The Simulation of Urban-Scale Evacuation: The Swinley Forest Fire
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Wildfire Event - Greenwich UK
10 April 2015
Evacuation in Large Scale Emergencies

Due to global warming, extreme weather events in the UK are increasing:
- with this comes an increased threat of floods, an estimated 3.6 million people will be at risk of flooding by 2050.
- warmer and drier conditions and more frequent and longer-lasting heat waves also raise the risk of wild fires.
- In the past 4 years there have been on average 45,000 wildfires each year attended by the fire and rescue services in Great Britain.
- The fire risk is compounded by the UK’s higher population density, which means that fires are more likely to encroach into urban environments posing a threat to life.
- These events will increase the frequency with which communities will need to be evacuated.
- To improve population resilience it is necessary to make appropriate plans for large-scale population evacuation resulting from natural or manmade emergency situations.
Evacuation in Large Scale Emergencies

- As part of planning, for a given range of scenarios it is necessary to:
  - Estimate the time required to evacuate a region,
  - Determine optimal evacuation routes,
  - Identify the best locations for refuge areas, and,
  - Prioritise evacuation regions - deployment of emergency services.

- Incident managers must also be able to quickly adapt emergency plans in light of real-time developments such as:
  - Actual or forecast loss of evacuation routes,
  - Changing hazard development,
  - Availability of resources

- Urban-scale evacuation simulation using multi-agent models offers:
  - Emergency planners a means to develop and test evacuation procedures before an emergency,
  - Incident managers real-time support to determine the best evacuation procedures to adopt during an on-going emergency.
EXODUS Software

- Developed by FSEG and under constant development since 1989

  • Agent based model with Rule Based Behaviour.
    • Behaviour is adaptive
    • Some rules stochastic.

  • Behaviour model considers:
    • People-people
    • People-fire
    • People-Structure

  • EXODUS unique features include:
    • ability to simulate impact of heat, smoke and toxic gases on evacuation capability of individuals
    • ability to include interaction of authorities with population
    • extensive validation history
Typical building EXODUS Applications

- High-Rise building evacuation using lifts.
- Underground station evacuation.
- Software routinely used for design applications.
buildingEXODUS and SMARTFIRE simulation of Station Nightclub fire

• Link fire simulation directly with evacuation analysis
• Directly expose agents to developing hazard environment
• Predict fatalities and injury levels.

• Last survivor evacuates after approx 127 seconds.
• Simulation predicts:
  • 84 fatalities compared with 100 in actual incident.
  • 25 serious injuries, of which 6 are life threatening.
Large external crowd simulation

• Hypothetical incident in Trafalgar Square: 125,000+ people simulation

• Love Parade Disaster reconstruction: 100,000 people simulation.
Large Scale Emergency Planning and Management

- As part of an EU FP7 project called IDIRA, a prototype version of the EXODUS software was developed for use in large-scale urban emergency applications.

- Intended applications include: wildfire, floods, tsunami, earthquakes, etc.

- Software is intended to assist in planning large-scale movement of people and for real-time use to assist in management.

- Two versions envisaged:
  - urbanEXODUS for use in planning applications
  - webEXODUS for use in real-time incident management applications
Proto-Type Features Developed as part of IDIRA

- EXODUS extended to incorporate GIS data (e.g. maps from OSM) and GIS data formats (e.g. shapefiles storing population distribution and density)
- Established a semi-automatic method of converting geospatial vector data (Open Street Maps) to EXODUS geometry data
- Extended fine network spatial representation within EXODUS to include: Course Nodes and Continuous Spatial representations.
  - Enables more efficient representation of very large urban spaces.
- Developed a Web UI allowing non-expert users to:
  - Enter scenario data and configure scenarios
  - Remote management of EXODUS simulations
  - Automatically analyse evacuation simulation results with ability to identify regions that developed critical congestion
  - Ability to integrate with modern web based GIS Crisis Management systems to provide support for real-time incident management.
urbanEXODUS prototype

- Define and explore evacuation scenarios for planning purposes
- User defines:
  - evacuation region, refuge locations, populations, evolving hazards.
- The evacuation region and scenario is constructed.
- Explore various what-if scenarios including:
  - variations in population characteristics and distribution, route availability, hazard locations, evacuation procedures, etc
- Establish evacuation efficiency for a given scenario.
- Save configurations and scenarios for real-time use

Planning and Preparation

Input

Spatial data
Fire Simulation data

Configure simulations on urbanEXODUS
Scenario configuration file

Run simulation
EXODUS Engine

EXODUS Geometry
Store EXODUS geometries
Database

Store simulation GIS data
GIS Server

Shapefiles
**webEXODUS prototype**

- **Pre-incident**: urbanEXODUS used to define procedures for a range of scenarios, create libraries of physical region and scenarios.
- **During-incident**: webEXODUS retrieves most similar library case.
- Incident managers can quickly modify an existing scenario or set up a new scenario.
- First responders in the field can dynamically update route availability, hazard spread, population distribution.
- Changes to the planned scenario dynamically updated to determine impact on procedures – faster than real time.
Swinley Forest Fire

- uEX used to simulate hypothetical evacuation associated with the Swinley forest fire.
- Fire simulation based on real incident but assumed slightly different weather conditions to assess the danger to nearby built up area.
- Fire simulation based on real meteorological data on 2 May 2011 (fuel maps, ignition locations, wind direction).
- Four evacuation scenarios were examined simulating different evacuation routes adopted by the at-risk population.
- Purpose of study to assess the available safety margins associated with each of the possible evacuation routes.
SWINLEY FOREST FIRE

- Swinley forest fire was the largest in Berkshire’s history
  - 5 May 2011, 300 hectares of forest
  - Very close to built up areas
  - Close to the high-security Broadmoor Hospital
SWINLEY FOREST FIRE
- Conditions were variable on the day.
- Concerned of repercussions if wind changed.
- Spread of fire modelled using Prometheus by Tom Smith KCL
  - Considered what would have happened if wind changed direction.
  - How long to evacuate threatened population?

- Actual region burnt
- Simulated burn region given wind change

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**Simulated Fire evolution** – from ignition to 273 minutes

- Criteria used to define safety margin:
  - Region assumed to be unsafe when fire front is within 500m.
  - Safety margin = time for fire front to be within 500m of region - time at which last person passes through region

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Fire (minutes)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>91.00</td>
<td>Fire close to NE section of A3095, RD occupants must clear A3095 before this time</td>
</tr>
<tr>
<td>2</td>
<td>126.00</td>
<td>Fire reaches A3095, the affected section of A3095 cannot be used,</td>
</tr>
<tr>
<td>3</td>
<td>210.00</td>
<td>Fire reaches middle section of B3348 therefore B3348 cannot be used</td>
</tr>
<tr>
<td>4</td>
<td>245.00</td>
<td>Fire crosses B3348</td>
</tr>
<tr>
<td>5</td>
<td>273.00</td>
<td>Fire approaches House 5 Fire approaches TRL</td>
</tr>
<tr>
<td>6</td>
<td>301.00</td>
<td>Fire reaches House 5 Fire approaches TRL</td>
</tr>
<tr>
<td>7</td>
<td>336.00</td>
<td>Fire consumes House 5 Fire reached TRL</td>
</tr>
<tr>
<td>8</td>
<td>364.00</td>
<td>Fire approaches Houses 1-4 Fire expands in area between TRL and houses</td>
</tr>
<tr>
<td>9</td>
<td>392.00</td>
<td>Fire consumes Houses 1-4 Fire expands towards BE</td>
</tr>
<tr>
<td>10</td>
<td>420.00</td>
<td>Fire reached BE Fire reached Old Wokingham Road</td>
</tr>
</tbody>
</table>
### Simulated Fire evolution – from 301 minutes to 420 minutes

<table>
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<tr>
<th>Milestone</th>
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</tr>
<tr>
<td>4</td>
<td>245.00</td>
<td>Fire crosses B3348</td>
</tr>
</tbody>
</table>
| 5         | 273.00         | Fire approaches House 5  
Fire approaches TRL |
| 6         | 301.00         | Fire reaches House 5  
Fire approaches TRL |
| 7         | 336.00         | Fire consumes House 5  
Fire reached TRL |
| 8         | 364.00         | Fire approaches Houses 1-4  
Fire expands in area between TRL and houses |
| 9         | 392.00         | Fire consumes Houses 1-4  
Fire expands towards BE |
| 10        | 420.00         | Fire reached BE  
Fire reached Old Wokingham Road |

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Evacuation Sequence

- For simplicity, assume evacuation and fire spread start at the same time.
  - In reality, evacuation initiation starts some time after fire starts
  - This delay should be considered when evaluating size of safety margin.

- TRL Evacuation: Initiated by phone call at $t=0\text{s}$, $RT=1–2\text{min}$

- BE Evacuation: Initiated by phone call at $t=0\text{s}$, $RT=1–2\text{min}$

- Pub Evacuation: Initiated by phone call at $t=0\text{s}$, $RT=0.5–1\text{min}$

- RD Evacuation: Initiated by police door to door, requires
  - 5 min for police to reach first house,
  - 1 min required for police to reach next house, etc.
  - Once alerted, occupants require 5 min to get ready.
Evacuation Scenario 1: Most Direct Routes adopted

**TRL:**
- Main exit, turn right onto B3430, go to Assembly Area.

**Business Estate:**
- Main exit, turn right and right onto B3430, go to Assembly Area.

**Pub:**
- Exit, turn left onto B3430, go to Assembly Area.

**Residential Dwellings:**
- Follow B3348 and then A3095 towards the pub, turn left onto B3430, go to Assembly Area.
Evacuation Scenario 2

Evacuation Scenario 2: TRL avoids using main entrance to allow emergency vehicles access

TRL:
- Main exit, left onto path towards and through Business Estate, follow then same path as Business Estate

Business Estate:
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:
- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:
- Follow B3348 and then A3095 towards the pub, turn left onto B3430, go to Assembly Area.
Evacuation Scenario 3

Evacuation Scenario 3: Most direct route adopted EXCEPT RD who take Old Wokingham Road due to advance of fire front threatening B3348.

TRL:
• Main exit, turn right onto B3430, go to Assembly Area

Business Estate:
• Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:
• Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:
• Follow B3348 (only isolated house) and then Old Wokingham Road towards the Business Estate, turn right onto B3430, go to Assembly Area.
Evacuation Scenario 4

Evacuation Scenario 4: TRL avoids using main entrance to allow emergency vehicles access AND RD take Old Wokingham Road due to advance of fire front threatening B3348.

TRL:
- Main exit, left onto path towards and through Business Estate, follow then same path as Business Estate

Business Estate:
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:
- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:
- Follow B3348 (only isolated house) and then Old Wokingham Road towards the Business Estate, turn right onto B3430, go to Assembly Area.
Assembly Simulation – Scenario 1

Each dot represents an area of 6m x 6m, colour represents population density
Safety Margins – Scenario 1

Safety of Pub
• Pub clears point (B) at 4 min 28 sec.
• Pub assembles at 18 min 38 sec.
• Fire approaches A3095 at 91 min (milestone 1).
• Pub has safety margin of 86 minutes.

Safety of TRL
• TRL clears point (A) in 10 min 48 sec.
• TRL assembles at 35 min 26 sec.
• Fire approaches TRL at 301 min (milestone 6).
• TRL has a safety margin of 290 min.

Safety of Business Estate
• BE clears point (E) at 13 min 11 sec.
• BE assembles at 51 min 36 sec.
• Fire approaches BE at 392 min (milestone 9).
• BE has a safety margin of 378 min.

Safety of Residential Dwellings
• RD clear safe point (C) at 53 min 52 sec.
• RD assemble at 1 hr 11 min 32 sec.
• Fire approaches A3095 at 91 min (milestone 1).
• RD have a safety margin of 37 min.
• Fire reaches A3095 at 126 min, a critical point deeming that section of the road is unusable.
Congestion on Evacuation Routes

<table>
<thead>
<tr>
<th>CWT/PET</th>
<th>Sc1 (%)</th>
<th>Sc2 (%)</th>
<th>Sc3 (%)</th>
<th>Sc4 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL</td>
<td>7.2</td>
<td>5.7</td>
<td>7.2</td>
<td>5.7</td>
</tr>
<tr>
<td>BE</td>
<td>1.2</td>
<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Pub</td>
<td>5.7</td>
<td>5.6</td>
<td>5.7</td>
<td>5.6</td>
</tr>
</tbody>
</table>

- Relatively small amounts of congestion experienced on evacuation routes.
  - Congestion is not an issue in any of the scenarios.
  - TRL pop experienced greatest levels of congestion in SC1/3 when they take the direct route to the assembly area.
    - However, only waste 7% of travel time in congestion.
  - BE pop experience marginally greater levels of congestion in SC2/4
    - Occurs when the TRL join them on their evacuation route.
    - However, BE waste less than 2% of evacuation time in congestion.
## Assembly Performance

<table>
<thead>
<tr>
<th>Proportion Assembled</th>
<th>50% (610)</th>
<th>80% (976)</th>
<th>95% (1159)</th>
<th>100% (1220)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>00:30:56</td>
<td>00:35:05</td>
<td>00:45:19</td>
<td>01:11:45</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>00:55:22</td>
<td>01:02:30</td>
<td>01:05:58</td>
<td>01:10:54</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>00:30:55</td>
<td>00:35:06</td>
<td>00:45:29</td>
<td>01:26:14</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>00:55:20</td>
<td>01:02:40</td>
<td>00:59:00</td>
<td>01:24:38</td>
</tr>
</tbody>
</table>

- In SC 3:
  - 50% of the population arrive in 30min – must be prepared asap.
  - 95% of the population are assembled in just over 45 min.
  - Last 5% require 50% of the total assembly time.

- In SC2:
  - 50% of the population arrive in 55min – more time to prepare.
  - 95% of the population are assembled in 1hr 6 min.
  - Last 5% require just 5 min or 7% of the assembly time.
Assembly Times – Scenario 1, 2, 3 and 4

RD: SC1,2 Average distance travelled: 2.7km
RD: SC3,4 Average distance travelled: 3.0km
TRL: SC1,3 Average distance travelled: 1.5km
TRL: SC2,4 Average distance travelled: 3.0km
PUB: Average distance travelled: 0.8km
BE: Average distance travelled: 2.3km

Last 5% require 50%
50% arrive in 30 min

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pub (hh:mm:ss)</th>
<th>TRL (hh:mm:ss)</th>
<th>BE (hh:mm:ss)</th>
<th>RD (hh:mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>18:38</td>
<td>35:26</td>
<td>51:36</td>
<td>1:11:32</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>18:37</td>
<td>1:07:05</td>
<td>52:09</td>
<td>1:10:26</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>18:42</td>
<td>35:35</td>
<td>51:16</td>
<td>1:26:01</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>18:40</td>
<td>1:07:25</td>
<td>52:31</td>
<td>1:24:25</td>
</tr>
</tbody>
</table>

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Assembly Performance – Scenario 1, 2, 3 and 4

Assembly average first and last use (hh:mm:ss)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pub</th>
<th>TRL</th>
<th>BE</th>
<th>RD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>12:27</td>
<td>21:36</td>
<td>34:34</td>
<td>1:00:43</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>12:18</td>
<td>45:11</td>
<td>34:09</td>
<td>1:01:09</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>12:17</td>
<td>21:30</td>
<td>34:15</td>
<td>1:04:09</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>12:23</td>
<td>45:12</td>
<td>34:13</td>
<td>1:05:36</td>
</tr>
</tbody>
</table>
Swinley Forest Fire – Safety Margins – Scenario 1, 2, 3 and 4

SAFETY MARGINS FOR SCENARIO 1

- Clearance time
- Safety Margin
- Fire Approach

SAFETY MARGINS FOR SCENARIO 2

SAFETY MARGINS FOR SCENARIO 3

SAFETY MARGINS FOR SCENARIO 4

Clearance time
Safety Margin
Fire Approach
### Evacuation Scenario Comparison

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assembly (hh:mm:ss)</th>
<th>Safety Margin (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pub</td>
<td>TRL</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>18:38</td>
<td>35:26</td>
</tr>
<tr>
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<td>18:40</td>
<td>1:07:25</td>
</tr>
</tbody>
</table>

- Longest distance travelled is 3.0 km, by:
  - RD occupants in SC3,4
  - TRL occupants in SC2,4
- FIRST to assemble always from PUB, LAST always from RD
- Minimum safety margins are:
  - 37 min incurred by the RD in SC1&2
  - 86 min incurred by the Pub in SC3&4
- Maximum safety margin always for BE, always greater than 365 min
- SC3 is the best option as it provides the maximum safety margin for each population group, even though it also produces:
  - LONGEST assembly time and MAX travel distance for RD
Evacuation Scenario Comparison

- Due to the likely delay between fire initiation and start of the evacuation, SC1&2 unlikely to be viable due to small safety margin.
  - Unlikely to be possible to alert the RD in time to make this a viable evacuation strategy.
- SC3 provides the largest safety margins for the entire population, but results in the RD having to travel the greatest distance and will result in the longest overall assembly time.
- In SC3,
  - PUB should be prioritised to be alerted first as they have the shortest SAFETY MARGIN – 86 min.
  - Next at risk group are the RD – they have a safety margin of 165 min.
- If unable to use the main entrance road to TRL (SC2&4), diverting the TRL population through the BE:
  - Doubles travel distance for TRL from 1.5km to 3.0km
  - Doubles assembly time for TRL from 35min to 67min
  - Decreases TRL safety margin by 30 min to 260min
  - Marginally increases congestion experienced by BE population
CONCLUSIONS

- Use of urban-scale evacuation modelling tools allow ‘WHAT-IF’ scenarios to be examined prior to an incident occurring.
  - Enhances population resilience by enabling authorities to plan and evaluate possible possible evacuation procedures.

- Provides insight into:
  - Timeframes required to get population to safety.
  - Safety margins available for various at risk groups.
  - Viability of designated safety refuges.
  - Prioritise alerting of at-risk groups.
  - Assist in prioritisation of tasks for emergency services.

- Integration with crises management systems enables:
  - Unforeseen events to be taken into consideration during the incident in real-time.
  - Formulation of new procedures to accommodate real situation as opposed to planned situation.
  - Confirmation of command decisions.