DANGEROUS GOODS TRANSPORTATION
PRACTICAL RISK ANALYSIS APPROACH

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Outline

• Transportation Risk Management Framework
• Dangerous Goods Transportation Practical Risk Analysis Approach
• Example Dangerous Goods Railway Transportation Risk
• Appendix
Transportation Risk Management Framework

- A collection of processes and methodologies for identifying, assessing and reducing transportation risks

- Fundamental questions:
  - What can go wrong?
  - How likely it is?
  - What are the consequences?
  - How to effectively use resources to reduce risks?

Note: Transportation Risk Management (TRM) framework shown on the right is modified from CCPS (2008) – Guidelines for Chemical Transportation Safety, Security and Risk Management

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Risk Analysis

• Consideration of causes and sources of risk, and their consequences and likelihood

• Methods can be
  – Qualitative,
  – Semi-quantitative, or
  – Quantitative risk analysis
Dangerous Goods Transportation
Practical Risk Analysis Approach

INITIATING EVENT
Accident or Non-Accident

RELEASE EVENT

CONSEQUENCE
Initiating Event: Accidents

- Example types of accident-initiated events

<table>
<thead>
<tr>
<th>Road</th>
<th>Rail</th>
<th>Waterway</th>
<th>Air</th>
<th>Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>Collision</td>
<td>Collision</td>
<td>Crash</td>
<td>External Impact</td>
</tr>
<tr>
<td>Overturning</td>
<td>Derailment</td>
<td>Grounding</td>
<td>Cargo Shifting</td>
<td></td>
</tr>
<tr>
<td>Grade Crossing</td>
<td>Grade Crossing</td>
<td>Ramming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo Shifting</td>
<td>Collision</td>
<td>Capsizing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Allision</td>
<td></td>
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</tr>
</tbody>
</table>

- Potential causes:
  - Infrastructure defects (e.g. road/rail track)
  - Equipment defects
  - Human factors
  - Navigational failures
  - Control system failures
  - External events
Initiating Event: Non-Accidents

- Potential causes:
  - Improper securement
  - Corrosion
  - Metallurgical failure
  - Overpressure
  - Equipment component failures (e.g. valves, rupture disks, fittings)
  - Overfilling or underfilling
  - Relief device activation due to surges
  - Contamination
  - Temperature changes
  - Control system failures
Release Incident

- The loss of containment of material
Consequence

- The direct results or impacts of an event
- Outcome of an event affecting objectives
- Examples:
  - Fatalities
  - Injuries
  - Property damage
  - Environmental impacts
  - Business interruption
  - Evacuation
  - Distribution system disruption
  - Negative publicity
  - Excess regulations
Example Dangerous Goods Railway Transportation Risk

- Basic risk equation = probability of an event multiplied by the consequence of that event
  \[ R = P_A \times P_{R|A} \times Q \times C \]

- Probability of a hazardous materials (HM) release event is typically the product of a series of other probabilities
  - Probability of a derailment occurring \( (P_A) \) \( \text{Train Accident} \)
  - Probability that the HM car releases product \( (P_{R|A}) \) \( \text{Tank Car} \)
  - Probability distribution of quantity lost \( (Q) \)
    (can also be expressed as average quantity lost)

- Consequences to people, property, or the environment is determined by what, where and when the material is spilled \( (C) \)
Environmental Risk Analysis of Railway Transportation of Dangerous Goods

- Tank Car Derailment
- Release from Tank Car
- Release Quantity as Percentage of Tank Car Capacity
- Soil Type
- Depth to Groundwater, (ft)
- Population Class
- Traffic Density Category (MGTM)

Environmental Cleanup Cost:
- Clay: 0-5%
- Silt: 5-20%
- Sand: 20-50%
- 80-100%

Evacuation Cost:
- Remote: 10
- Rural: 20
- Suburban: 50
- Urban: 100
- High: 200
- Extremely High: ≥ 100

Train Delay Cost:
- 0.1-4.9
- 5-9.9
- 10-19.9
- 20-39.9
- 40-59.9
- 60-99.9
- ≥ 100

Accident-Caused Release Rate
- Yes
- No

Consequences
- Environmental Cleanup Cost
- Evacuation Cost
- Train Delay Cost

Probability Analysis

- Accident-caused release rate metric was used to estimate the annual rate of a release event:

\[ P_R = P_A \times P_{R|A} \times M \]

where:

- \( P_A \) = tank car derailment annual rate per car-mile (Anderson & Barkan 2004)
- \( P_{R|A} \) = tank car conditional probability of release (Treichel et al. 2006)
- \( M \) = total number of car miles

References:


### Chemicals of Interest’s Routes & Annual Car Miles

<table>
<thead>
<tr>
<th>Commodity Name</th>
<th>Annual Car Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylonitrile</td>
<td>1,406,133</td>
</tr>
<tr>
<td>Benzene</td>
<td>1,541,225</td>
</tr>
<tr>
<td>Butyl Acrylates</td>
<td>2,910,782</td>
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<tr>
<td>Cyclohexane</td>
<td>2,036,186</td>
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<tr>
<td>Ethanol</td>
<td>3,013,480</td>
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<tr>
<td>Ethyl Acetate</td>
<td>881,173</td>
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<tr>
<td>Ethyl Acrylate</td>
<td>649,216</td>
</tr>
<tr>
<td>Methanol</td>
<td>16,361,224</td>
</tr>
<tr>
<td>Methyl Methacrylate</td>
<td>3,944,250</td>
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<tr>
<td>Styrene</td>
<td>6,167,904</td>
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<tr>
<td>Toluene</td>
<td>2,604,849</td>
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<tr>
<td>Vinyl Acetate</td>
<td>5,033,087</td>
</tr>
<tr>
<td>Xylenes</td>
<td>9,234,437</td>
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</tbody>
</table>
Accident-caused Release Rate Summary

(The “probability” or frequency term in the risk definition)

- Methanol: 0.647
- Xylenes: 0.365
- Vinyl Acetate: 0.199
- Methyl Methacrylate: 0.156
- Styrene: 0.152
- Ethanol: 0.119
- Toluene: 0.103
- Cyclohexane: 0.081
- Butyl Acrylates: 0.072
- Acrylonitrile: 0.050
- Benzene: 0.038
- Ethyl Acetate: 0.035
- Ethyl Acrylate: 0.026

Accident-Caused Release Rate per Year
Consequence Analysis

- Impacts to Soil and Groundwater
  - Hazardous Materials Transportation Environmental Consequence Model (HMTECM) was used to estimate soil and groundwater cleanup cost.
  - Accounts for physicochemical properties, soil type and depth to groundwater.

- Population Exposure
  - US Emergency Response Guidebook (ERG) was used to determine hazard area.
  - Impact in terms of evacuation cost was estimated.

- Train Delay
  - Estimate impact due to additional costs related to locomotives, railcars, fuel and labor.
  - Accounts for traffic density to estimate total number of trains delayed.

References:

Total Expected Consequence Cost

- Expected Cleanup Cost + Evacuation Cost + Train Delay Cost

(The consequence term in the risk definition)

- Cyclohexane: 1,239,038
- Xylenes: 1,069,583
- Toluene: 907,833
- Acrylonitrile: 898,507
- Ethyl Acrylate: 859,578
- Ethyl Acetate: 882,007
- Methyl Methacrylate: 844,454
- Benzene: 815,172
- Methanol: 795,799
- Styrene: 775,925
- Butyl Acrylates: 643,117
- Vinyl Acetate: 627,185
- Ethanol: 559,041

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Risk Estimation

- Accident-Caused Release Rate x Total Expected Consequence Cost

### Annual Release Risk ($)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Annual Release Risk ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>515,051</td>
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<tr>
<td>Xylenes</td>
<td>390,711</td>
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<tr>
<td>Methyl Methacrylate</td>
<td>131,756</td>
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<td>Vinyl Acetate</td>
<td>124,871</td>
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<tr>
<td>Styrene</td>
<td>118,081</td>
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<tr>
<td>Cyclohexane</td>
<td>99,801</td>
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<tr>
<td>Toluene</td>
<td>93,545</td>
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<td>Ethanol</td>
<td>66,641</td>
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<td>Butyl Acrylates</td>
<td>46,187</td>
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<tr>
<td>Acrylonitrile</td>
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<td>Benzene</td>
<td>30,998</td>
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<td>Ethyl Acetate</td>
<td>30,744</td>
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<tr>
<td>Ethyl Acrylate</td>
<td>22,075</td>
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</table>

### Risk per Ton-Mile (¢)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Risk per Ton-Mile (¢)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclohexane</td>
<td>0,048</td>
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<tr>
<td>Xylenes</td>
<td>0,042</td>
</tr>
<tr>
<td>Toluene</td>
<td>0,035</td>
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<tr>
<td>Ethyl Acetate</td>
<td>0,034</td>
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<tr>
<td>Ethyl Acrylate</td>
<td>0,033</td>
</tr>
<tr>
<td>Methyl Methacrylate</td>
<td>0,032</td>
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<tr>
<td>Acrylonitrile</td>
<td>0,032</td>
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<tr>
<td>Methanol</td>
<td>0,031</td>
</tr>
<tr>
<td>Vinyl Acetate</td>
<td>0,024</td>
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<tr>
<td>Ethanol</td>
<td>0,022</td>
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<tr>
<td>Benzene</td>
<td>0,020</td>
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<tr>
<td>Styrene</td>
<td>0,020</td>
</tr>
<tr>
<td>Butyl Acrylates</td>
<td>0,016</td>
</tr>
</tbody>
</table>
Risk Profile

Example risk profile for rail transportation of methanol
Acknowledgements

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BNSF RAILWAY

U.S. Department of Transportation
Federal Railroad Administration

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