IN-PREP

Wildfire: trapped on the seashore and seaborne evacuation

urbanEXODUS Evacuation Simulation Information Layer

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FSEG: Modelling safety and security

- Research and development work of the Fire Safety Engineering Group includes the mathematical modelling and experimental analysis of:
  - Pedestrian and Evacuation dynamics in complex spaces
  - Combustion and fire/smoke spread
  - Fire suppression

- Evacuation Simulation Layer in IN-PREP provided by urbanEXODUS

- EXODUS current state-of-the-art, capable of modelling large scale evacuation scenarios in urban or rural settings

- EXODUS can represent the evacuation process of 10s or 100s of thousands of people, called agents, in large complex spaces spanning several km²

- EXODUS tools have extensive validation history
EXODUS in a nutshell…

- EXODUS is a multi-modal microsimulation evacuation tool capable of representing **pedestrians** and **vehicles** at the individual level.
- EXODUS predicts the likely evacuation performance.
- Each agent has distinct **attributes, characteristics and abilities** (physiological, psychological, experiential).
- Interactions between **pedestrians** and **vehicles** modelled by EXODUS but **traffic model** modelled by SUMO.
- Uses a set of **rules** or heuristics to simulate human behaviour.
- Some rules are **stochastic** (e.g., determining outcome of conflict resolution).
- Incorporates **adaptive behaviour** such as:
  - Smoke avoidance, exit selection, congestion avoidance, itineraries, signage interaction, communication with other agents, use of lifts, escalators, travelators, etc.
- Data that governs agent movement and behaviour comes from literature, experiments or studies of real events or incidents.
- Can utilise a **hybrid** approach to represent the **discretisation of space**.
- Can utilise a **hybrid** approach in population representation.
EXODUS – Large scale evacuation simulation

- EXODUS: Used to predict the likely evacuation behaviour of large crowds from large complex spaces

  - Trafalgar Square demonstration: simulation of 125,000 agents
  - Love Parade disaster reconstruction: simulation of 100,000 agents
Why use Evacuation Simulation tools?

- **How** would you answer the following questions when **planning** or **managing** for a disaster?
- **How** can one **test** or **assess** the safety levels afforded by **existing evacuation procedures**?
- **How long** will it take to evacuate the area?
- What are the **safety margins** afforded by the incoming hazards (e.g., fire front/smoke plume, flood waters) as the population evacuates?
- **How can you assess the impact of hazards** (e.g., chemical hazard, fire products) on evacuating population?
- Which are the **best routes** for the people to follow?
- **How can you compensate if a route gets blocked** during the incident? **What** will your **options** be and how will you be able to **assess** them?
- **How can you accommodate** for the **varied demographics, response times, travel speeds, behaviours** and the people's interactions with each other and with the environment?
- **EXODUS** simulates the **evacuation** process and attempts to provide these answers.
Google and OSM estimates vs Simulated estimates

- A single person estimate walking a distance provides no evidence of how long a large group of people would take to traverse the same distance.

- Single person estimates significantly underestimate the time needed for a population to evacuate an area.

- There is no consideration for response times, group dynamics, interactions between evacuees, individual strategies, selection of paths, etc.

<table>
<thead>
<tr>
<th>Model</th>
<th>Path A</th>
<th>Path B</th>
<th>Path C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google</td>
<td>9.0</td>
<td>16.0</td>
<td>28.0</td>
</tr>
<tr>
<td>OSM</td>
<td>8.0</td>
<td>14.0</td>
<td>23.0</td>
</tr>
<tr>
<td>urbanEXODUS*</td>
<td>8.6 – 14.8</td>
<td>20.8 – 34.3</td>
<td>36.3 – 47.9</td>
</tr>
</tbody>
</table>

*For each path urbanEXODUS assumes the following populations: Path A 200 agents, Path B 800 agents, Path C 200 agents.
EXODUS Evacuation process timeline

- Incident start:
  - Incident Detection
  - Incident Severity Assessment
  - Decision to Evacuate Area

- Evacuation process:
  - Response Stage:
    - Notification
    - Recognition
    - Responding
  - Evacuation Phase:
    - People notified and responding
    - People moving towards exit points or safety locations

- Pre-incident:
  - Area and people may be affected by hazard

- Post-incident:
  - Person i Incident cue:
    - Individual starts evacuation independently and prior to alarm
    - *Further actions and tasks undertaken may be similar to Person j
  - Person j:
    - Notification
    - Recognition
    - Action tasks
  - Response:
    - Decision to move
  - Max Response Time:
    - All agents that could respond have responded.
  - End of evacuation process:
    - All agents that could evacuate have reached safety.

- Post-Evacuation process:
  - Reach Refuge Locations or Dispersal
  - Leave scene
  - Go home
  - Regroup with others

Athens, March 2021
**FSX03 – urbanEXODUS evacuation layer**

- **First model** that demonstrates unified pedestrian evacuation Agent Based Model (ABM) and vehicle traffic model coupled with fire and smoke plume data that acts on the individual agent level including an attempt to represent seaborne evacuation.

- **Modelled Area** – Kallithea Springs and surroundings (Rhodes), covering approximately an area of 0.85km x 2.1km.

- **Population distribution** – assumed uniformly distributed population at the seafront, forested area and resorts. Assumed 2.4 passengers per vehicle.

- **Vehicle distribution** – background traffic assumed to use the main road, some vehicles are parked in the three car parks within the Kallithea Springs area.

- **Response time distribution** – assumed that at different locations the pedestrians would have different RTs (see slide 10).

- **Fire scenario** – the forested area in Kallithea Springs turns into a wildfire that burns the entire forest.

- **Evacuation process** – agents move away from progressing fire hazard through seaborne evacuation.
### FSX03 – Evacuation scenario timeline

<table>
<thead>
<tr>
<th>Clock Time</th>
<th>Dt (min)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>0</td>
<td><strong>FSX3 scenario start</strong> – simulating background traffic</td>
</tr>
<tr>
<td>10:01</td>
<td>1</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Accident between tourist bus and private car at E1, traffic building up on main road</td>
</tr>
<tr>
<td>10:04</td>
<td>~4</td>
<td><strong>Main road</strong> is now completely congested</td>
</tr>
<tr>
<td>10:18</td>
<td>18</td>
<td>Bus passengers move south into pine forested area waiting for another bus</td>
</tr>
<tr>
<td>10:26</td>
<td>26</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Accident at E2, the collision causes a <strong>FIRE</strong> to start</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrians in forested area start moving towards the beaches</td>
</tr>
<tr>
<td>10:28</td>
<td>29</td>
<td>Ped. in forested area, near E2, start moving away from fire and towards the seashore, vehicle passengers start evacuating away from fire too, some move towards north and south exits</td>
</tr>
<tr>
<td>10:31</td>
<td>31</td>
<td><strong>Heavy smoke</strong> can be seen at E2, ped. in forested area redirect towards the seashore, pedestrians further away from fire start responding too, <strong>seaborne evacuation</strong> has commenced, pedestrians and pax continue to evacuate via north and south exits</td>
</tr>
<tr>
<td>11:05</td>
<td>66</td>
<td><strong>Evacuation</strong> of nearby resorts and hotels commences</td>
</tr>
</tbody>
</table>

*NOTE: only the events of the FSX3 scenario relevant to the evacuation process are listed*
FSX03 – Fire and plume model

- The 1st accident blocks the main road leading to heavy congestion
- The 2nd accident causes a fire that evolves into a wildfire
- Wildfire eventually burns the entire forested area
- Fire modelled using FARSITE and smoke plume using HYPSLIT wildfire data provided by IN-PREP partner IES
- **Fire data** estimates at each time step the area that has been burned
- **Plume data** estimates at each time step the $\text{PM}_{2.5}$ concentration levels ($\mu g/m^3$)
- **Plume model** estimated $\text{PM}_{2.5}$ concentration levels @ 150, 300, 600, 1200, 2400 $\mu g/m^3$ average between 0m to 50m above ground level (agl)
Exposure to PM\textsubscript{2.5} follows Haber’s Law → physiological effect occurs at a constant $D = C \times t$

The WHO set Air Quality Guideline (AQG) value for daily mean concentration of PM\textsubscript{2.5} at $25\mu g/m^3$

European Air Quality Index (AQI) levels indicate that conditions are poor at this level:

<table>
<thead>
<tr>
<th>European AQI</th>
<th>Good</th>
<th>Fair</th>
<th>Moderate</th>
<th>Poor</th>
<th>Very Poor</th>
<th>Extremely poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM\textsubscript{2.5} (\mu g/m^3) 24-hour average</td>
<td>0 - 10</td>
<td>10 - 20</td>
<td>20 - 25</td>
<td>25 - 50</td>
<td>50 - 75</td>
<td>75 - 800</td>
</tr>
</tbody>
</table>

The equivalent exposure dose to $25\mu g/m^3$ average for 24h for different exposure concentrations and times:

<table>
<thead>
<tr>
<th>PM\textsubscript{2.5} concentration ( (\mu g/m^3))</th>
<th>2400</th>
<th>1200</th>
<th>600</th>
<th>300</th>
<th>150</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure time (min)</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td>120</td>
<td>240</td>
<td>1440</td>
</tr>
</tbody>
</table>

Developed exposure dose model to determine cumulative effect of PM\textsubscript{2.5} on exposed agents at various concentration levels:

$$FD\textsubscript{AQG} = \frac{150 \times t\textsubscript{150} + 300 \times t\textsubscript{300} + 600 \times t\textsubscript{600} + 1200 \times t\textsubscript{1200} + 2400 \times t\textsubscript{2400}}{36000}$$

At $FD\textsubscript{AQG} = 1.0$ the equivalent of daily mean of $25\mu g/m^3$ would be reached where the conditions are considered poor.
FSX03 – Air quality index

<table>
<thead>
<tr>
<th>POLLUTANT</th>
<th>INDEX LEVEL (based on pollutant concentrations in μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Very good</td>
</tr>
<tr>
<td>Ozone (O₃)</td>
<td>0-50</td>
</tr>
<tr>
<td>Nitrogen dioxide (NO₂)</td>
<td>0-40</td>
</tr>
<tr>
<td>Sulphur dioxide (SO₂)</td>
<td>0-100</td>
</tr>
<tr>
<td>Particles less than 10 μm</td>
<td>0-20</td>
</tr>
<tr>
<td>(PM₁₀)</td>
<td></td>
</tr>
<tr>
<td>Particles less than 2.5 μm</td>
<td>0-10</td>
</tr>
<tr>
<td>(PM₂.₅)</td>
<td></td>
</tr>
</tbody>
</table>

Note: PM₁₀ and PM₂.₅ values are based on 24-hour running means.

Health warnings of emergency conditions, the entire population is likely to be affected. **Everyone** should **avoid** prolonged or heavy exertion outdoors. **Sensitive groups** should **avoid all** physical activity.

- Everyone may begin to experience health effects.
- Sensitive groups affected more severely.
- Everyone should reduce prolonged or heavy exertion outdoors.
- **Sensitive groups** such as children with asthma, adults with heart or lung diseases should **avoid** prolonged or heavy exertion.
Two evacuation points exist on the main road: North exit and South exit.

Four evacuation points exist on the seashore, each served by five “boats”.

Simplified flow model used to represent boats:
- Boat capacity: 15 pax
- Boarding rate: 2 p/min
- Boat round-trip: 10min
FSX03 – Population distribution and vehicles

- People in Kallithea Springs and forested area: 280
- People on seafront: 1100
- Residents at hotels: 500
- Bus passengers: 50
- **Total pedestrians**: 1930

- **Vehicles** on main road and three car parks: 501 with 1195 pax

- Total number of agents ped. & pax: 3125
FSX03 – Evacuation process vehicle/pedestrian and seaborne evacuation

Forest fire propagates towards the south, southwest.

Evacuation via boats continues...
FSX03 – Evacuation process results

1 min: 1st Acc.
36 min: Seaborne evac. starts at S1 and S4
26 min: 2nd Acc.
31 min: Seaborne evac. starts at S2
18 min: Bus pax move to forested area
66 min: Elysium resort & beach evac.
67 min: Mitsis resort & beach evac.
FSX03 – Evacuation process results

- Total population: 3125
- First to evacuate at 1.6min, last to evacuate at 2h 28min via S4 boat

- Evacuees (ped. and pax): 2931 (94%)
  - Avg. Personal Evacuation Time 61min [1.6min – 2h 28min]
  - Avg. distance travelled 0.93k [2.4m – 3.7k]
- Trapped/fatalities by wildfire: 194 (6%), 138 ped. & 56 pax
  - Avg. Personal Elapsed Time 38 min [31 min – 42 min]
  - Avg. distance travelled 0.27k [1.4m – 1.7k]

- Vehicles:
  - Vehicles evacuated 227 (45%) avg. distance travelled 2.2k [1.9k – 3.7k]
  - Vehicles stuck 274 (55%) avg. distance travelled 0.6k [6m – 1.4k]

- North exit usage: 143 (5%), first: 23min – Last:40.51min
- South exit usage: 1890 (64%), first: 1.6min – Last: 1h 28min
- Boat usage: 898 (31%) S1:299, S2:75, S3:0, S4:524 (last to finish)
FSX03 – Evacuation results and effects of smoke plume

Evacuees 2931 (94%)
FDAQG = 0.0  2465 (84%)
FDAQG < 1.0  56 (2%)
FDAQG ≥ 1.0  410 (14%)  
(14% of evacuees)

Avg FDAQG: 0.66 [0 – 17]

Trapped/Fatalities: 194 (6%)  Fatalities due to being engulfed/trapped by wildfire near the seashore
Avg FDAQG: 4.9 [0 – 13]

AQG = 25μg/m³ daily mean
• Without simulation tools it is **practically impossible** to **examine** such scenarios and compose appropriate **evacuation plans**

• **Unified urbanEXODUS** model combines the pedestrian and vehicle evacuation process while **considering** the **effects** of the **hazard** on this process.

• When no alternatives exist people may **seek escape** towards the **sea** but **access** to the sea is **not always possible** and there is a **danger** that **people** may get **trapped**.

• **Seaborne evacuations** have **occurred** on several occasions **in the past**.

• **Effects of wildfire products** on evacuated population may become **evident long after the event**.

• **Quick response** and **efficient notification** is of paramount importance to **improve** evacuation efficiency.
# Data Output from Evacuation Simulation

**EXODUS** can provide a plethora of data...

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Evacuation times and (overall and average for individual agents)</td>
<td></td>
</tr>
<tr>
<td>- Times of first person out and last person out</td>
<td></td>
</tr>
<tr>
<td>- Total number of people evacuated</td>
<td></td>
</tr>
<tr>
<td>- Clearing times</td>
<td></td>
</tr>
<tr>
<td>- Time agents waited stationary due to congestion</td>
<td></td>
</tr>
<tr>
<td>- Number of trapped pedestrians, number of fatalities</td>
<td></td>
</tr>
<tr>
<td>- Arrival times and usage of exit points, routes or refuge locations (assembly locations)</td>
<td></td>
</tr>
<tr>
<td>- Distance travelled by agents</td>
<td></td>
</tr>
<tr>
<td>- Population density information</td>
<td></td>
</tr>
<tr>
<td>- Identification of safety margins (time that hazard reaches a location minus the time that the population clears that location)</td>
<td></td>
</tr>
<tr>
<td>- Overview of entire evacuation process</td>
<td></td>
</tr>
<tr>
<td>- Live population movement/density contours indicating density or Level of Service (LOS)</td>
<td></td>
</tr>
<tr>
<td>- Popularity of evacuation paths contours</td>
<td></td>
</tr>
<tr>
<td>- Identification of regions reaching critical congestion (4p/m² for &gt; 10% of total evacuation time)</td>
<td></td>
</tr>
<tr>
<td>- Impact of critical regions (regions or paths blocked by hazards)</td>
<td></td>
</tr>
<tr>
<td>- Spread of hazard over evacuation area</td>
<td></td>
</tr>
<tr>
<td>- Severity of hazard over evacuation area</td>
<td></td>
</tr>
<tr>
<td>- Level of injury for population</td>
<td></td>
</tr>
</tbody>
</table>

Athens, March 2021
Evacuation simulation aided decisions

- **Without simulating** the whole evacuation process it is **difficult**, if not **impossible**, to:
  - Test and assess validity of existing evacuation procedures
  - Test what-if scenarios
  - Predict what may happen during a crisis

- **With modelling** you can achieve all of the above plus…
  - You do not have to rely only on the crisis manager’s experience to determine the evacuation outcome
  - You can augment the operator’s knowledge and experience (which may be scenario/region specific) allowing them to take informed decisions at both planning stage and during incident management stage

- **With modelling** you can plan for future incidents
  - Save lives, time and money!
  - Public’s confidence in the preparedness for future incidents is increased!
  - Provide increased safety during the management of a disaster.
References

- EU Framework 7 IDIRA project (261726)
- Horizon 2020 projects GEO-SAFE (691161) and IN-PREP (740627)
- http://burningissues.org/car-www/science/Harber-Rule.html (Habers Law and PM2.5.pdf)
- Ricardo/ED60428/EU AQI Final Report, Issue 1.1
Have a plan and evacuate safely...

Any questions?

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This can’t be good...