Engineering Safety, Security and Efficiency through Simulation

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FSEG

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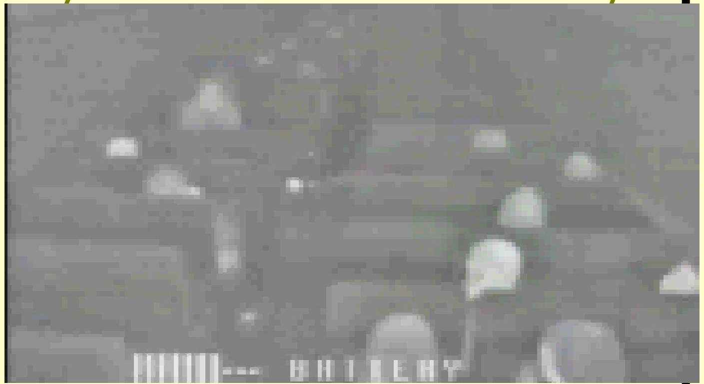
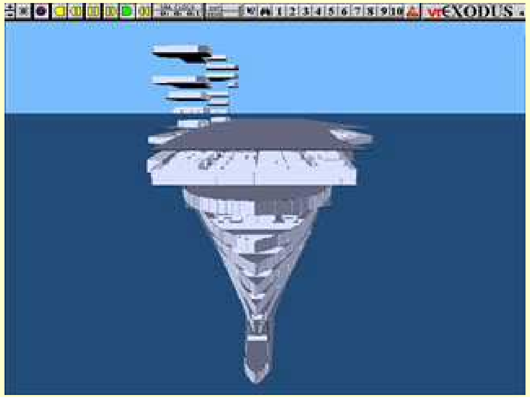
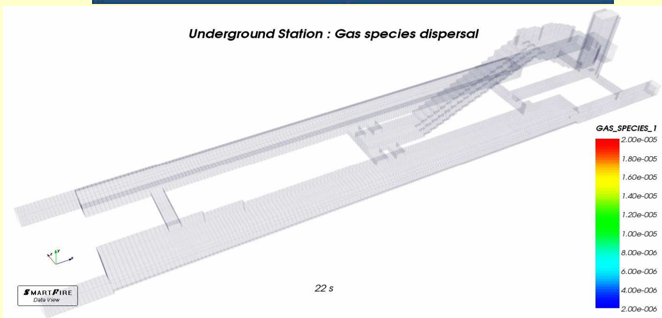
FSEG: Modelling safety and security

- FSEG was Founded in 1986 by Prof Galea in response to the Manchester Airport B737 fire.
- Today it consists of 30 researchers including:
  - fire engineers, CFD specialists, psychologists, mathematicians and software engineers.
- Research interests include the mathematical modelling and experimental analysis of:
  - evacuation dynamics in complex spaces,
  - pedestrian dynamics in complex spaces,
  - combustion and fire/smoke spread,
  - fire suppression,
  - security
- Application areas include:
  - aerospace, built environment, marine and rail.







Applications of FSEG software

A380 – Super Jumbo

Millennium Dome

Airbus flying wing

Stadium Australia

Royal Ascot

Canary Wharf

Historic Buildings

Rail Stations

Large PAX Ships

Naval Ships

Beijing Olympic Stadium

Statue of Liberty

WTC 9/11 analysis

Pentagon Shield

Forensic analysis
Rhode Island

Safety and Security in Crowded Places

- Crowded places such as airport terminals, rail stations, shopping malls, entertainment venues, and sports stadia pose a challenge to designers and operators to ensure the safety and security of the population.
- The **safe, efficient** and **comfortable** movement of people is an IMPORTANT design consideration for the efficient day to day operation of crowded places.
- **ESSENTIAL** design feature for emergencies.
  - Structural design and management procedures must take into consideration not only threats caused by accidental hazards such as fire but must also be sufficiently flexible to cope with terrorist situations.
- Failing to imbed an understanding of human behaviour into the design of buildings and emergency procedures can lead to disaster.

Disasters in Crowded Places

Kings Cross Underground Station fire (UK) 18/11/87 – 31 fatalities

Dusseldorf Airport fire (Germany) 11/04/96 – 17 fatalities

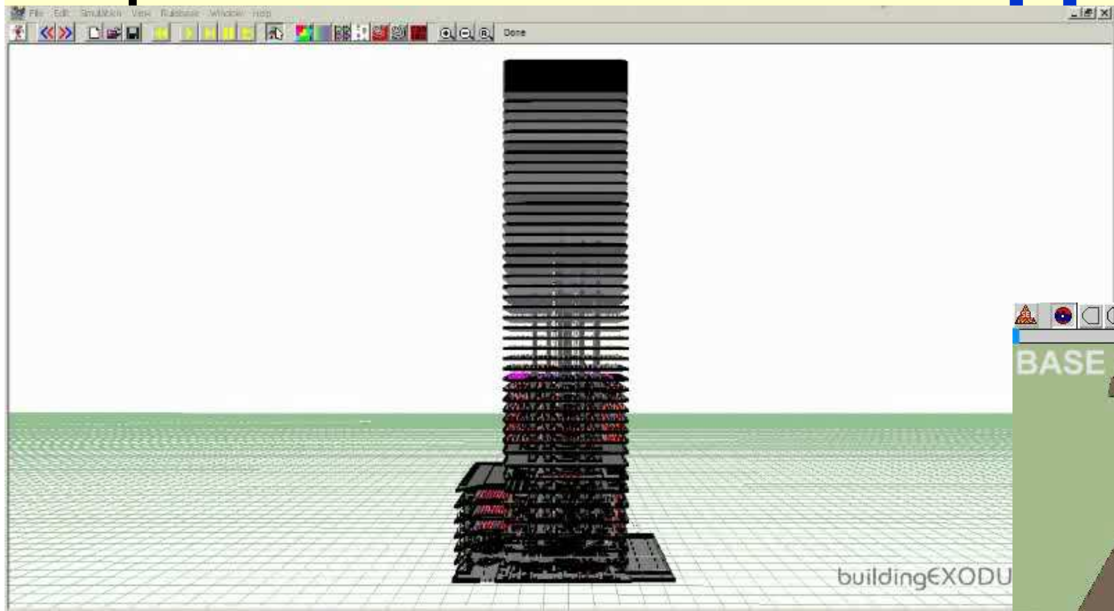
Station Disco fire, Rhode Island (USA) 20/02/03 – 100 fatalities

Love Parade (Duisburg Germany) 24/07/10 – 21 fatalities

Hajj, Mecca (Saudi Arabia) 87: 402; 90: 1,426; 94: 270; 97: 500; 98: 180; 01: 35; 04: 251; 06: 360; 15: 2,000? fatalities

Grenfell London (UK) 14/06/17 – 72 fatalities

Common Applications



New EXODUS Application Areas

New Application Areas

- Discuss three new application areas for agent based evacuation simulation:
  - Evacuation from high-rise construction sites.
    - Establish evidence base describing human performance on construction sites.
    - Expand modelling capability to include unique features.
  - Augmented and Virtual training Environments.
    - Develop capability for external users to take control of their avatar
    - Develop series of new behavioural capabilities
    - Integrate with gaming environment
  - Urban-scale evacuation simulation
    - Include capability to interact with Open Street Maps
    - Real-Time analysis
    - Integrate with traffic models allowing pedestrians to be 'aware' of vehicles and 'vehicles' to be aware of pedestrians

Part 1: Evacuation From High-Rise Construction Sites

Who can hope to be safe? who sufficiently cautious?
Guard himself as he may, every moment's an ambush. Horace

Construction Site Evacuation

- Around the world construction is considered one of the most dangerous industries.
- 2015-2016, 43 fatal accidents in the UK
  - 3rd highest rate of fatal injuries in the work place
- Catastrophic events will require the full evacuation of the site

Collingdale 2006
Timber Frame
Smoking

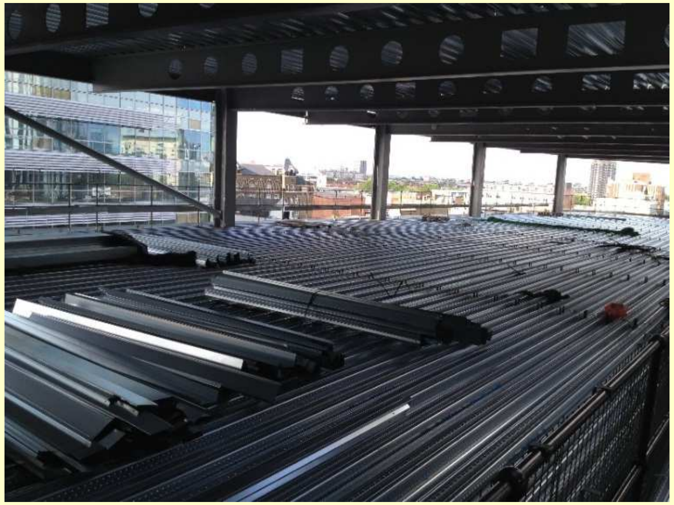
Belway Homes 2008

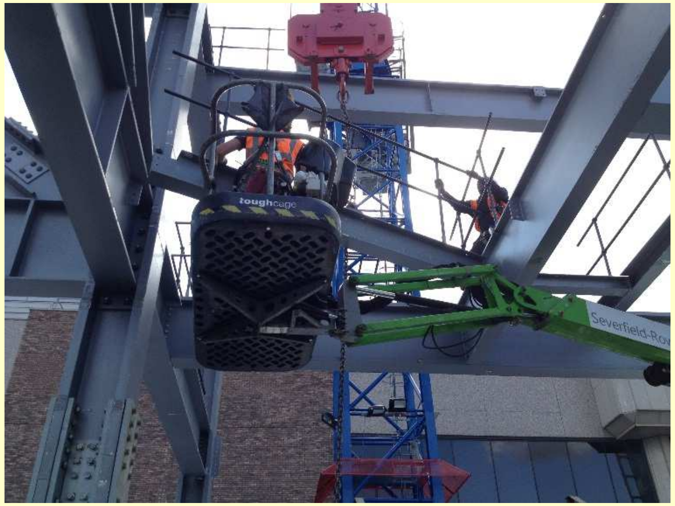
Basingstoke 2010
Timber Frame
Arson


EMAAR

Construction Site Evacuation - Issues

- Does not have fire engineered evacuation solution
- Not governed by evacuation regulations.
- Physical layout constantly changing making wayfinding difficult and requiring that evacuation rotes are constantly updated
- Floor surfaces can be physically challenging hindering rapid movement.
- Some activities must be made safe prior to evacuation.
- Working at height.





- 2 High-rise Construction sites
- 4 Evacuation Trials

iosh

MULTIPLEX
Built to outperform.

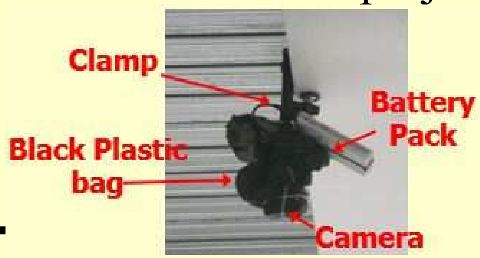
Introduction To The Trials

- Two construction sites were identified for use in the evacuation trials.
  - 100 Bishopsgate (100 BG) and 22 Bishopsgate (22 BG).
- 100 BG - 37 storey office building (expected completion in 2018)
- 22 BG - 62 storey office block (expected completion in 2019).
  - Largest core in Europe, tallest structure in the City of London, 2nd tallest in UK.

*Images of completed buildings taken from Wikipedia




- Trial data collection using strategically placed video cameras and surveys.
- 30 GoPro cameras used for the project



Three Areas of Construction

Jump/Slip Form

Core

Partially completed floors

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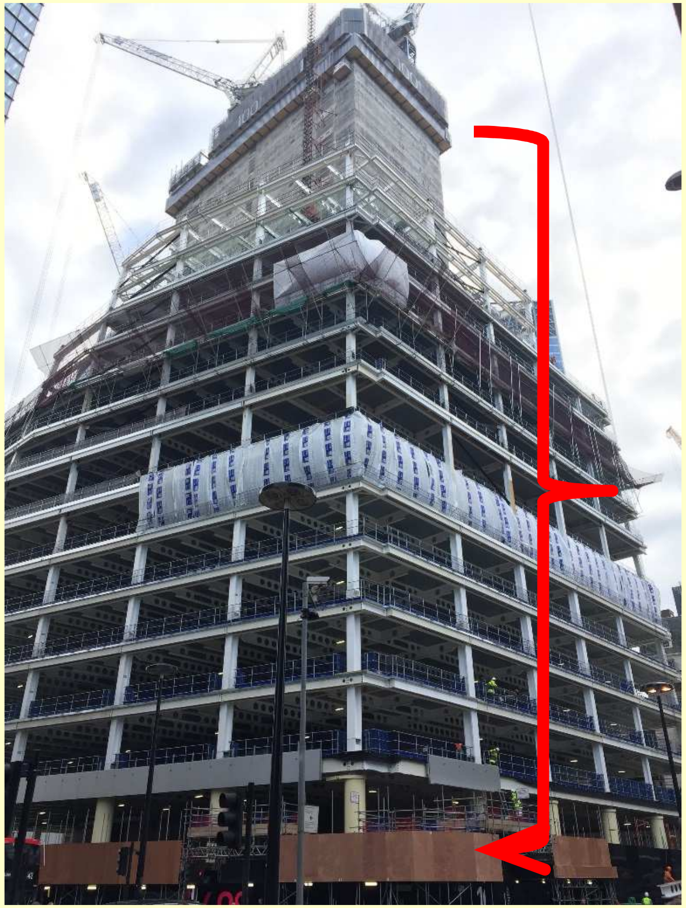
Response Time Analysis



Core and partially completed floors

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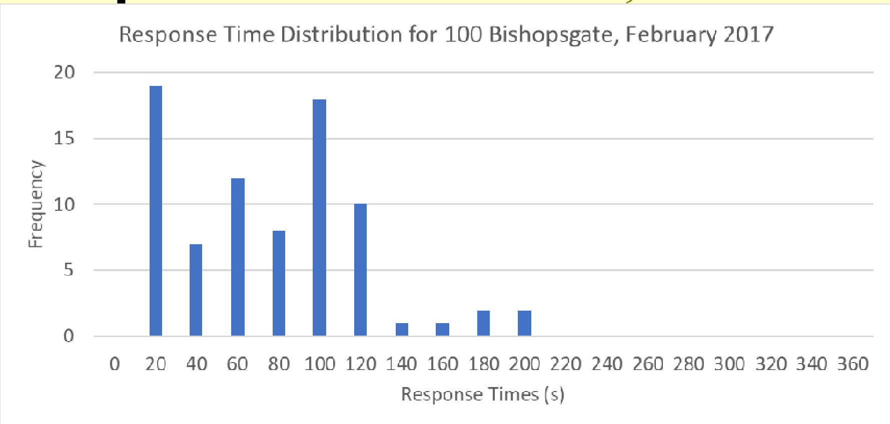
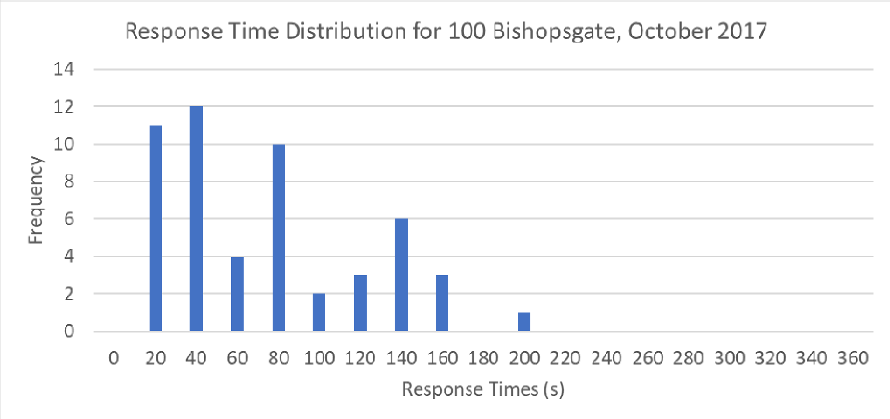
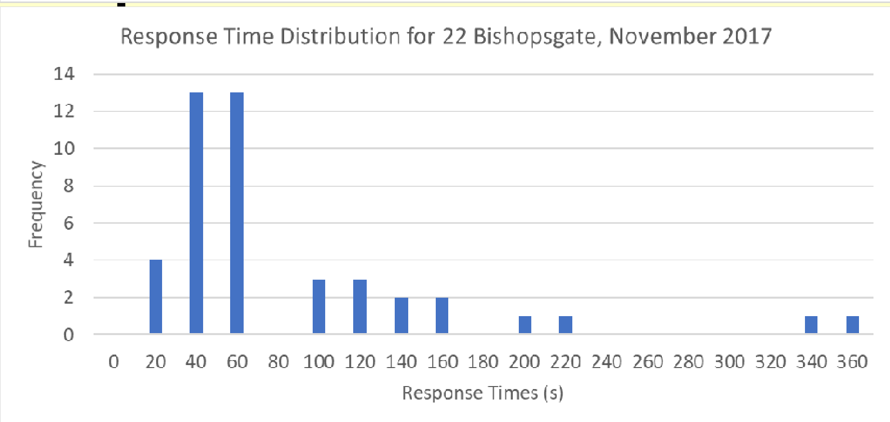
Trial 1, 3 and 4 without Jump/Slip data







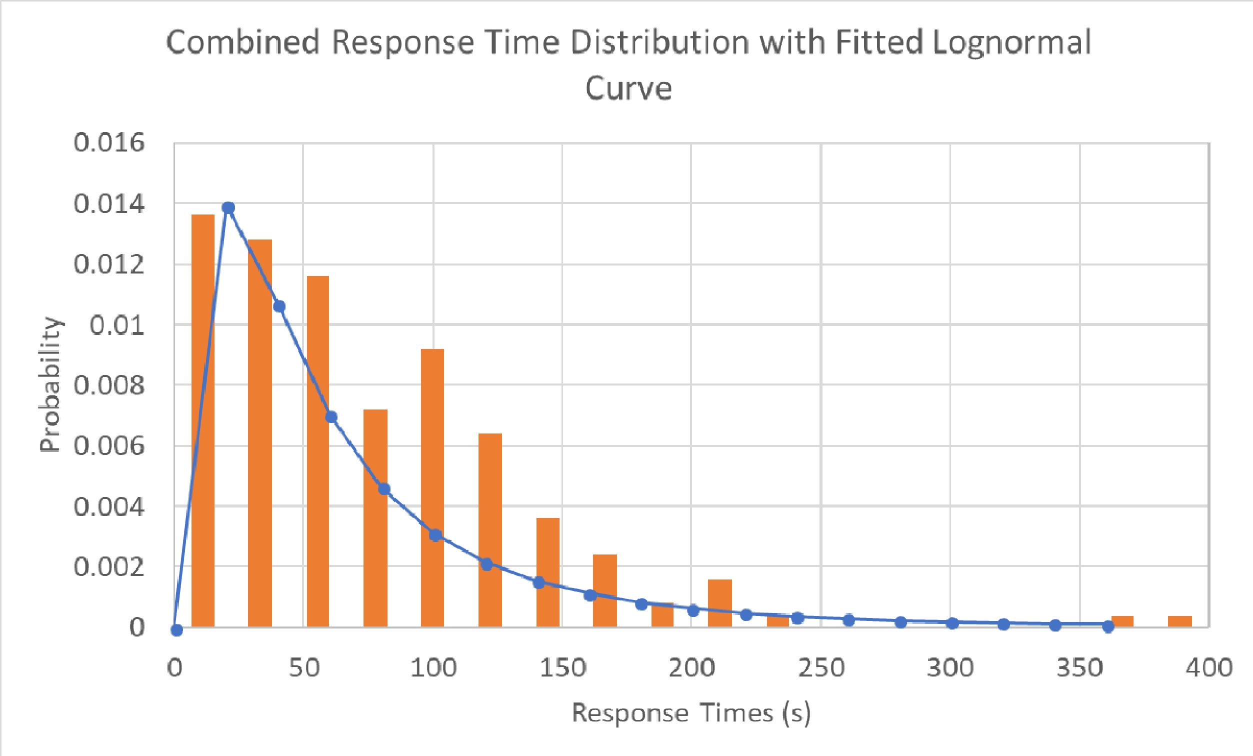
- Trial 1: 100 BG Feb 17
  - Slipform at floor 19
  - 12 floors almost completed
  - 80 RTs excluding slipform
  - RT excludes Slipform
- Trial 3 100 BG Oct 17
  - Building at floor 38 (max height)
  - 33 floors almost completed
  - 53 RTs excluding slipform
  - RT excludes Slipform
- Trial 4 22 BG Nov 17
  - Jumpform at floor 34
  - 31 floors almost completed
  - 44 RTs excluding jumpform
  - RT distribution excludes Jumpform

Comparing RT Distributions excluding Jump/Slip Form Data

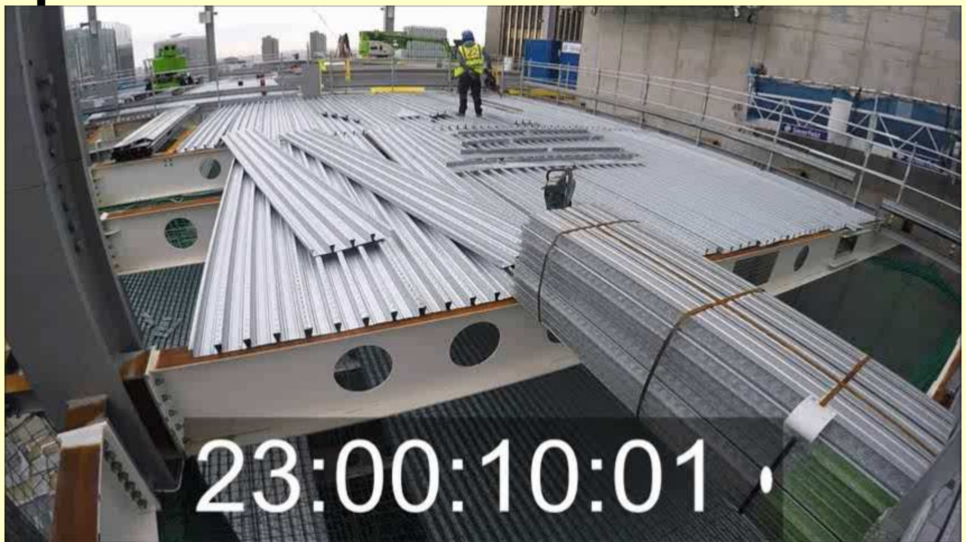
- Comparing the RT distributions for three trials excluding the jump/slip data (highest populated floors) involving 178 data points:
  - Independent two Tail T Test, 99% confidence level
- Trial-1 Feb (100 BSG 15 floors) vs Trial-3 Oct (100 BSG 38 floors),
  - T Test suggests distributions are identical (P = 0.64 at 99% confidence level).
- Trial-1 Feb (100 BSG 15 floors) vs Trial-4 Nov (22 BSG 19 floors),
  - T Test suggests distributions are identical (P = 0.38 at 99% confidence level).
- Trial-3 Oct (100 BSG 38 floors) vs Trial-4 Nov (22 BSG 19 floors),
  - T Test suggests distributions are identical (P = 0.3 at 99% confidence level).
- Results suggest:
  - Data from all three distributions are from similar distributions.
  - Can merge RT data from these three trials.
  - Distribution is Log-Normal in appearance.

Combined Response Time Distribution for Building Core

- Curve Description: $$y = \frac{1}{\sqrt{2\pi}(0.917)x} exp^{\left[-\frac{(ln(x)-3.861)^2}{2(0.917)^2}\right]}$$
- Mean: 3.861 s; standard deviation: 0.917 s

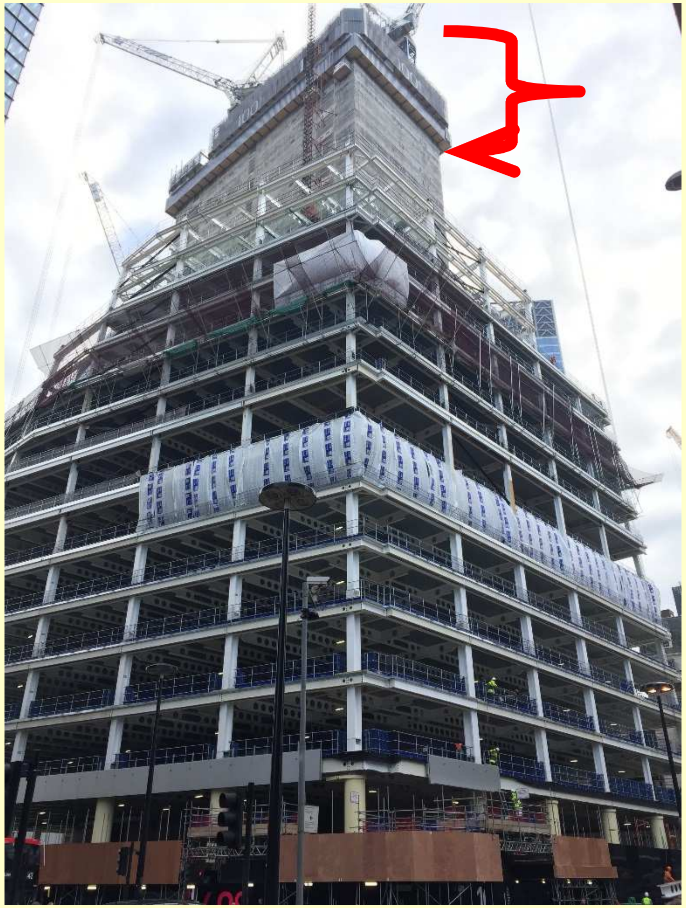


Exceptionally Long Response Times



- Glaziers cannot begin evacuation process until glazing made safe.
- Isolated workers prolong response unless staff intervention

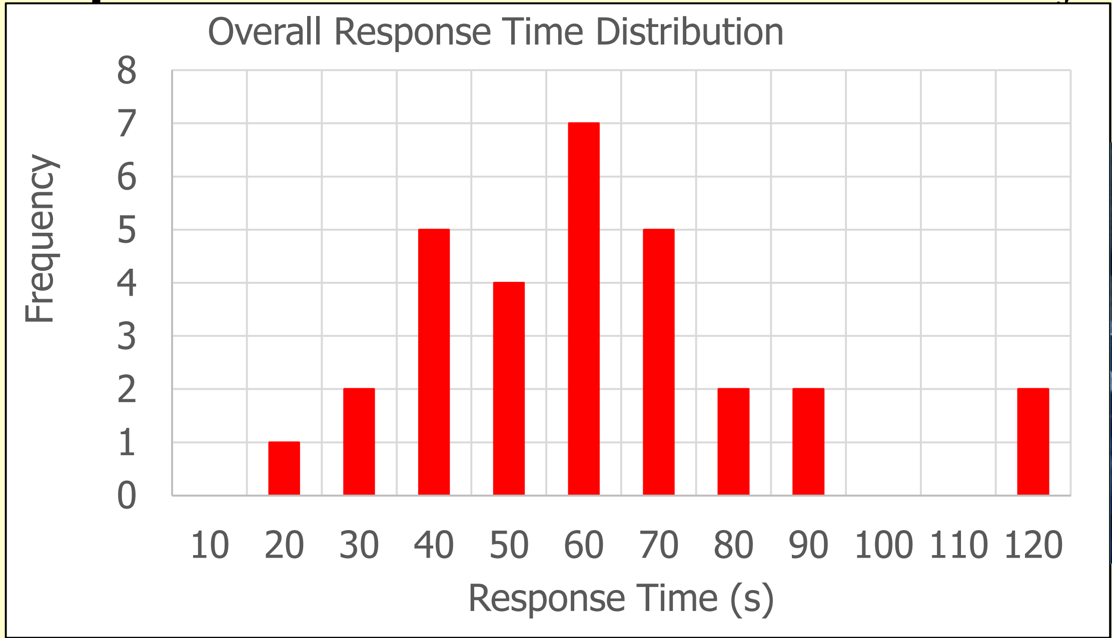
Jump/Slip Form Response Time Analysis



Jump/Slip Form

Video Analysis of 22 Bishopsgate (Trial 2, Feb 17)

- Consider the RT of the workers 43 workers in the North Core Jump Form.
- RT could be measured for 30 workers in the jump form



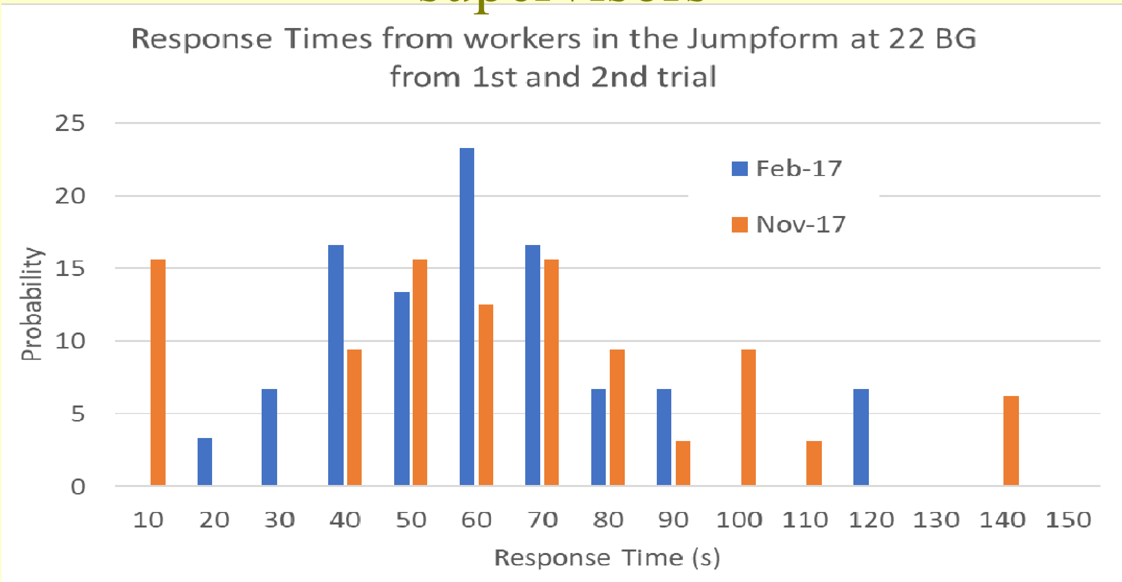
- RT distribution is:
  - **NORMAL rather than LOG-NORMAL.**
  - ***DIFFERENT* compared to the rest of building**
  - **Require two separate RT distributions, one for slip/jump, one for the rest of the building.**

Is RT Dependent on Height of Construction?

Comparing RT Distributions excluding Jump/Slip Form Data

- Comparing the RT distributions for the three trials excluding the jump/slip data:
  - Independent two Tail T Test, 99% confidence level
- **Trial-1 Feb (100 BSG 15 floors)** vs **Trial-3 Oct (100 BSG 38 floors),**
  - T Test suggests distributions are identical (P = 0.64 at 99% confidence level).
- **Trial-3 Oct (100 BSG 38 floors)** vs **Trial-4 Nov (22 BSG 19 floors),**
  - T Test suggests distributions are identical (P = 0.3 at 99% confidence level).
- Results suggest:
  - Data from all three distributions are from similar distributions.
  - **Height does not appear to influence RT within the core of the building.**

RT distribution for Jumpform (22BG) Trial 2 & 4 excluding supervisors

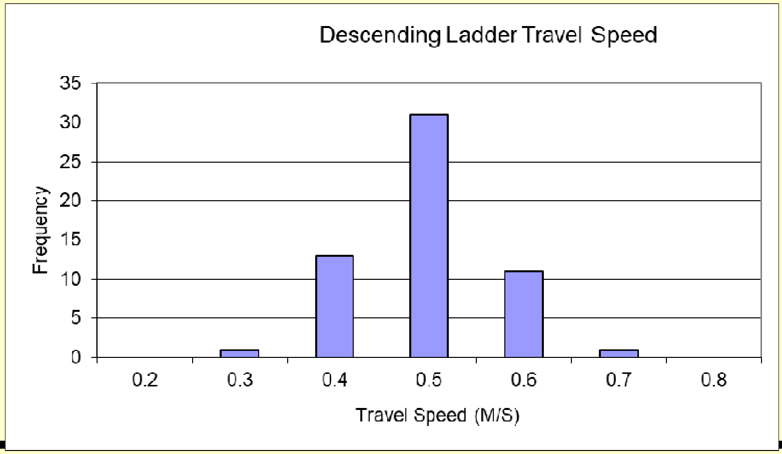


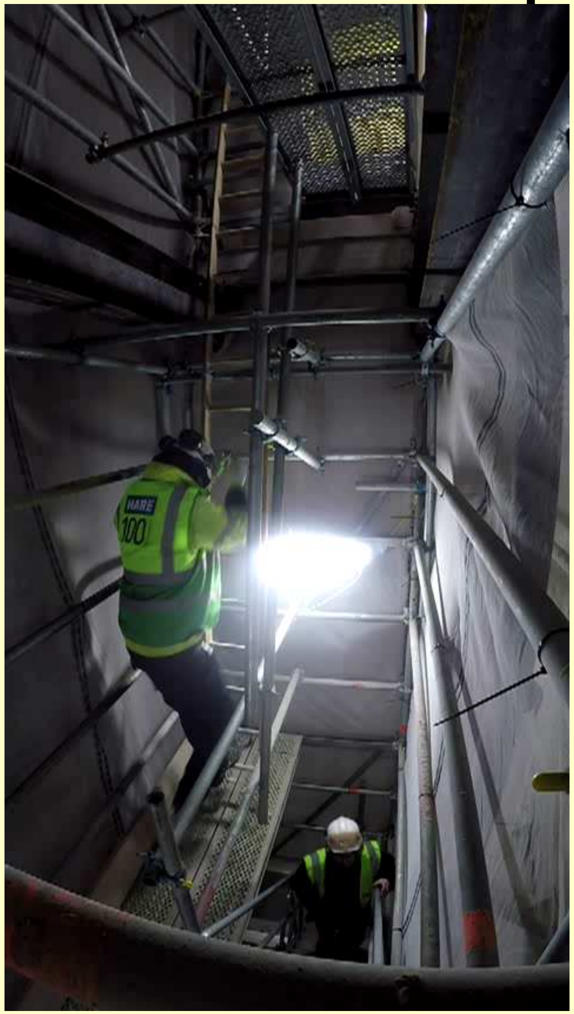
- Excluding supervisors, RT distributions look very similar.
- Unlike most RT distributions, these appear to follow normal distributions
  - Shapiro-Wilks test confirmed both distributions are normal (28 & 32 data points, p=0.12 & 0.26)
- T Test suggests distributions are identical (P = 0.7 at 99% confidence level).
- Hence can combine both RT distributions to form definitive RT distribution which is also normal (Shapiro-Wilks test confirms).
- Building height does not appear to impact RT distribution (17 and 34 floors)

Vertical Speeds – Ladders and Scaffold Stairs

Ladder Travel Speeds

- Collected data for 59 workers using ladders.
  - Speed up ladder:
    - Average 0.42 m/s
    - Range: 0.39 – 0.44 m/s
  - Speed descending ladder:
    - Average: 0.45 m/s
    - Range: 0.29 – 0.61 m/s
  - **Descent ladder speed is 45% of stair speed.**
  - **Ascent ladder speed is 63% of stair speed.**





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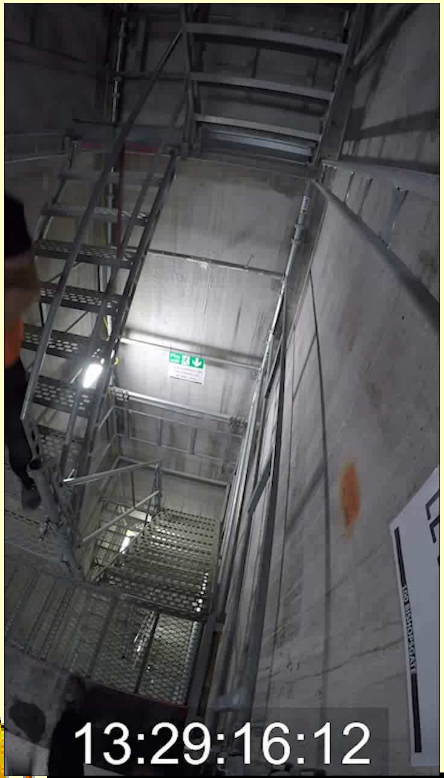
Scaffold Stairs

- Two types of scaffold stairs were used on the construction sites.
- Dog-Leg stairs: each flight is off-set by a landing
- Layered stairs: each flight is arranged on top of each other resulting in limited head clearance per flight – impacts travel speed.
- Results for Layered stairs presented here.



Dog-leg stair down

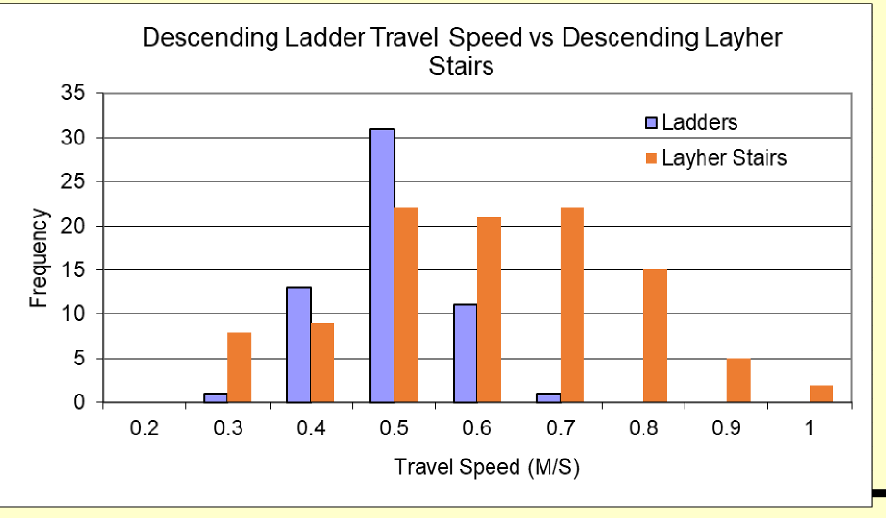
Layered stair down

Ladders vs Layered Stairs vs Building Stairs

- Ladders are clearly a bottleneck in any evacuation route and their use should be limited

	Descending Ladder	Descending Layered Stairs	Descending Standard Stairs Average (Fruin)
Max	0.61 m/s	0.93 m/s	Male 17-29 1.01 m/s
Average	0.45 m/s	0.66 m/s	Male 30-50 0.70 m/s
Min	0.29 m/s	0.36 m/s	Male 51-80 0.53 m/s

	Ascending Ladder	Ascending Layered Stairs	Ascending Standard Stairs Average (Fruin)
Max	0.45 m/s	0.74 m/s	Male 17-29 0.67 m/s
Average	0.42 m/s	0.52 m/s	Male 30-50 0.63 m/s
Min	0.39 m/s	0.36 m/s	Male 51-80 0.51 m/s



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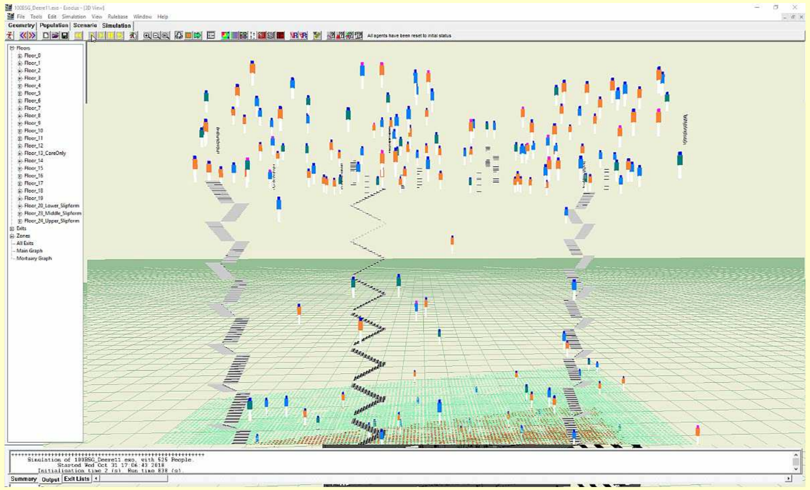
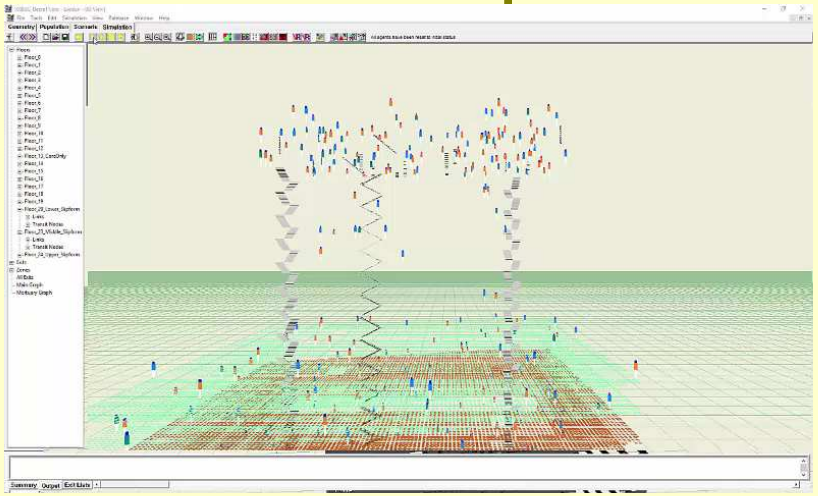
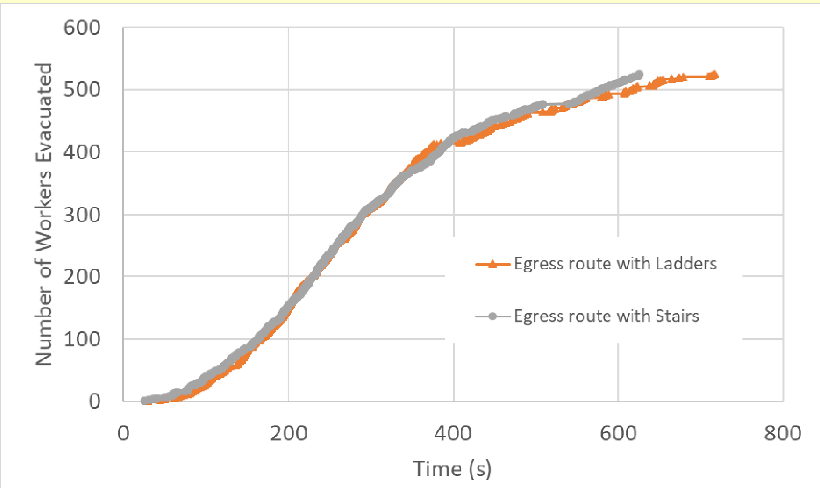
Potential issue with ladders in slipform





120 workers in slipform: 6 m 12 s to clear slipform with ladders
8 m 15 s to evacuate building

120 workers in slipform: 4 m 16 s to clear slipform with layered stairs
11 m 57 s to evacuate building



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Walking Speeds – The Impact of Floor Surface

Walking Speed Trials – 144 data pts per category

Person 1 walking in both directions across metal decking

Person 1 walking across rebar

Person 20 walking across concrete

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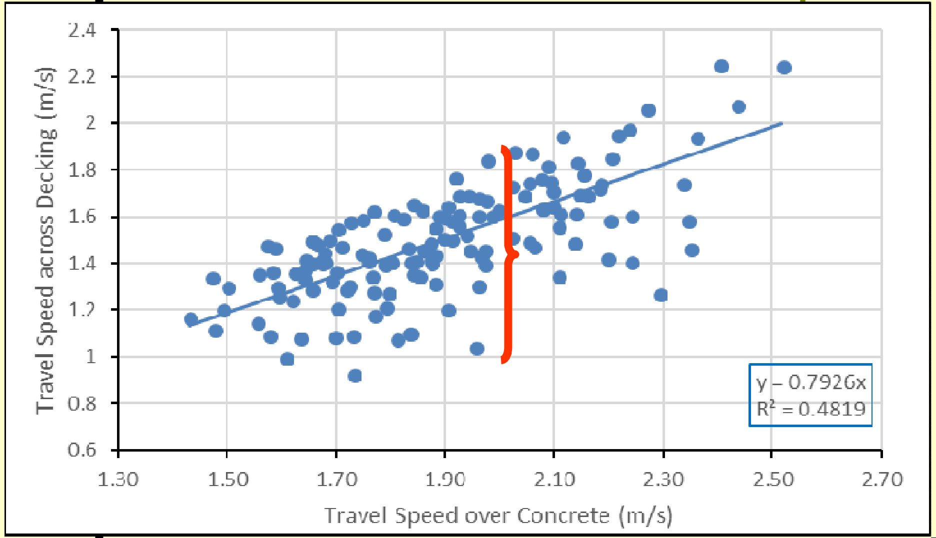
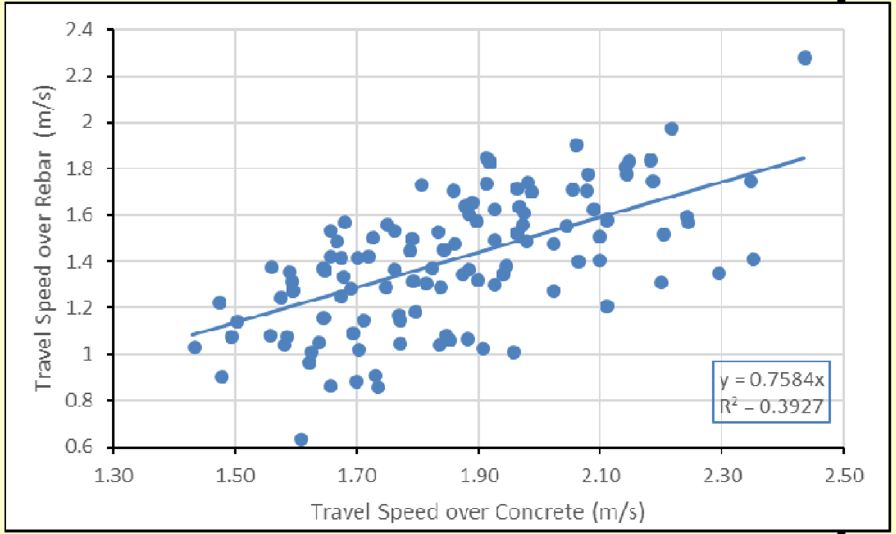
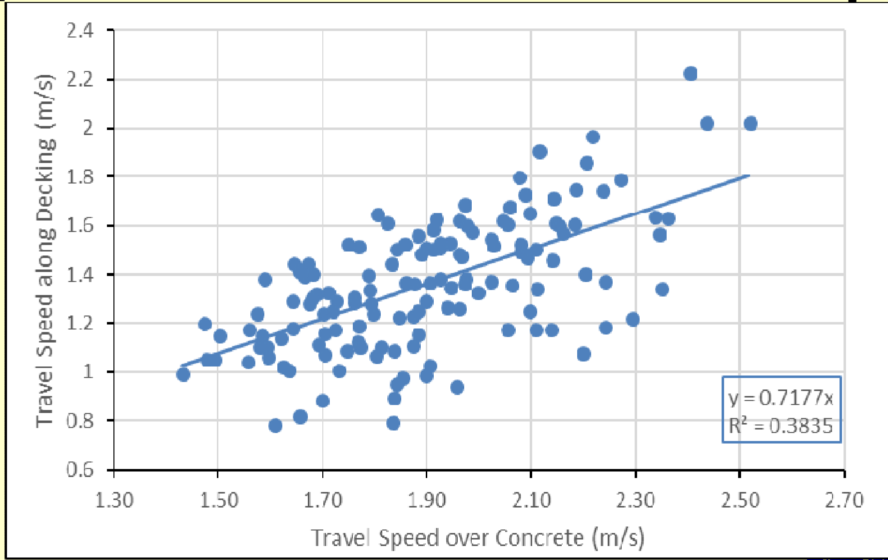
Travel Speed Trials Results

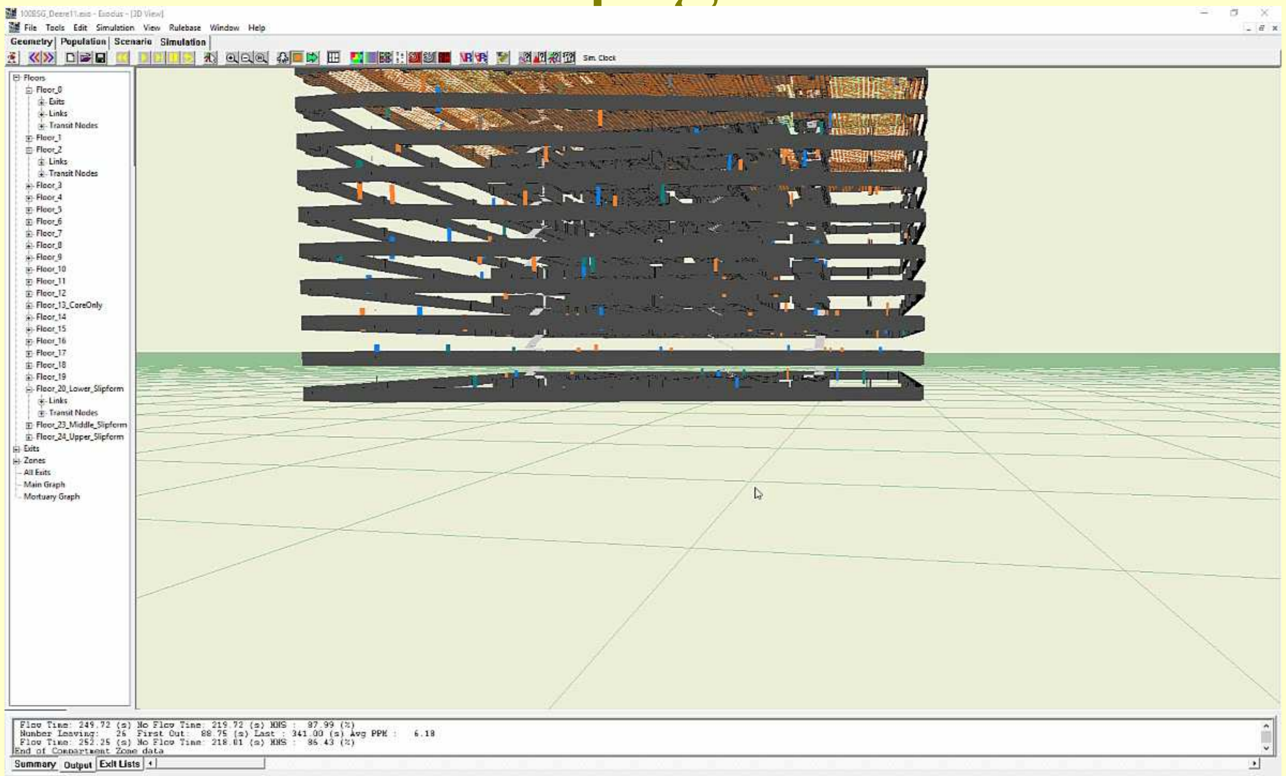




- Generally Speeds follow trend:
  - Concrete > Across Decking > Rebar > Along decking
  - But large variation.
- Speed reduction can be as much as 30%



100 Bishopsgate Demo



- 24 floors: 13 floors in construction, 8 core levels and 3 slip levels
- 184 agents: 20 in the slip, 164 elsewhere
    - Brown floor tiles represent Rebar flooring
    - Cyan floor tiles represent Metal Decked flooring
    - In the 2D window, direction of the metal decking is indicated by a line on each node

Part 2: MIXED REALITY TRAINING ENVIRONMENT

"Being virtually killed by a virtual laser in a virtual space is just as effective as the real thing, because you are as dead as you think you are." Douglas Adams.

Marauding Armed Terrorists and Agent Based Modelling

- Recent marauding armed terrorist attacks highlight the need for clear guidance on how best to ***defend, respond and react*** to such events.
  - 2008 Mumbai, 2011 Norway, 2013 Westgate Shopping Mall Nairobi, 2014 Kunming Railway Station, 2015 Bataclan Paris, 2015 Amsterdam-Paris train, 2015 Sousse Tunisia, 2017 London Bridge UK, 2018 Melbourne Australia.

- Terror groups have shifted focus onto ***'soft'*** targets – crowded places e.g. shopping malls, public buildings, transportation infrastructure, etc.
  - Mumbai demonstrates how several individuals with small explosive devices and automatic weapons could cause significant loss of life attacking crowded places.

- Due to the dynamic nature of such attacks, it is difficult to prepare security forces, including first responders, to deal with these situations.

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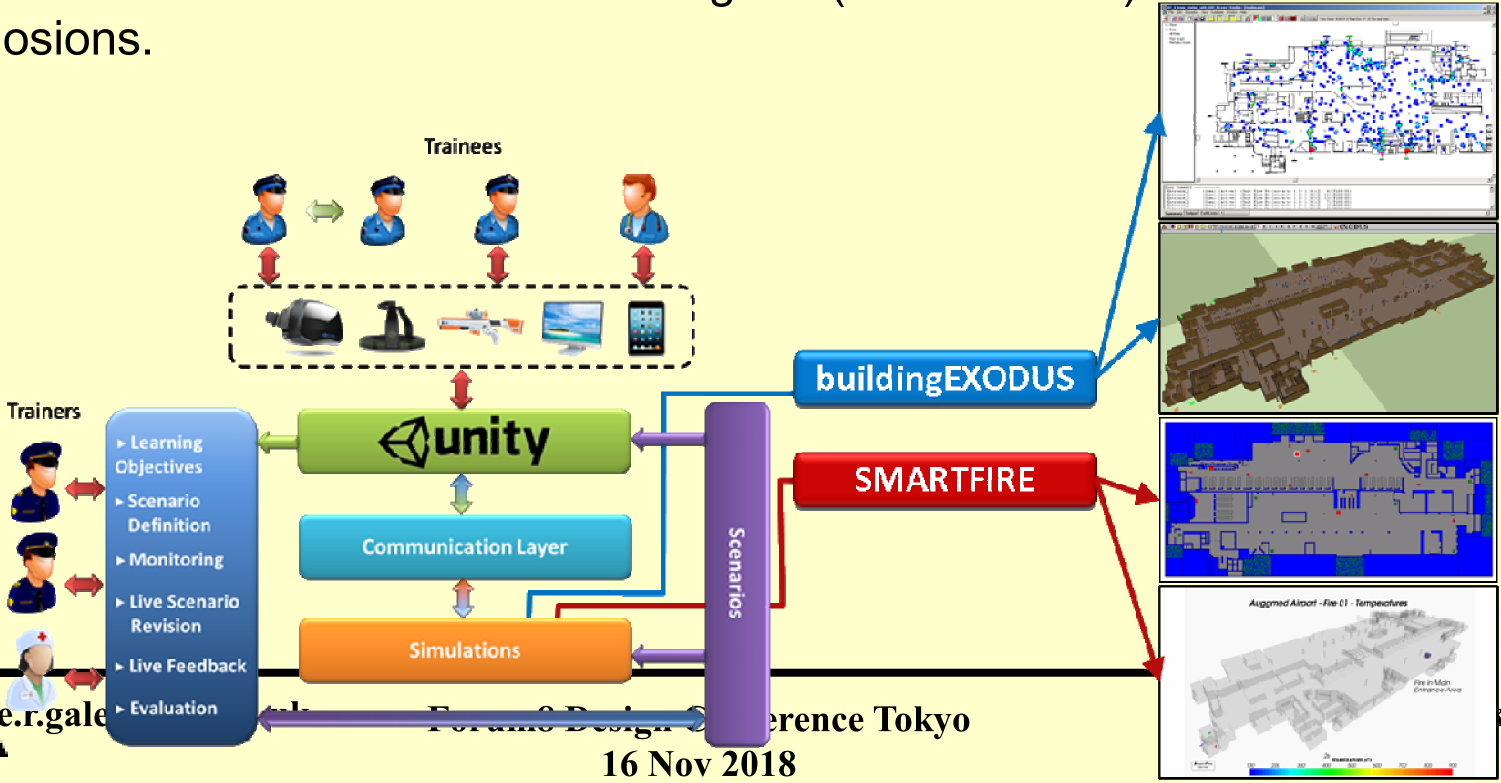
AUGGMED – Automated Serious Game Scenario Generator for Mixed Reality Training

- Aim was to develop a serious game platform to enable single and team-based training of security staff, police, counter-terrorism officers, etc responding to terrorist scenarios in crowded places
- AUGGMED platform will generate non-linear scenarios designed to improve skills such as: problem solving, analytical thinking, quick reactions,
- Scenarios include advanced simulations of crowds (EXODUS) and hazardous environments including fire (SMARTFIRE) and explosions.



Modifications to EXODUS and SMARTFIRE

- Embed EXODUS into the UNITY 3D environment allowing two directional communication between the tools and UNITY environment.
- Increase SMARTFIRE smoke output from 2-Layer to multilayer to allow better visualisation within UNITY 3D (and vrEXODUS)
- Enable external user to take control of an avatar and interact within the simulation environment with the other avatars.
- Introduce a range of voice and jester features allowing avatars to react to voice and hand gestures.
- Introduce a shooting capability into EXODUS.
- Introduce gun shot and explosion injury capability into EXODUS
- Introduce concept of awareness and threat zones

Capabilities

- As part of the AUGGMED training environment, three capability levels were developed:
  - **Level 1:** trainee uses mouse + keyboard, views game play on computer screen. No mobility, no tactile feedback. Trainees can join locally or remotely.

  - **Level 2:** trainee using immersed VR head mounted display and hand controllers. Limited mobility and tactile feedback. Trainees can join locally or remotely.

  - **Level 3:** AR environment, training on site, full mobility and advanced tactile feedback. Trainees can join locally or remotely.

EXODUS linked to UNITY3D game environment

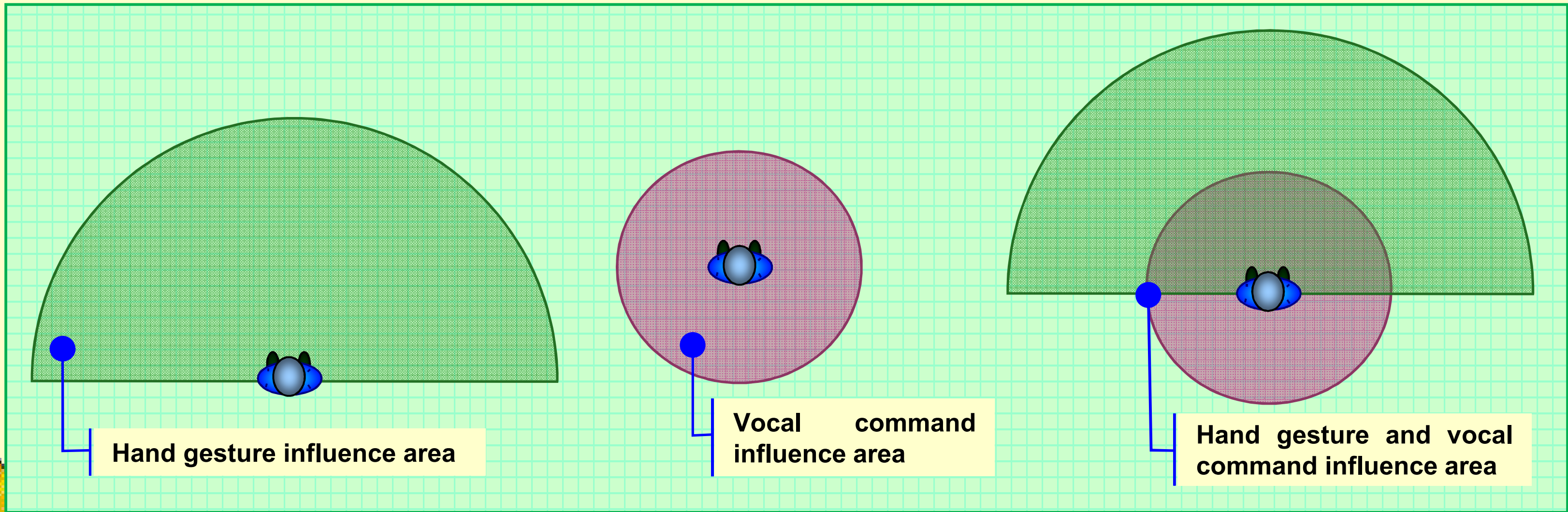
buildingEXODUS general circulation simulation within an Airport Terminal:

SMARTFIRE linked to UNITY3D game environment

Fire predictions (i.e. smoke, heat and toxic gas environment) calculated prior to runtime using SMARTFIRE.

Hand Gestures and Vocal Commands

- Hand Gestures: Semi-circular influence area – radius set as max arbitrary visibility distance of 20m
  - % compliance parameter: function of distance to person giving order and mimicking behaviour of surrounding population.
- Vocal Command: Compliments hand gesture
  - Circular influence area – smaller radius compared to hand gesture, also need to specify % compliance
- Hand gesture and vocal commands: More influential, compliance increases but influence of hand gesture > influence of vocal command
- Blue team and red team able to communicate to both individuals and groups
- Total of 8 different voice commands including:
  - Stop, Go, Get Down, Get Up, Start Evacuating, Get out of the Way.



Additional EXODUS Behaviours

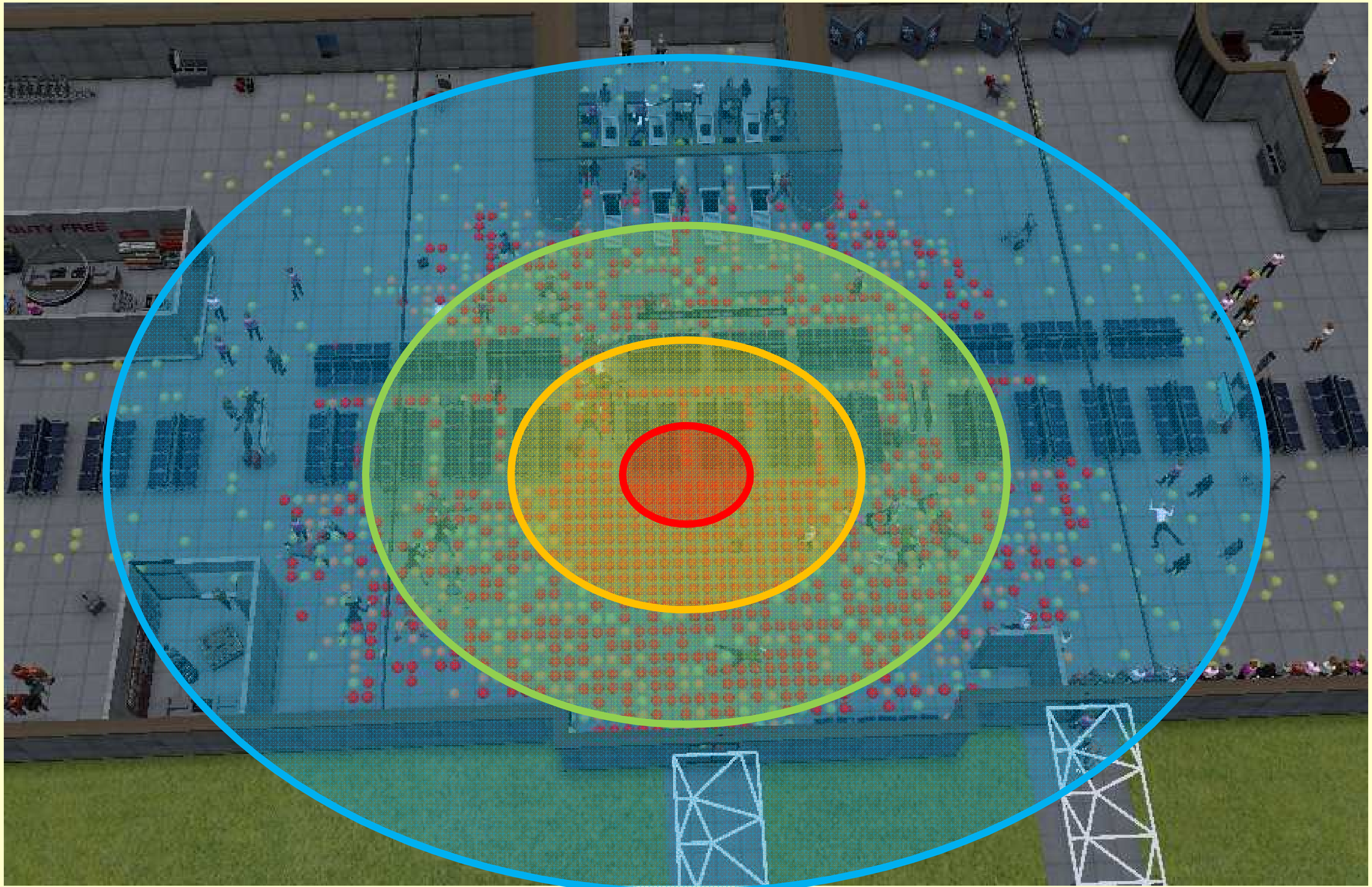
Hand Gestures and Vocal Commands:

"Stop" Command

Additional EXODUS Behaviours

Hand Gestures and Vocal Commands:
"Get Down" Command

EXPLOSION MODELLING



RED = Very Serious/Fatal, Orange = Serious, Light Green = Medium, Cyan = Minor

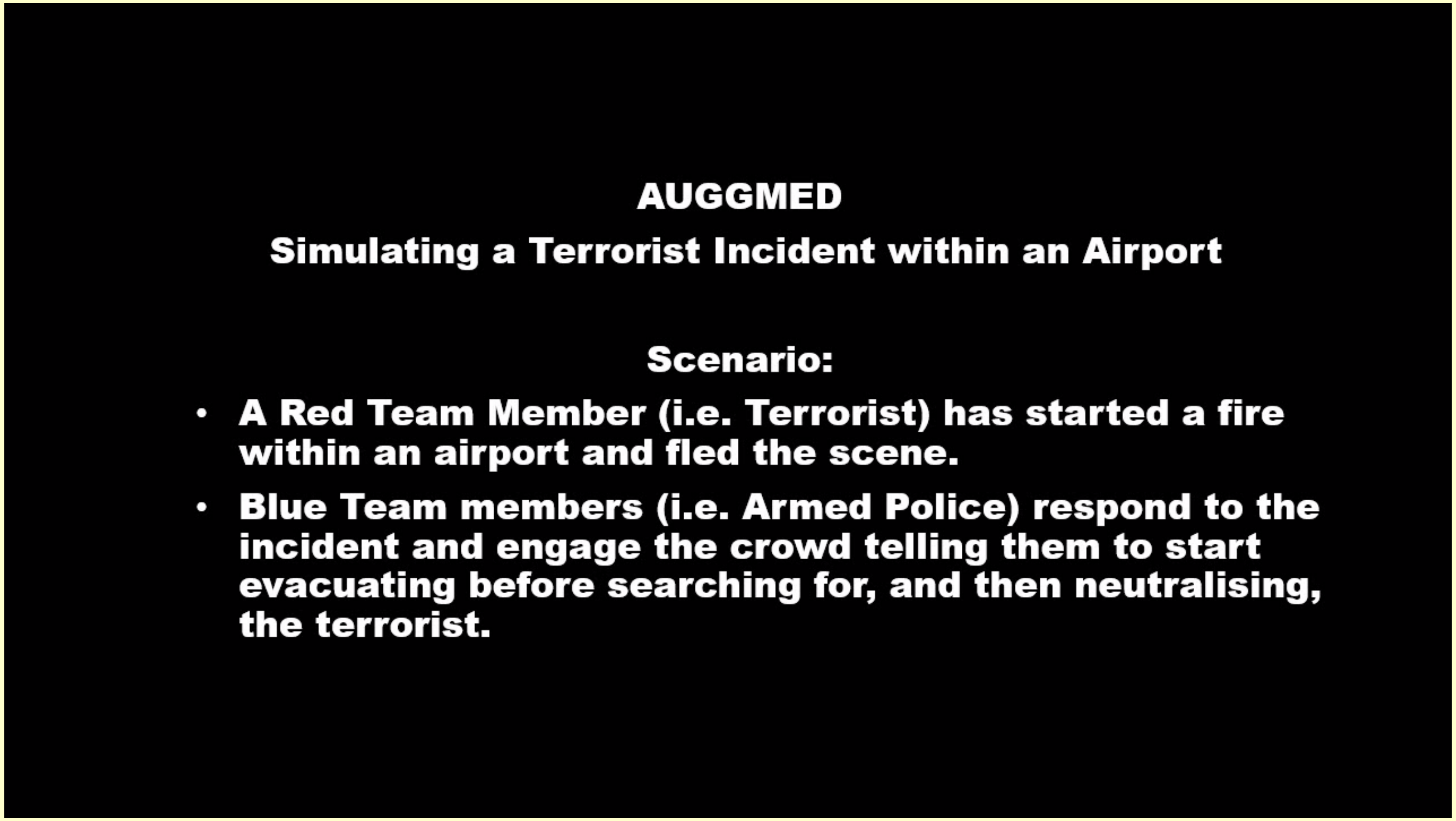
RED = Severe Damage, Orange = Moderate Damage, Light Green = Medium Damage

Level 1 : External user control of EXODUS agent

- God's view on main screen, used by 'trainer'
- External user's view on insert, user is controlling the flagged agent

Level 1 : External user control of EXODUS agent

- Red has set off a bomb starting a fire
- Blue team sent in to track down Red during fire and people trying to evacuate.



Red Team Member = Terrorist

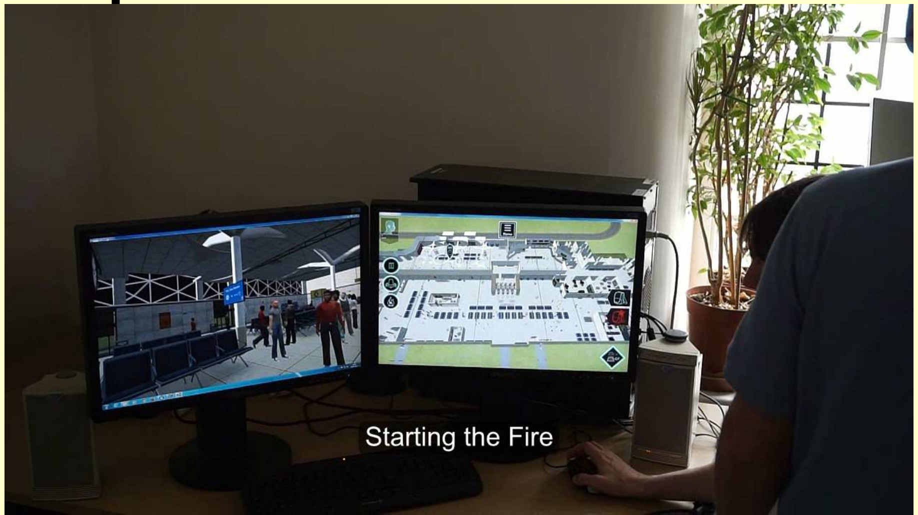
Blue Team member = Armed Police Response

Level 2 : Immersive VR Environment

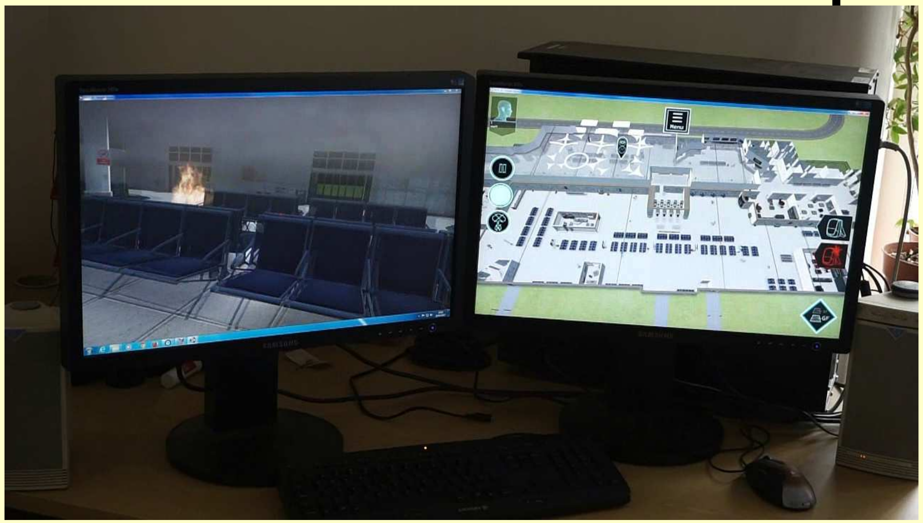
- Head set: HTC Vive set-up.
- Headset provides the user with an immersive experience.
- Actual physical movement of the user, while wearing the headset, is tracked via 2 beacons (about 5m apart).
- As the user moves, there movement is recorded and sent to UNITY to enable the users avatar to be moved accordingly within the virtual space.
- The controllers are used for:
  - Moving within the virtual environment (i.e. walking or running),
  - Issuing voice or gesture commands to avatars within the simulation
  - Tagging injured avatars during triage scenarios,
  - Selecting, Aiming, Firing and Reloading weapons (i.e. pistols, automatic weapons, knives and explosives)

Level 2 : Immersive VR Environment

- Left screen shows the trainees view through his head set
- Right screen shows trainers view. Trainer can switch to see any of view of any of the trainees.



- Trainee assists with the evacuation of the terminal.
- Instructing airport staff to evacuate.

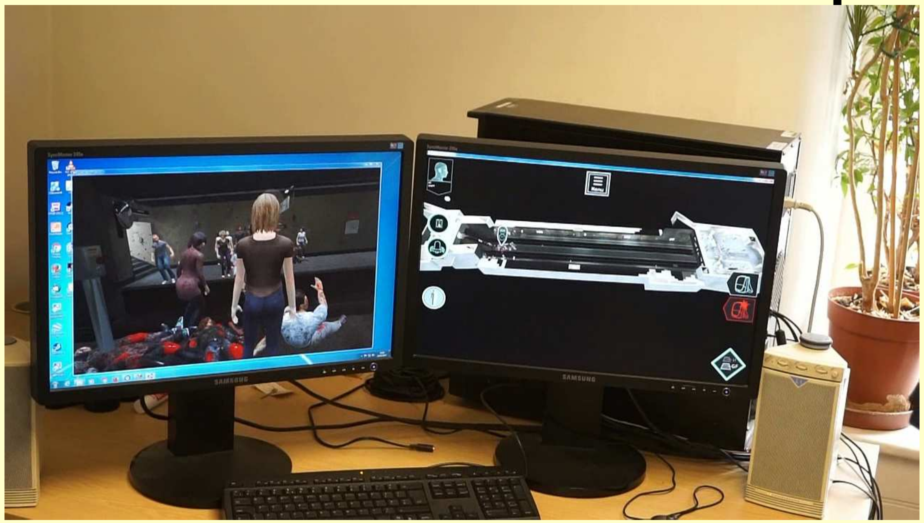


- Trainee views the fire.
- Fire is determined by SMARTFIRE including smoke, heat and toxic gases
- FED is being calculated, so trainee may be overcome by toxic products or heat.

Level 2 : Immersive VR Environment – triage scenario

- Bomb blast in Muntaner Metro station, with killed, seriously injured and minor injuries
- Trainee is meant to triage the seriously injured.

- Trainee realises the other platform has more seriously injured and so has to get around to the other platform.



- Trainee is on central platform where the most seriously injured are located.

Level 2 : Immersive VR Environment – triage scenario

•Actual training session with real paramedics familiar with the station

•2 paramedics and trainer involved in the scenario.

•Large screen flicks between trainers view and trainees view.

•Both paramedics stay together to assist each other.

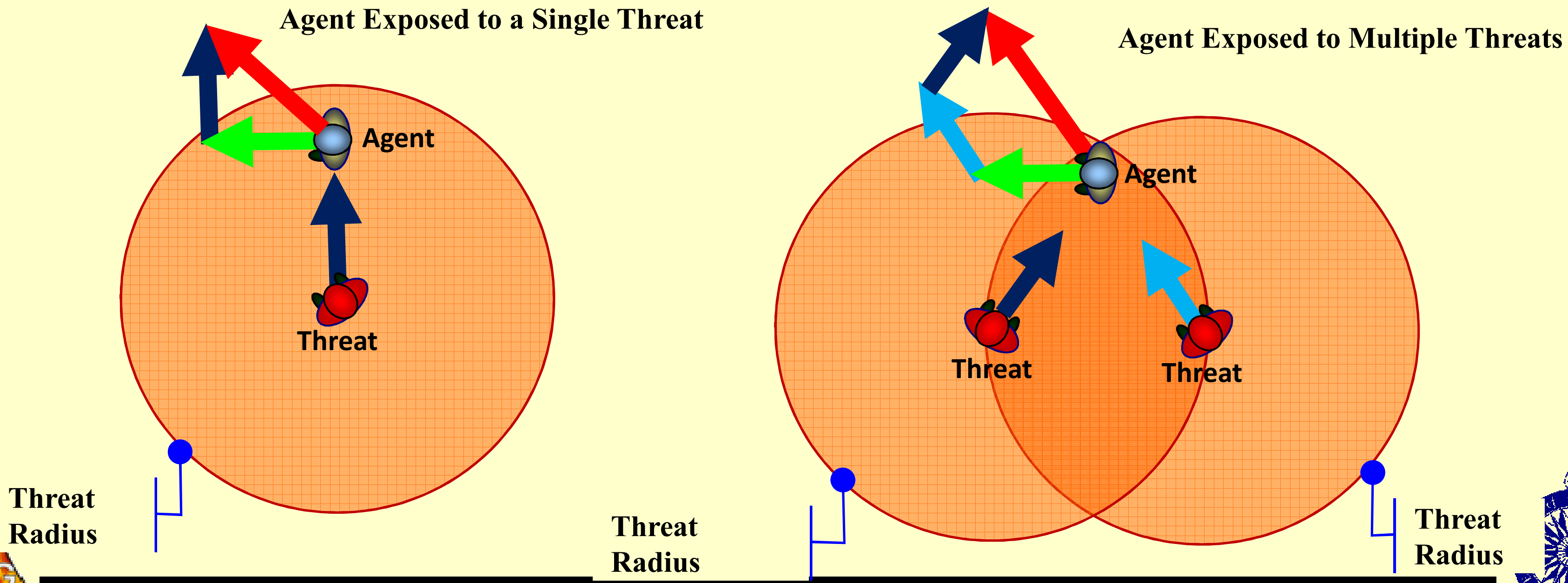
•Laptops show the paramedic view.

•Working as a team, communicating with the victims to assess their condition.

•Trainer views and interjects.

EXODUS Threat Zone Behaviour – Fleeing Behaviour

- Agents within the **Threat Zone** attempt to flee the terrorist as quickly as possible. They are not thinking about the nearest exit, simply attempting to get away from the perceived threat as quickly as possible.
- Flee direction determined by summing unit vector between terrorist and Agent and unit vector in the direction of agent travel – as if there is a repulsive force between terrorist and agent.
- The direction of travel for a threatened agent takes into account multiple threats



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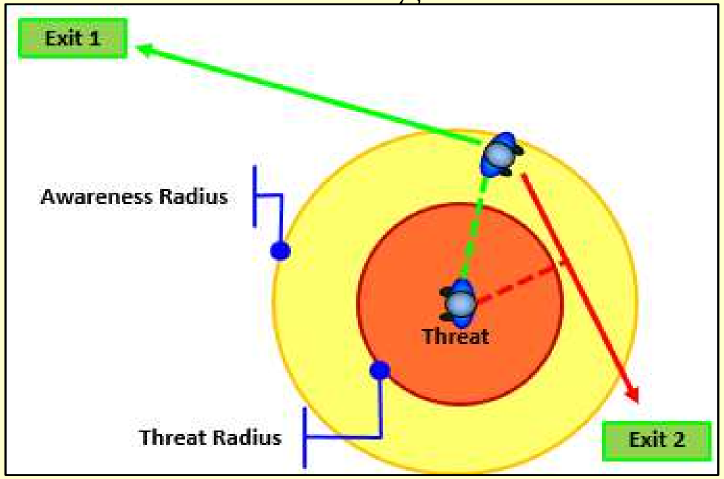
Awareness Behaviour – Evacuation Behaviour

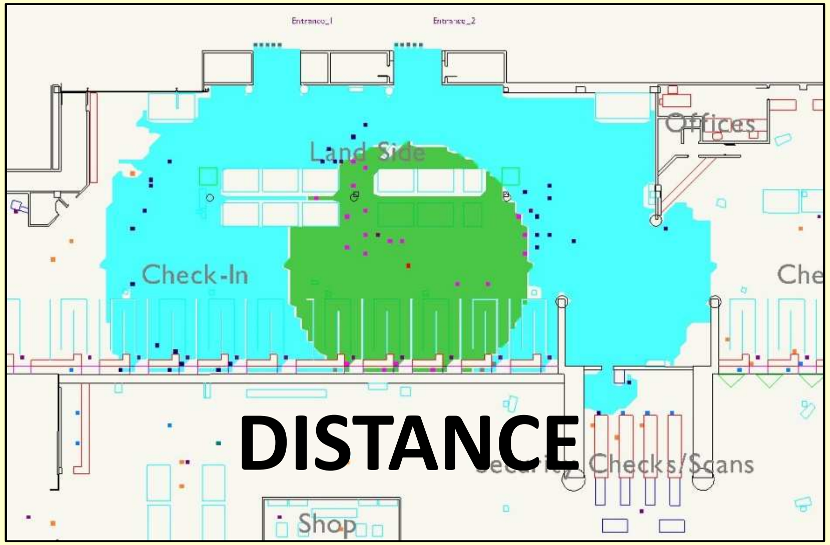
- Agents within the **Awareness zone** will attempt to determine which (if any) exit represents the best means of escape.
- Agent considers the **shortest route** to each available exit point.
- Routes which pass through the **Threat Zone** of a known threat are excluded.
- Routes considered viable are scanned along their **entire route** to determine the **shortest distance** to a known threat i.e. the last known location of the terrorist within the target agents memory.
- The exit route that has the **greatest shortest distance** from known threats is deemed the **safest**, and so is selected as the escape route.
- If **two or more exits** are equally safe, the **nearest** exit is selected.
- Exit 1 selected even though it is further away.



- If agent cannot reach **an available exit** without passing through the **threat zone** of a known threat, then the target agent will alternatively consider targeting **safe zones**.

Threat and Awareness Zones

- The Threat and Awareness radii are based on **line of sight** or **distance** from the terrorist, depending on the action of the terrorist.
- When the terrorist **fires** their **Threat and Awareness radii** are based on **distance,** so agents with no direct line of sight of the MAT can become **threatened or aware of the threat**.
- When the terrorist **reloads**, their **Threat and Awareness** radii are based **on line of sight** i.e. only agents who can **see** the shooter become t**hreatened** or **aware of the threat**.



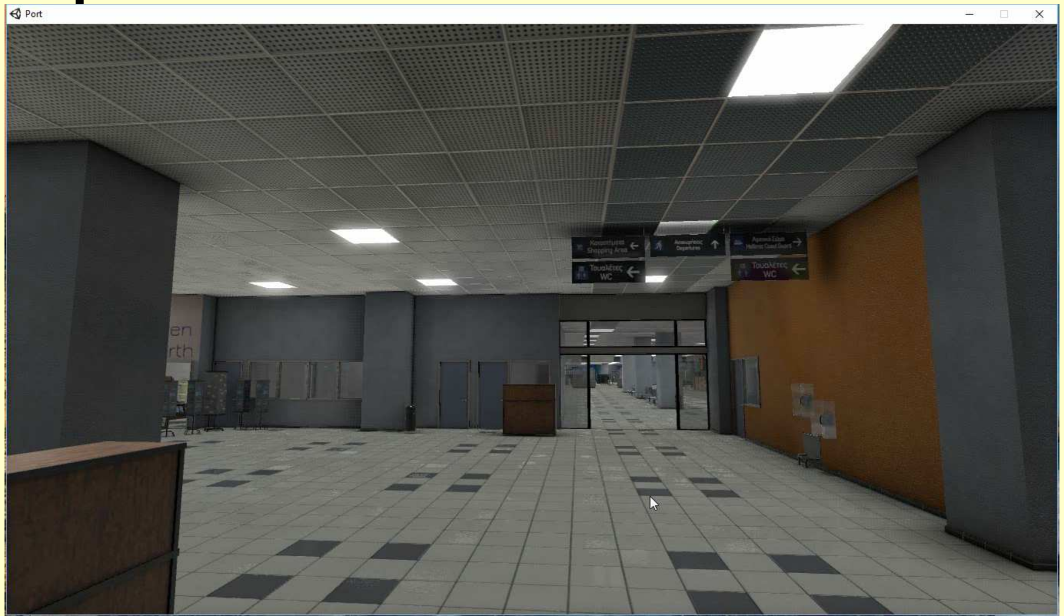
Flee Behaviour

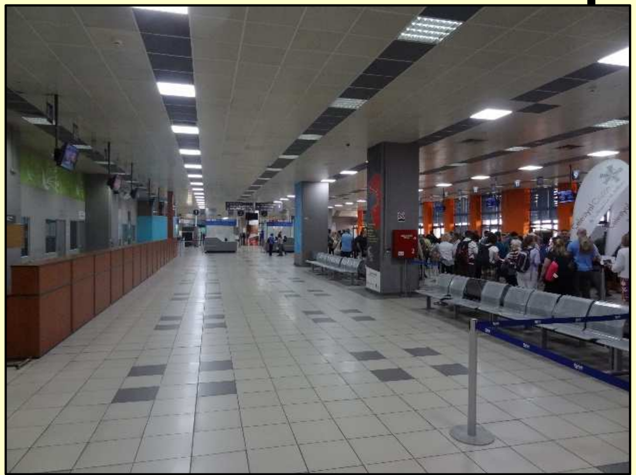
- Agents within a given **Threat zone** will attempt to move **directly away** from the threat.
- As a result, agents may find themselves effectively forced into **dead ends**, up against **walls**, **barriers** etc., from where they are **unable to retreat** any further.
- Agents who are effectively **trapped** will immediately **crouch** in an attempt to become **less visible**, pose a **smaller target** and appear **less threatening** to the shooter.
- **Trapped agents** may **make a dash for safety** if a given threat enters the agents **Flee Radius**.
  - **Flee radius:** critical distance between terrorist and agent defining how close the threat has to be before agents will consider making a dash for safety,
  - **Flee Probability:** likelihood that **trapped agents** will consider a dash for safety when terrorist enters the **Flee radius**.

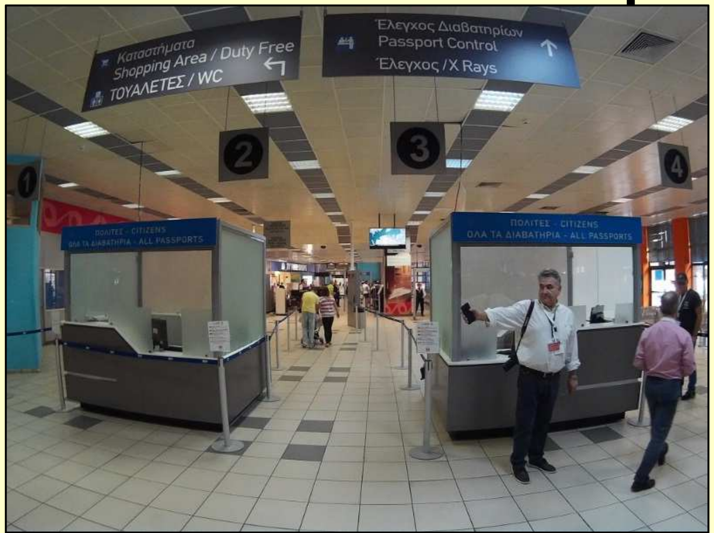
Level 2 : Immersive VR Environment

- Demonstration of RED team shooting at population
- Threat and Awareness zones shown around RED team member.
- This changes as the RED fires and reloads.

Level 2 : Immersive VR Environment







Photographs of the Pilot 2 location in Piraeus Port, Greece.

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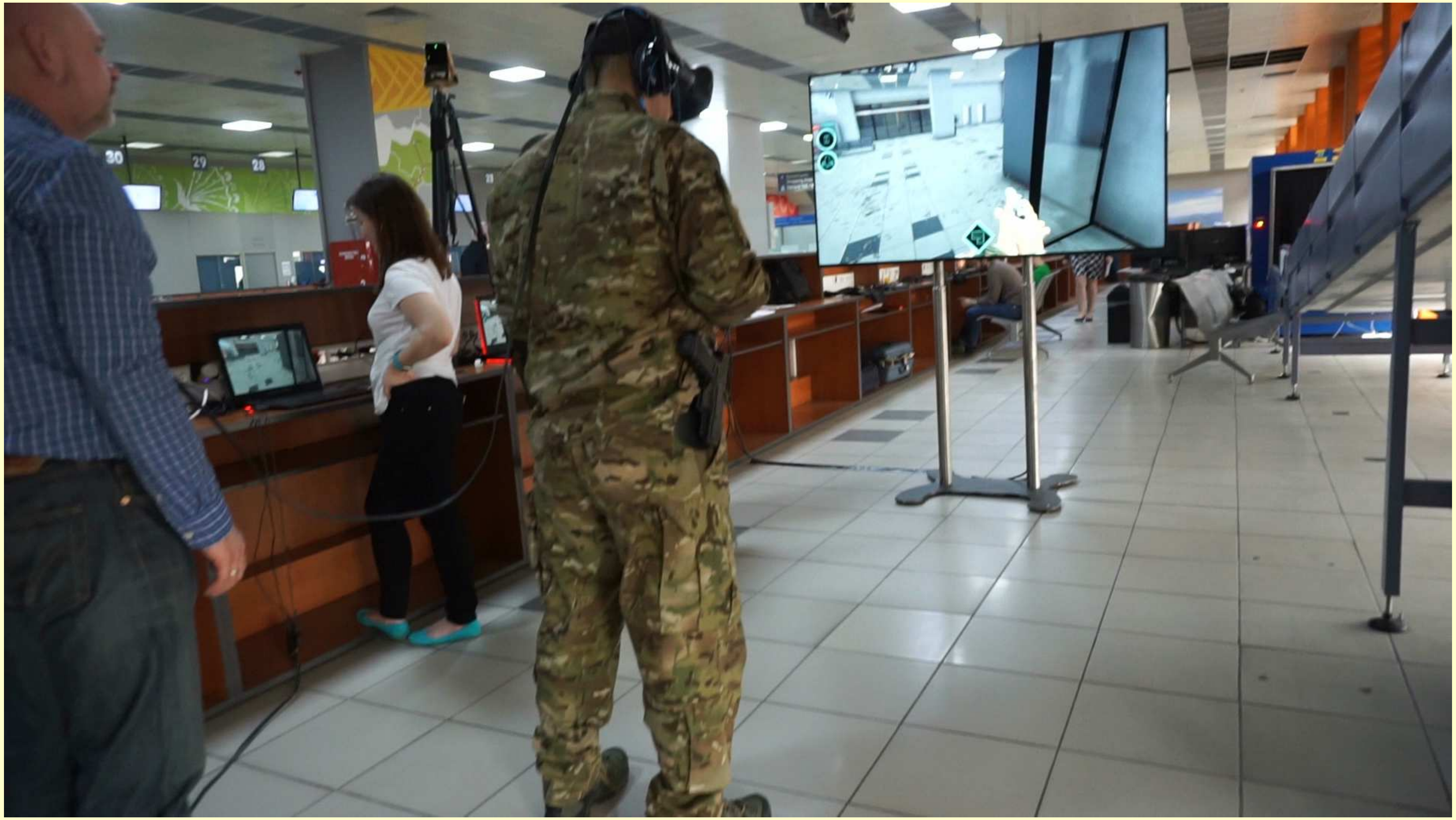
Level 2 : Immersive VR Environment

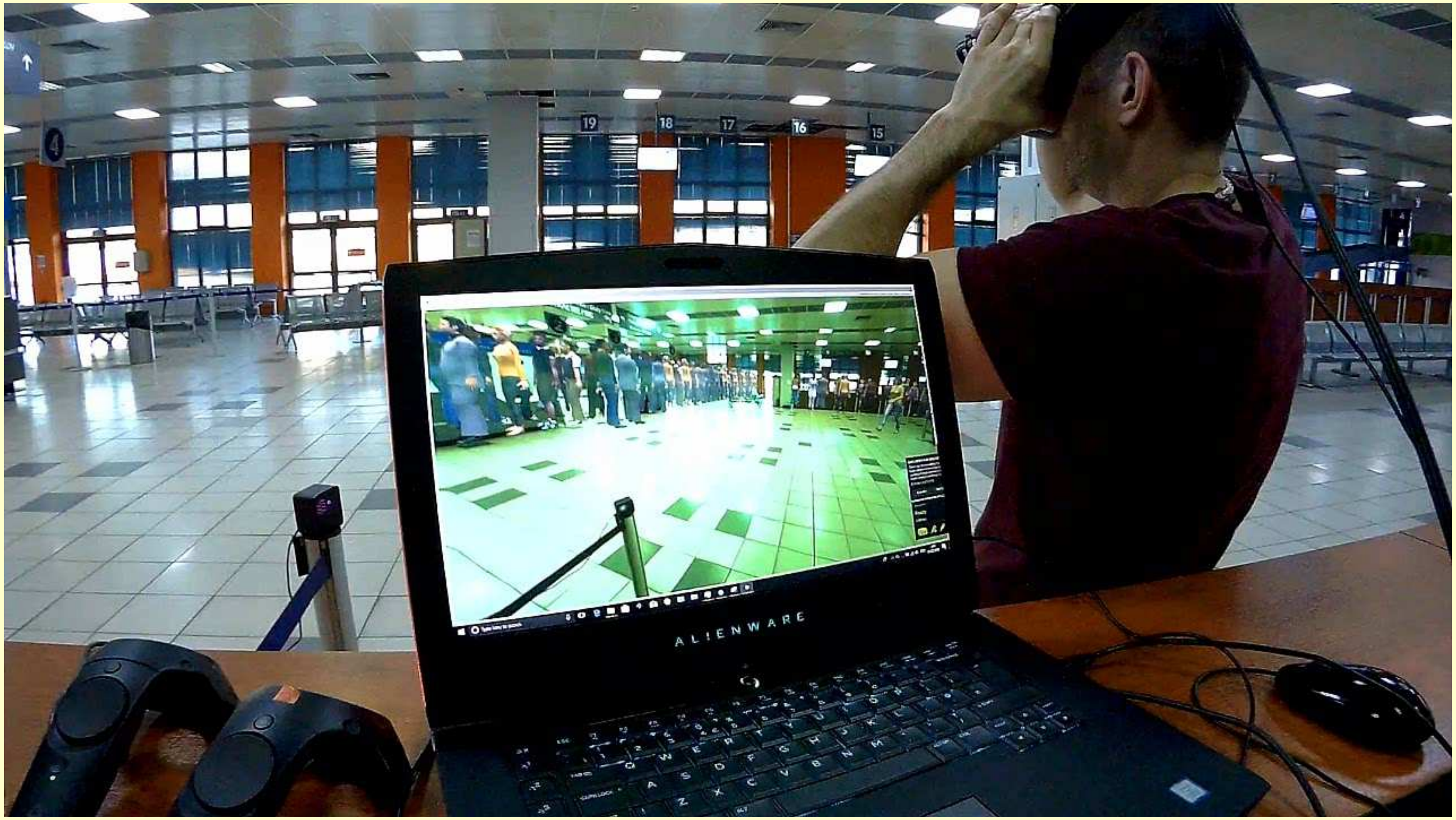


- Greek military special forces (BLUE team) performing a sweep of the Piraeus Port looking for terrorists (RED Team) following attack

Level 3 : Augmented Reality Environment

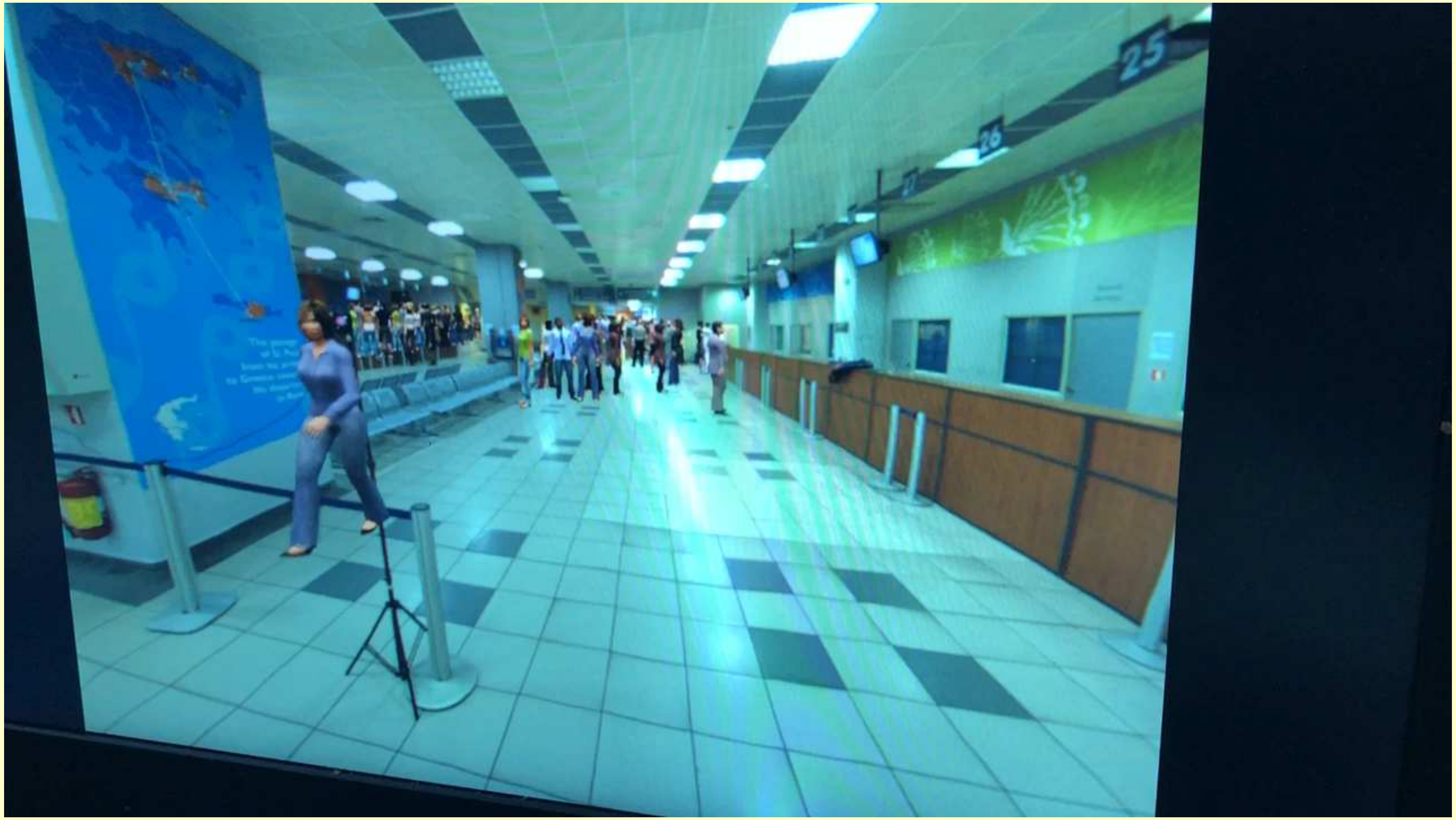
- AR uses HTC Vive set-up as with the Level 2 arrangement.
- Hololens was considered but not used due to severe limitations with the current hardware:
  - Unrealistic very narrow viewing window provided by the headset requires unnatural head movements to capture full field of view,
  - Images of avatars appear semi-transparent.
- HTC headset modified with addition of centrally mounted HD camera.
- Camera streams real-time HD video into L+R displays within the headset.
- Simulated avatars are rendered on top of streamed video images to each eye.
- In this way it appears that the avatars are actually present and moving around within the real structure.
- Due to the slight delay associated with the time taken to capture and stream the real video, some disconnect between the avatars and the real world is observed – particularly with rapid head movements.
- Due to inconsistencies between the virtual geometry and the real world e.g. location of taped barriers, agents may appear to walk through barriers/obstacles etc.

Level 3 : Augmented Reality Environment



- View on screen is view through headset. Passive observer during simulation.
- Gunman dressed as port official (Red Jacket) opens fire in Piraeus port.
- Gunman controlled remotely via Level 1 interface – but visualised using AR.

Level 3 : Augmented Reality Environment



- Team member in the role of a Policeman commands agents and they comply.
- Policeman then opens fire on crowd and they attempt to evacuate, some try to crouch down to become a smaller target.

Part 3: Urban Scale Evacuation and Crowd Dynamics

"….while the individual man is an insoluble puzzle, in the aggregate he becomes a mathematical certainty." –

Sherlock Holmes, The Sign of Four

Large Scale Disaster Planning and Management

- As part of EU FP7 project IDIRA EXODUS was expanded to applications involving large scale urban disasters.
  - floods, Tsunami, earthquakes, forest fires, terrorist situations, etc.
- urbanEXODUS is used to assist in planning large-scale movement of people AND webEXODUS is used during an incident.
- As part of this development EXODUS has been configured to read street geometries from open source resources such as:
  - Googlemaps
  - Open Street Maps (OSM)
- EXODUS can interpret the geography and identify roads, open spaces and buildings.
- Work is being expanded in two a EU Horizon 2020 projects:
  – GEO-SAFE http://fseg.gre.ac.uk/fire/geo-safe.html
  – IN-PREP

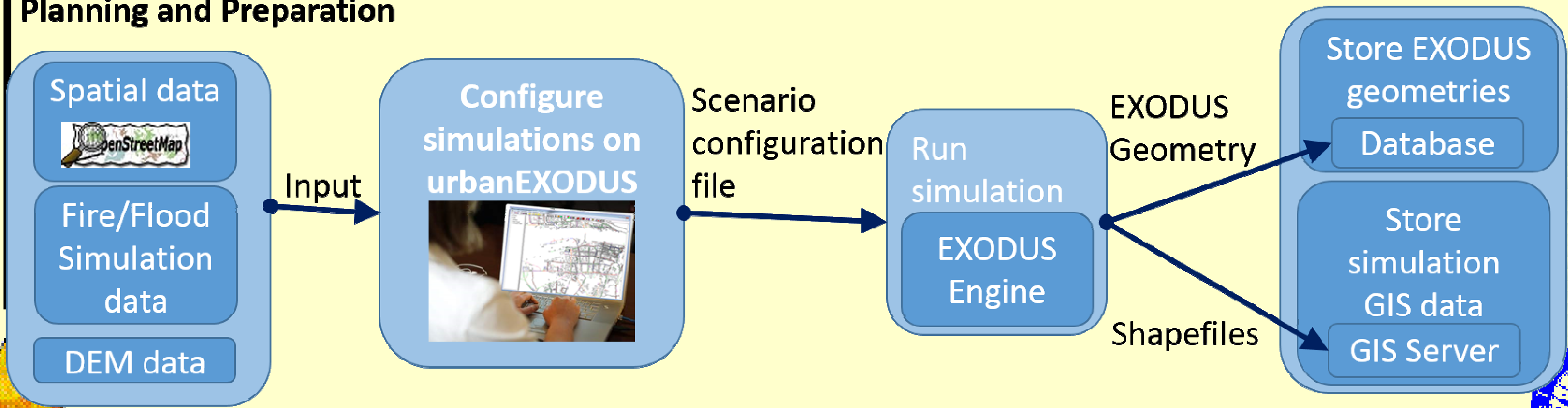
urbanEXODUS Concept

urbanEXODUS

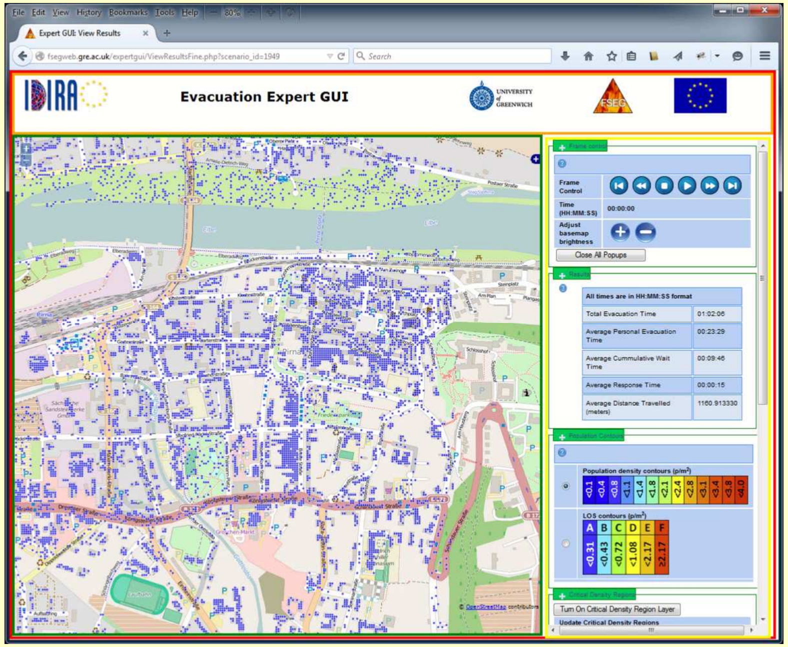
•**Pre-incident**: urbanEXODUS used to define procedures for a range of scenarios,

- create libraries of physical region and scenarios.

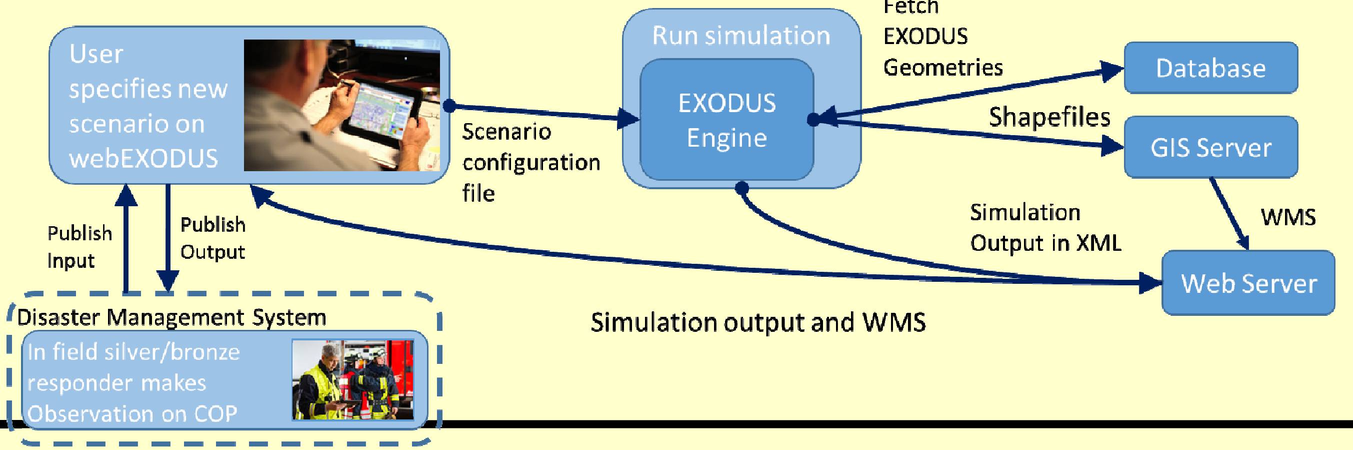
Planning and Preparation



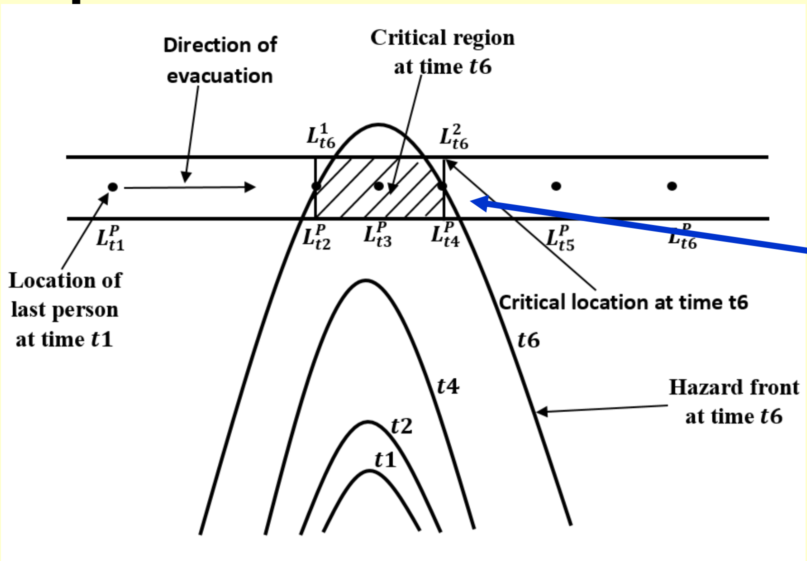
webEXODUS Concept

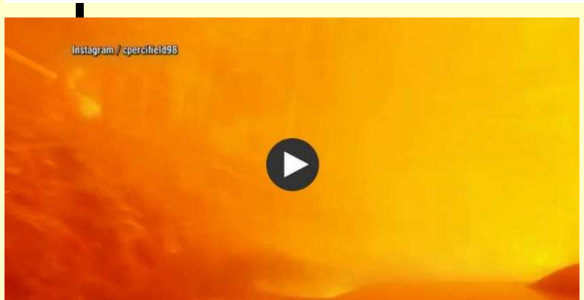


- **During-incident**: webEXODUS retrieves most similar library case.
- Incident managers can rapidly modify an existing scenario or set up an entirely new scenario.
- Incident managers or first responders in the field can dynamically update route availability, hazard spread, population distribution.



Coupling evacuation and fire simulation tools to determine safe evacuation routes and safety margins





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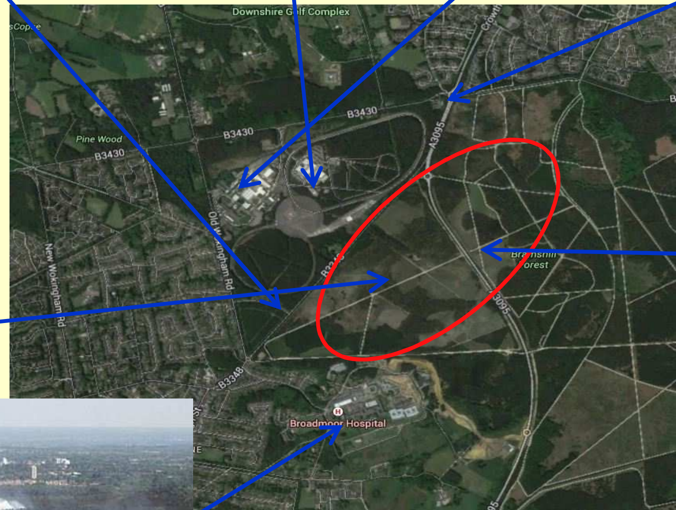
Pedestrian Wildfire Evacuation

- 2018 Attica Greece wildfires – 99 fatalities

- 2016 Haifa Israel wildfires – 75,000 residents evacuated from 11 neighbourhoods, 163 people were hurt mainly due to smoke inhalation.

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
  - 1220 people directly affected: TRL - 800 , Business Estate - 200, Pub - 200, Residential dwellings 20
  - Close to the high-security Broadmoor Hospital



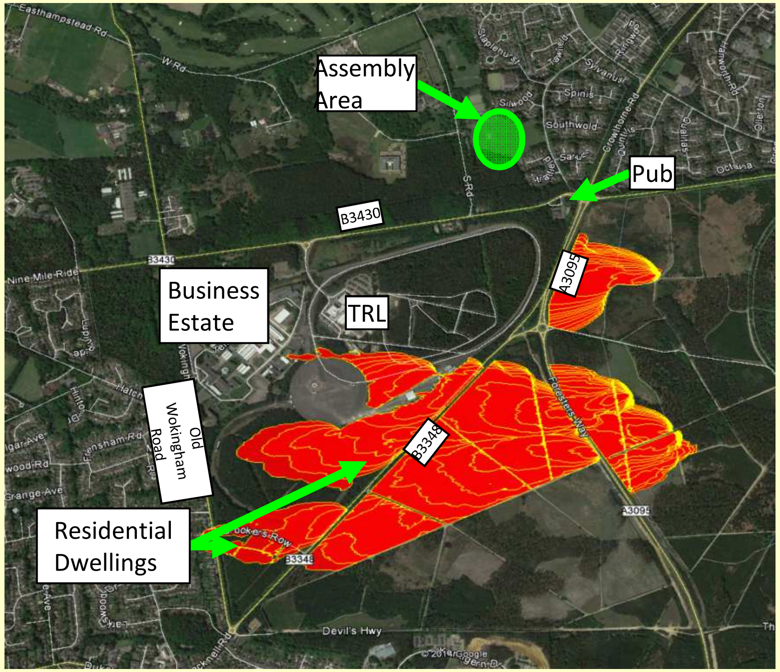
A3095

Broadmoor Hospital

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?

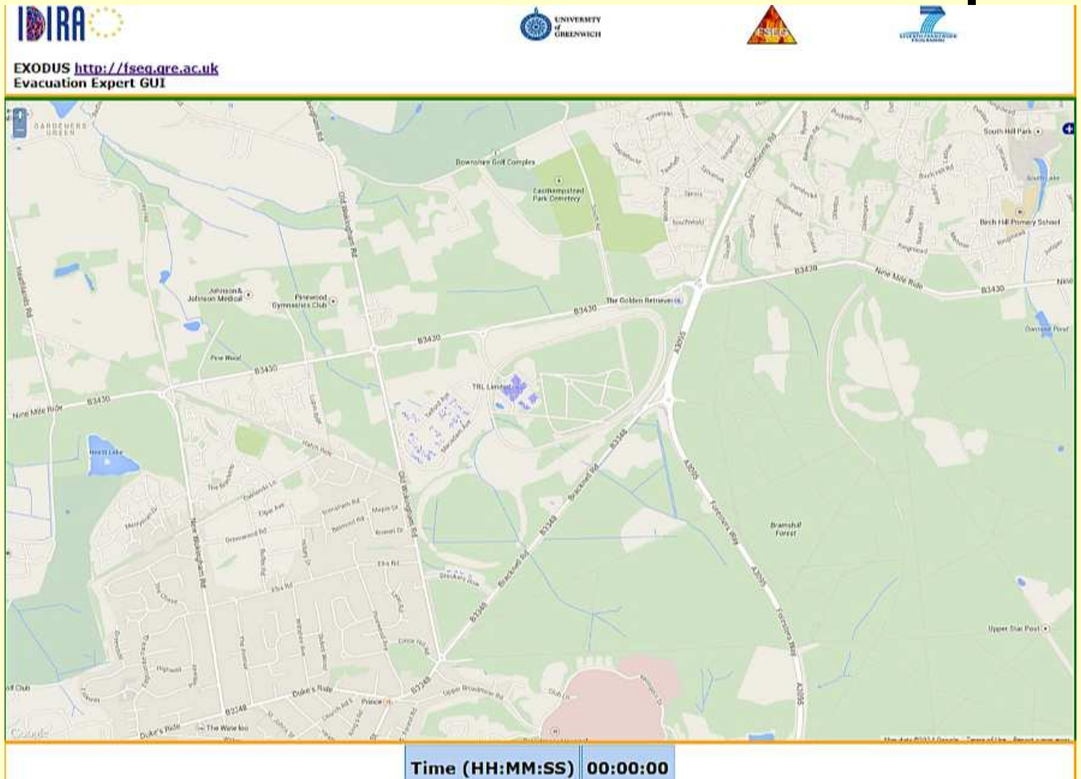
- Actual region burnt



- Simulated burn region given wind change

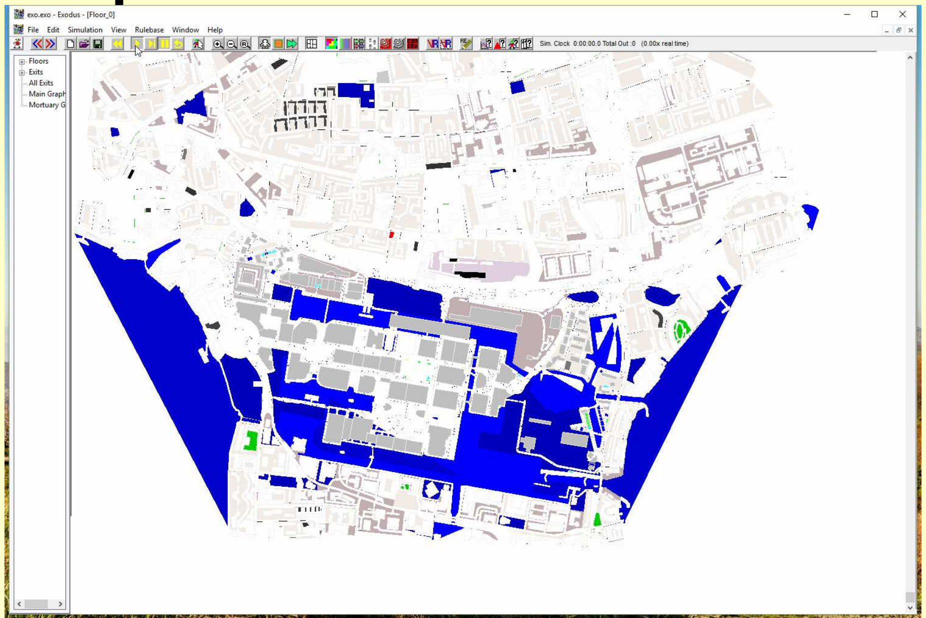
WildFire - Assembly Simulation

•Each dot represents an area of 6m x 6m, colour represents population density



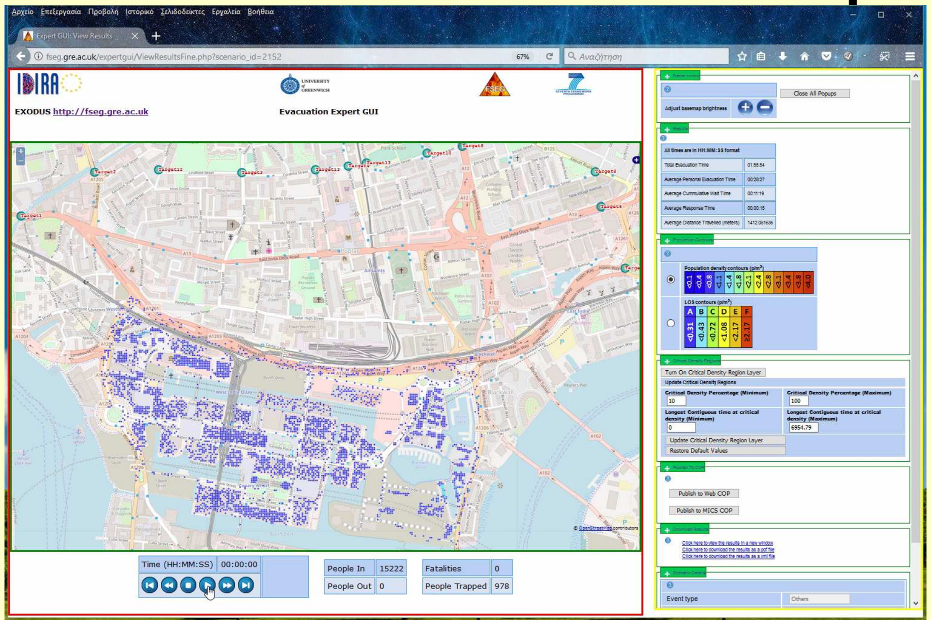
Evacuation Scenarios 205,000 people

- Scenario 3 is the fastest: 3.2 hrs, Average distance: 739m
- Scenario 4 is the slowest: 6.7 hrs, Average distance: 643m
- Run time: 15 hours on average
- PC: Xeon at 3.6GHz with 64GB RAM



urbanEXODUS

(Scenario 3 – exit 13 closed)



webEXODUS

(Scenario 3 - exit 13 closed)

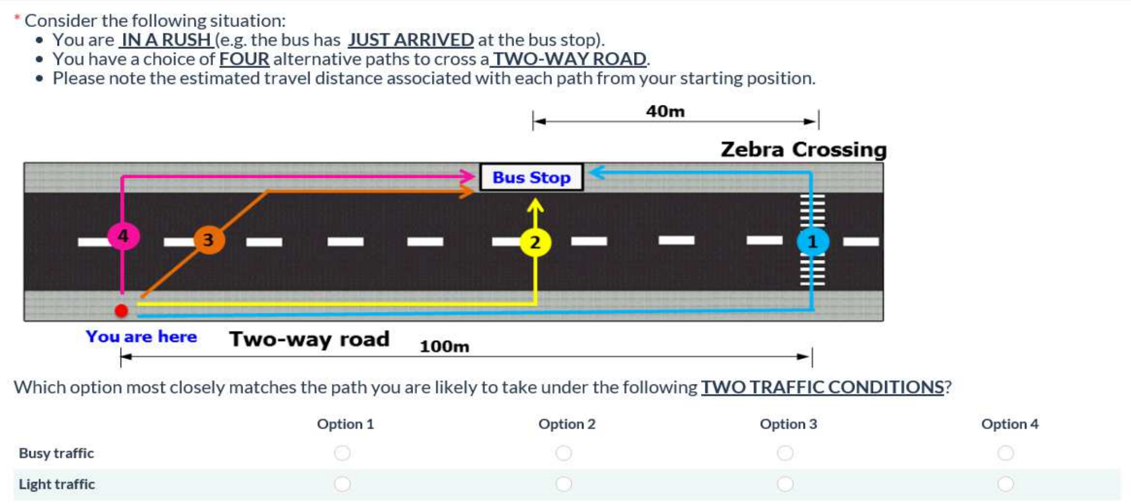
Pedestrian-Vehicle interaction Model

- In many urban evacuation and circulation applications it is necessary to include the interaction of pedestrians with vehicles.
- **Circulation Applications:** pedestrian movement around busy road traffic, including crossing behaviours.
- **Evacuation Applications:** Two types of application:
  - Post-Exiting Behaviour: Evacuation from large infrastructure where evacuation simulation continues to the external of the building and may involve pedestrians interacting or avoiding traffic flows.
  - Urban-Scale Behaviour: Pedestrian evacuation to/from vehicular transportation to remove them from the scene. This could involve agents moving to private vehicles or to rendezvous points for connection with mass transportation.
- In all cases it is necessary to understand and quantify how pedestrians interact with traffic, in particular crossing behaviours.
- Some data is available, but ………

Vehicle Interaction - Data Collection

- While there are many studies on pedestrian crossing behaviour there is a lack of quantifiable information concerning:
  - Precise circumstances of the nature of the data collection including, traffic conditions, target destinations, travel distances and sense of urgency

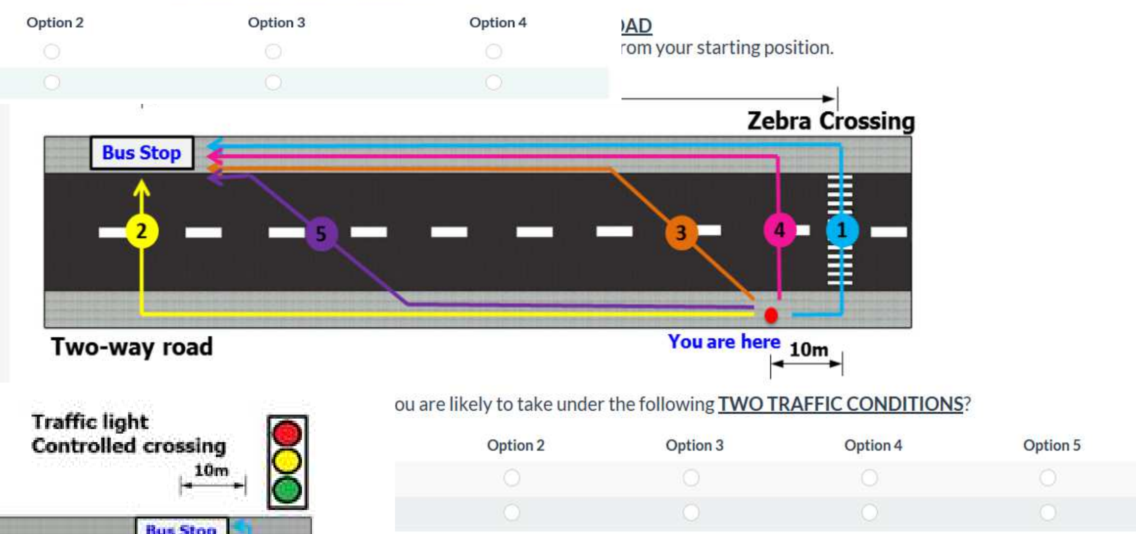
Online Questionnaire

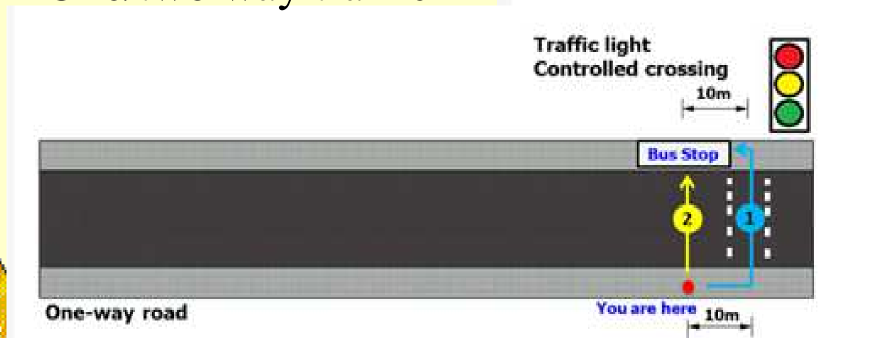


- 1176 people responded
- 36 Different Scenarios
- Road segments
  - 100 metres long

Routes Choices

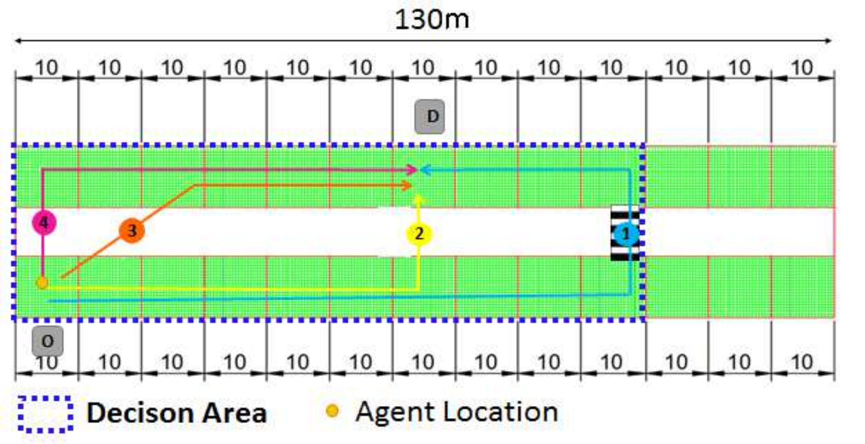
- Signalised Crossing
- Zebra Crossing
- Busy/Light Traffic
- Urgent/non-urgent
- One/two way traffic

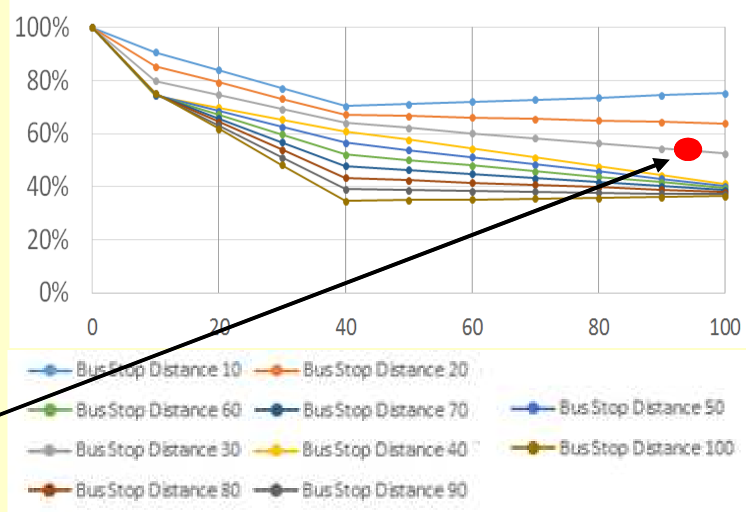




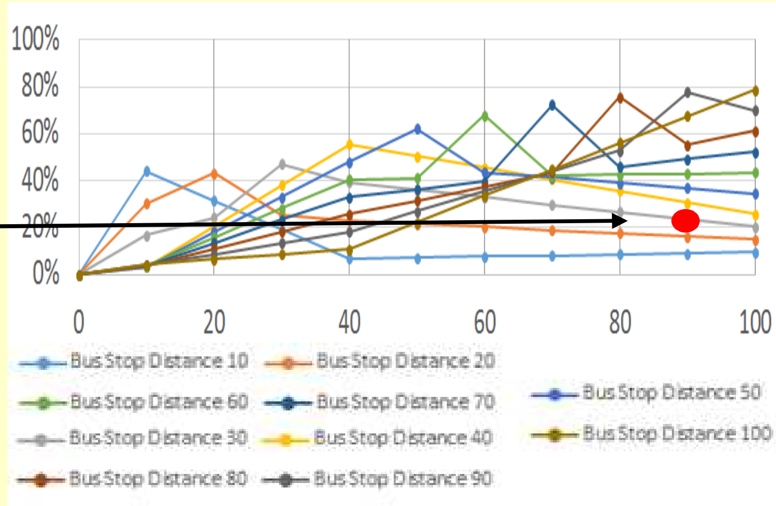
https://fseg.gre.ac.uk/surveys

Crossing Behaviour Probability





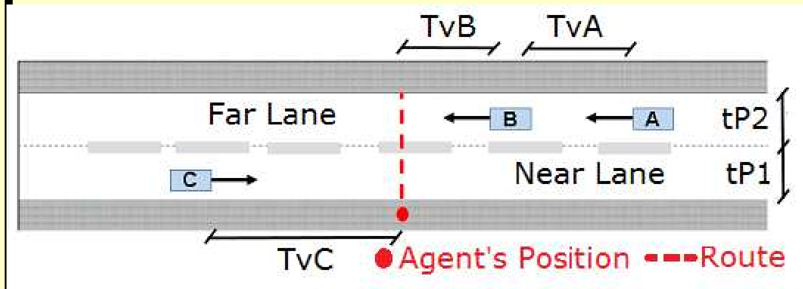
Option 1 – Use crossing
Busy traffic – rush – bus stop 30 metre
Agent distance 90
Around 50% but proportion increases the closer the bus stop is to the crossing.

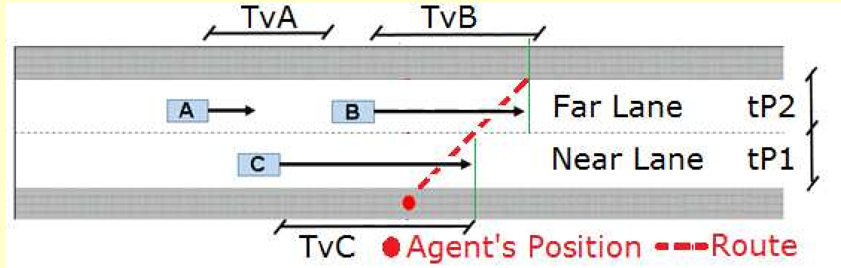


Option 2
First walk and then cross
Light traffic – no rush – bus stop 30 metre
Agent distance 90
Is less than 20% but proportion increases the further the bus stop from the crossing

When to Cross - Gap Acceptance

- Decision based on:
  - head way
  - number of lanes
- Behaviour model controls how and when agent crosses road.
  - one go - known as double gap or one stage crossing
  - lane by lane - known as rolling gap or risk-taker





- Agents consider:
  - the first vehicle in the near lane
  - And the first two in the far lane

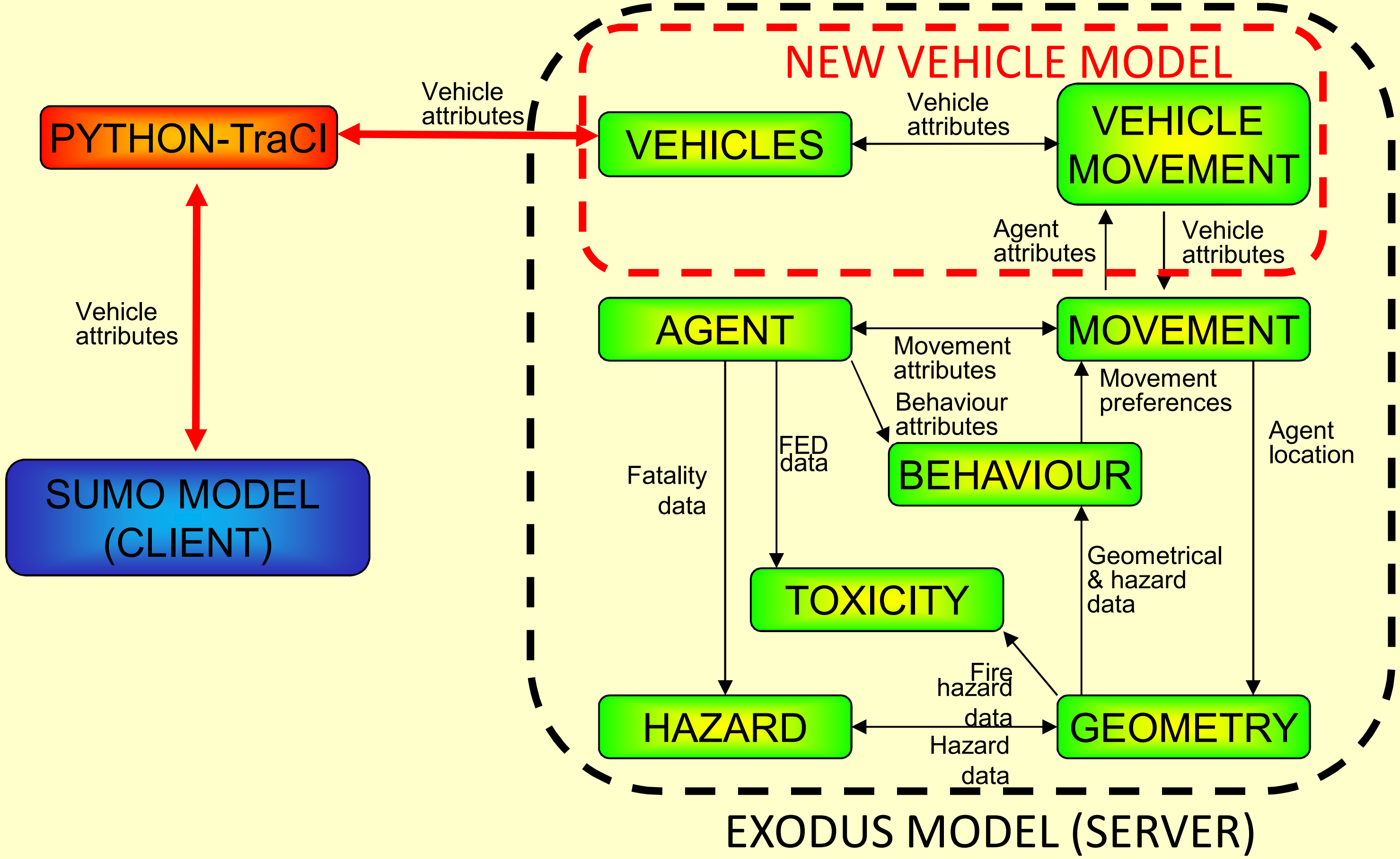
Agent-Vehicle Interaction Model

- Explore the possibility of agents interacting with vehicles
- This requires the agents to be 'aware' of the vehicles and vehicles to be 'aware' of the agents.
- In the current EXODUS - UC WINROAD link there is no agent-vehicle awareness.
- To achieve this, it is necessary for EXODUS to have an internal representation of vehicles and to be able to take control of the vehicle when there is a potential for vehicle-pedestrian interaction.
- The vehicle model must:
    - Interface with Open Street Map allowing the import of large urban environments
    - Have an ability to represent thousands of vehicles in a large urban environment road network.
    - Have APIs enabling external software to remotely control the traffic model, essentially allowing EXODUS to act as the SERVER and the traffic model act as the CLIENT
    - Have an ability to couple easily with C++ software (EXODUS)
    - EXODUS must be able to take control of the vehicles interacting with the pedestrians while the traffic model controls the vehicle-vehicle interaction.

Agent-Vehicle Interaction Model

- To represent vehicles within EXODUS a prototype two way coupling has been developed between EXODUS and SUMO.
- SUMO - Simulation of Urban Mobility (http://sumo.dlr.de)
- Developed by the Institute of Transportation Systems at the German Aerospace Centre, open source tool (since 2001).
    - Links with OpenStreetMap (OSM).
    - Provides APIs to enable external software to remotely control SUMO.
    - Python-TraCI Library allows interfacing a python script with a running SUMO simulation.
- EXODUS links to SUMO by using embedded python to call and run external python scripts using the TraCI Library.
    - EXODUS pedestrian crosses road ahead of vehicle, EXODUS sends message to SUMO to slow down/stop the vehicle
- This integration allows the modelling large scale circulation/evacuation scenarios where pedestrians can interact with moving vehicles.

EXODUS-SUMO Architecture



TraCI stands for Traffic Control Interface

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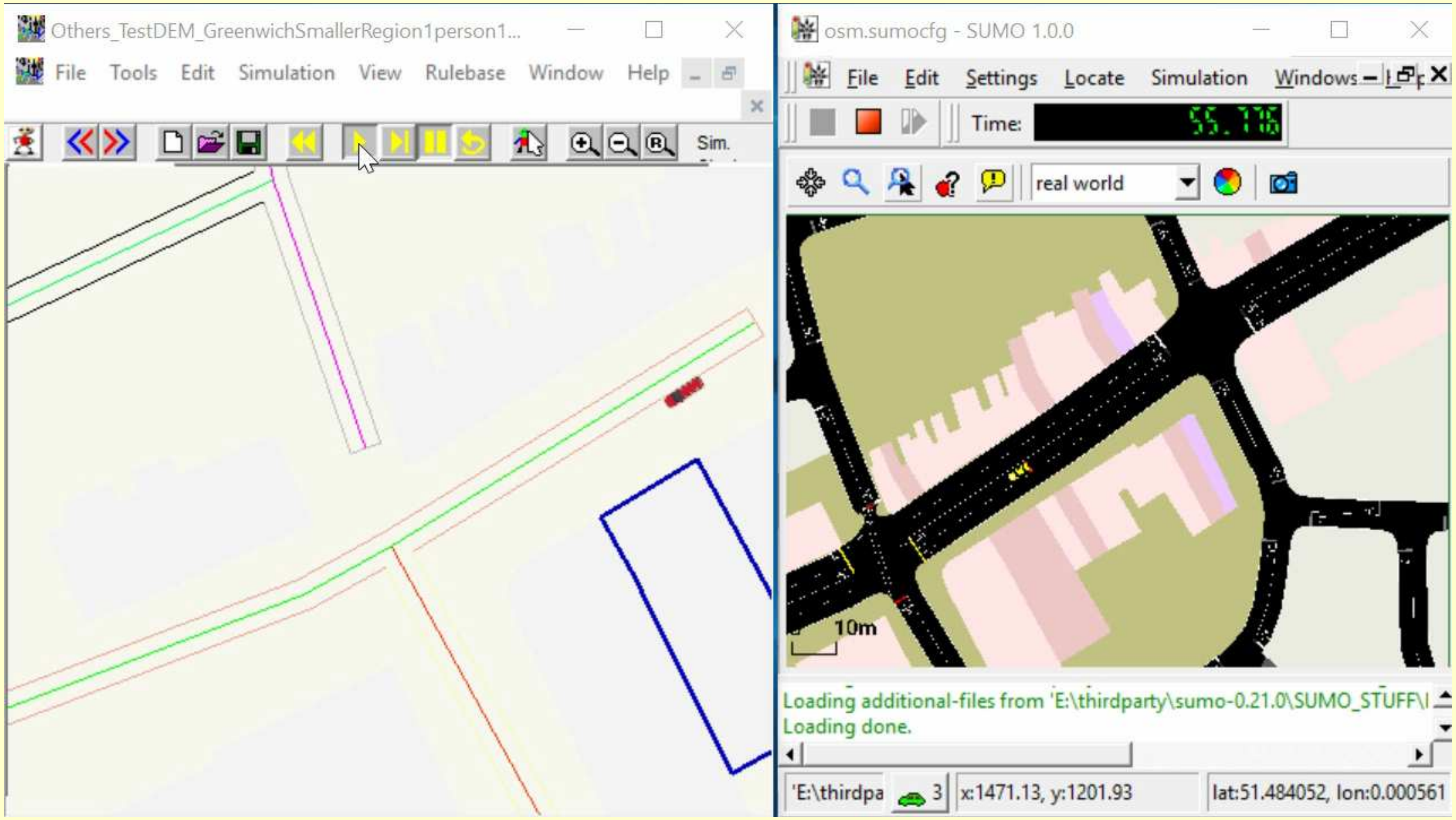
EXODUS-SUMO Architecture

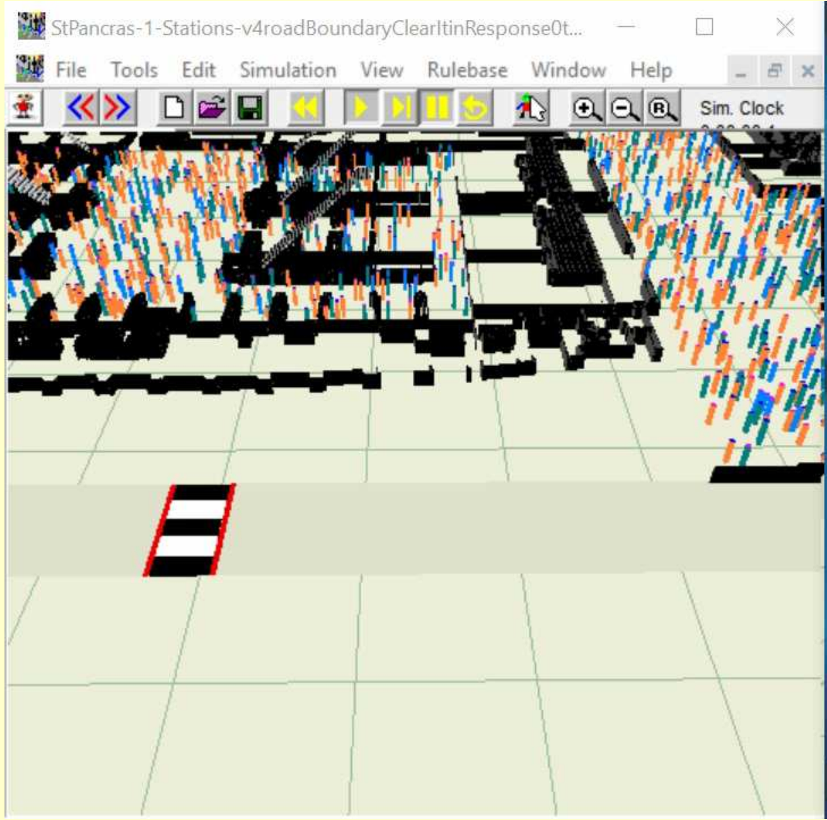
- EXODUS extended to include two new models:
  - **VEHICLE MODEL**
    - specifies vehicle location, speed, acceleration, dimensions, etc.
    - obtained from SUMO via an external python file utilising TraCI library
    - Thus SUMO vehicles are replicated within EXODUS.
  - **VEHICLE MOVEMENT MODEL**
    - assesses movement of vehicles (from VEHICLE Model) and agents (from MOVEMENT Model)
    - determines whether EXODUS needs to intervene to stop a collision between agents and vehicles, and if so, then updates the vehicles behaviour by sending a command to the VEHICLE Model to brake.
    - Also controls the status of traffic lights
    - this information is sent back to SUMO via the external python TraCI file.
- The agent movement is also affected by the presence of vehicles and so agents consider the location and behaviour of vehicles when considering crossing roads.
- EXODUS thus controls the SUMO vehicles remotely – while SUMO has no knowledge of where the pedestrians are at any time, the vehicle movement can be adapted to ensure that collisions do not occur.
- Within this set-up EXODUS acts like the server, and SUMO acts like the client. Hence, EXODUS is effectively controlling SUMO.

EXODUS-Traffic Model Integration

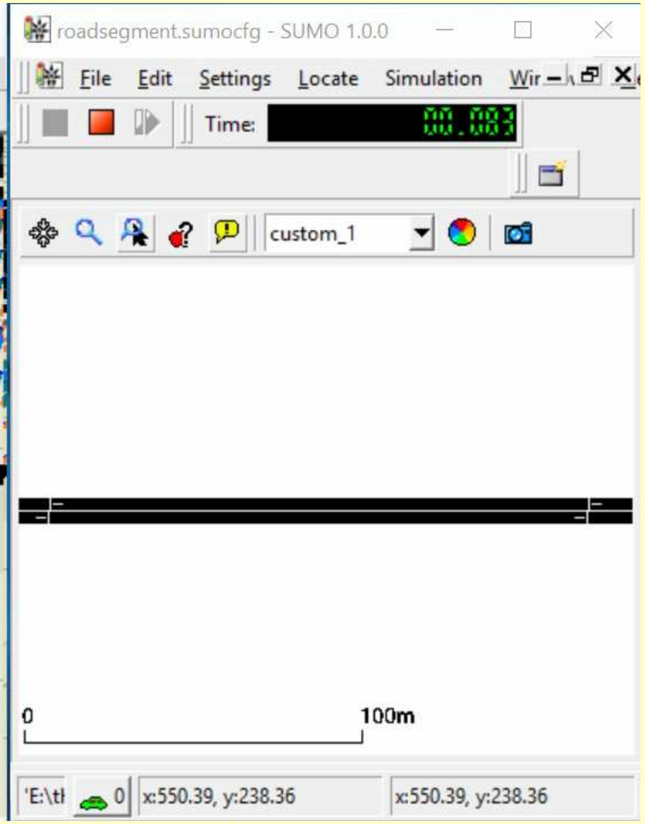


EXODUS 2D VIEW SUMO-GUI

- SUMO controlled cars replicated within EXODUS
- Greenwich geometry imported from OSM into EXODUS and SUMO

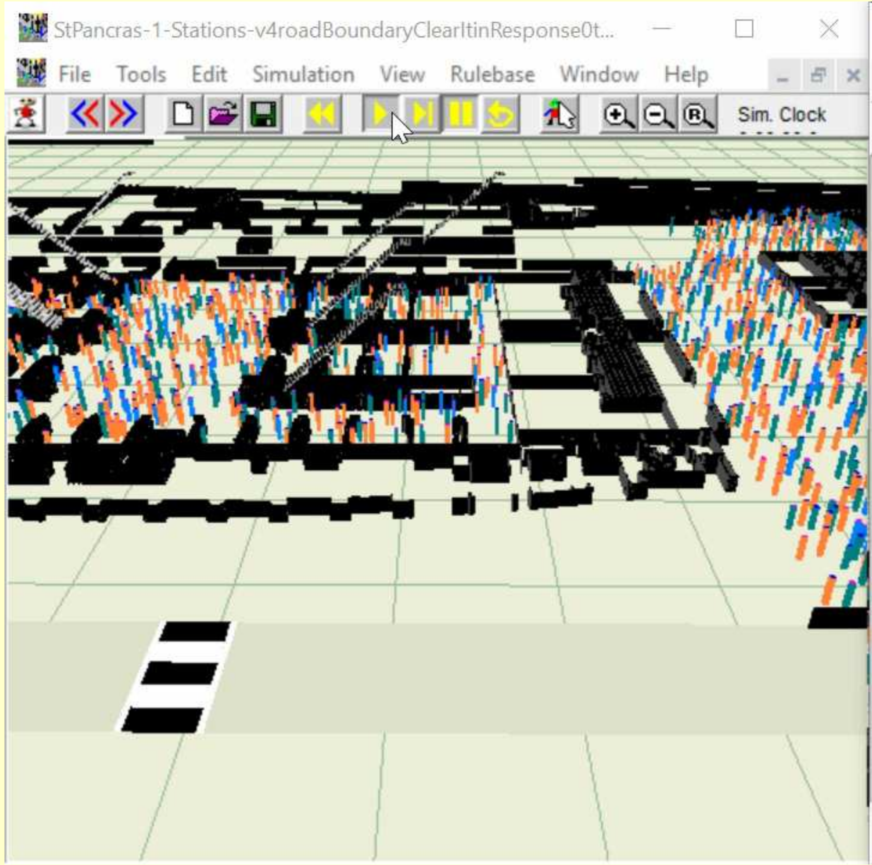


EXODUS 3D VIEW

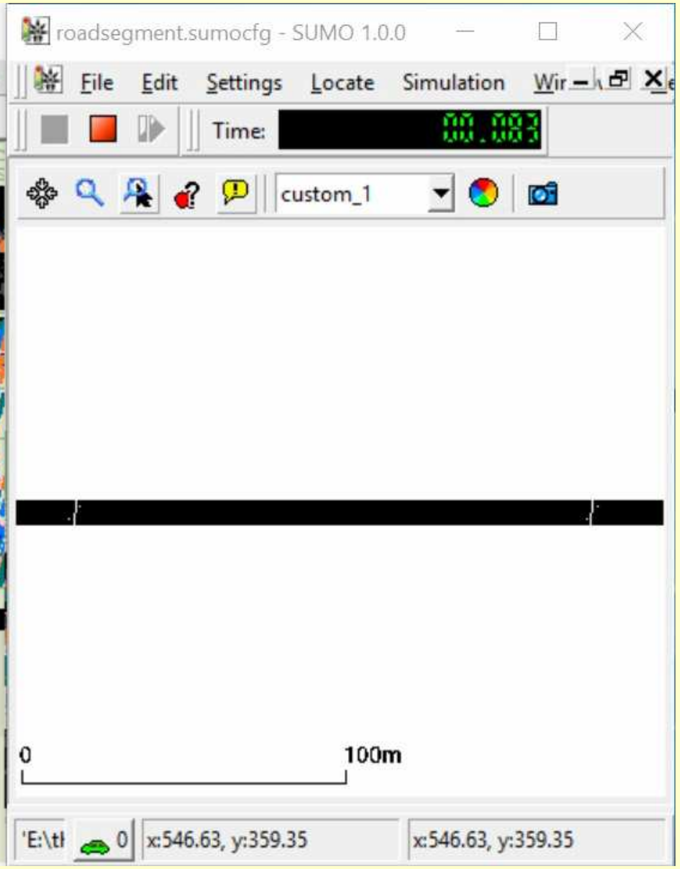


SUMO-GUI

- Agents have a target across the road and high urgency, traffic lights controlled by EXODUS,
- Traffic flow controlled by SUMO, very light to begin and traffic density increasing with time.
- Most agents use crossing but some agents attempt to cross at random point, probability of random cross decreases with volume of traffic.
- EXODUS applies brakes to vehicles when necessary to avoid collision with pedestrians.



EXODUS 3D VIEW



SUMO-GUI

- As previous case, but using a Zebra crossing.
- Greater number of agents cross randomly as vehicles stopped for greater period of time.

HELP US WITH OUR RESEARCH

- FSEG are involved in a research project to explore new concepts in dynamic emergency exit signs, similar to that shown below.
- We need your input to assist us with our research.
- We are particularly interested in how the Japanese interpret the signage concept.
- Why not participate in citizen science and complete the survey – it only takes 5 minutes of your time
  - http://bit.ly/fseg-signage

CONCLUDING COMMENTS

- Safe evacuation is challenging and requires careful planning, it doesn't just happen.
- Use of ***reliable modelling*** tools in conjunction with ***good data*** enable fewer arbitrary assumptions to be imposed, allowing conditions to be modelled rather than assumed.
- Simulation can be used to assist in planning to ensure:
  - efficient throughput,
  - comfort,
  - safety and
  - security.
- Finally, while it may be appealing to make simplifying assumptions concerning human behaviour it is essential to remember people are not ball bearings and they will not always behave the way the engineer would like them to behave.