Modelling the Impact of Smoke on the Evacuee
S.M.V. Gwynne

FCIA Firestop Industry Conference and Trade Show, 2015
Overview

• How do we expect evacuees to behave?

• How do evacuees actually behave?

• Why do differences in expected/actual behaviour matter?

• What can we do to quantify evacuee performance?

• How does this aid in judging benefits of fire stopping or similar systems?
NRC capabilities include:

- Small-scale test; e.g. fire development from a component
- Onsite test; e.g. smoke movement
- Egress/Fire Analysis and Modelling; e.g. tenability analysis, risk assessment
- Bench-scale test; e.g. products from small sample
- Component test; e.g. structural resistance
- Full-scale test; e.g. fire development
- Mitigation efforts and requirements; e.g. suppression efforts, water demand
How do we expect evacuees to behave?
What we would like people to do?
The Damaging Myth of Panic!

- **MYTH** – Panic is normal and dominates response.
- Perpetuated by media. Not instructive.
- Panic is relatively rare and seldom dominates response.
- Behaviour typically more rational – goal driven and sensitive to information. *The exact opposite of the mythical evacuee!*

*Title*:

-Towering Inferno, 1974.
-20th Century Fox. Fair Use Copyright
Previous Contradictory Assumptions

• **Assumption 1:** Evacuees will panic – respond quickly
  • Reluctance to share information
  • Delay in notification - potential for incident to develop, increasing likelihood for evacuees to face difficulties

• **Assumption 2:** Design routes used (efficiently).

![Egress Width per Occupant Served Table]

<table>
<thead>
<tr>
<th>OCCUPANCY</th>
<th>WITHOUT SPRINKLER SYSTEM</th>
<th>WITH SPRINKLER SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stairways (Inches per occupant)</td>
<td>Other egress components (Inches per occupant)</td>
</tr>
<tr>
<td>Occupancies other than those listed below</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Hazardous: H-1, H-2, H-3 and H-4</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Institutional: I-2</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>

ICC, 2003

• Behavioural assumptions may have impact on design decisions
How do evacuees actually behave?
Summerland, Isle of Man, UK (1973); 50 fatalities

- Unprotected ‘flying’ staircases
- Inconsistent alarm
- No call to Fire Brigade
- Poor staff training
- Complex evacuee behaviour
  - Reference Sime (1999)

Social identity matters
People do not necessarily move directly towards safety
Beverly Hills Supper Club (1977); 164 fatalities

- 2400-2800 patrons
- Found at two overloaded exits.
- Rapid arrival of smoke.
- Visual separation of people from incident.
- More horrific tragedy avoided by actions of employees.

Staff actions had an impact. Route familiarity a factor. Access to information. Panic not dominant response.
Information Matters to the Decision-Making Process

- Instead of panic-based or stimulus-response, people sensitive to information available – acquired and/or brought with them.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
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<tbody>
<tr>
<td><strong>Pc</strong></td>
<td>Perception: Whether it is possible for the information to be perceived</td>
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<td>Action: Whether the pertinent information indicates an appropriate action</td>
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Kuligowski et al [2011].
Response preceded by perception and assessment
Nature of Subsequent Decision-Making Process

- Complex
- Iterative and individual
- Sensitive to information
- Goal-driven

[Canter, Breaux and Sime]
Physical, Social, Situational and Psychological Variability
Physical, Social, Situational and Psychological Variability
Interaction with fire effluent

• Impact on evacuee physical/physiological well-being
  • Elevated temperatures, narcotic/irritant gases and impeded breathing – incapacitation, injury and death

• Impact on evacuee perception of incident
  • Reduced visibility
  • Initial cue of incident existence
  • Influence perception of incident
  • Impact on situational awareness – reduced visual access

• Impact on evacuee performance
  • Reduced movement
  • Reduced access to routes

• Human interaction with environmental conditions key indicator of success of procedural measures
Help identify key interactions with smoke, narcotic gases, elevated temperatures, etc.

- How many people encountered smoke?
- How many people were exposed to toxins?
- How many people were exposed to high temperatures?
- How many people were injured?
- How many people would have been incapacitated?

Why might answering these questions be of value?
What is a model?

• All attempts to observe, understand and influence (and design for) human behaviour in fire depends on a model of human response.
• The assumptions we make influences the accuracy of this model and its impact.
What is a model?

<table>
<thead>
<tr>
<th>OCCUPANCY</th>
<th>WITHOUT SPRINKLER SYSTEM (feet)</th>
<th>WITH SPRINKLER SYSTEM (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, E, F-1, I-1, M, R, S-1</td>
<td>200</td>
<td>250&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td>300&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>F-2, S-2, U</td>
<td>300</td>
<td>400&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>H-1</td>
<td>Not Permitted</td>
<td>75&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>H-2</td>
<td>Not Permitted</td>
<td>100&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>H-3</td>
<td>Not Permitted</td>
<td>150&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>H-4</td>
<td>Not Permitted</td>
<td>175&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>H-5</td>
<td>Not Permitted</td>
<td>200&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>I-2, I-3, I-4</td>
<td>150</td>
<td>200&lt;sup&gt;c&lt;/sup&gt;</td>
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[ICC, 2003]

Fire Safety Engineering Group

[www.ola.com]
Why should we care?

What are the implications of getting these assumptions wrong?
Translating Assumptions into Practice

**Panic-based alarm design**

- Incident may lead to rapid, simultaneous response – potentially overloading exits.
- Response likely uncontrolled and competitive—‘stampede’.
- Veering between selfish/rational and self-destructive/irrational.
- Process will contaminate observers.
- Information provided may not have desired impact...

**Process Model (PADM)**

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Kuligowski et al [2011].
### Translating Assumptions into Practice

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<th>Panic-based alarm design</th>
<th>Process-based design</th>
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<tr>
<td>• Delay notification.</td>
<td>• Ensure coverage – reduce background noise.</td>
</tr>
<tr>
<td>• Quietly inform some people.</td>
<td>• Address sensory issues.</td>
</tr>
<tr>
<td>• Content is irrelevant, provide a bell. Coverage should still be checked.</td>
<td>• Employ pictograms / icons to ensure messages reaches maximum number of people</td>
</tr>
<tr>
<td>• Deploy staff to control evacuees.</td>
<td>• Increase message credibility.</td>
</tr>
<tr>
<td>• Not much basis for further analysis – except to effectiveness of alert.</td>
<td>• Tailor announcement to target populations.</td>
</tr>
<tr>
<td></td>
<td>• Who needs to act</td>
</tr>
<tr>
<td></td>
<td>• What they need to do.</td>
</tr>
<tr>
<td></td>
<td>• When they need to do it</td>
</tr>
<tr>
<td></td>
<td>• Why they need to do it</td>
</tr>
<tr>
<td></td>
<td>• What is currently being done about it.</td>
</tr>
</tbody>
</table>
How can quantify evacuee performance?

Translating Assumptions into Forecasts
Translating Assumptions into Practice – Evidence-Based Approach


Skeptical Advocacy

• Always query the model assumptions!

• Visual sophistication of interface is not related to the credibility of the underlying model assumptions.

  • Model only as good as the assumptions adopted, the data available, and the expertise of the user!

  • Limitations should be understood and documented.
Quantifying impact of design

- Human behaviour influences effectiveness of structural/technical/procedural designs
- Provides opportunity to quantify performance and differentiate between designs

**Building Design 1:**
- Insufficient fire barriers/stops
- Assumed fire scenario
- Represent fire/smoke progression
- Simulate evacuee movement and interaction with deteriorating environment
- Quantify exposure levels, impact on evacuee well-being and on evacuee performance.

**Building Design 2:**
- Fire barrier/stop technology X
- Assumed fire scenario
- Represent new fire/smoke progression
- Simulate evacuee movement and interaction with deteriorating environment
- Quantify exposure levels, impact on evacuee well-being and on evacuee performance.

*Determine relative merits of introducing new system.*
Design Comparison – Model Fire / Smoke Movement

- **Building Design 1:**
  - Fire / smoke conditions established (e.g. simulated)

- **Building Design 2:**

  VS.

- **Fire / smoke conditions established (e.g. simulated)**
• Establish impact of environmental conditions on evacuating population.
Insights Provided by Modelling

<table>
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<tr>
<th>Avg. Individual Performance</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion Experienced (s)</td>
<td>78</td>
<td>[76-79]</td>
<td></td>
</tr>
<tr>
<td>Time to evacuate building(s)</td>
<td>133</td>
<td>[132-134]</td>
<td></td>
</tr>
<tr>
<td>Distance Travelled (m)</td>
<td>58</td>
<td>[56-59]</td>
<td></td>
</tr>
<tr>
<td>Response (s)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **How long does it take to evacuate the building given use of procedure X?**
- **How many people are incapacitated?**
- **How much time did evacuee Y spend in congestion?**
Effectiveness of Procedural / Technical Responses

- Simulate outcome for different scenarios: population, incident, procedure, building.

<table>
<thead>
<tr>
<th>Incident A: Fire – 1st floor</th>
<th>Design 1: Fire Stop 1</th>
<th>Outcome (A,1)</th>
<th>Design 2: Fire Stop 2</th>
<th>Outcome (A,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident B: Fire – 10th floor</td>
<td>Design 1: Fire Stop 1</td>
<td>Outcome (B,1)</td>
<td>Design 2: Fire Stop 2</td>
<td>Outcome (B,2)</td>
</tr>
</tbody>
</table>

- Establish the primary impact (environmental conditions), and the secondary impact (e.g. effect on the population).

- Provides another means of discriminating between designs.
Summary

• Evacuee response: sensitive to situation, information and their own abilities.
• Smoke effluent influences more than physical well-being – also influences decision-making.
• Procedural measures can manage smoke spread
• Using simulation tools can quantify impact of these measures on evacuees.

• To do this, critical to have reasonable model of evacuee performance.
Questions that this analysis can help resolve

• **Design:**
  • *Does the design perform as expected?*
  • *How do we address shortfalls in the design’s performance?*

• **Selection / Sales:**
  • *Which of the available systems is of most benefit?*

• **Compliance:**
  • *Does the system meet regulatory requirements?*

• **Implementation:**
  • *Can the implemented system be made more effective / efficient?*

• **Mitigation:**
  • *How can we communicate the impact of different responses to staff?*

• **Maintenance:**
  • *Is the current design sufficient given changes in building use or occupant demographics?*
Thanks!

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