} \times P_{\text{OLA}} \times P_{\text{OR}} \]

Scenario - Specific Input

1.0

Response Effectiveness \( (P_{\text{RE}}) \)

AND

1.1

Design Application Basis Effective \( (P_{\text{DAB}}) \)

AND

1.1.1

Suitability

1.1.2

Capacity

1.1.3

Duration

AND

Time-System Response

1.2

System Response Time Effectiveness

AND

2.0

On-Line Availability \( (P_{\text{OLA}}) \)

AND

3.0

Operational Reliability \( (P_{\text{OR}}) \)

OR

Operational Failure On Demand Probability \( (P_{\text{FOD}}) \)

AND

Is Not On-Line

Subsystem(s) Fail on Demand

Mission Time Failure Probability

Time-System is On-Line

Time-System Duration
Fire Exposure to Control Room Target

Potential Process Source Fire

Hot Smoke Layer, $T_g$

$\dot{q}_r = \text{incident radiant heat flux}$

$h_i = \text{smoke layer heights above floor in production equipment area}$

$T_g = \text{hot smoke layer temperature}$
# Cost Considerations Associated With Risk Reduction Alternatives

<table>
<thead>
<tr>
<th><strong>Initial Costs, $I_c$</strong></th>
<th><strong>Annual Costs, $A_c$</strong></th>
<th><strong>Remarks</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Costs $I_c$</td>
<td></td>
<td>Conceptual design and detailed specifications</td>
</tr>
<tr>
<td>Equipment Costs $I_c$</td>
<td></td>
<td>Individual components or turn-key system costs</td>
</tr>
<tr>
<td>Installation Costs $I_c$</td>
<td></td>
<td>Consider plant or process shutdown time to install equipment</td>
</tr>
<tr>
<td>Permit / License $I_c$</td>
<td></td>
<td>In some cases besides a building code permit, an environmental permit may be required</td>
</tr>
<tr>
<td>Pre-Startup Acceptance Testing $I_c$</td>
<td></td>
<td>Very important consideration to prove reliability prior to operation</td>
</tr>
<tr>
<td>Procedures / Training $I_c$</td>
<td></td>
<td>Procedures and training functions may have to be conducted prior to equipment/system operation</td>
</tr>
<tr>
<td>Operating Costs $A_c$</td>
<td></td>
<td>Utilities usage (electrical, air)</td>
</tr>
<tr>
<td>Inspection and Testing $A_c$</td>
<td></td>
<td>In-house or contracted</td>
</tr>
<tr>
<td>Maintenance $A_c$</td>
<td></td>
<td>In-house or contracted</td>
</tr>
<tr>
<td>Replacement Costs $A_c$</td>
<td></td>
<td>Useful life of components, system, extinguishing agent</td>
</tr>
</tbody>
</table>
Calculation Approach

The benefit/cost ratio (B/C) can be calculated as follows [2]:

\[
B/C = \frac{A (P/A, i, n)}{Ic}
\]

Where \(A = ARB - Ac\)

- \(ARB = \text{Annualized Risk Benefit}\)
- \(Ac = \text{Annualized Cost}\)
- \(Ic = \text{Initial Cost}\)
- \(P/A = \text{Present Worth Factor}\)
- \(i = \text{Interest Rate}\)
- \(n = \text{Time Frame, Years}\)
In some cases there will be more than one alternative strategy where the B/C ratio is greater than 1.0. When this occurs then the next decision making step usually fits into one of the following three approaches:

- Select the alternative strategy with the highest B/C ratio
- If the B/C ratios are close, then conduct additional Engineering Economic analysis
- Evaluate the decision maker’s preferences
Decision Maker’s Preferences

The risk reduction strategy selection team generally includes members of the team who conducted the risk-based study along with additional management decision makers from Risk Management, Engineering, and Operations.

Let’s assume that the following decision making factors are developed by the team:

- Cost Effectiveness (defined by B/C ratios)
- Ease of Installation / Maintenance
- Independent of Manual Fire Extinguishment (i.e., minimal reliance on manual intervention and exposure to fire brigade members)
Recent Applications of Risk-Informed, Performance-Based Fire Protection

- Nuclear Fuels Reprocessing
- Oil Terminals
- Fossil Fuel Power Plant Upgrades
- Specialty Chemical Manufacturers
- LP Gas Bulk Storage Facilities
- Hazardous Waste Processing and Storage
- Product Distribution Warehouses