Cost-Benefit Analysis of Fire Risk Reduction Alternatives

Thomas F. Barry, P.E.
Director Risk & Reliability, HSB Professional Loss Control
• 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>6 Systems Performance Success Probability</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></td>
<td>8 Cost/Benefit Analysis of Risk Reduction Alternatives</td>
</tr>
<tr>
<td></td>
<td>5 Exposure Profile Modeling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Risk Estimation & Comparison With Risk Tolerance

Cost/Benefit Analysis of Risk Reduction Alternatives
Risk Reduction Evaluation Process

Is Risk Tolerable?

Evaluate Risk Reduction Alternatives
- Reduce Likelihood
- Improve Fire Protection System Performance
- Modify Consequences

Perform Cost-Benefit Analysis

Recalculate Risk and Compare with Risk Tolerance Criteria

Yes

Tolerable

No

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

Flammable Liquid Fire Exposure – Process XYZ

AMOUNT OF RISK REDUCTION NEEDED

$93,898
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>Injuries</th>
<th>Description</th>
<th>LS, Equivalent Monetary Value, EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First Aid – One Person (primarily smoke related)</td>
<td>* $1,000</td>
</tr>
<tr>
<td>2</td>
<td>Moderate Burn Injury – One person (may require hospital treatment)</td>
<td>$10,000</td>
</tr>
<tr>
<td>3</td>
<td>Severe Burn Injuries – Hospital Treatment 1-3 people</td>
<td>$100,000 - $500,000</td>
</tr>
<tr>
<td>Fatalities</td>
<td>Employee/On-Site Contractor – Single Fatality</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>5</td>
<td>On-Site – 1-3 Fatalities</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>6</td>
<td>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

![Diagram showing existing life safety risk profile versus life safety risk tolerance. The graph plots likelihood (events/year) against life safety exposure levels. The existing life safety risk profile is shown by a black line with an arrow indicating a decrease in likelihood as exposure levels increase. The life safety risk tolerance profile is shown by another black line with an arrow indicating a lower likelihood for the same 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>
</table>
| Initiating Fire Events | Likelihood Modification:  
• Modify abnormal failure situation which provide fuel available for combustion (i.e., equipment failure, human error, external failures)  
• Reduce oxygen availability  
• Minimize ignition potential | [IDENTIFICATION] | [SCREENING] |
| Fire Protection Systems (FPS) | Improvements to Fire Protection Systems:  
• Detection Systems  
• Emergency Control Systems  
• Automatic Suppression Systems  
• Propagation Limiting Measures (i.e., Fire Barriers)  
• Manual Loss Control Intervention. | | |
| Consequences, Exposure at the Target | Consequence Modification:  
• Modify source fire heat release rate  
• Modify life safety exposure levels  
• Modify production downtime exposure levels | | |
Risk Reduction Approaches

- Option 1: Reduce Severity
- Option 2: Reduce Likelihood
- Option 3: Reduce Both

Risk Tolerance Curve

Existing Risk Level

Optimum Risk Tolerance Quadrant

Frequency or Likelihood

Severity or Consequences
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>On-Line Availability [OLA]</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>Operational Reliability [OPR]</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>
</tbody>
</table>
Primary Performance Measure

- RE: Response Effectiveness
- OLA: On-Line Availability
- OPR: Operational Reliability

FPS Performance Success Probability ($P_s$)

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

Performance Requirements

P_s = P_R x P_O x P_D

FPS Performance Success (P_s)

Response Effectiveness (P_RE)

P_RE = P_R x P_E

OLA On-Line Availability (P_OLA)

P_OLA = 1 - P_DT

Operational Failure On Demand Probability (P_FOD)

P_FOD = 1 - P_O

Operational Reliability (P_O)

P_O = 1 - P_FOD

System Down-Time Probability (P_DT)

P_DT = 1 - P_DAB

Design Application Basis Effective (P_DAB)

P_DAB = P_SI x P_CA x P_DU

Scenario - Specific Input

Time-System Response

Time-System Duration

Time System is On-Line

Time System is Off-Line

Is Not On-Line

Subsystem(s) Fail on Demand

Mission Time Failure Probability

Suitability

Capacity

Duration

1.0

1.1

1.1.1

1.1.2

1.1.3

2.0

3.0

AND

OR

AND

OR

AND

OR

1.0

P_R = P_RE x P_R

P_O = P_OLA x P_O

P_D = P_DAB x P_D
Fire Exposure to Control Room Target

*Potential Process Source Fire*

- $T_g$ = hot smoke layer temperature
- $q_r$ = incident radiant heat flux
- $h_i$ = smoke layer heights above floor in production equipment area

NOTE: Sectional View
## Cost Considerations Associated With Risk Reduction Alternatives

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

- \( ARB = \) Annualized Risk Benefit
- \( Ac = \) Annualized Cost
- \( Ic = \) Initial Cost
- \( P/A = \) Present Worth Factor
- \( i = \) Interest Rate
- \( n = \) 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