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Wildfire: trapped on the seashore and seaborne evacuation

urbanEXODUS Evacuation Simulation Information Layer

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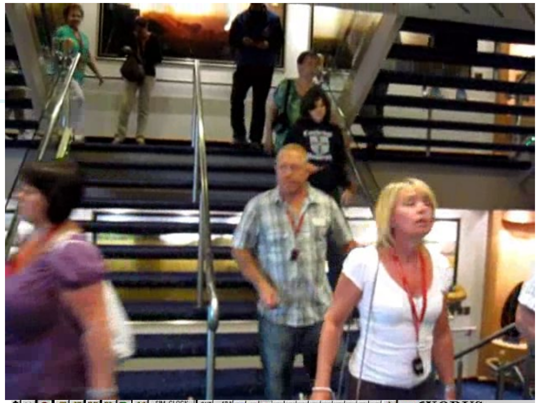
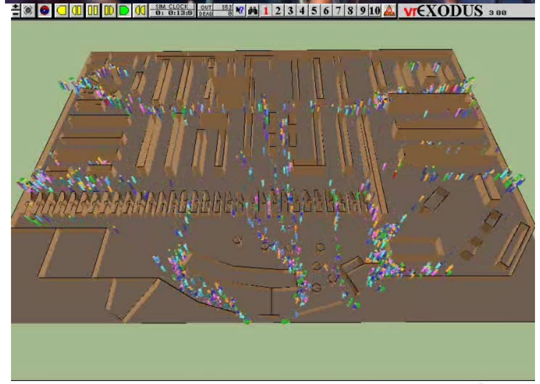
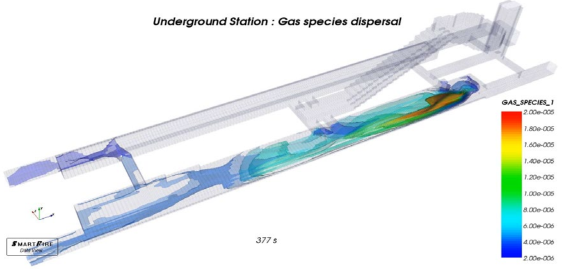
FSEG: Modelling safety and security

- 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 km^2
- EXODUS tools have extensive validation history







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FSEG: Modelling safety and security


A380 – Super Jumbo


Millennium Dome


Airbus flying wing


Stadium Australia

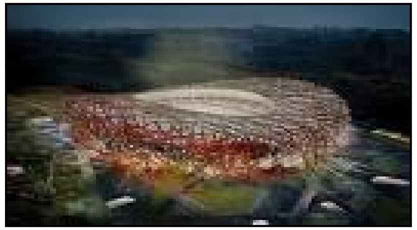

Royal Ascot


Canary Wharf


Historic Buildings

Large PAX Ships


Naval Ships


Beijing Olympic Stadium


WTC 9/11 analysis


Pentagon Shield


Forensic analysis
Rhode Island

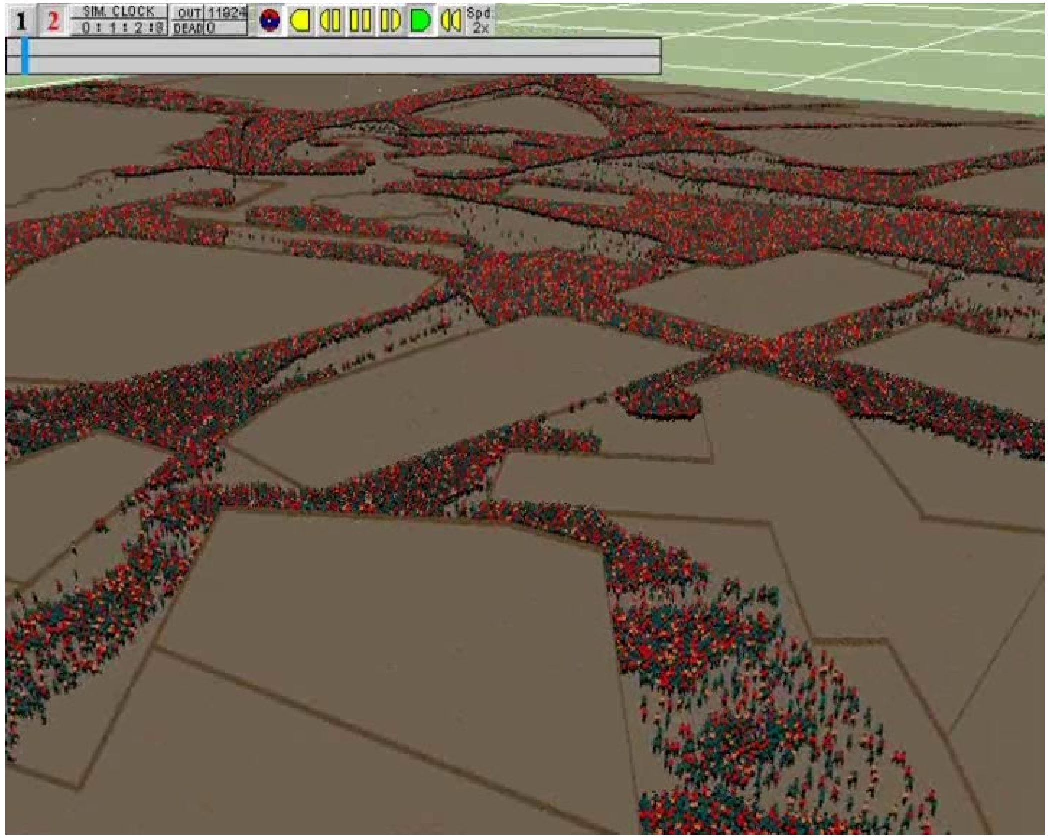

Statue of Liberty

EXODUS in a nutshell…

- **EXODUS** is a multi-modal microsimulation evacuation tool capable of representing **pedestrians** and **vehicles** at the individual level
- EXODUS **predicting 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 100000 agents

Why use Evacuation Simulation tools?

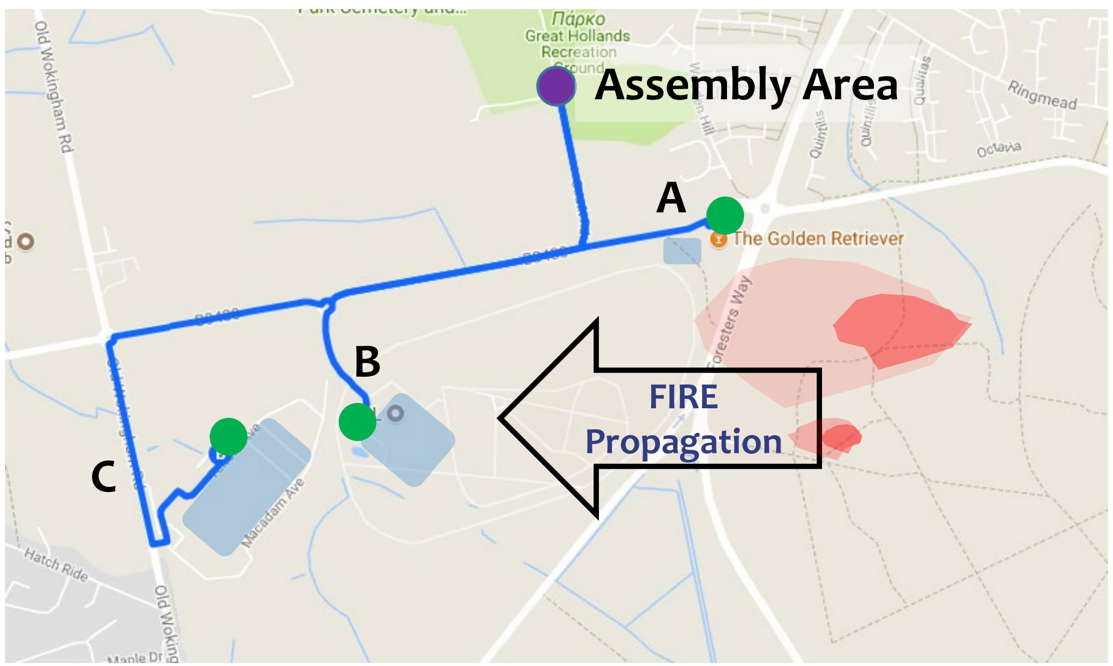
- **How** would you answer the following questions when **planning** or **managing** for a disaster?
- **How** can one **test** or **assess** the safety levels afforded by **existing evacuation procedures**?
- **How long** it will take to evacuate the area?
- What are **the safety margins** afforded 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

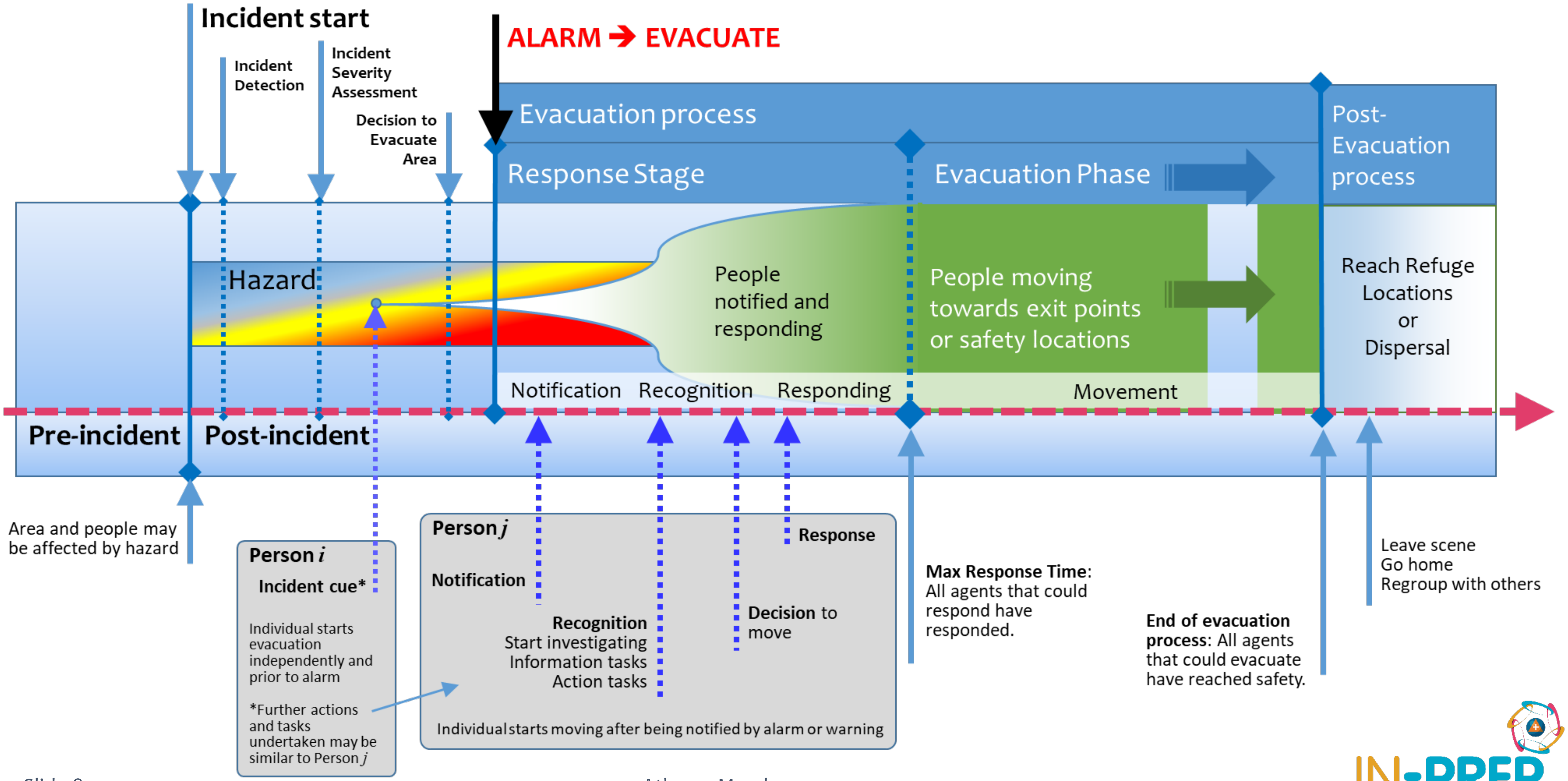
- A **single person estimate** walking a distance provides **no** evidence of how long a **large group of people** would take to traverse the same distance.
- Single person estimates significantly underestimate the time needed for a population to evacuate an area
- There is no consideration for response times, group dynamics, interactions between evacuees, individual strategies, selection of paths, etc

Model	**Walking Time* (minutes)**		
	Path A	**Path B**	Path C
Google	9.0	**16.0**	28.0
OSM	8.0	**14.0**	23.0
urbanEXODUS* (First – Last to arrive)	8.6 – 14.8	**20.8 – 34.3**	36.3 – 47.9

*For each path urbanEXODUS assumes the following populations: Path A 200 agents, Path B 800 agents, Path C 200 agents



EXODUS Evacuation process timeline



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 pars 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

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

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 **$PM_{2.5}$** concentration levels (μg/m³)
- **Plume model** estimated $PM_{2.5}$ concentration levels @ 150, 300, 600, 1200, 2400 μg/m³ average between 0m to 50m above ground level (agl)

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FSX03 – Fire and plume model

- Exposure to $PM_{2.5}$ follows Haber's Law → **physiological effect occurs at a constant** $D = C\,x\,t$
- The **WHO** set Air Quality Guideline (AQG) value for daily mean concentration of $PM_{2.5}$ at **25µg/m³**
- European Air Quality Index (AQI) levels indicate that conditions are **poor** at this level:

European AQI	Good	Fair	Moderate	**Poor**	Very Poor	Extremely poor
PM2.5 µg/m³ 24-hour average	0 - 10	10 - 20	20 - 25	**25 - 50**	50 - 75	75 - 800

- The equivalent exposure dose to 25µg/m³ average for 24h for different exposure concentrations and times:

$PM_{2.5}$ concentration (µg/m³)	2400	1200	600	300	150	**25**	D = C x t = 36000
Exposure time (min)	15	30	60	120	240	**1440**	

- Developed exposure dose model to determine cumulative effect of $PM_{2.5}$ on exposed agents at various concentration levels:

$$FD_{AQG} = \frac{150 \times t_{150} + 300 \times t_{300} + 600 \times t_{600} + 1200 \times t_{1200} + 2400 \times t_{2400}}{36000}$$

- At $FD_{AQG} = 1.0$ the equivalent of daily mean of 25µg/m³ would be reached where the conditions are considered *poor*

FSX03 – Air quality index

POLLUTANT	INDEX LEVEL *(based on polluant concentrations in μg/m3)*					
	1 Very good	2 Good	3 Medium	4 Poor	5 Very Poor	6 Extremely Poor
Ozone (O_3)	0-50	50-100	100-130	130-240	240-380	380-800
Nitrogen dioxide (NO_2)	0-40	40-90	90-120	120-230	230-340	340-1000
Sulphur dioxide (So_2)	0-100	100-200	200-350	350-500	500-750	750-1250
Particules less than 10 μm (PM_{10})	0-20	20-40	40-50	50-100	100-150	150-1200
Particules less than 2.5 μm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-75	75-800

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

$PM_{2.5}$ at 25 μg/m³ daily average

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

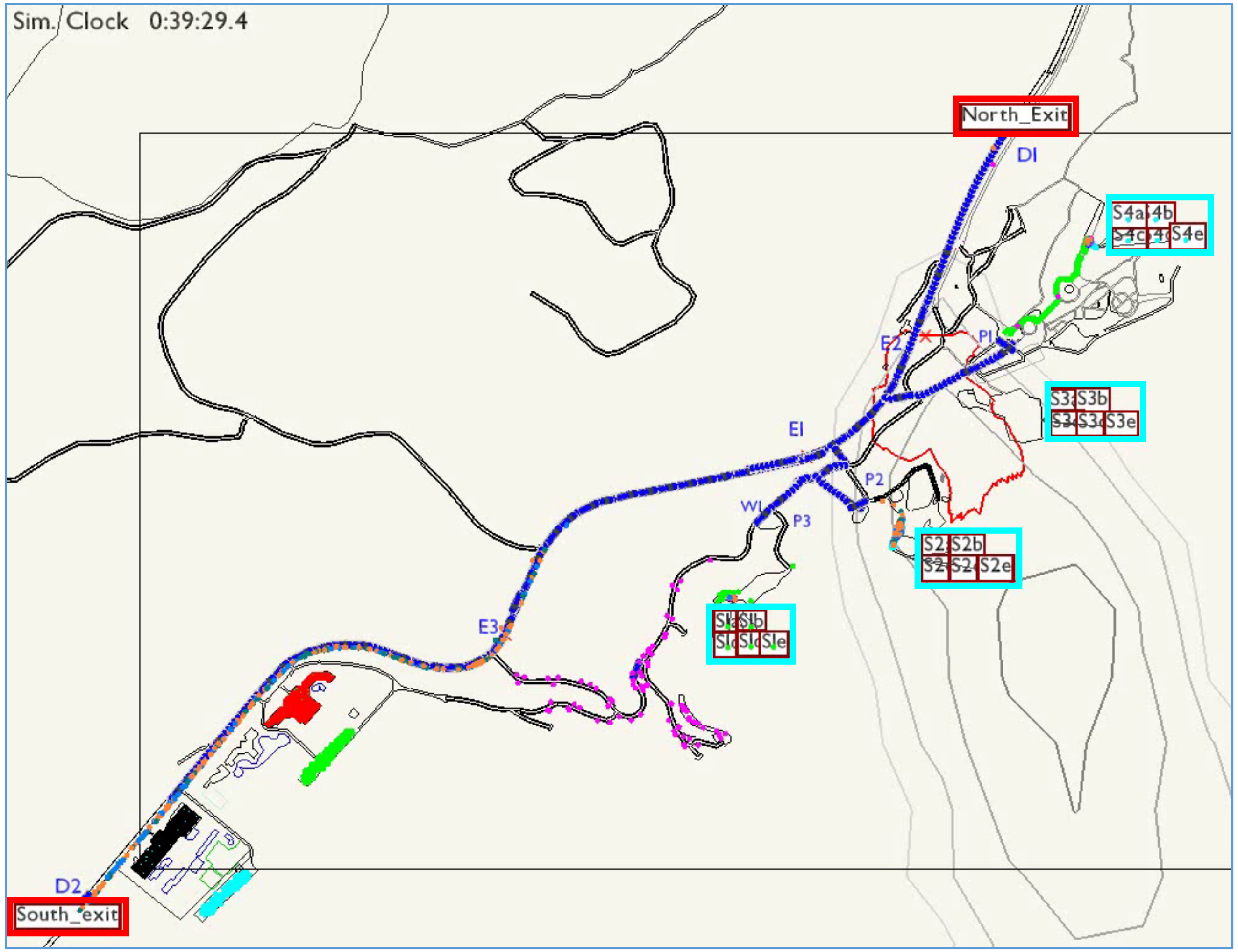
Everyone may begin to experience health effects
Sensitive groups affected more severely
Everyone should reduce prolonged or heavy exertion outdoors
Sensitive groups such as children with asthma, adults with heart or lung diseases should **avoid** prolonged or heavy exertion

FSX03 – Modelled area and target locations

- **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



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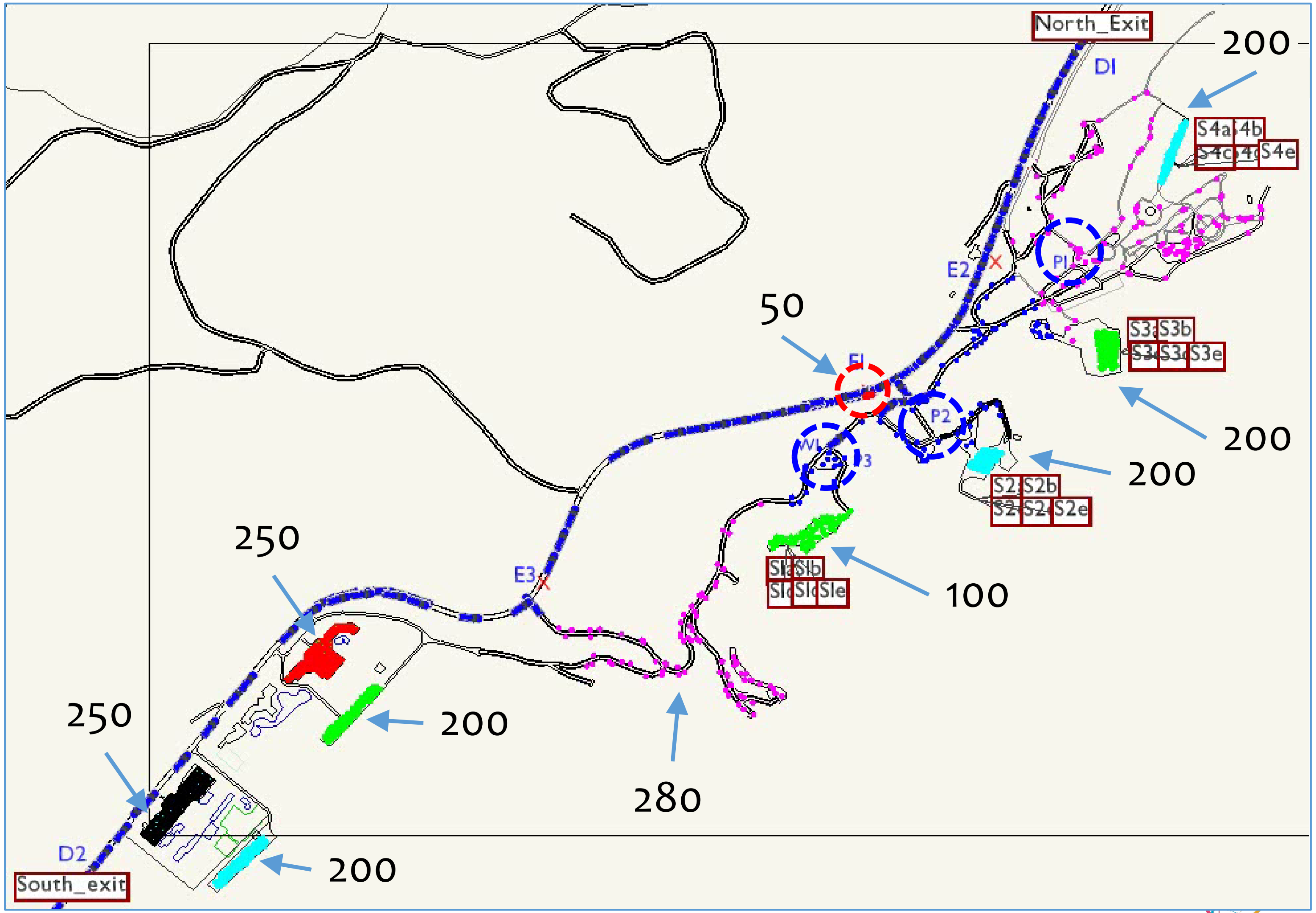
FSX03 – Population distribution and vehicles

- 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**



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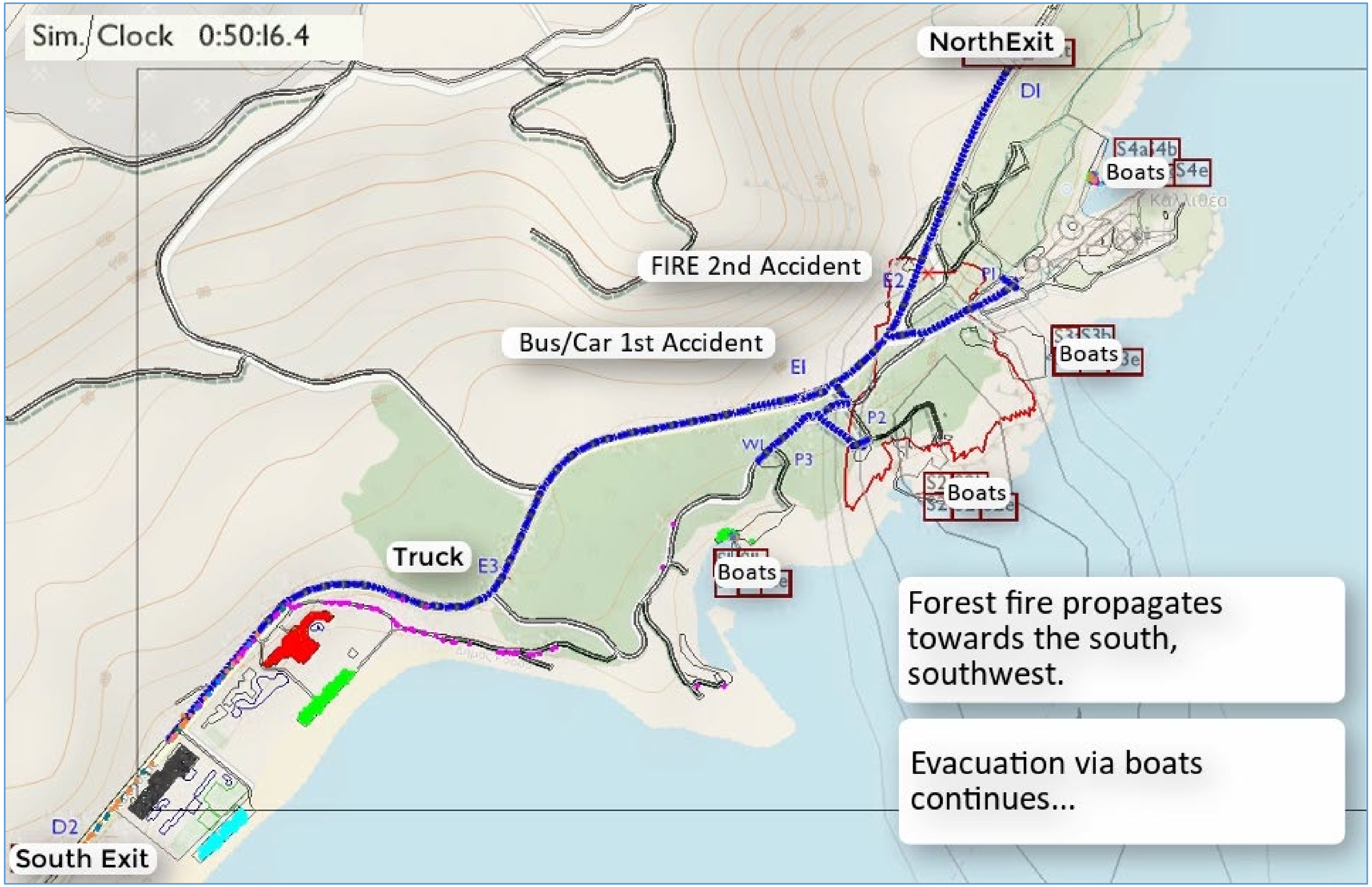
FSX03 – Evacuation process vehicle/pedestrian and seaborne evacuation



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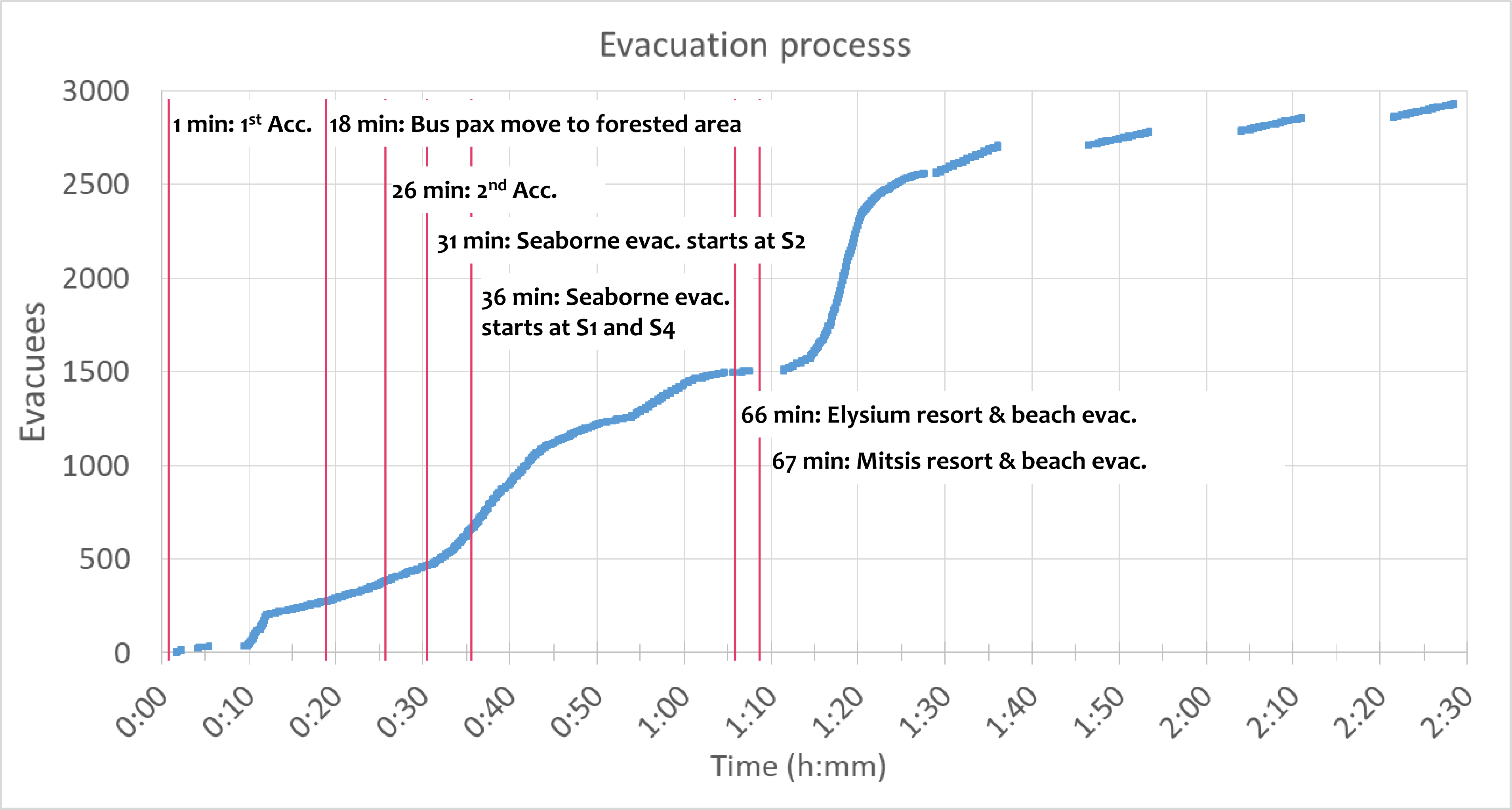
FSX03 – Evacuation process results



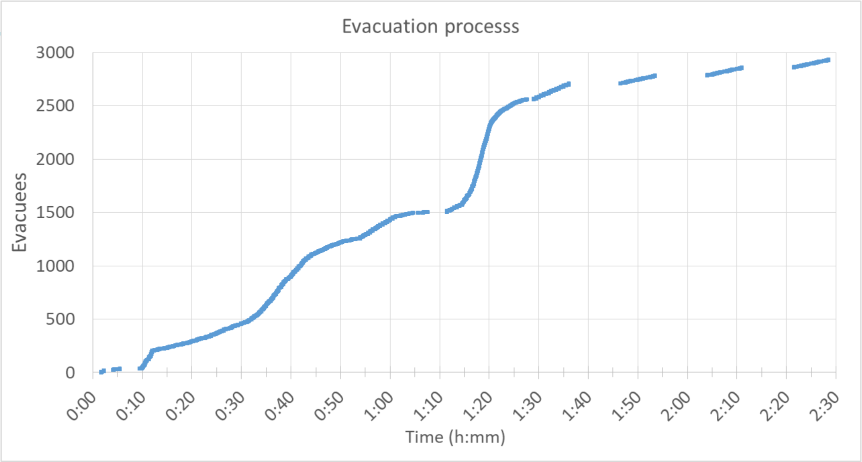
FSX03 – Evacuation process results

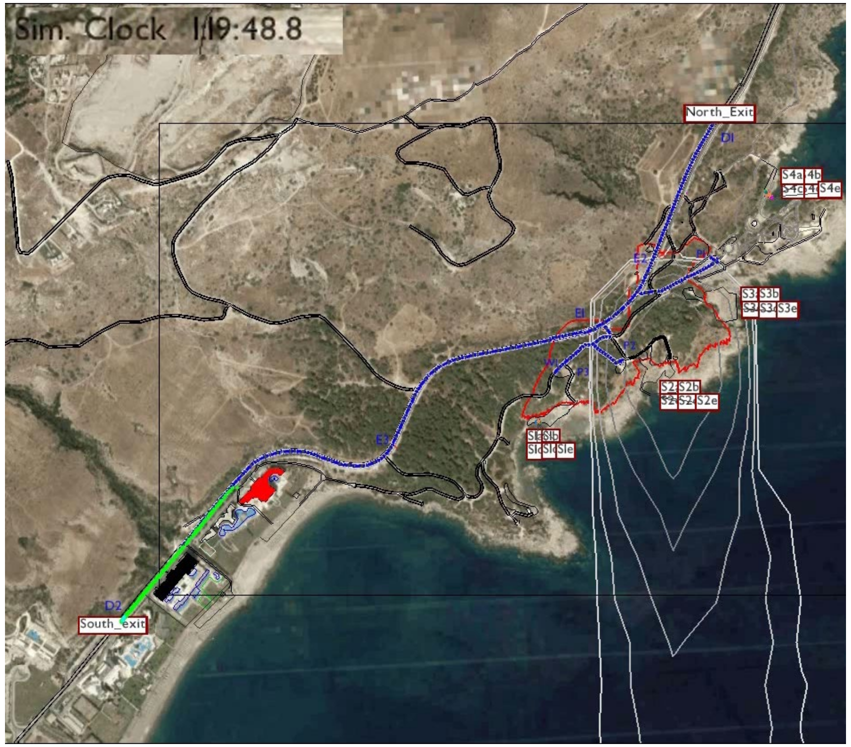
- Total population: **3125**
- First to evacuate at 1.6min, last to evacuate at **2h 28min** via S4 boat

- 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)



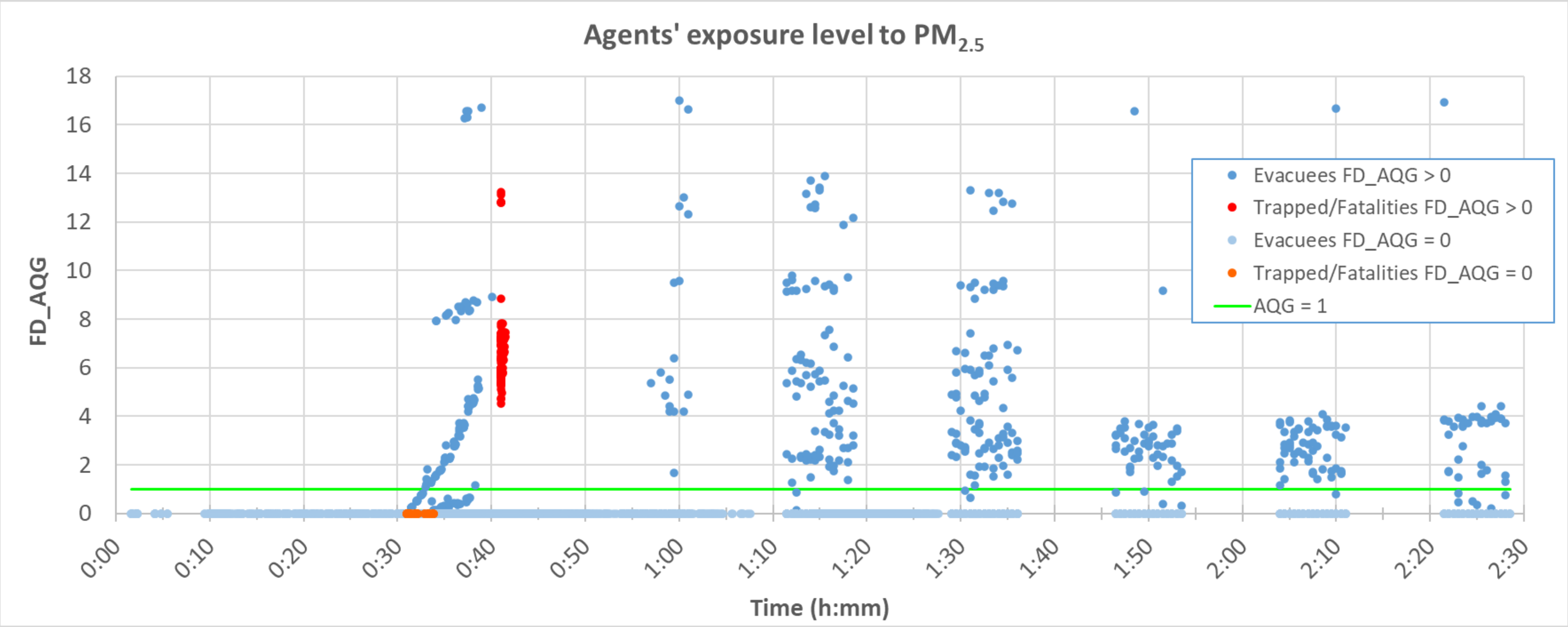


FSX03 – Evacuation results and effects of smoke plume

AQG = 25μg/m³ daily mean

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]

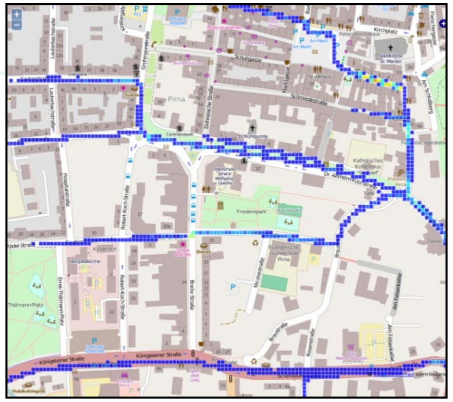
FSX03 – Evacuation Results

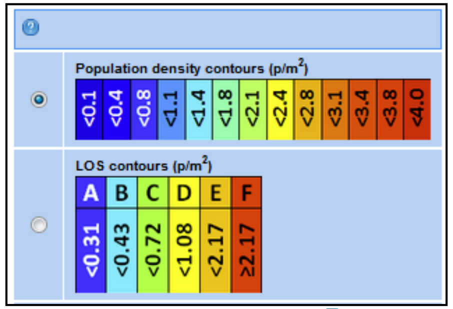
- **Without simulation** tools it is **practically impossible** to **examine** such scenarios and **compose** appropriate **evacuation plans**
- **Unified urbanEXODUS** model combines the pedestrian and vehicle evacuation process while **considering** the **effects** of the **hazard** on this process.
- 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…

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





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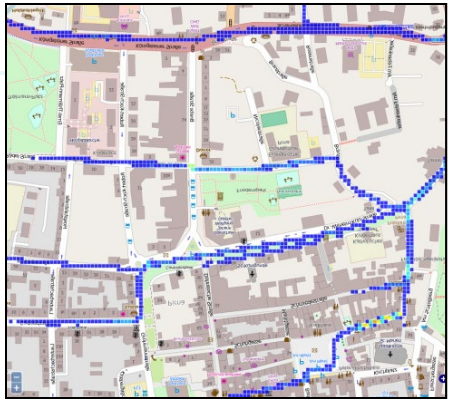
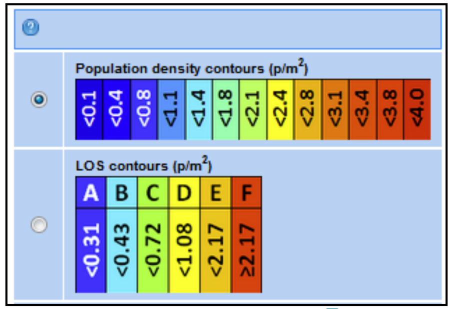
Evacuation simulation aided decisions





- **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 modeling** 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.

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Have a plan and evacuate safely…

Any questions?

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