Property Risk Optimization by Predictive Hazard Evaluation Tool (PROPHET)

Austin Anderson and O.A. Ezekoye

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Motivation

- Traditional fire inspection processes are generally more qualitative.
  - Checklist approaches
  - Matrix Methods

- These approaches often do not capitalize on historical fire data.

- What kind of fires might come from this office?
Purposes of the Framework

- Identify and produce relevant fire scenarios whose outputs are useful for informing various stakeholders regarding the potential severity of fires in the building.

- Provide a roadmap for translating the information present in BIM models, coupled with external fire data sources, into a feasible, working fire model.

- Obtain feasible probabilities of ignition for room contents to weight fire scenarios.

- This methodology complies with the elements of risk frameworks posited by Hall and Sekizawa.
A three step approach

1. Perform fire load survey of building
   - Provides room contents configuration and material properties.

2. Translation of building and fire survey information into a fire model.
   - Necessary to evaluate fire performance of various scenarios.
   - Provides a measure of severity of potential fires.

3. Scenario weighting via ignition probabilities.
   - Provides a measure of expected frequency/probability of potential fires.

The outcome is an indicator of Fire risk, calculated as frequency times severity.
Methodology

- Examine room contents, identify combustibles, their respective materials, and their material properties.
- Either locate room items in a catalogue, asset database, or manually measure their volume and apply a material density to approximate combustible mass.
- This is the inventory method pioneered by Culver, and explored in more detail by Zalok.
Examples of combustible items
Work process

- Add Room contents
  - Import
  - Export as .IFC
    - Import Material Properties
      - BlenderFDS module
      - Blender (Only Geometry Information is retained)
        - Simplify Geometry
  - Import
  - Google Sketchup Compartment Model (Stand-in for BIM model)

- External Database
  - Designate obstructions
    - Place vents
      - Place heat detectors and temperature sensors
        - Construct configuration file
          - Export and debug FDS input file
            - Generate independent input files for each fire scenario
              - Run FDS for each scenario

- Identify room contents fire scenarios
Visual overview
Geometry Simplification

- FDS uses rectilinear geometry specification.
- It is necessary to simplify the often complex geometry of contents visualizations.
Eight ignition scenarios of interest were identified, for which FDS simulations were run.
For the purposes of this study, a simple loss model was posited for fire scenario output:

$$\text{Room Loss} = \min \left( \frac{T_{\text{max}} - 25^\circ C}{600^\circ C - 25^\circ C}, 1 \right)$$

Where $T_{\text{max}}$ is the peak average upper gas layer temperature experienced in the compartment.

Example:

$$L_{\text{Loss}_{\text{Frontshelfbooks}}} = \min \left( \frac{169^\circ C - 25^\circ C}{600^\circ C - 25^\circ C}, 1 \right) = 0.25$$
## Applying loss model to fire scenario output

<table>
<thead>
<tr>
<th>Ignition Scenario</th>
<th>Peak Average Upper Gas Layer Temperature (°C)</th>
<th>Room loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printer</td>
<td>95</td>
<td>0.12</td>
</tr>
<tr>
<td>Pile of paper</td>
<td>44</td>
<td>0.03</td>
</tr>
<tr>
<td>Computer chair</td>
<td>340</td>
<td>0.55</td>
</tr>
<tr>
<td>Books (backshelf)</td>
<td>191</td>
<td>0.29</td>
</tr>
<tr>
<td>Books (frontshelf)</td>
<td>169</td>
<td>0.25</td>
</tr>
<tr>
<td>Round table</td>
<td>239</td>
<td>0.37</td>
</tr>
<tr>
<td>Metal-frame chair</td>
<td>46</td>
<td>0.04</td>
</tr>
<tr>
<td>Box of printer paper</td>
<td>52</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Note that the room never reached above 0.55 loss due to an underventilated condition preventing flashover from occurring.
Determining ignition frequency of fuel packages

- Individual fuel package probability of ignition, given that a fire occurred in the compartment, was calculated as follows:

\[ P_{pkg \; ignition} = P_{matl \; ignition} \times \frac{\%matl \; comb \; mass \; room}{\%matl \; comb \; mass, \; zalok} \div n_{matl \; fuel \; pkgs} \]

- This equation apportions the selection probability of a material to fuel packages made from that material, after adjusting the selection probability for a room’s deviation from the standard compartment as determined by Zalok.

- Example:

\[ P_{paper \; pkg \; ignition} = 15.03\% \times \frac{88\%}{33\%} \div 41 \; pkgs. = 0.98\% \]
### Determining ignition frequency of fuel packages

<table>
<thead>
<tr>
<th>Material</th>
<th>Average Frequency (%)</th>
<th>NHB adjusted frequency (%)</th>
<th>Discrete fuel packages (#)</th>
<th>Individual package frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>15.03</td>
<td>40.13</td>
<td>41</td>
<td>0.98</td>
</tr>
<tr>
<td>Wood</td>
<td>16.59</td>
<td>1.49</td>
<td>3</td>
<td>0.50</td>
</tr>
<tr>
<td>Plastic</td>
<td>16.58</td>
<td>8.95</td>
<td>12</td>
<td>0.75</td>
</tr>
</tbody>
</table>
The eight identified fire scenarios of interest had weighting probabilities calculated based on the relative proportion of their frequency as follows:

$$P_{scenario} = \frac{\text{\# related pkgs} \times P_{pkg \text{ ignition}}}{\text{total pkg ignition frequency}}$$

Example:

$$P_{Frontshelfbooks} = \frac{16 \times 0.98}{50.57} = 0.310$$
## Representative weighting of fire scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Object membership</th>
<th>Rep. frequency (%)</th>
<th>Normalized probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printer</td>
<td>7 (plastic)</td>
<td>5.22</td>
<td>0.103</td>
</tr>
<tr>
<td>Pile of paper</td>
<td>11 (paper)</td>
<td>10.77</td>
<td>0.213</td>
</tr>
<tr>
<td>Computer chair</td>
<td>1 (plastic)</td>
<td>0.75</td>
<td>0.015</td>
</tr>
<tr>
<td>Books (backshelf)</td>
<td>8 (paper)</td>
<td>7.83</td>
<td>0.155</td>
</tr>
<tr>
<td>Books (frontshelf)</td>
<td>16 (paper)</td>
<td>15.66</td>
<td>0.310</td>
</tr>
<tr>
<td>Round table</td>
<td>3 (wood)</td>
<td>1.49</td>
<td>0.029</td>
</tr>
<tr>
<td>Metal-frame chair</td>
<td>4 (plastic)</td>
<td>2.98</td>
<td>0.059</td>
</tr>
<tr>
<td>Box of printer paper</td>
<td>6 (paper)</td>
<td>5.87</td>
<td>0.116</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56</strong></td>
<td><strong>50.57</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
Expected loss, the fire risk

- expected loss of the fire scenarios was calculated very simply:

\[ E(loss)_{scenario} = P_{scenario} \times loss_{scenario} \]

- returning to our front bookshelves example:

\[ E(loss)_{Frontshelfbooks} = 0.310 \times 0.25 = 0.078 \]

- Then the total expected loss is easily calculated as the sum of the expected loss from all possible scenarios:

\[ E(loss)_{fire} = \sum P_{scenario} \times loss_{scenario} \]

- For the NHB compartment this was 0.17
### Expected loss, the fire risk

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Normalized Probability</th>
<th>Loss</th>
<th>Expected Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Books (frontshelf)</td>
<td>0.310</td>
<td>0.25</td>
<td>0.0775</td>
</tr>
<tr>
<td>Books (backshelf)</td>
<td>0.155</td>
<td>0.29</td>
<td>0.045</td>
</tr>
<tr>
<td>Printer</td>
<td>0.103</td>
<td>0.12</td>
<td>0.012</td>
</tr>
<tr>
<td>Round table</td>
<td>0.029</td>
<td>0.37</td>
<td>0.011</td>
</tr>
<tr>
<td>Computer chair</td>
<td>0.015</td>
<td>0.55</td>
<td>0.008</td>
</tr>
<tr>
<td>Pile of paper</td>
<td>0.213</td>
<td>0.03</td>
<td>0.006</td>
</tr>
<tr>
<td>Box of printer paper</td>
<td>0.116</td>
<td>0.05</td>
<td>0.006</td>
</tr>
<tr>
<td>Metal-frame chair</td>
<td>0.059</td>
<td>0.04</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1</strong></td>
<td><strong>-</strong></td>
<td><strong>0.17</strong></td>
</tr>
</tbody>
</table>
Expected loss, the fire risk

Another way to display this information is with a survivor curve.
Improved model

- This compartment analysis did not account for other aspects of the fire problem in a room, such as fire protection features or varying ventilation conditions.

- These can be easily added! You just need discrete points representing new families of scenarios and their associated probabilities.

- For example, if we wanted to perform this analysis with sprinklers, we would have another “branch” of probabilities and losses for sprinkler operation:

\[
E(\text{loss})_{\text{fire}} = \sum P(\text{sprinklers}_{\text{operate}}) \times P_{\text{scenario sprinklers}} \times \text{loss}_{\text{scenario sprinklers}} \\
+ \sum P(\text{sprinklers}_{\text{not operate}}) \times P_{\text{scenario nosprinklers}} \times \text{loss}_{\text{scenario nosprinklers}}
\]
Expensive difficulties

Original Analysis  8 Total Scenarios

New Analysis  48 Total Scenarios

- Fire occurs within compartment
- 8 possible scenarios represent universe of item ignition

**8 scenarios w/ high vent no sprinklers**

**8 scenarios w/ med vent no sprinklers**

**8 scenarios w/ low vent no sprinklers**

Ventilation condition? (no)

- **8 scenarios w/ high vent w/sprinklers**
- **8 scenarios w/ med vent w/sprinklers**
- **8 scenarios w/ low vent w/sprinklers**

Sprinklers operating?

Ventilation condition? (yes)
Potential solutions

- Exclude obvious near-zero loss scenarios from computation, and approximate their loss as zero.
- Perform extensive amounts of computation up-front to build a library of compartments under various scenarios, then apply results across buildings with minor compartmental corrections to values.
Conclusions

- This framework is potentially robust for predicting the potential fires a building might experience.
- Such information would aid a wide variety of building stakeholders:
  - Fire departments could identify trouble spots within the building for either training exercises or pre-planning tactics for potential building fires.
  - Owners would have a better idea of the building’s fire hazard for negotiating with insurance companies.
- There yet remains a large amount of work and refinement necessary to produce effective output from models generated by this framework:
  - Automation of model transition between BIM and fire models
  - Better ignition probabilities for room contents.
  - Better capturing of object burning and flame spread within the fire model.
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Questions?