Safety and Security in Crowded Places through Evacuation Simulation

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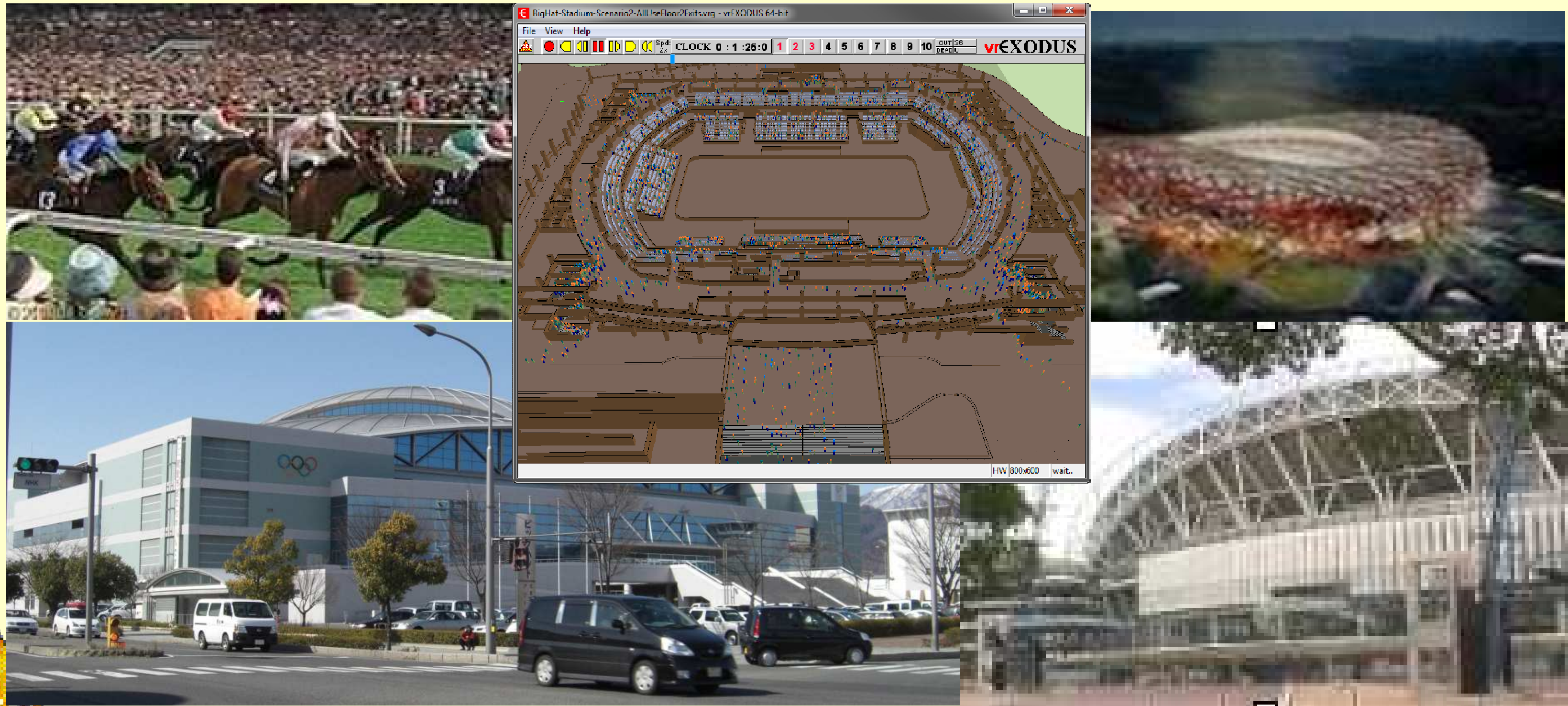

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Tokyo Japan
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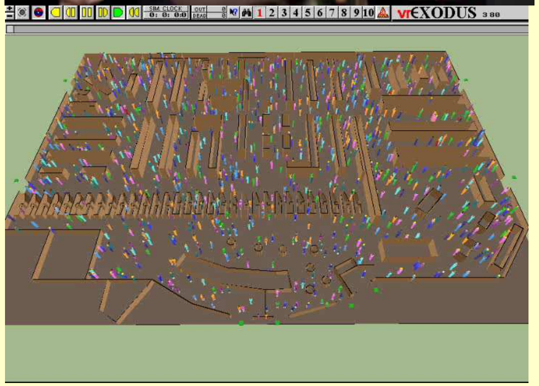
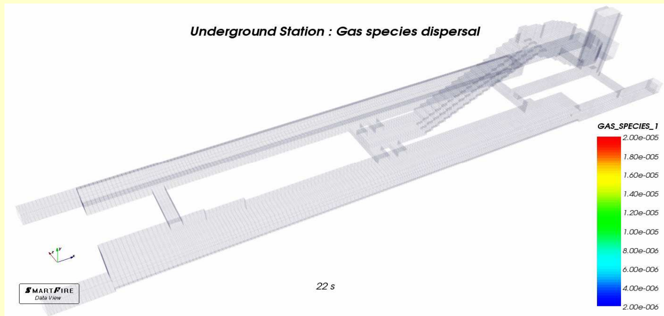
http://fseg.gre.ac.uk

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,
  - homeland 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

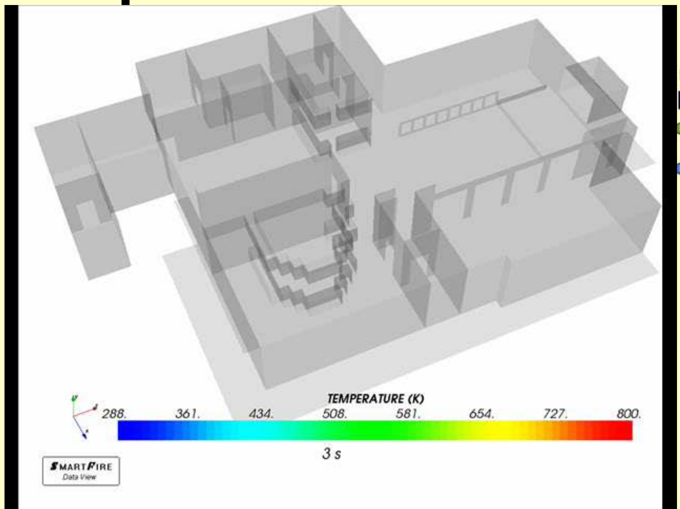
EXODUS Applications

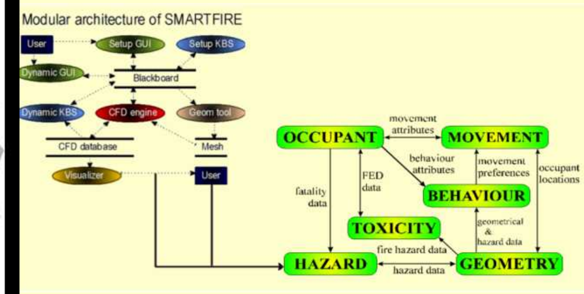
Underground station evacuation

• LuL station with fire.

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.

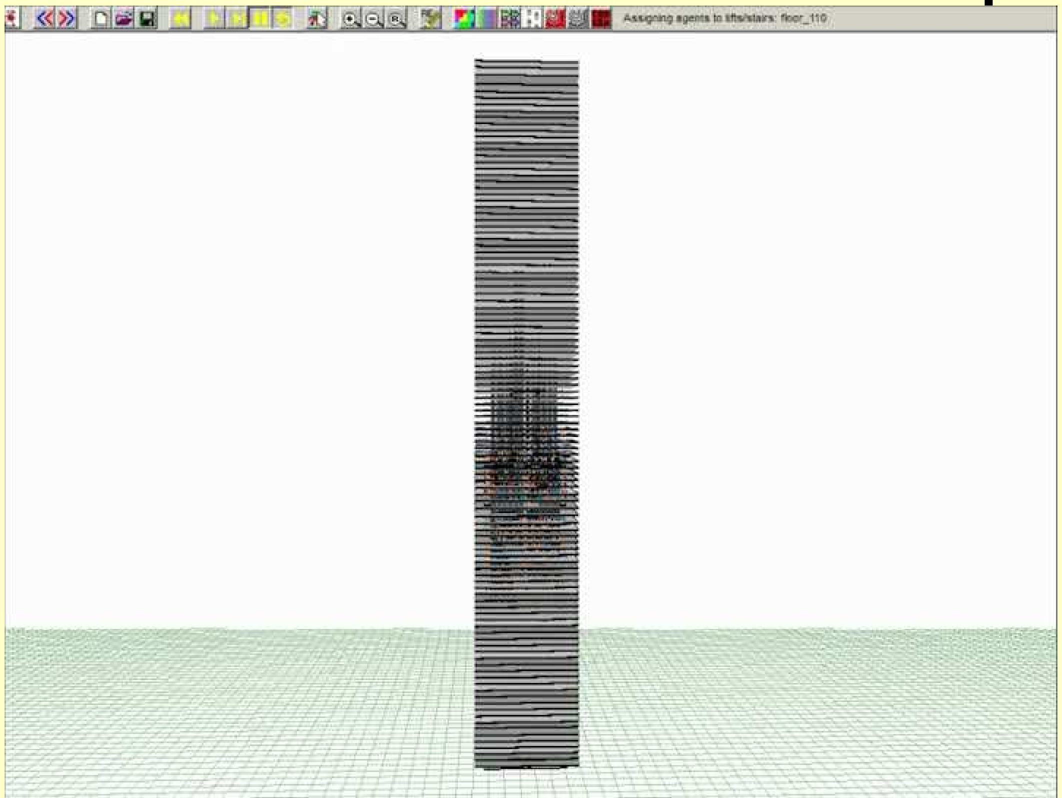




- Last survivor evacuates after approx 127 seconds.
- Simulation predicts :
  - 84 fatalities compared with 100 in actual incident.
  - 25 serious injuries, of which 6 are life threatening.

High Rise Building Evacuation

- 110 floor building with 25,500 people.
- The building has 20 express lifts servicing the Sky Lobbies and 60 local lifts.



- buildingEXODUS suggests:
  - 1 hr 23 mins to clear tower
  - 40% faster than stairs
  - 58% only use stairs
  - 39% only use lifts

Crowded Places

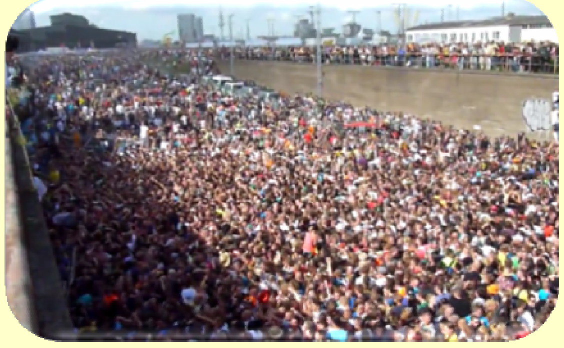
Safety and Security in Crowded Places

- 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 …..

Disasters in Crowded Places

Heysel Stadium riot, Brussels (Belgium) 29/05/85 – 39 fatalities

Bradford City Football stadium fire (UK) 11/05/85 – 56 fatalities



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

Hajj, Mecca (Saudi Arabia) 31/07/87, 402; 02/07/90, 1,426; 23/05/94, 270; 15/04/97, 500; 09/04/98, 180; 05/03/01, 35; 01/02/04, 251; 12/01/06, 360; 24/09/15, 2,000? fatalities

Safety and Security in Crowded Places

- Due to the large numbers of people gathered within a confined space, stadia are a significant challenge.
  - Particularly if crowd are not familiar with the stadia e.g. for international events such as Olympics.
- Most recent example 13 November when 80,000 people were evacuated from the Stade de France due to terrorist attacks in France.
  - Essential to have flexible evacuation strategy and means of directing the population
  - Normal procedure in event of fire is to get people out of stadium as quickly as possible.
  - For an exterior terror incident, may be more appropriate to evacuate onto pitch and to exit via certain safe exits.
  - For a interior terror threat e.g. more appropriate to evacuate out of the stadium as quickly as possible.

Safety and Security in Crowded Places

- Evacuation onto pitch

- Directing people to specific exits

Safety and Security in Crowded Places

- On 12 December 2004, stadium Santiago Bernabeu in Madrid was evacuated following a bomb threat.
- 69,000 people were safely evacuated in 7.5 minutes.
  - Used stadium's speaker system, megaphones, 315 CCTV cameras, and 1168 staff (500 police, 190 security guards and 478 assistants).

64000 people exit via 122 vomitaries and 49 exits

Crowd first alerted by public radio, people alerted others and then public

5000 people from lower stands exit via pitch

Safety and Security in Crowded Places

- Computer simulation of human behaviour and evacuation can be used to:
  - Assist in venue design to ensure that people flows under normal conditions are quick, efficient and comfortable.
  - Ensure that the venue design is appropriate for emergency evacuation for a range of emergency scenarios, not just fire.
  - Ensure that the procedures are sufficiently robust so that they can deal with a range of emergency scenarios, including terrorist related.
  - Demonstrate verify emergency procedures.
  - Through virtual and augmented reality, provide a means to train emergency personnel in conditions that would not normally be possible.
- Demonstrate venue and procedure design application using Big Hat geometry.

Big Hat Nagano

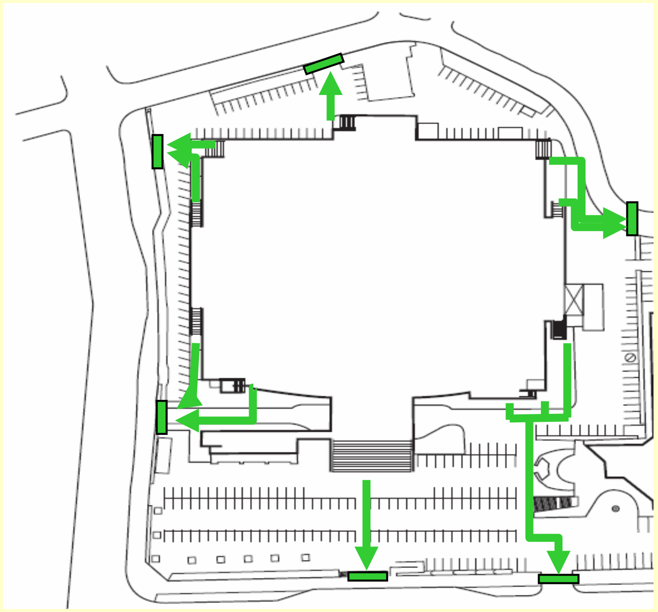
- Big Hat is a large scale multipurpose arena located in Nagano.
- It was the main venue for the ice hockey events of the Nagano Winter Olympic Games 1998.
- In winter it continues to be used for ice hockey and figure skating competitions.
- The venue comprises 3 floors and has a ceiling height of 35m.
- Here we consider the Cyudan seating arrangement–4083 people

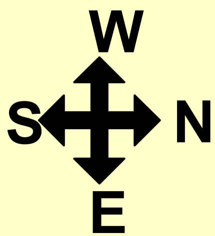
Evacuation Scenario

- Base Scenario:
  - Managed evacuation in which all agents evacuate using the nearest route off of their initial floor and then the nearest exit from the venue.
  - 4083 people initially located in their seats.
  - Assume log-normal response time with a 2 min max.
  - As observed in the Marlowe Theatre evacuation, the distribution of response times within each seat block were assumed to be dependant upon how far agents were initially seated from an available exit point.
  - Once complete, 30% of the response times within the block were then randomised to ensure more realistic response behaviour.
  - Population exit their initial seat block via the nearest aisle.

Evacuation Scenario

- Population correspond to default buildingEXODUS population.
- On exiting the arena, population move to one of the designated locations a safe distance from the arena.
- Thus any congestion that may occur outside of the arena may influence the ability for the population to exit the structure.
    - Assumes there are sufficient staff outside arena to manage the exiting flows and other flows around the arena are controlled.





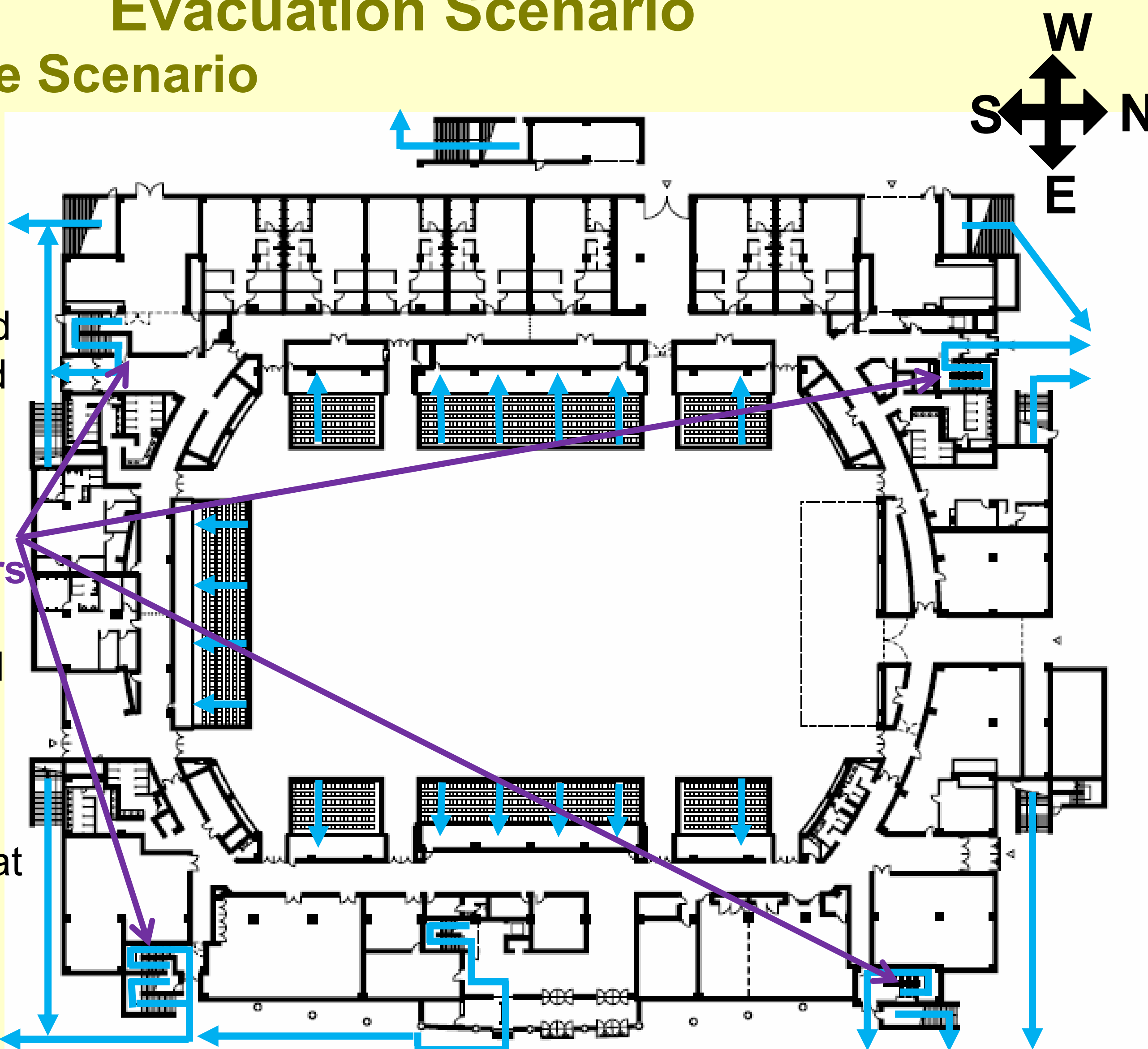
Evacuation Scenario

Floor 1: Base Scenario

Exiting Process:

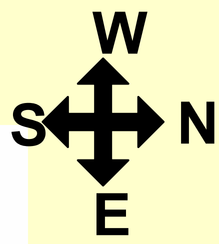
Use of External Stairs:
Exit on Floor 2 and descend to ground via external staircases
OR
Use Internal Stairs
Descend all the way to Floor 1 and exit.

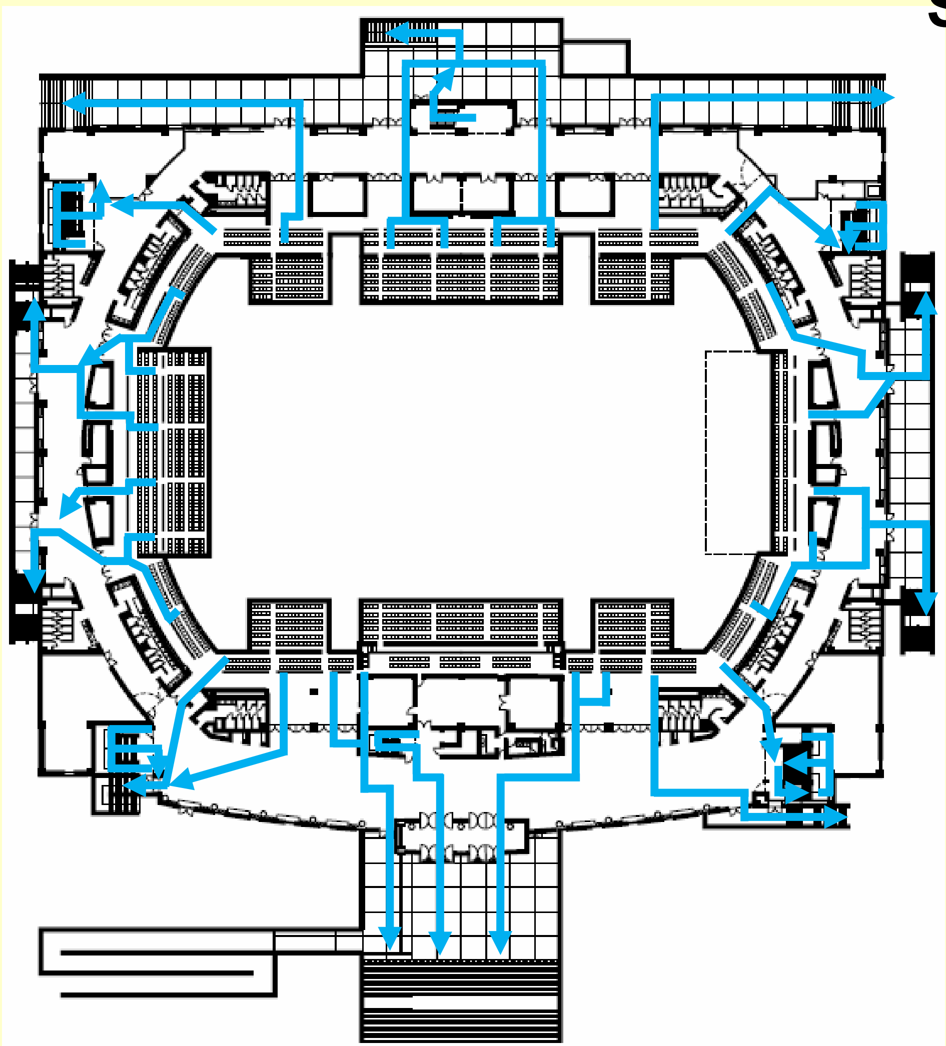
Those in lower seat tiers leave their seat blocks and ascend to Floor 2.



Evacuation Scenario

Floor 2: Base Scenario

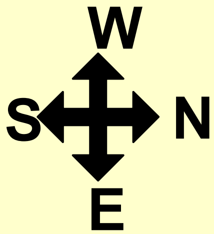


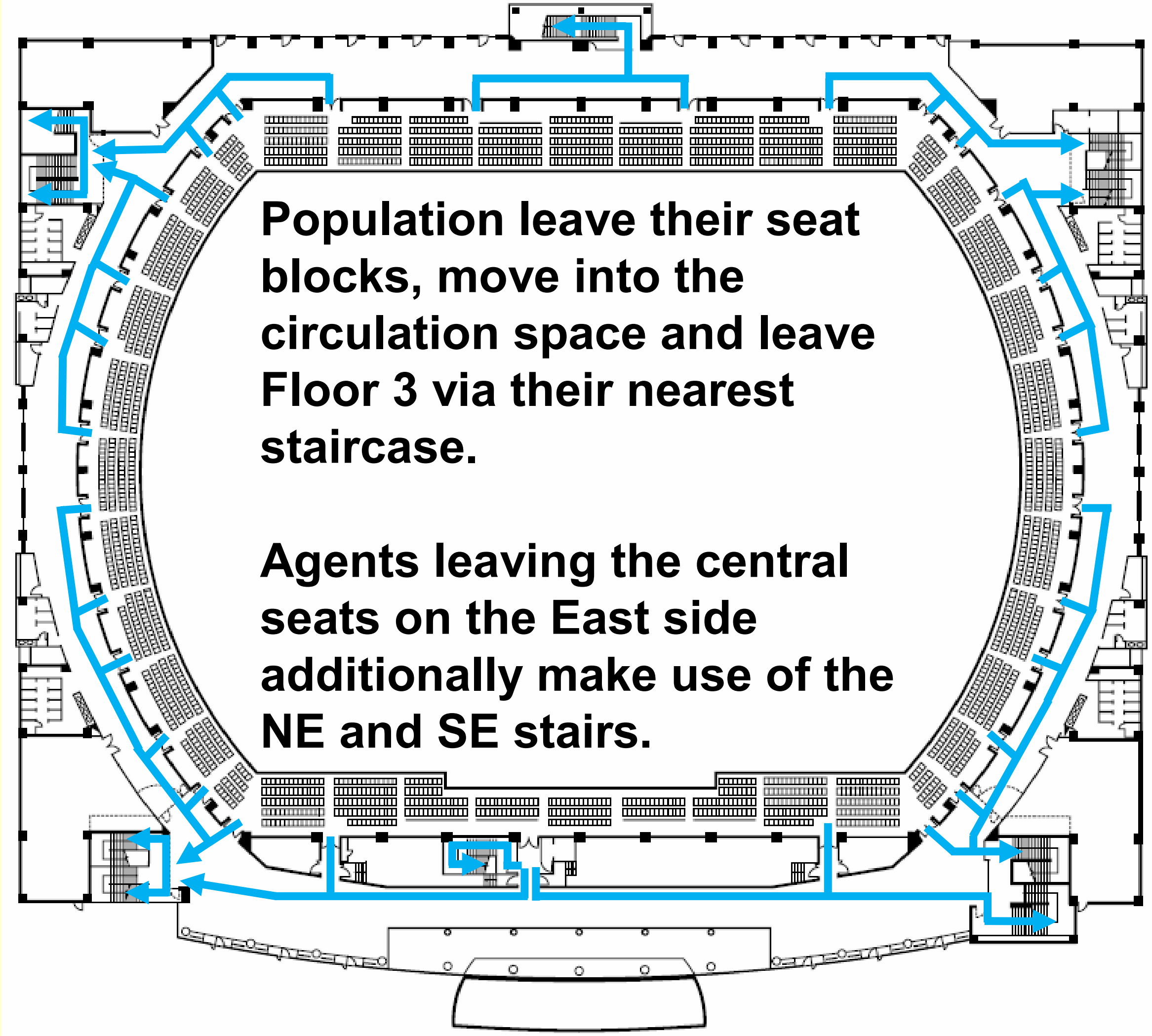


Population exits seat blocks and move into the circulation space on Floor 2 and then head towards the nearest route off the floor.

Evacuation Scenario

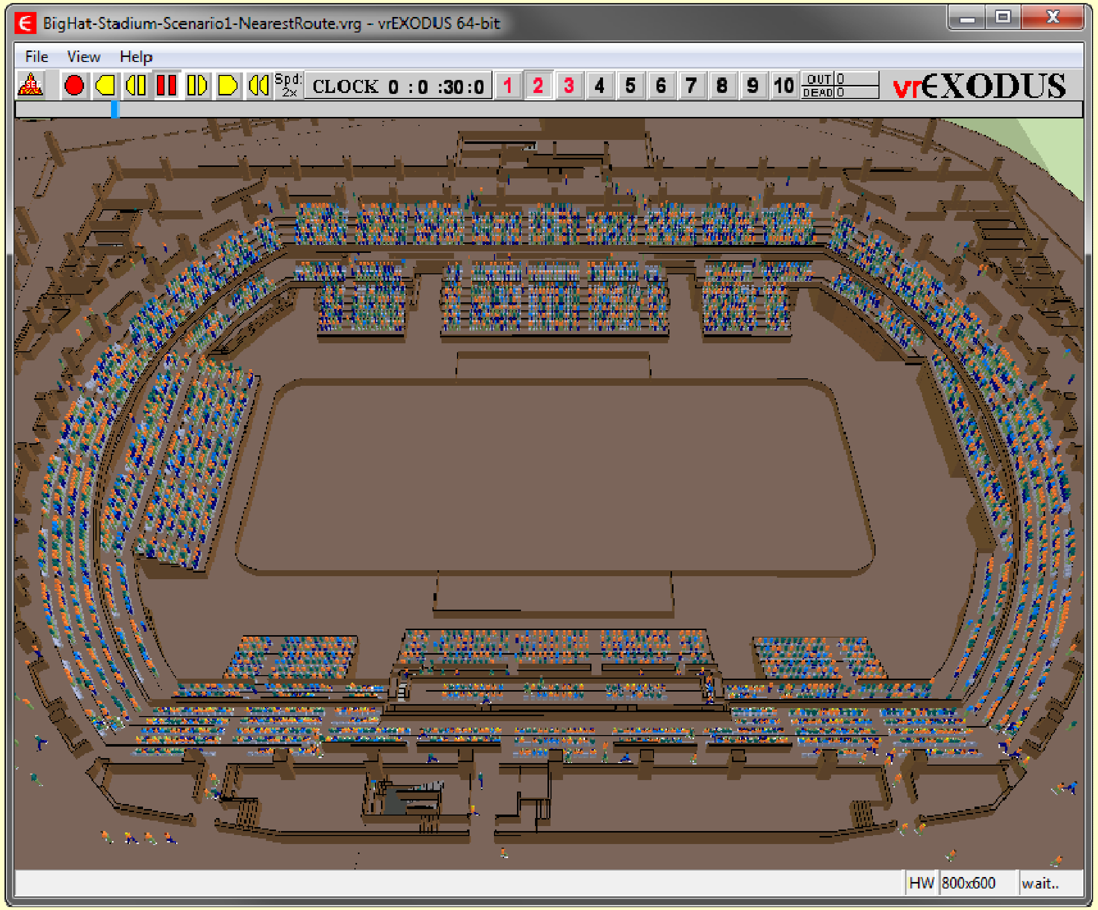
Floor 3: Base Scenario





Base Case Evacuation Scenario

	TET (min)	PET (min)	CWT (min)	Floor2 seats (min)	Floor3 seats (min)	Floor2 (min)	Floor3 (min)
Base	5.5	3.0	0.44	4.0	2.2	4.7	3.3



0 min 30 sec

Base Case Evacuation Scenario

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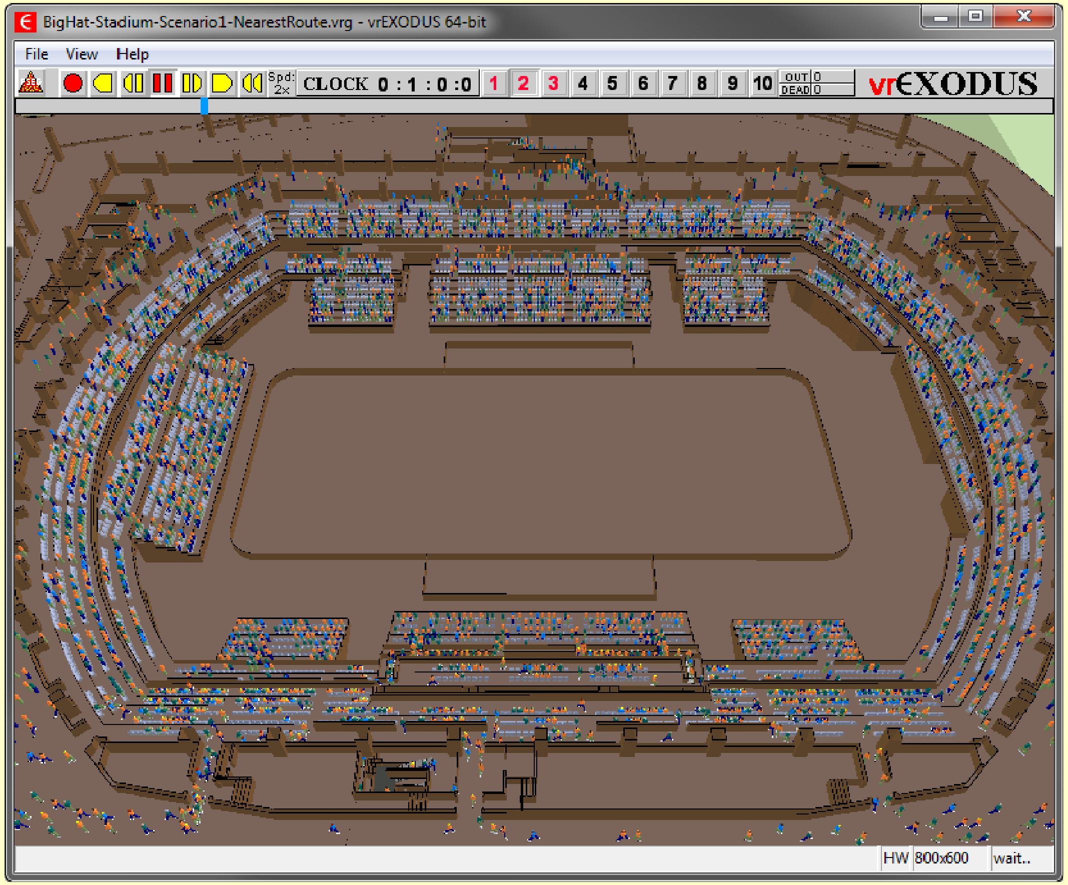

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Base Case Evacuation Scenario

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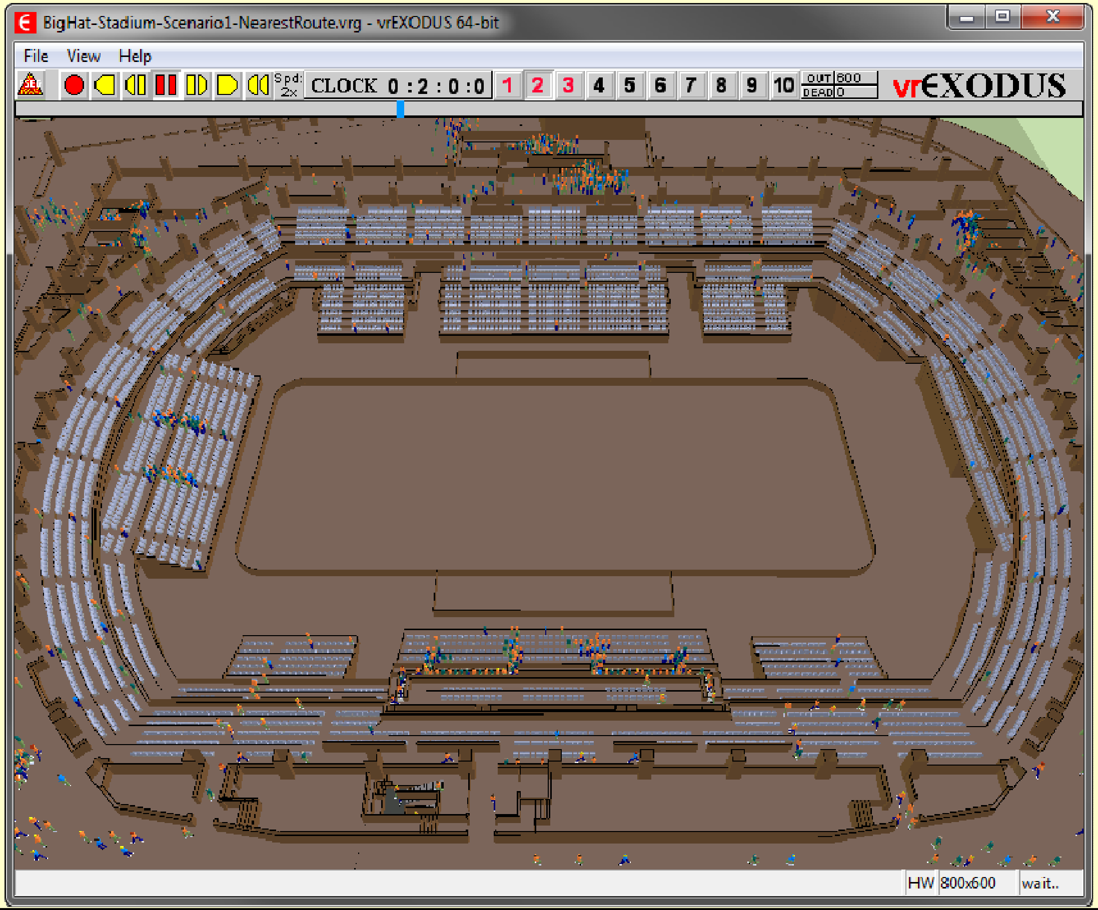

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Base Case Evacuation Scenario

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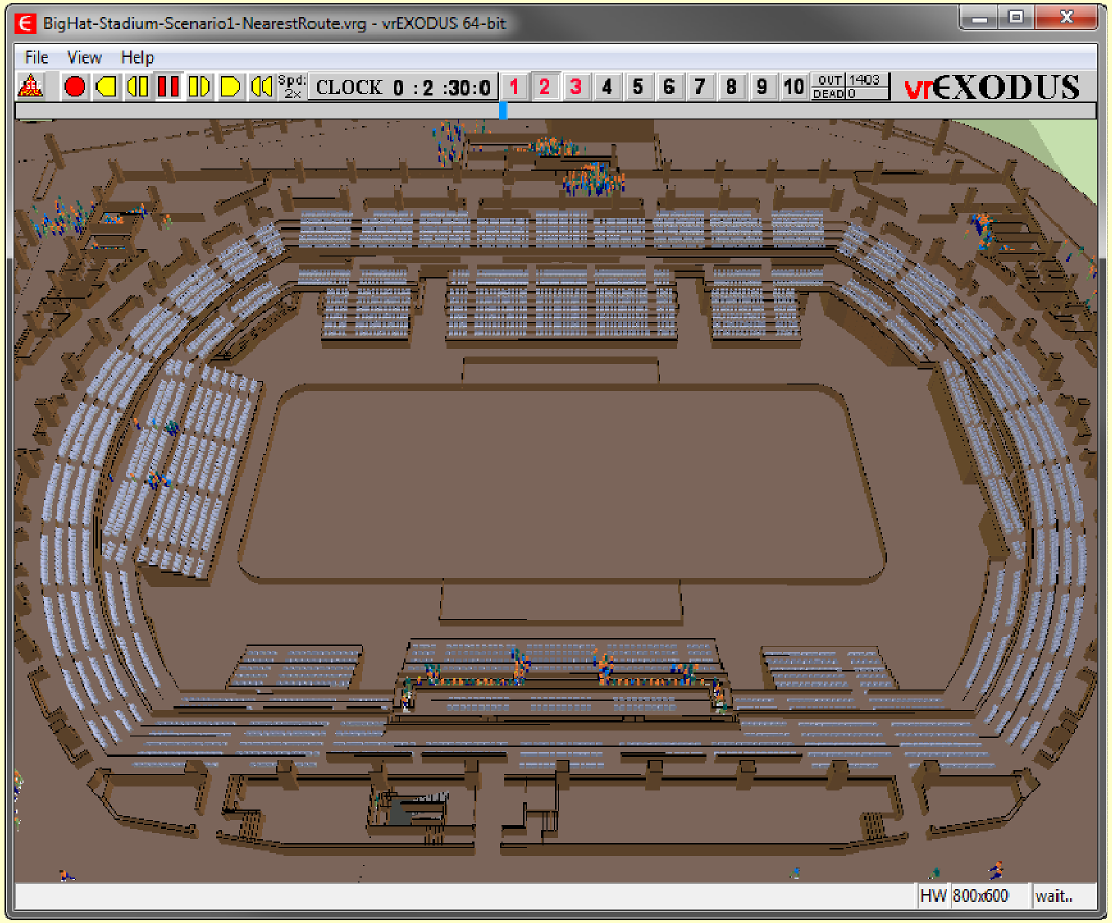

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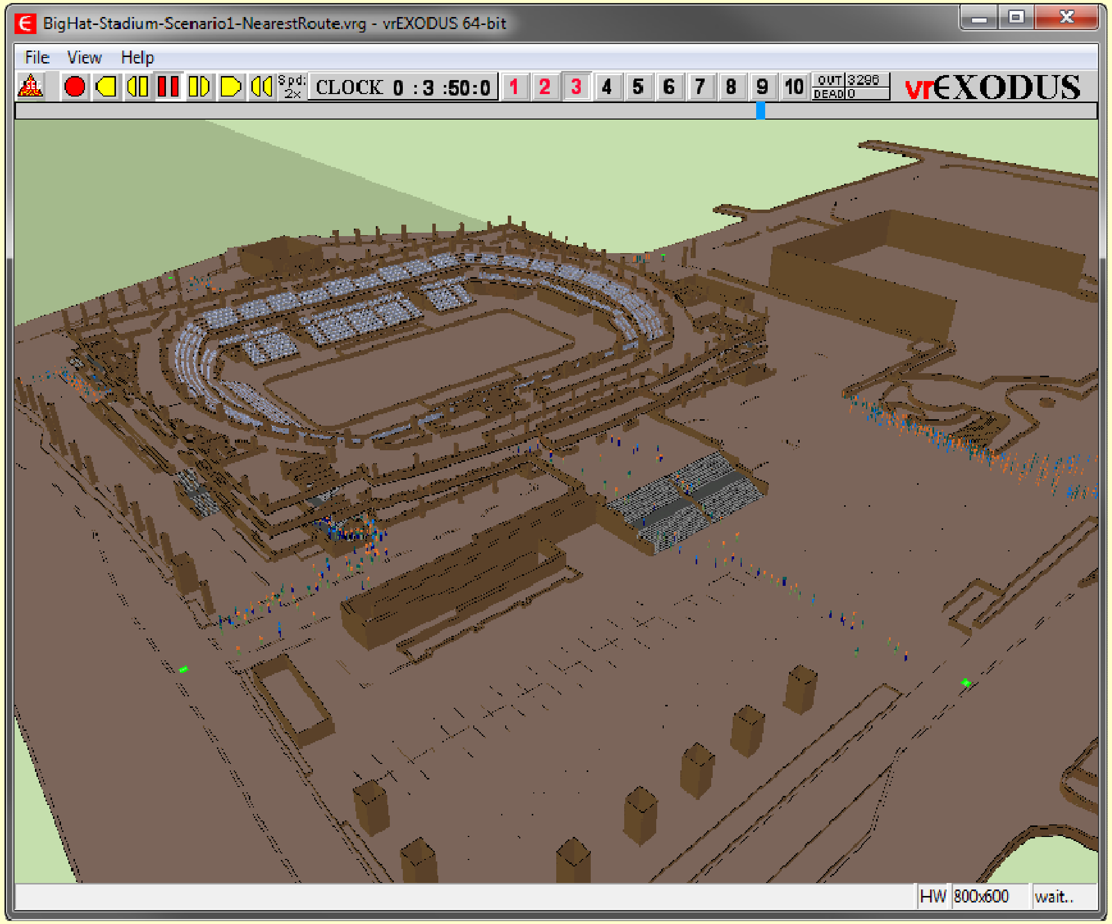
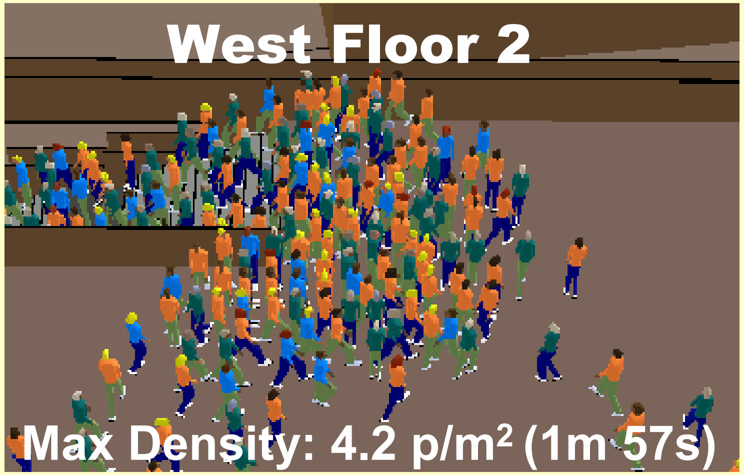
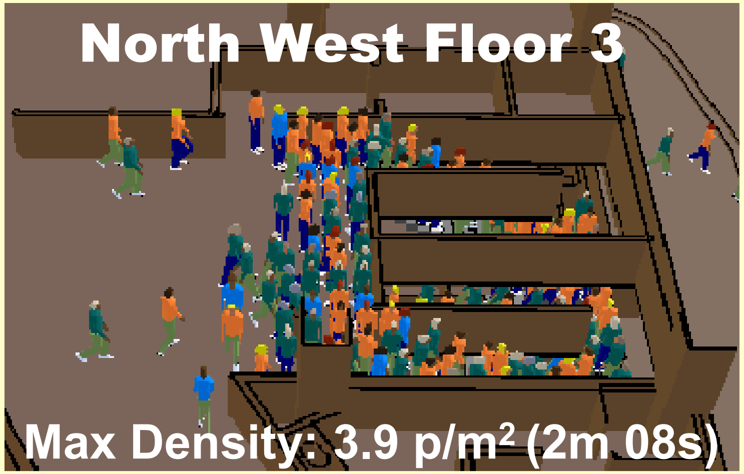


3 min 50 sec

Summary of Scenarios

Base Scenario: Four Areas of Heaviest Congestion





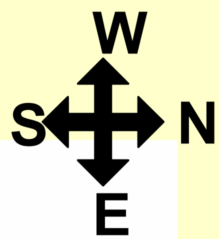
Modified Scenario

- Introduce crowd management to reduce the congestion at entrance to stairs.
- Introduce active signage to direct people away from congested stairs.
- This primarily involves population initially located on floor 2 directly exiting using the external stairs rather than descending to floor 1 via the internal stairs.

- Modified exiting strategy achieved using Active Dynamic Signage OR through the intervention of stafff

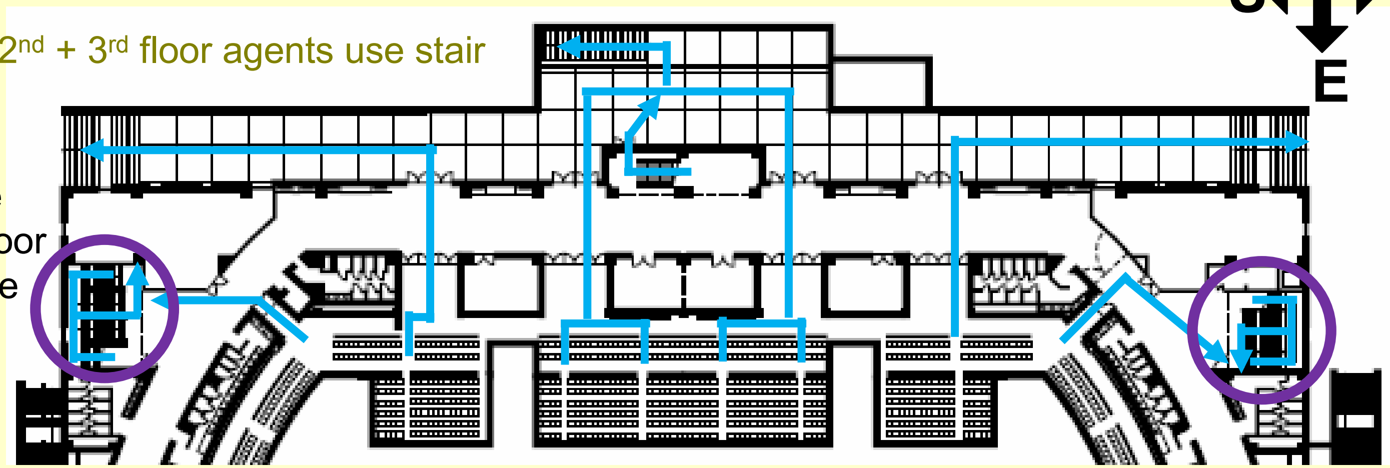
Modified Scenario

Floor 2: Changes to routes on West side



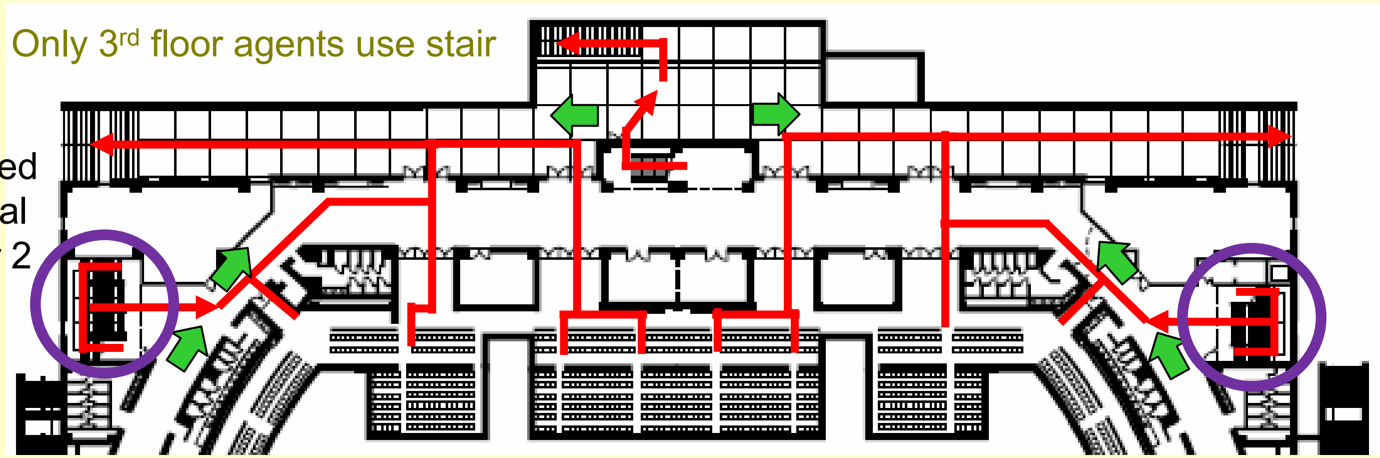
Congestion points where 2nd and 3rd floor agents merge on stairs

Base



2nd +3rd floor agents directed to use external stair on Floor 2

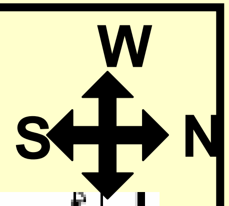
Modified



Exit sign redirecting agents along modified path

Modified Scenario

Floor 2: Changes to routes on East side



Congestion points where 2nd and 3rd floor agents merge on stairs

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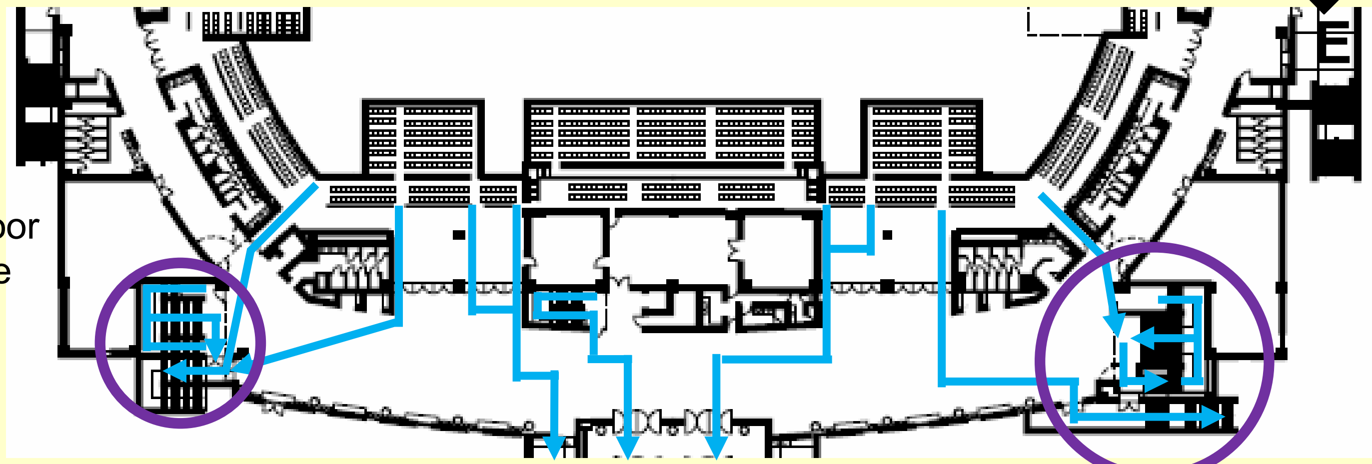
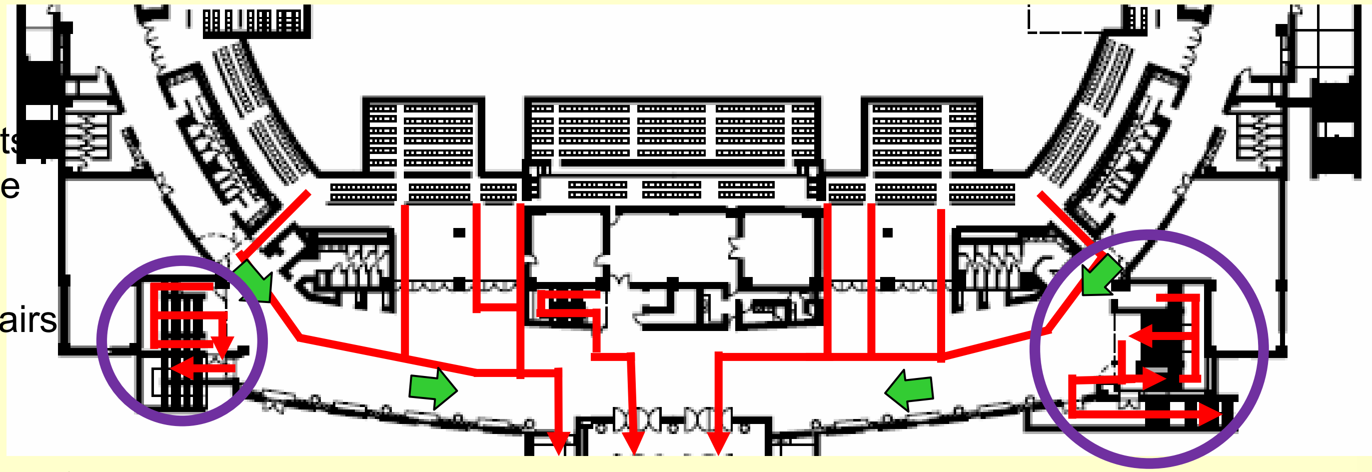


2nd floor agents directed to use main exit and only 3rd floor agents use stairs

Modified



Exit sign redirecting agents along modified path

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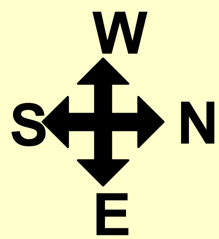
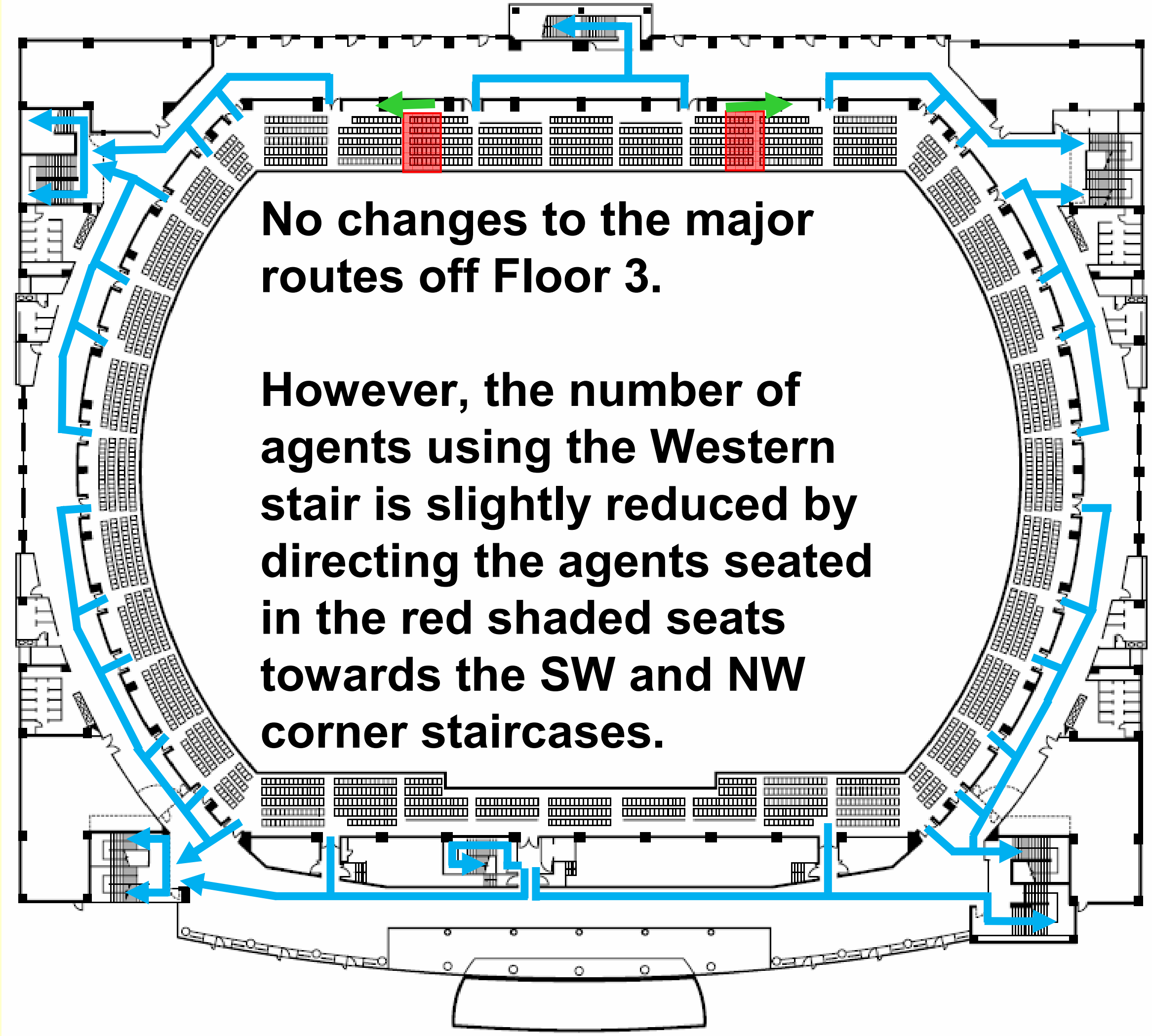
Modified Scenario

Floor 3: Modified Scenario





No changes to the major routes off Floor 3.

However, the number of agents using the Western stair is slightly reduced by directing the agents seated in the red shaded seats towards the SW and NW corner staircases.

Summary of Scenarios

Summary of Modifications to Routes:

•All agents initially located on Floor 2 leave their seat blocks and move into the circulation space around the arena.

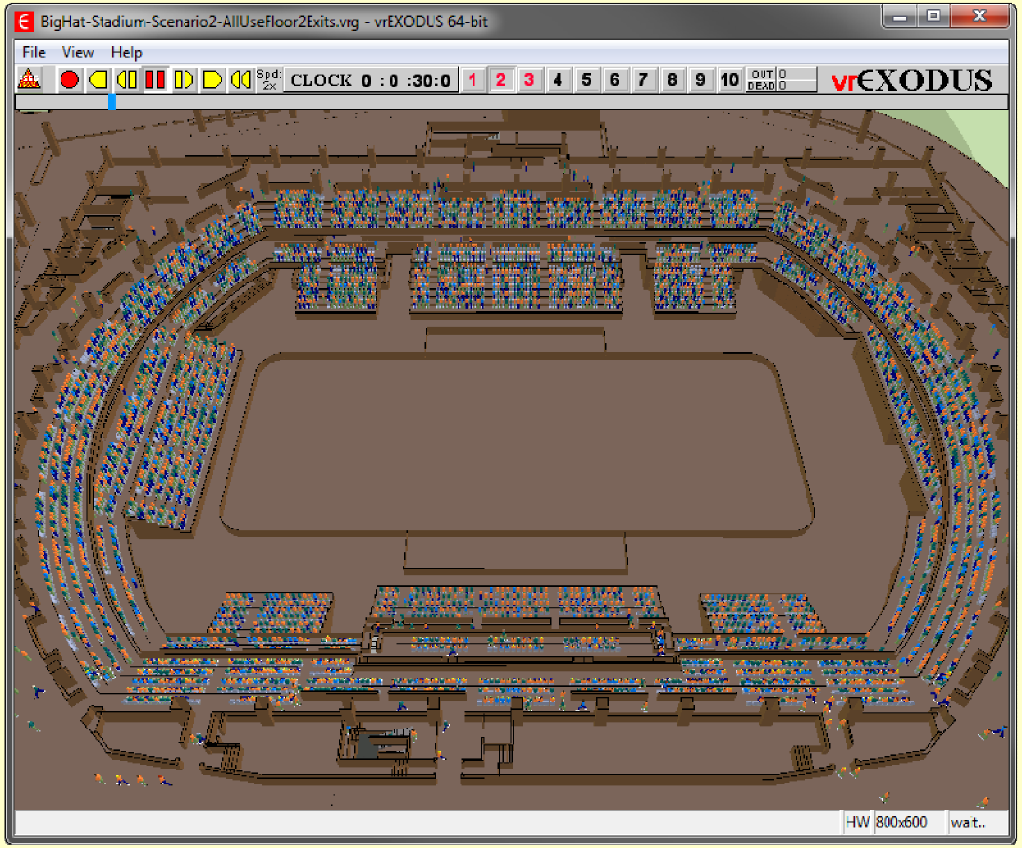
- Agents on the West side are directed to the NW & SW exits on Floor 2.
- Agents on the East side are directed to exit Floor 2 via the main entrance.

•Agents descending from Floor 3 via the NW and SW stairs exit on Floor 2 rather than descending to Floor 1. Hence, no agents can use these stairs in the modified scenario to exit the arena on Floor 1.

•The number of people using the Western staircase on Floor 3 is slightly reduced by directing some people towards the SW and NW corner staircases.

Modified Evacuation Scenario

	TET (min)	PET (min)	CWT (min)	Floor2 seats (min)	Floor3 seats (min)	Floor2 (min)	Floor3 (min)
Base	5.5	3.0	0.44	4.0	2.2	4.7	3.3
Modified	5.2	2.9	0.24	4.0	2.2	4.4	2.9



0 min 30 sec

Modified Evacuation Scenario

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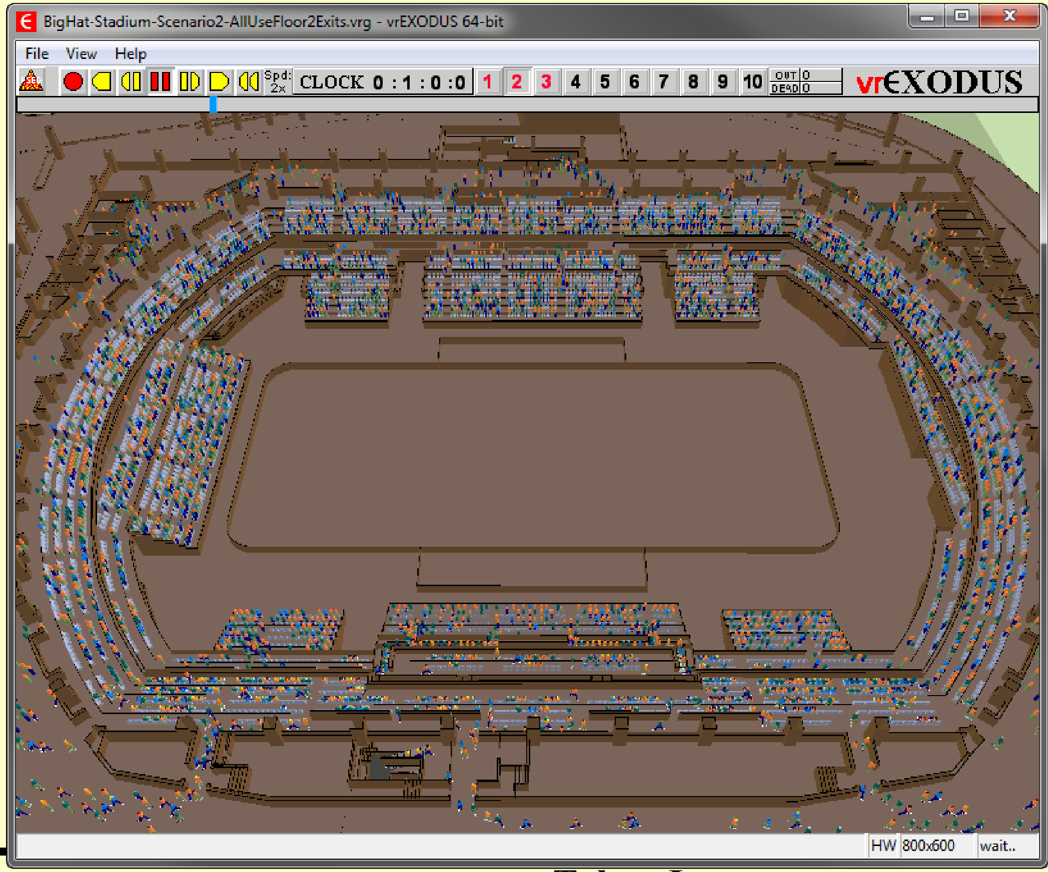

1 min 0 sec

Modified Evacuation Scenario

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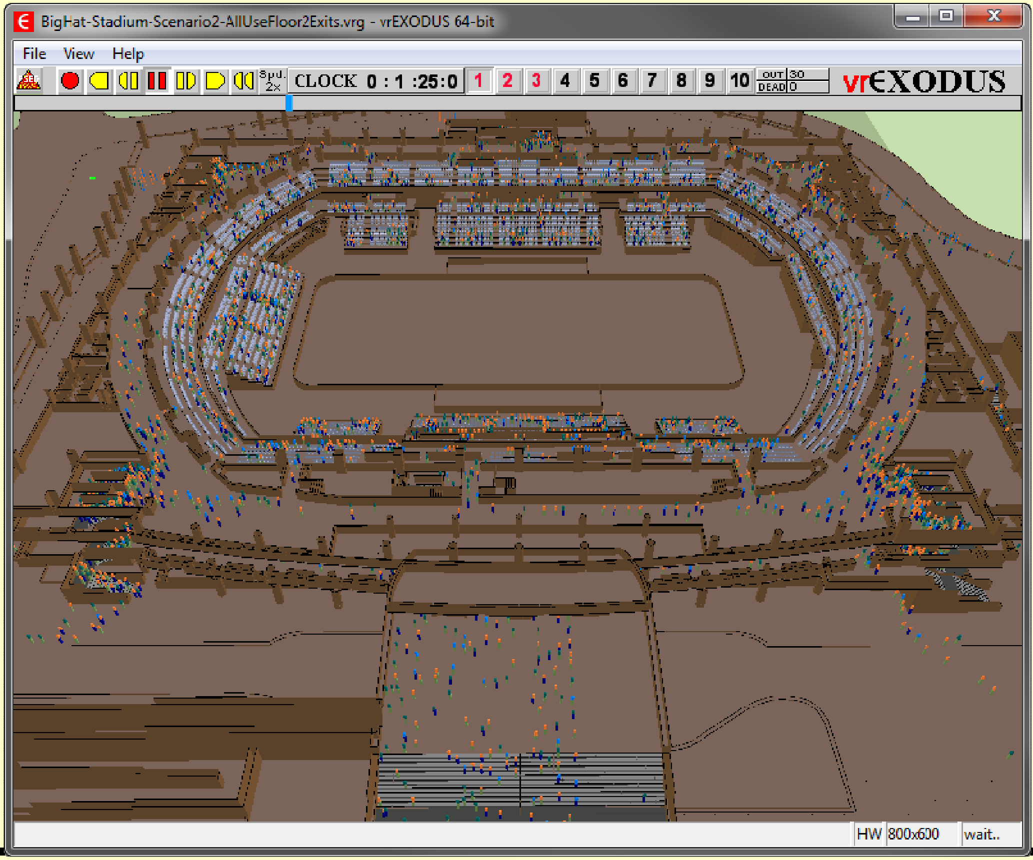

1 min 25 sec

Modified Evacuation Scenario

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Base	5.5	3.0	0.44	4.0	2.2	4.7	3.3
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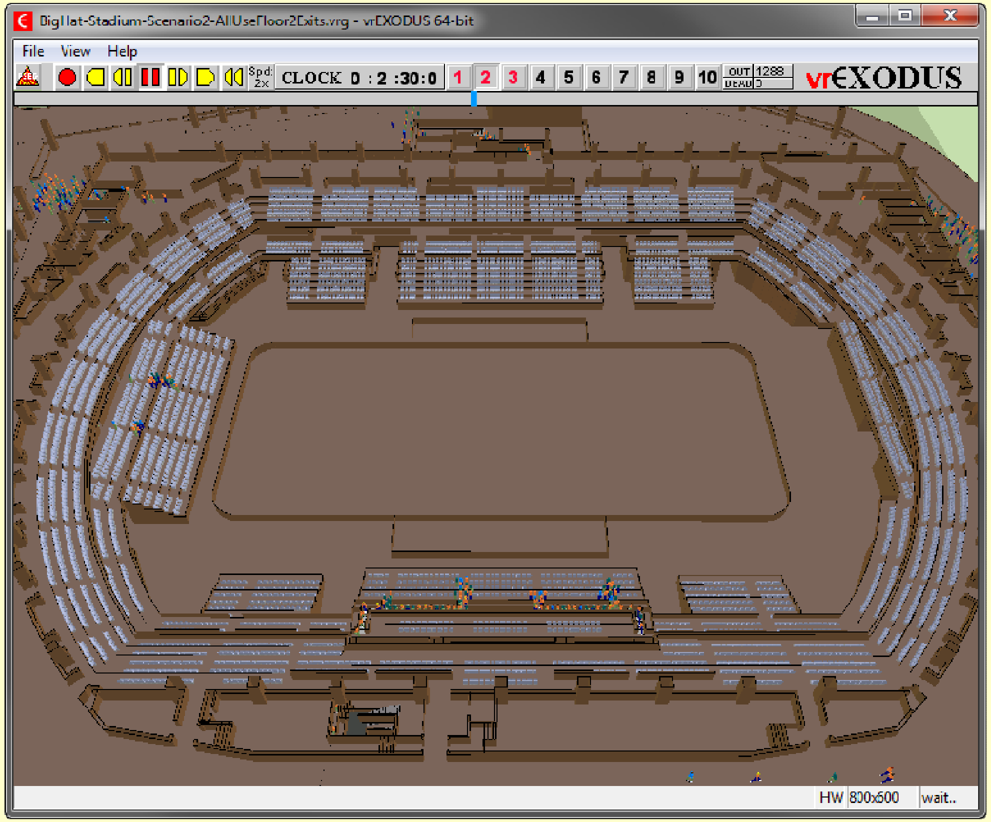

2 min 30 sec

Modified Evacuation Scenario

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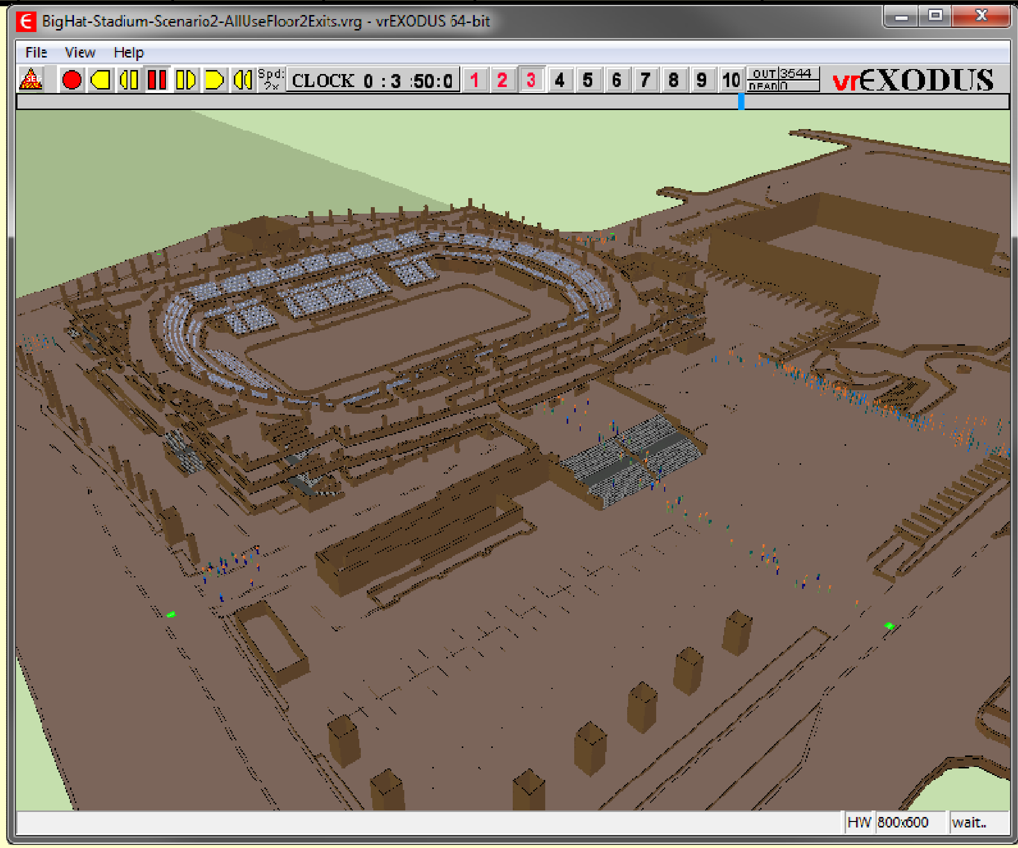

3 min 50 sec

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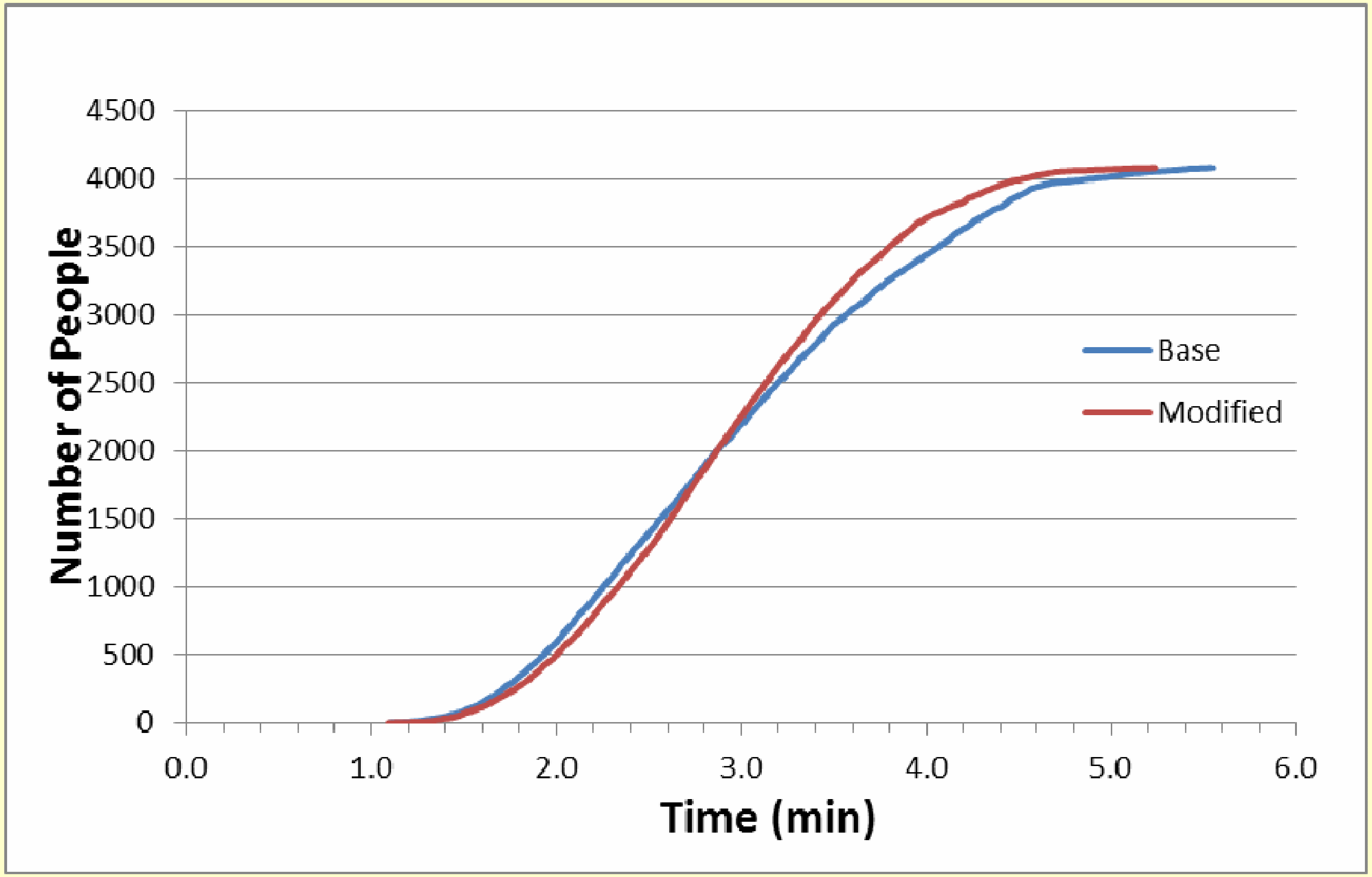
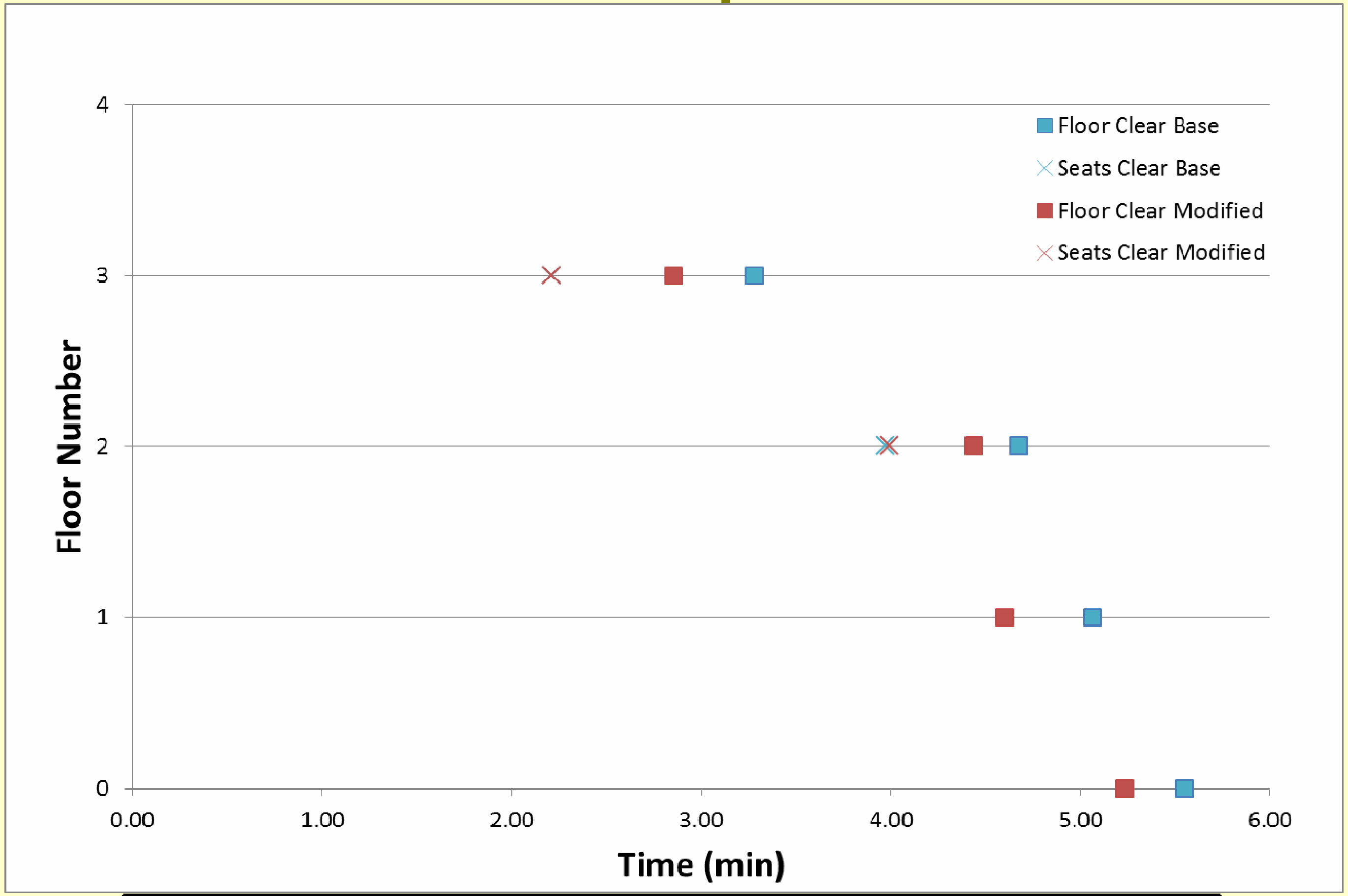
Exit Profile



Scenario	Total	25%	50%	75%	100%
Base	4083	2.3	2.9	3.6	5.5
Modified	4083	2.3	2.9	3.5	5.2

Floor Comparison



	Time to Clear (min)					
Scenario	Floor 3 Seats	Floor 3	Floor 2 Seats	Floor 2	Floor 1	Area
Base	2.21	3.28	3.97	4.67	5.07	5.55
Modified	2.21	2.86	3.99	4.44	4.60	5.23

Comparison – Congestion Analysis

Floor 2: Maximum Population Densities Around Stairs

West Base: 4.2 p/m^2

Modified: 1.2 p/m^2

South West

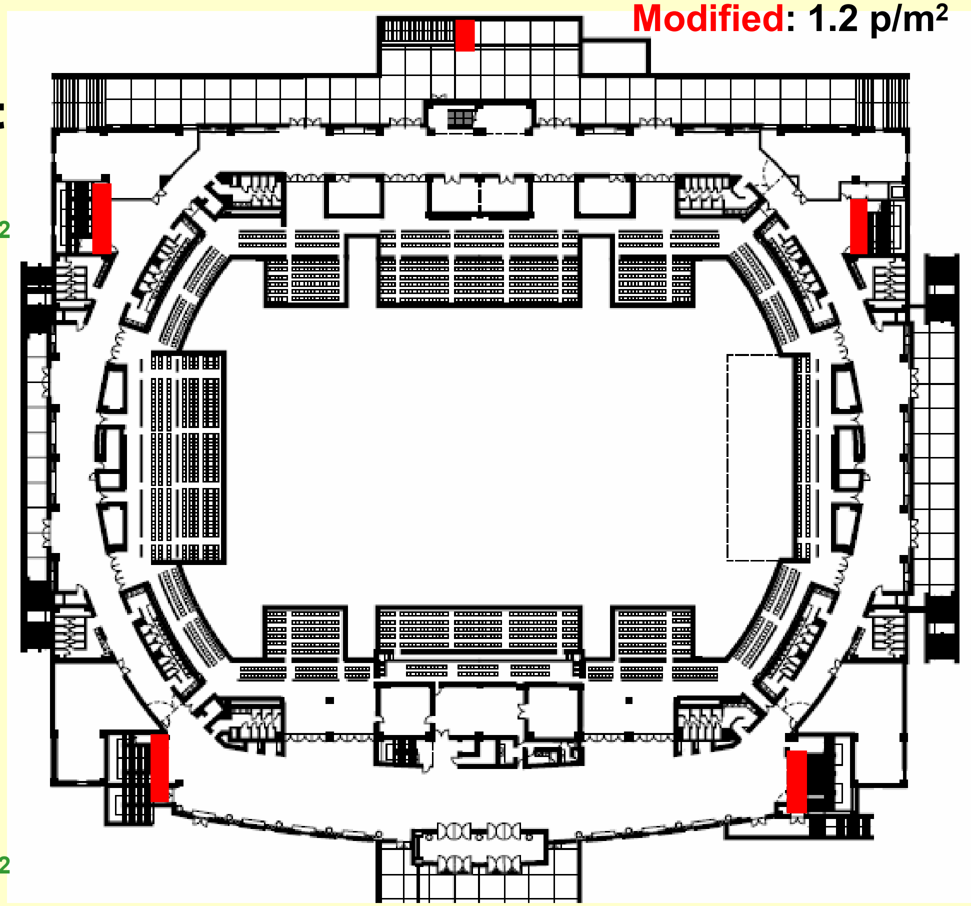
Base: 2.5 p/m^2

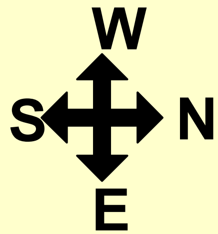
Modified: 0.8 p/m^2

North West

Base: 2.9 p/m^2

Modified: 1.2 p/m^2





South East

Base: 3.3 p/m^2

Modified: 2.3 p/m^2

North East

Base: 3.0 p/m^2

Modified: 3.1 p/m^2

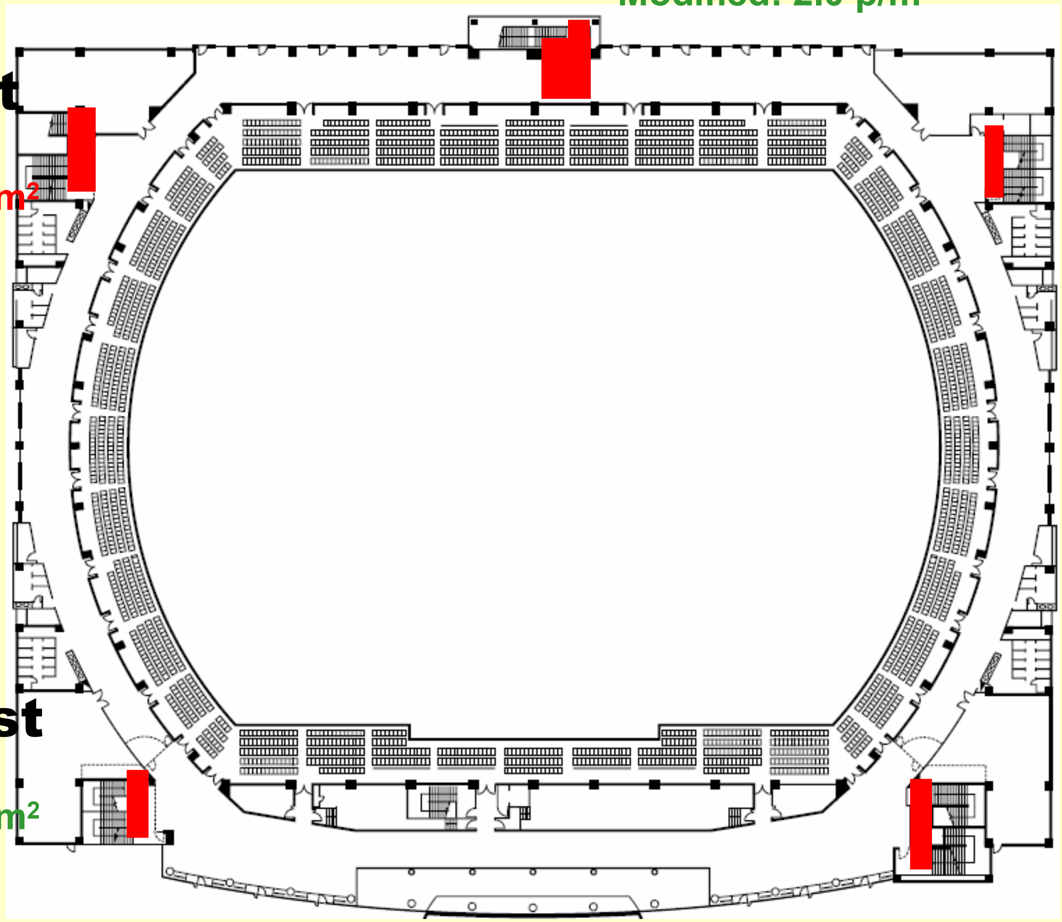
Comparison – Congestion Analysis

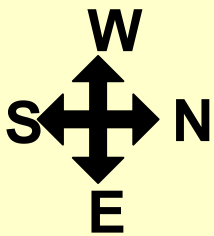
Floor 3: Maximum Population Densities Around Stairs

West
Base: 3.0 p/m²
Modified: 2.0 p/m²

South West
Base: 2.6 p/m²
Modified: 3.2 p/m²

North West
Base: 3.9 p/m²
Modified: 3.1 p/m²



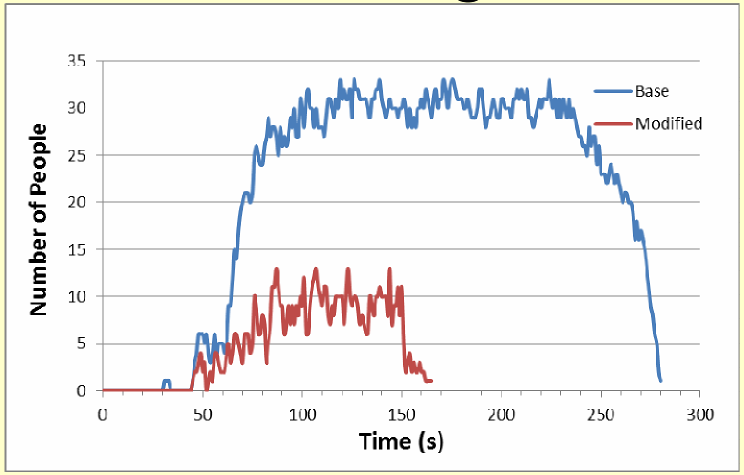


South East
Base: 4.1 p/m²
Modified: 3.6 p/m²

North East
Base: 3.3 p/m²
Modified: 3.1 p/m²

Results – Congestion Analysis

Floor 2 Congestion: North West Staircase

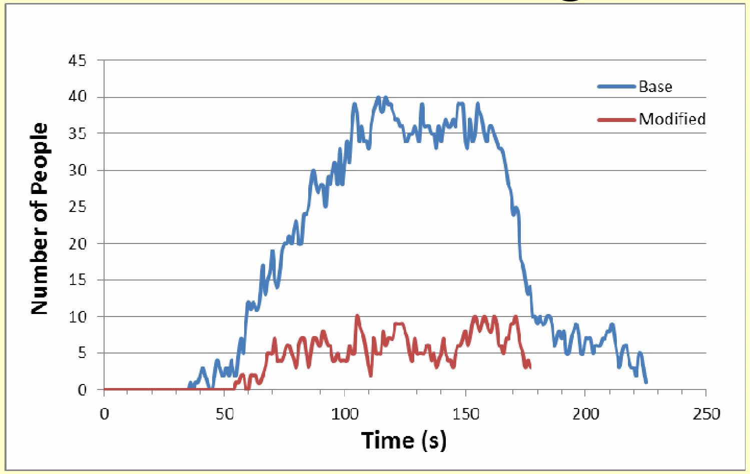


- Base case density peeks at 2.9 p/m²

- Modified case density peeks at 1.2 p/m²

Results – Congestion Analysis

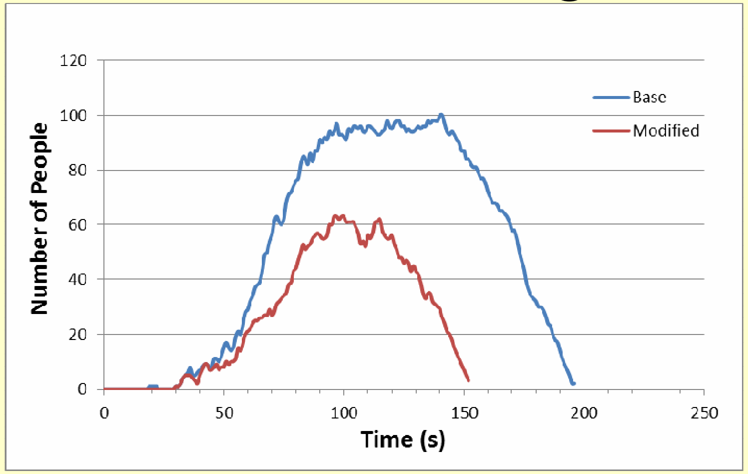
Floor 2 Congestion: West Staircase



- Base case density peeks at 4.2 p/m^2
- Modified case density peeks at 1.2 p/m^2

Results – Congestion Analysis

Floor 3 Congestion: West Staircase



- Base case density peeks at 3.0 p/m^2
- Modified case density peeks at 2.0 p/m^2

Wayfinding

How do people find their way out?

Importance of Signage Systems

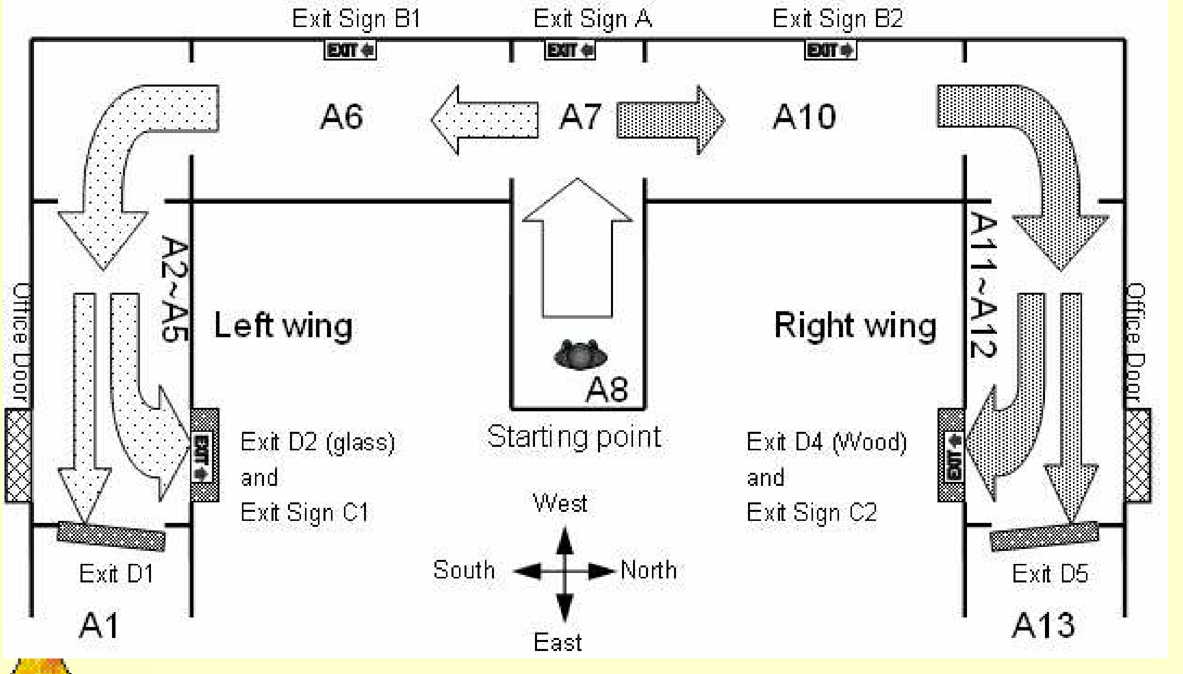
- Signage is essential for navigation and general circulation
  - In complex buildings occupants may be unaware of most suitable routes due to lack of knowledge of internal connectivity or unable to find commercial target without the aid of directional signs.
  - Signage reduces the apparent building complexity by increasing wayfinding efficiency and decreasing time spent wayfinding.
- Signage is even more important in emergencies
  - In emergency situations occupants tend to use familiar routes while ignoring emergency exits or exits not used for normal circulation.
  - Signage is intended to direct people to appropriate unfamiliar emergency exits.
  - Employ many emergency staff to direct people to appropriate exits.

WTC WAYFINDING

- WTC1/025/0002:
  - P "**honestly I didn't know where the evacuation stairwells where**….. they say, … look for the exit signs when you go in a place, they really mean that because, y'know unless something's happened before, you're not go to be able to find it.
- WTC1/057/0002:
  - P "… **we couldn't at that point find the exit**. Our stairwell had ended and there were no guide posts to go anywhere….so a number of people started searching for some place to go for another stairwell to go down from the 44th floor. Eventually someone found it so we continued down."
- WTC1/087/BDAG
  - P "…**we actually walked past the fire escape**, kinda had to turn around and double back until we found the fire escape…
- Many people were unable to find the stairs, even though they had been in the building for months.
- Many people failed to see the emergency signage

Sign Recognition Experiments

- Experimentally examine how occupants interact with signage in both normal movement and evacuation.
- Attempt to determine likelihood that those who can see a sign, recognise the sign, correctly interpret the information and follow the information.



•68 test subjects

•41 naïve subjects

Sign Recognition - T intersection

•Correct choice

•Incorrect choice

- Female, naïve subject, 2 sec decision time, makes correct decision. From questionnaire subject said they saw and followed the sign.
- Female, naïve subject, 9 sec decision region, makes incorrect decision. From questionnaire did not see sign
- For T intersection, 61% of naïve subjects failed to “see” the sign.
- Of those who “registered presence of sign”, 100% followed instructions
- Average decision time for those who see sign **2.6 s**, those who do not see sign **5.6s**

Sign Recognition – Improved affordance

- It is suggested that poor identification of signs is due to poor affordance associated with signs.
- Can improve affordance of a sign in several ways:
    - make larger – improve sensory and cognitive affordance
    - introduce lights – improve sensory affordance
    - introduce green lights – improve cognitive affordance
    - introduce flashing lights - improve sensory affordance
    - introduce running lights - improve cognitive affordance
- FSEG in collaboration with UK company EVACLITE (www.evaclite.com) have come up with a sign addressing the poor affordance issue by introducing running, flashing, green lights to the sign.
- Sign is activated on alarm – Active Dynamic Signage System

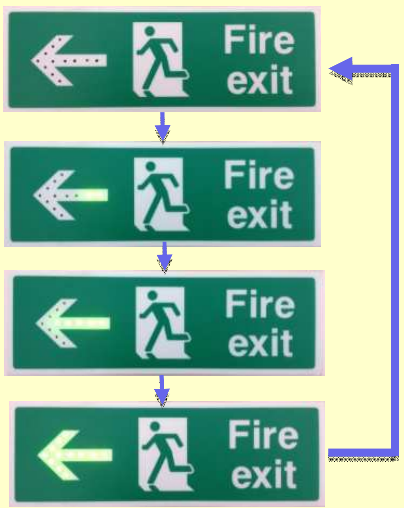
Sign Recognition – Improved affordance

• Using the ADSS, the wayfinding experiments were repeated in July 2012 with 48 unfamiliar participants

• 85% (41/48) of people 'see' the dynamic sign – an increase in detection rate of 120%.

• 100% of people who see the dynamic sign follow the sign.

• The vast majority of people interpret the flashing arrow correctly and find the new design useful.

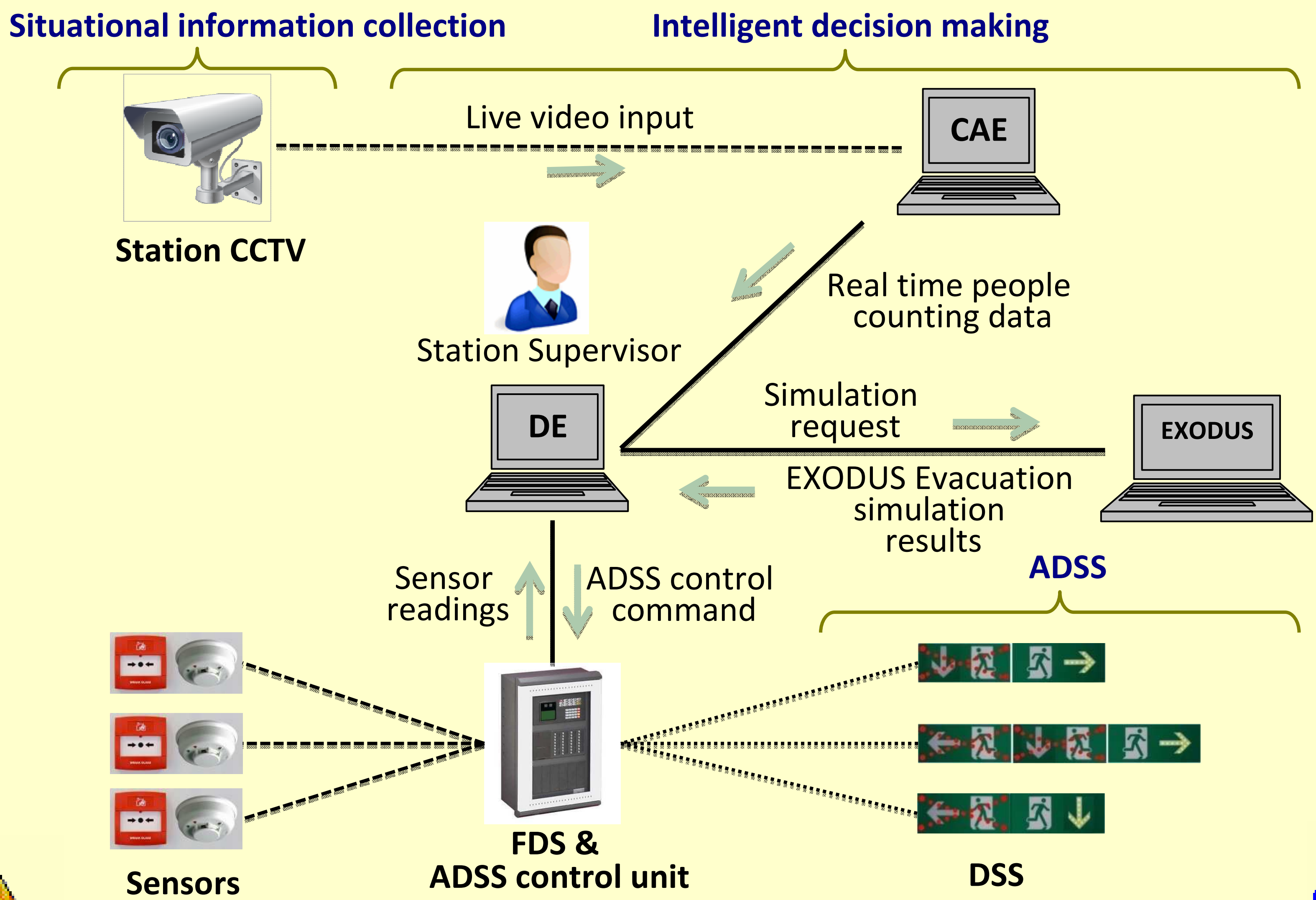


Detected sign?	DSS	Conventional sign
Yes	1.8 s	2.6 s
No	5.7 s	5.6 s

Intelligent Signage Systems

- As part of EU FP7 project GETAWAY, the ADSS concept was expanded to include Intelligent Active Dynamic Signage System - IADSS.
- In addition to making the exit sign more noticeable:
  - Signage system also indicates that an emergency exit route is no longer considered viable
  - ADSS is controlled via simulation and human intervention to identify the optimal exit route given the current situation.
  - Optimal route can be determined by faster than real time buildingEXODUS simulation taking into consideration:
    - Current population distribution and
    - Spread of fire hazards (heat, smoke and toxic gases)
  - Optimal route can also be determined by human operator

The GETAWAY Intelligent Active Dynamic Signage System



Intelligent Signage Systems

- ADSS not only has application for fire applications but also for terrorist situations.
- Using CCTV security staff identify regions were the hazard (gunmen) is located and direct people away from the region by activating appropriate signs

ADSS Showing Negated Route

- ADSS extended to indicate that an evacuation route is no longer considered viable.
  - Understanding of negation concept demonstrated through international survey.

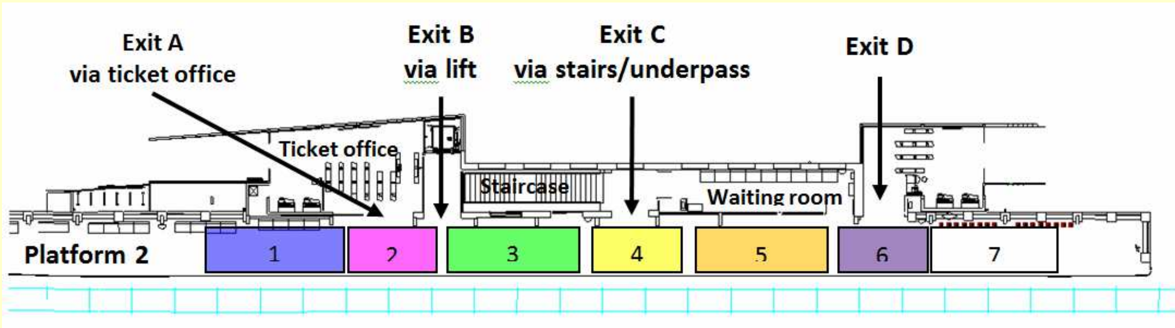
ADSS Negated Sign Concept

- Survey involving 451 people from 10 countries
- 4 potential designs shown to each participant, without providing an explanation of what the sign meant.
- Participants asked to write what they thought the sign meant.

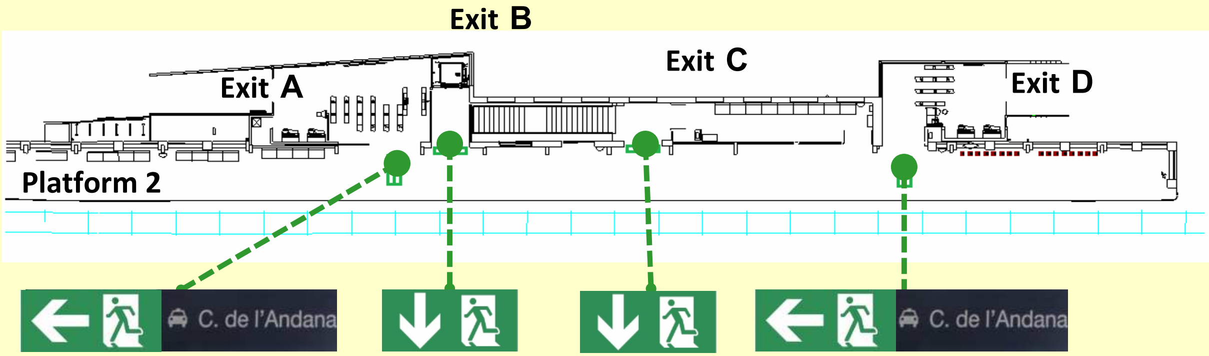
	Non-Fire Correct	Fire Correct	Total Correct
	93% (193 total)	93% (238 total)	93% (431 total)
	85% (196 total)	83% (240 total)	84% (436 total)
	72% (182 total)	79% (227 total)	76% (409 total)
	56% (191 total)	63% (239 total)	59% (430 total)

Configuration and Signage Systems Tested

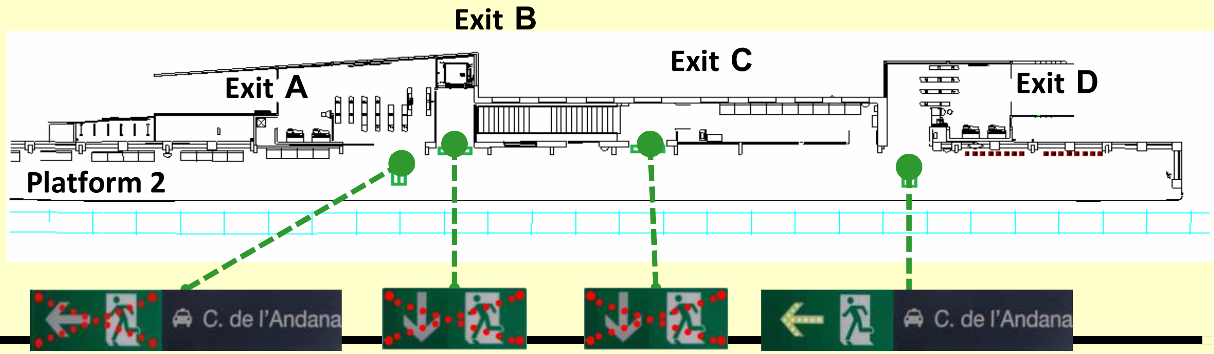
- Participants distributed across boxes 1-7 on platform



- T1 – 139 participants



- T2 – 152 participants



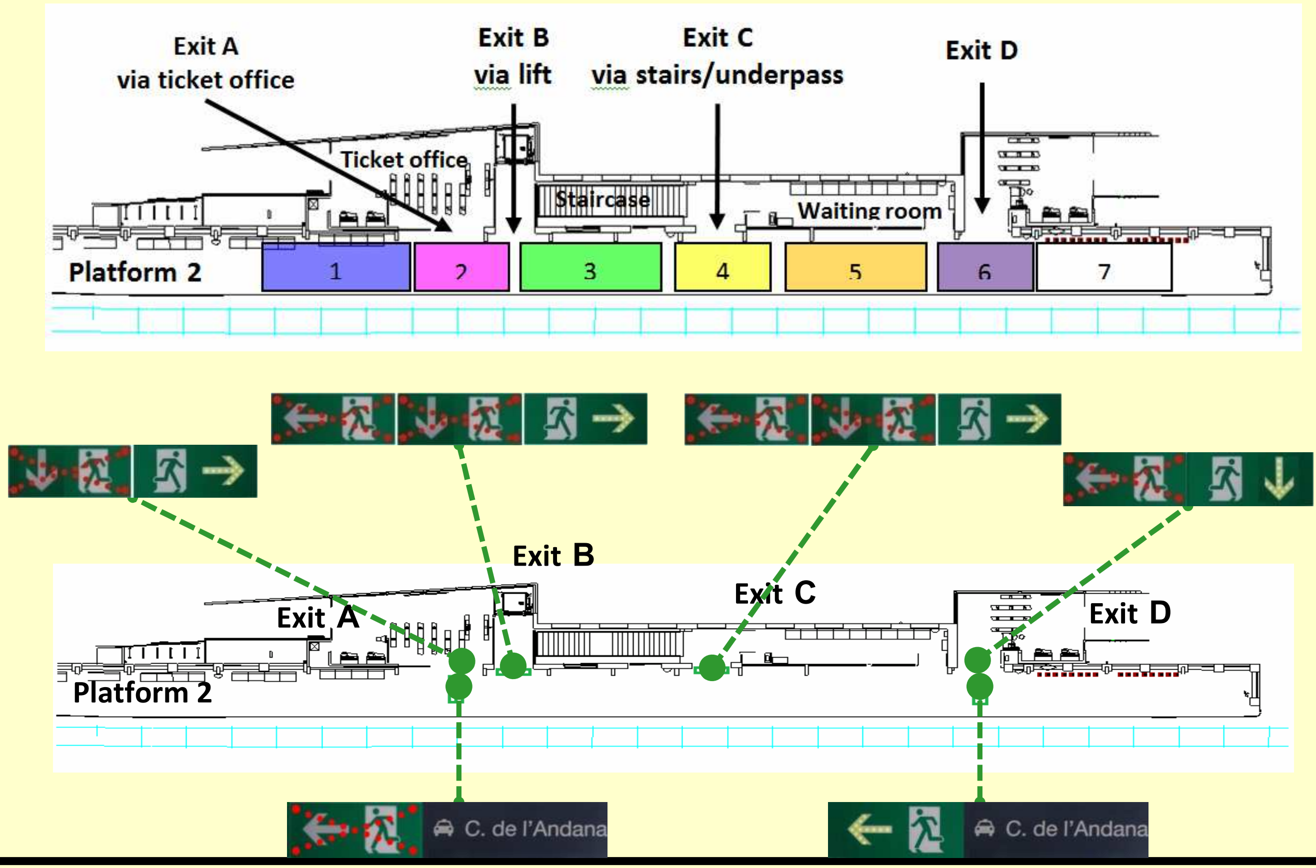
Comparing Trial 1 and Trial 2

Trial 1 – 100% of participants use their nearest exit. Signage only accounted for 26.8% of participant exit selection

Trial 2 – 63% of participants use the indicated exit. 57% used their nearest exit, compared with 100% in Trial1.

TS3 – Configuration and Signage Systems Tested

- TS3 – 64 participants, distributed in box 1 and left blank area



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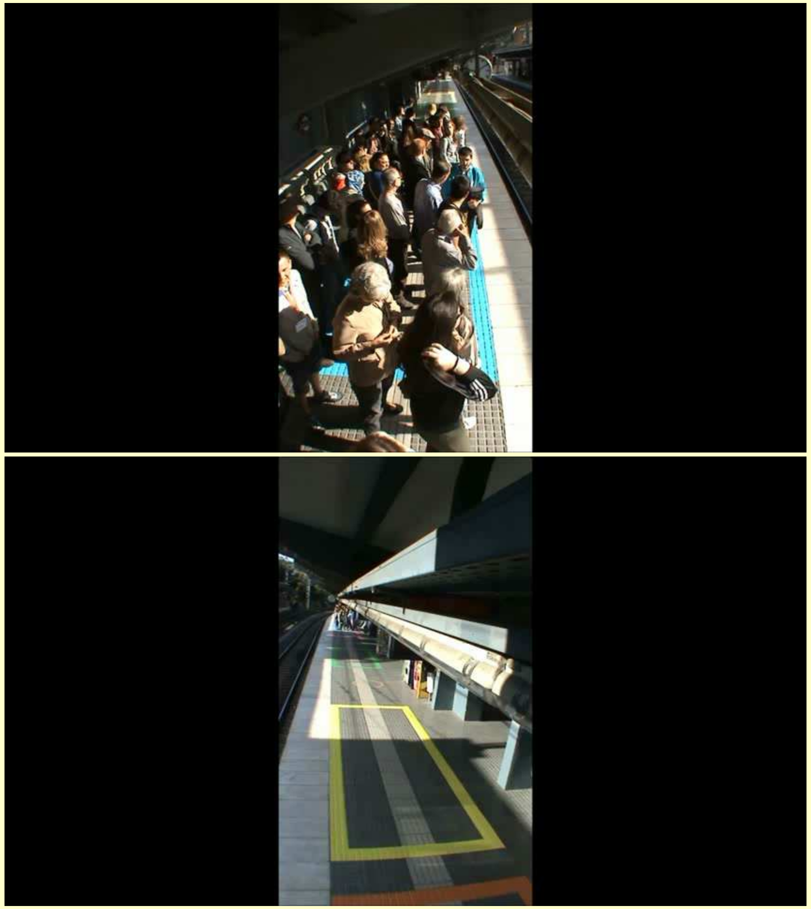
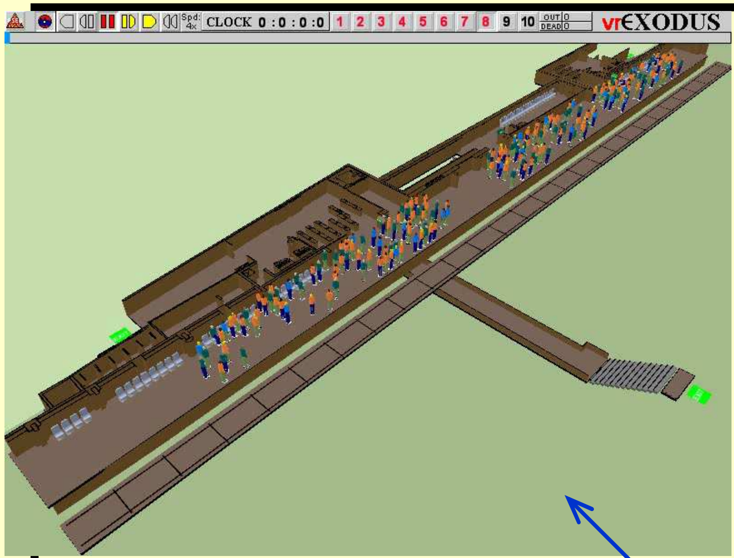
TS3 2014, Trial 2



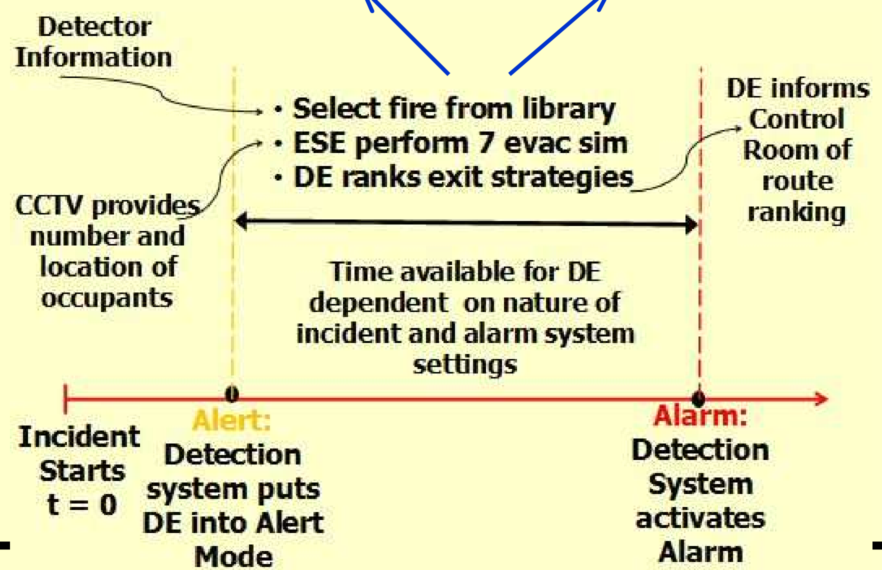
- 66% of participants by-pass exits 1, 2 and 3 and utilise target exit.
- 34% of participants chose to use their nearest exit compared to 100%

IADSS



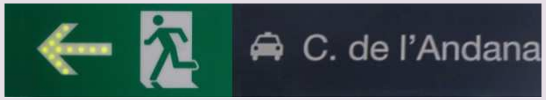
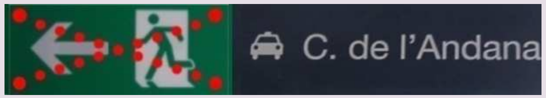
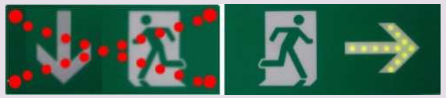
Ranking algorithm identified optimal exit strategy and was able to activate signage prior to alarm activation

EXODUS required 33 sec to perform all 7 evacuation scenarios



TS3 Questionnaire Analysis Results

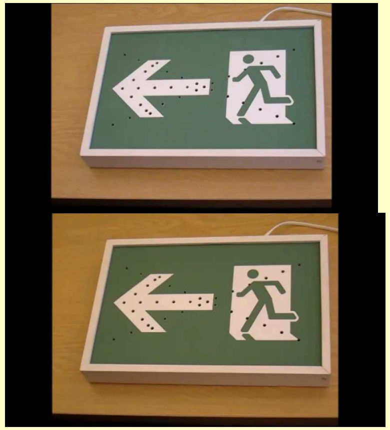
- Participants’ level of agreement that the sign assisted them in identifying an exit to use (TS3.2 and TS3.3).

Statement 1	*“This sign assisted me in selecting an exit to use/ which exit NOT to use/which exit not to use and which exit to use.”*		
Level of agreement	Agree / Strongly Agree	Disagree / Strongly Disagree	Total
	94%	3%	79
	74%	19%	53
	83%	13%	80
	70%	25%	77
Weighted Average	81%	14%	289

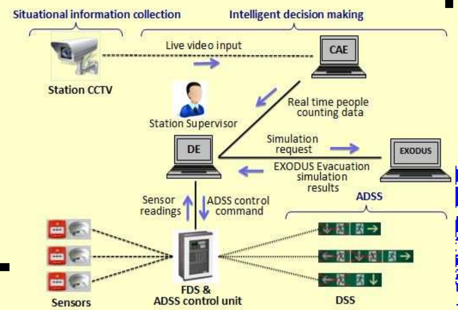
IADSS System Options

- Level 1: ADSS with flashing arrow
  - •Option1: Battery system with alarm detector
  - •Option2: Electrical system with digital logic
  - •Option3: Alarm system

- Level 2: ADSS flashing arrow with negation
  - •Manual operation or simple logic
  - •Option1: Electrical system with digital logic
  - •Option2: Alarm system



- Level 3: IADSS flashing arrow with negation
  - •Simulation logic with manual over-ride
  - •Option1: Electrical system with digital logic
  - •Option2: Alarm system



Exit Flows

Use of Bollards

- Bollard Arrays are intended to protect critical infrastructure from hostile vehicles or “car bombs”
- Had a bollard array been present around the entrance to Glasgow airport it would have prevented the vehicle from approaching the airport terminal.

Glasgow airport
30 June 2007

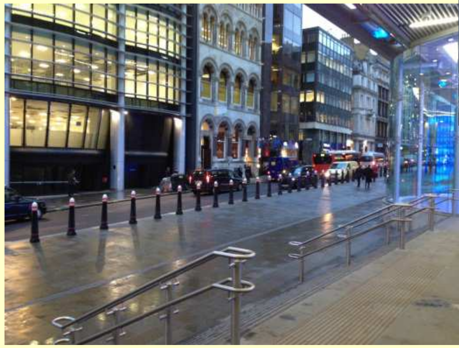
Use of Bollards

- Today, security bollards are a common sight in London and other cities around the world.





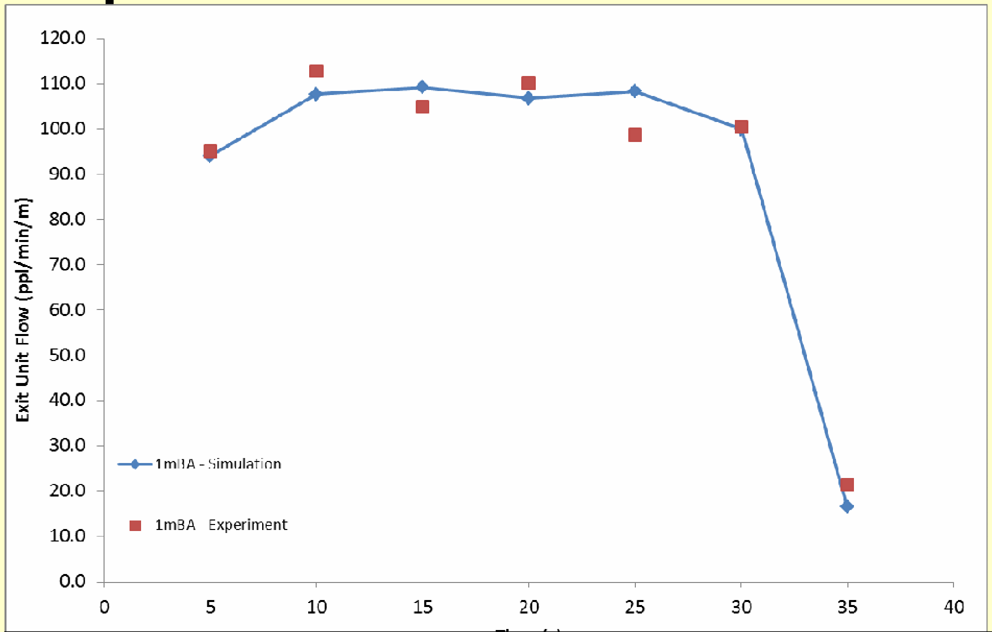


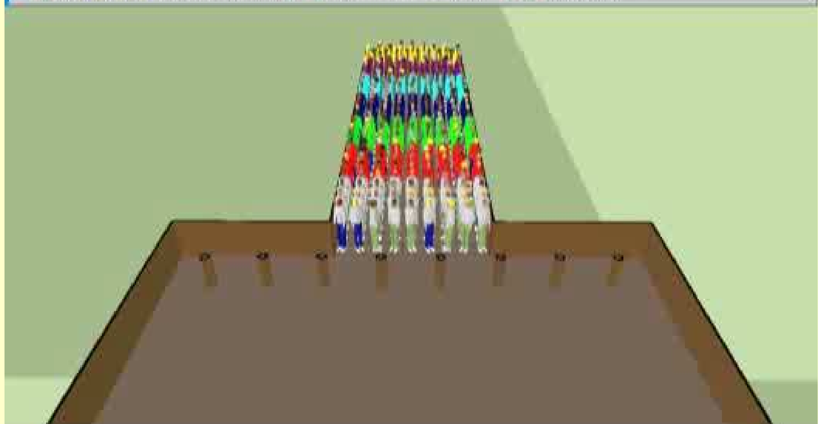



4.5m exit, No BA, 1m, 2m and 3m BA

No BA	1m BA	2m BA	3m BA
Unit Flow (p/m/s)	Unit Flow (p/m/s)	Unit Flow (p/m/s)	Unit Flow (p/m/s)
1.92	**1.76 (-9%)**	**1.75 (-9%)**	**1.79 (-6%)**

Modelling VS Experiment: 4.5m exit, 1m BA



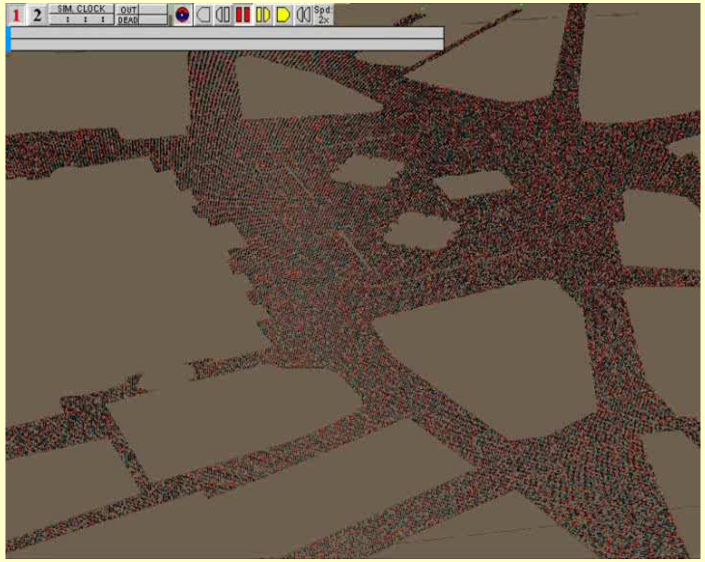


Time (s)	3 Trial Average (ppl/m/min)	100 Sim Average (ppl/m/min)	Difference (%)
5-10	112.9	107.7	-4.6%
10-15	104.9	109.2	+4.1%
15-20	110.2	106.8	-3.1%
20-25	98.7	108.3	+9.8%
25-30	100.4	100.0	-0.4%
Average	105.4	106.4	+0.9%

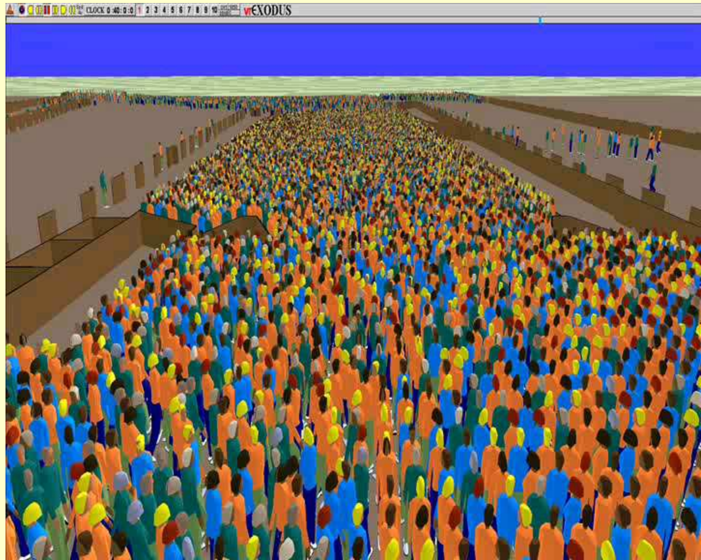
Research: Urban Scale Evacuation and Crowd Dynamics

Large crowd simulation and visualisation

- Trafalgar Square demonstration: 125,000+ people simulation



- Love Parade Disaster reconstruction: 100,000 people simulation.

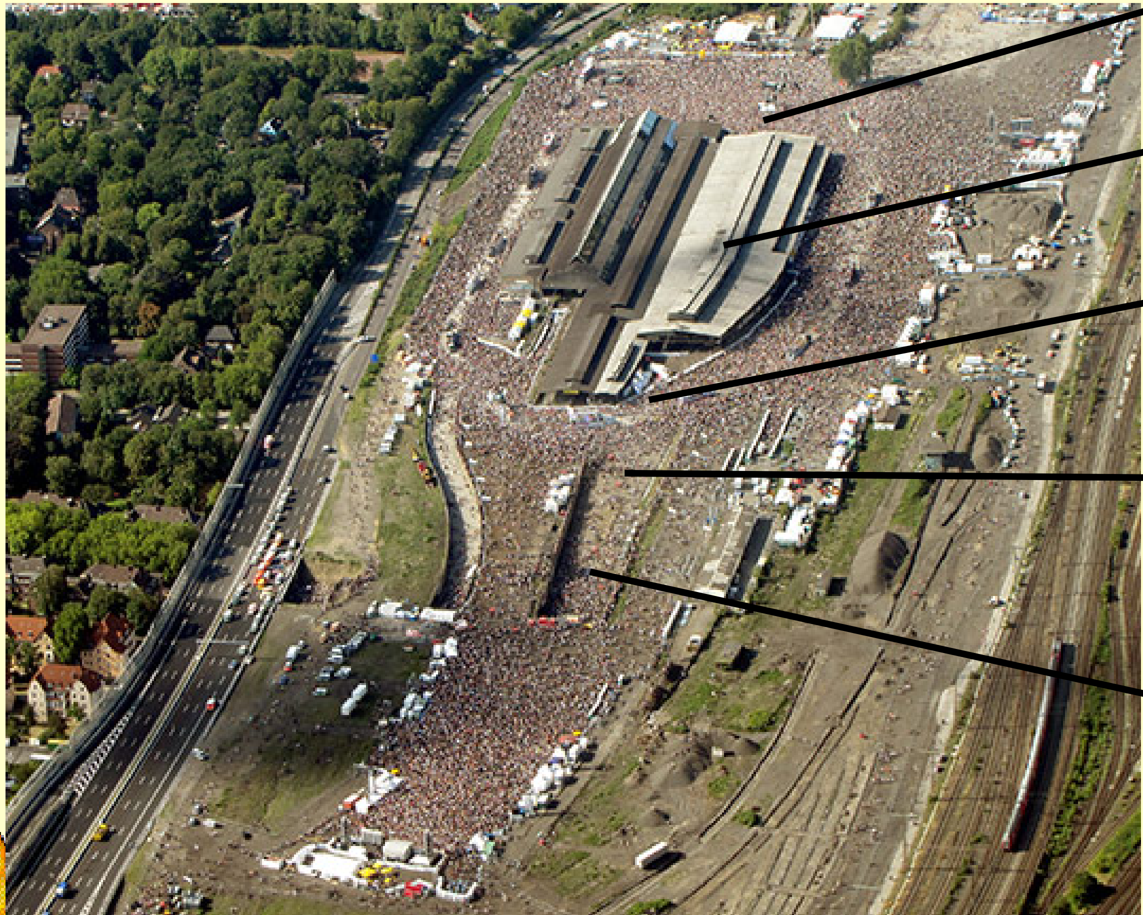


2010 Love Parade in Duisburg, Germany

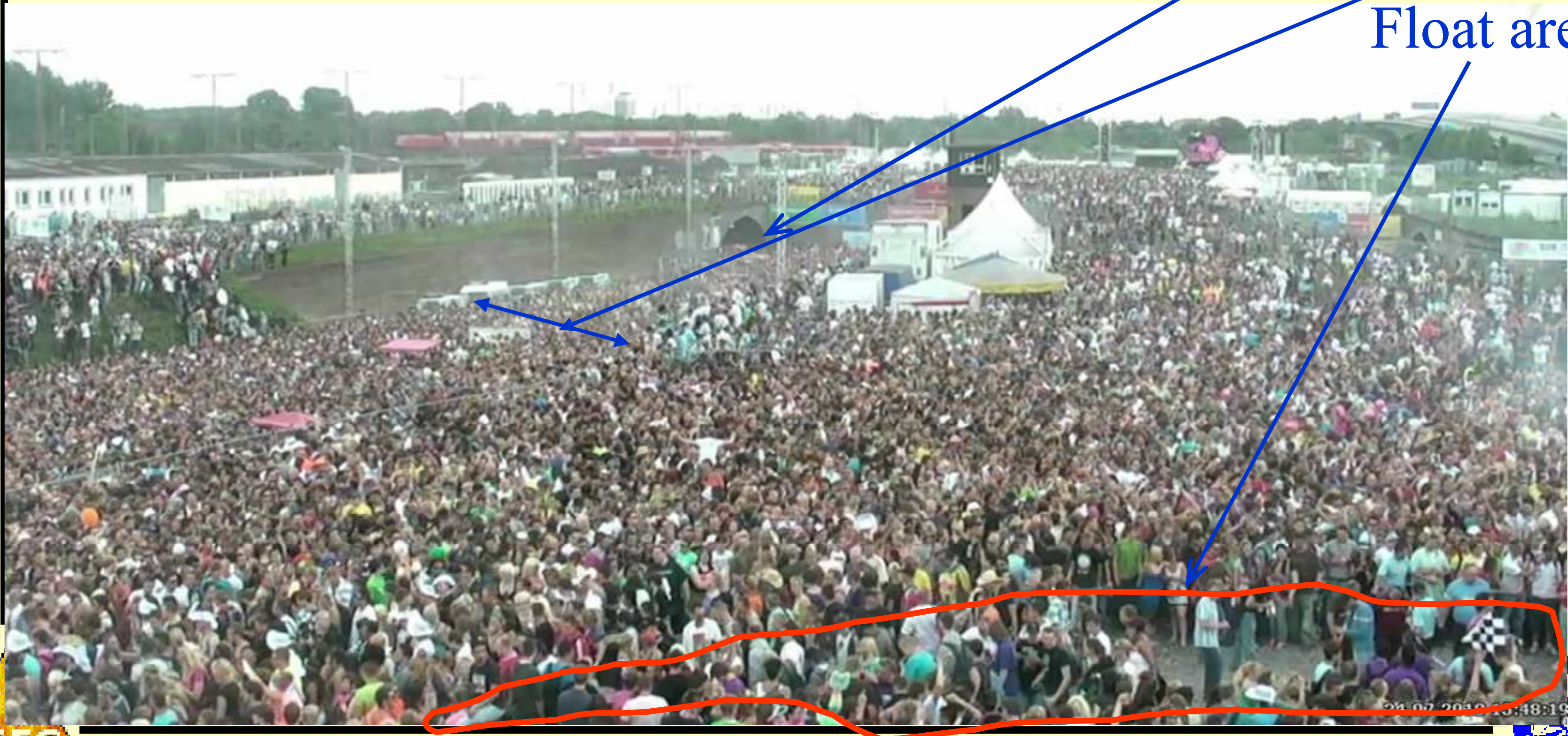
24th July 2010

•Reportedly attracted a crowd of 1.4 million people

•Crush resulted in 21 fatalities, over 500 injured



Recreation of 2010 Love Parade in Duisburg



eastern tunnel

ramp

Float area

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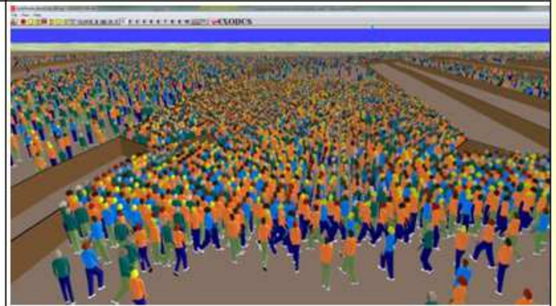
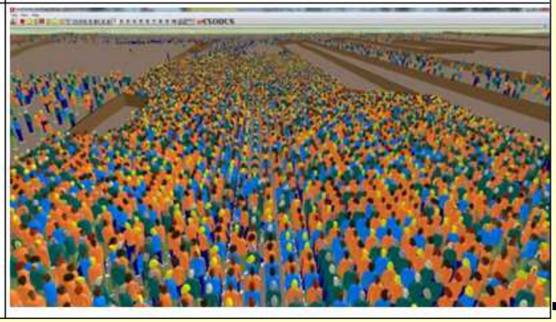
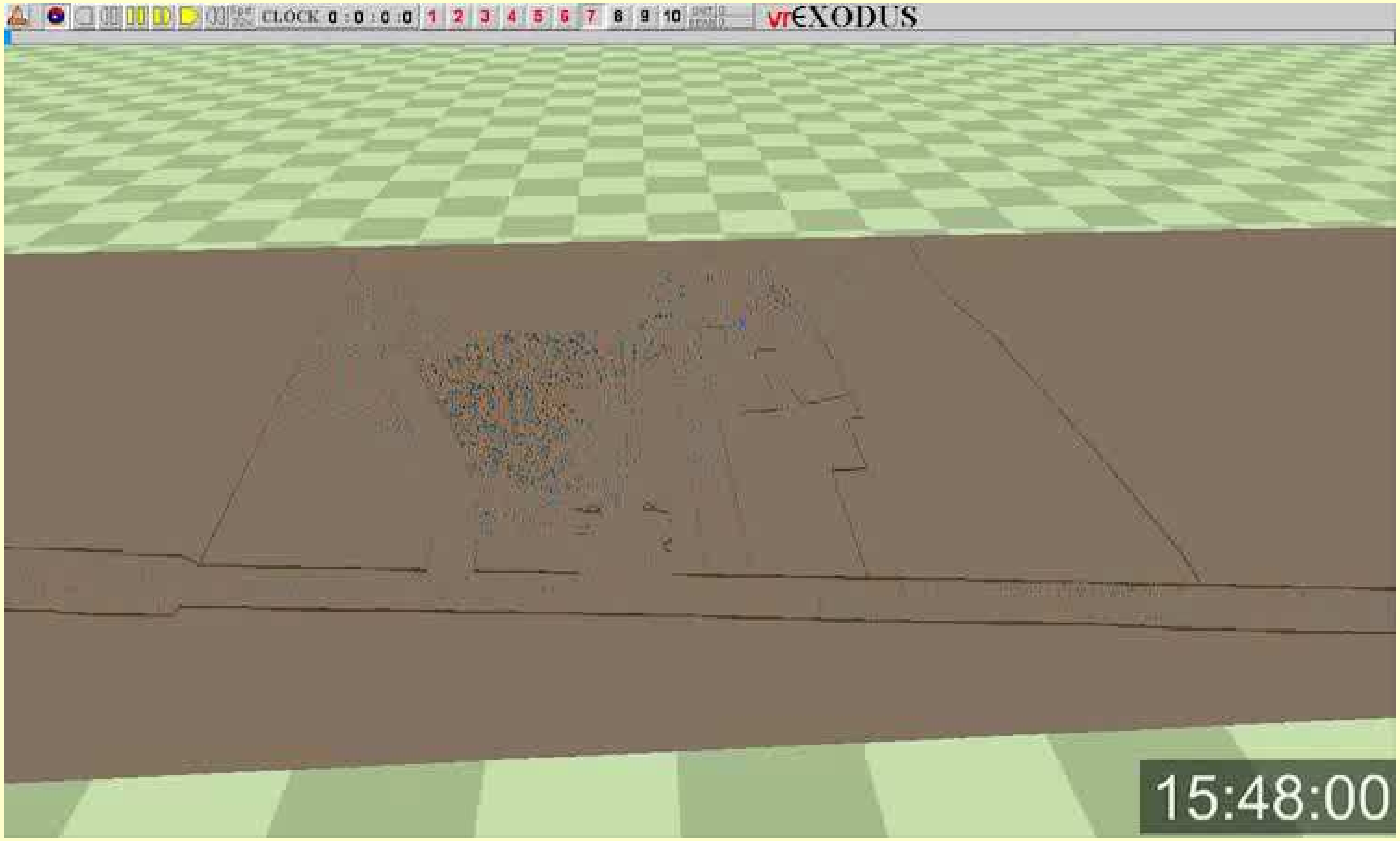
Verification of the simulated results
CCTV footage and simulated output

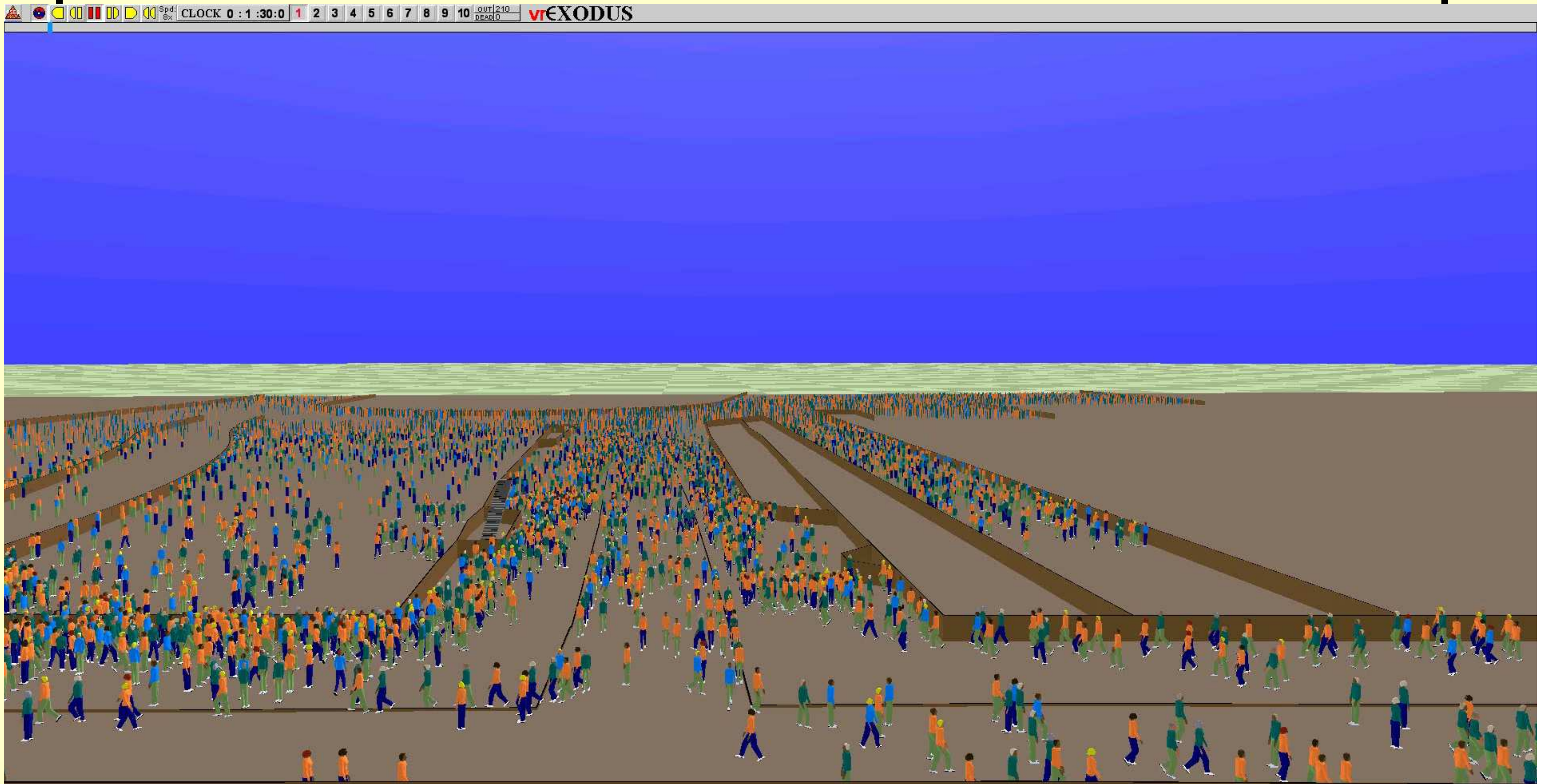
Time	Sim (s)	CCTV Footage	Simulation
16:02	720s (14 mins)		
16:20	1,920s (32mins)		
16:39	3,060s (51mins)		

Qualitative Validation: Recreating the Incident



Also Investigated Possible Mitigation Strategies

Example Mitigation

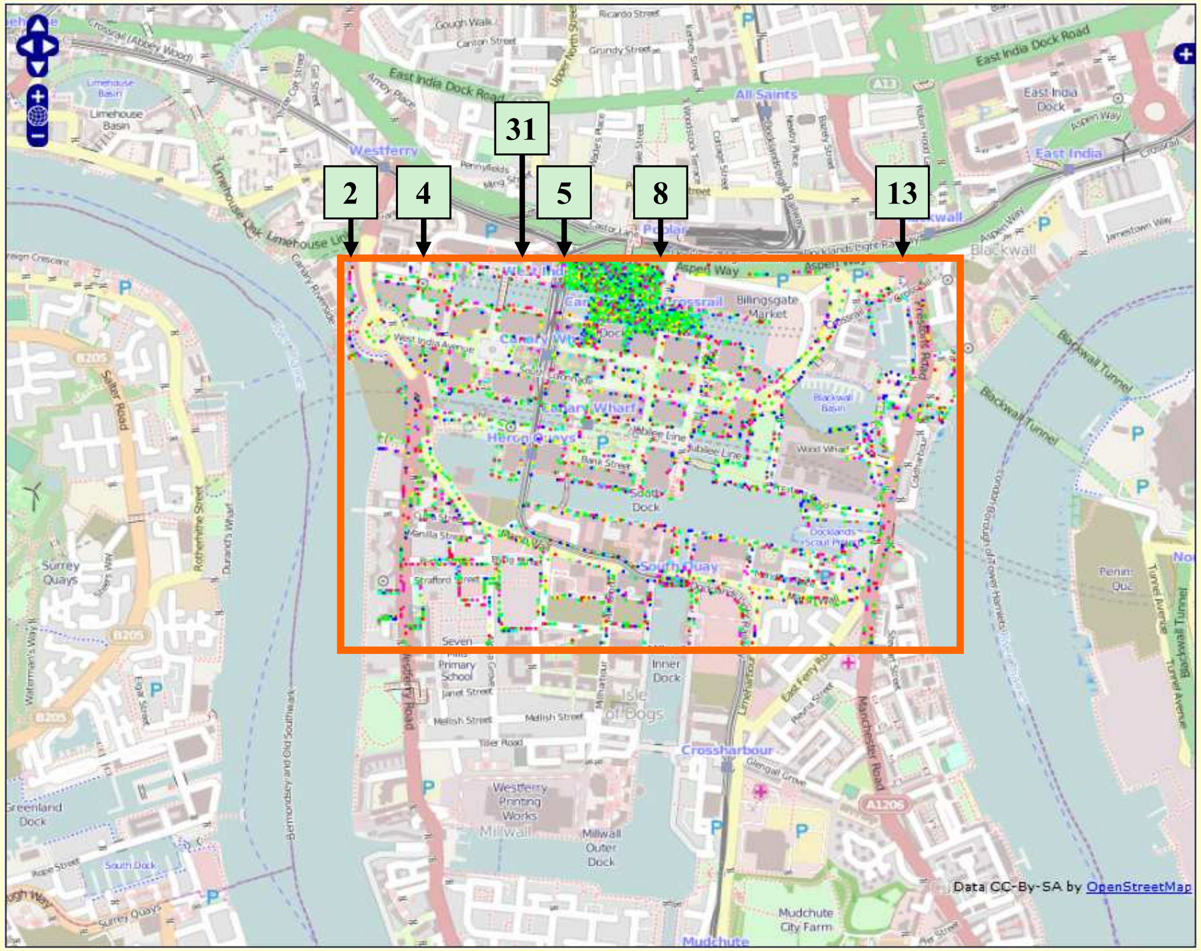


Large Scale Disaster Planning and Management

- As part of EU FP7 project IDIRA EXODUS is being configured for use in large scale urban disaster applications.
- This could be for applications in floods, Tsunami, earthquakes, forest fires, terrorist situations etc.
- Software is used to assist in planning large-scale movement of people and for use during an incident to assist in management.
- Models of urban regions can be pre-built and stored for use during an incident or regions of interest can be built during an incident.
- During an incident the model can be reconfigured as new information is made available as the scenario changes.
  - e.g. loss of evacuation routes, changes in status of refuge areas, etc.
- Web Application – An easy to use GUI for clients to interact with the EXODUS simulation tool.
  - OpenLayers – Client application used to display base maps (Googlemaps/OSM) and Overlays (Population density contours)

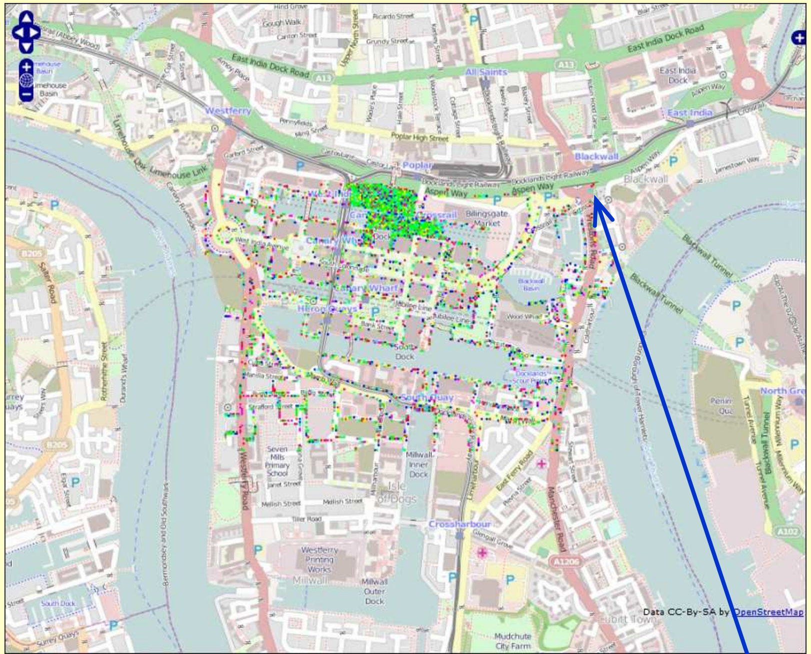
Canary Wharf Region Modelled showing main exit points

Canary Wharf Region to be modelled

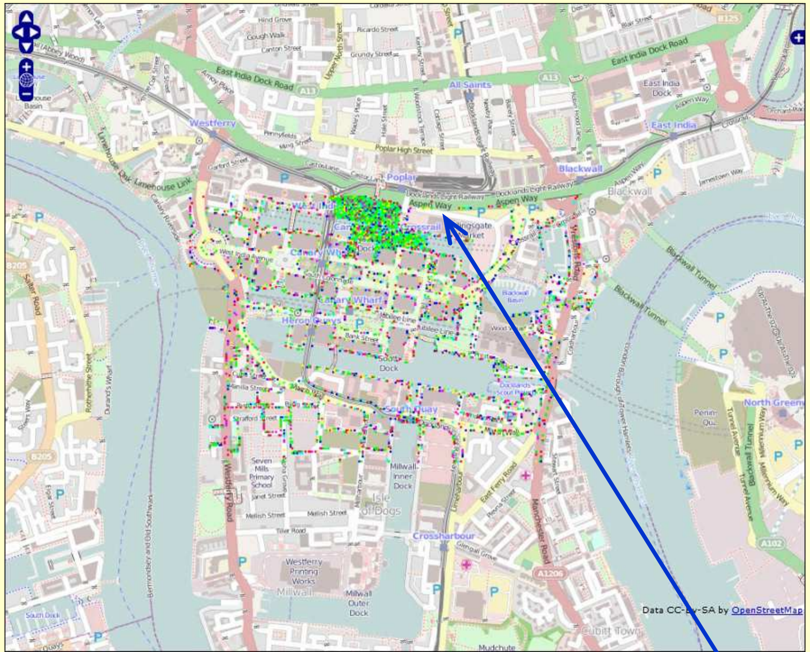


Evacuation Scenarios 205,000 people

- 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



Scenario 3 – exit 13 closed



Scenario 4 – exit 8 closed

MIXED REALITY TRAINING ENVIRONMENT

HORIZON 2020

The EU Framework Programme for Research and Innovation

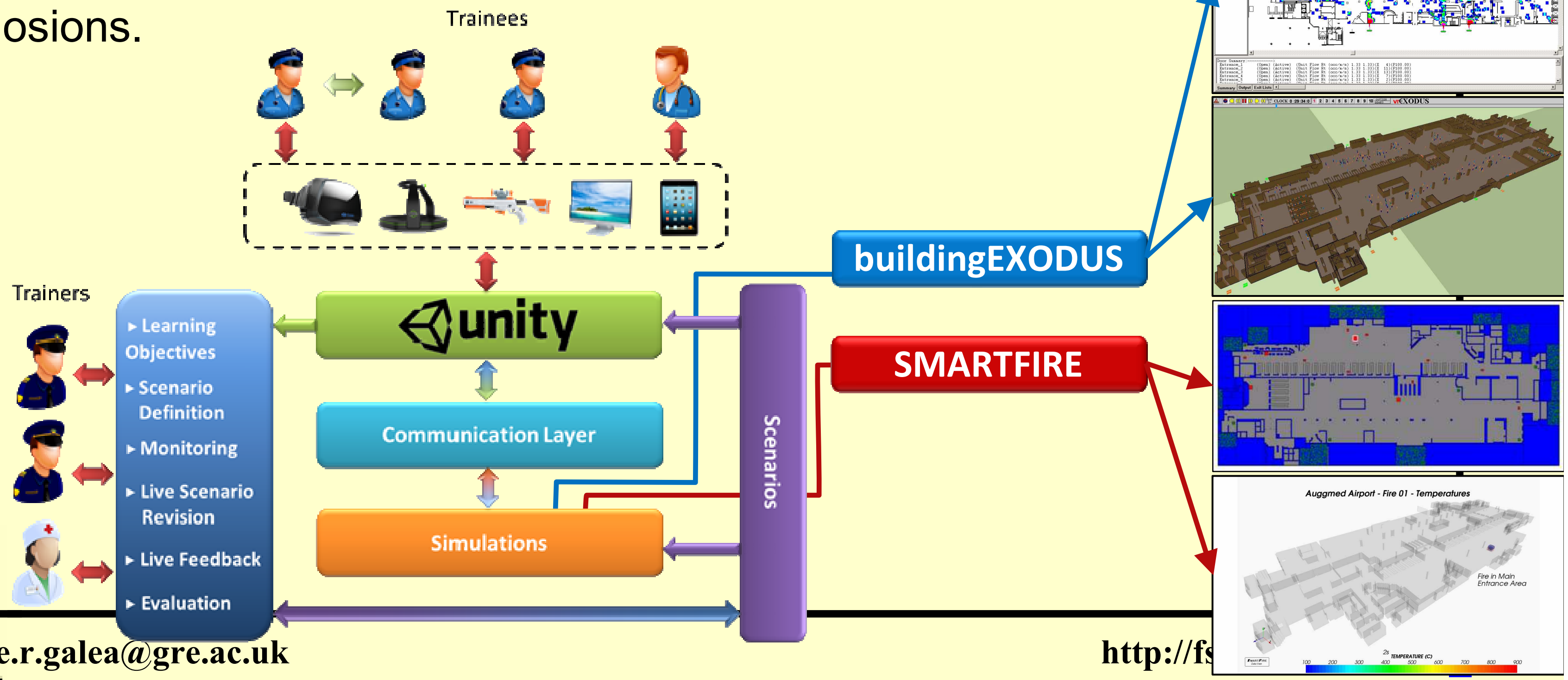
European Commission

AUGGMED

http://auggmed-project.eu

AUGGMED – Automated Serious Game Scenario Generator for Mixed Reality Training

- Aim is 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.

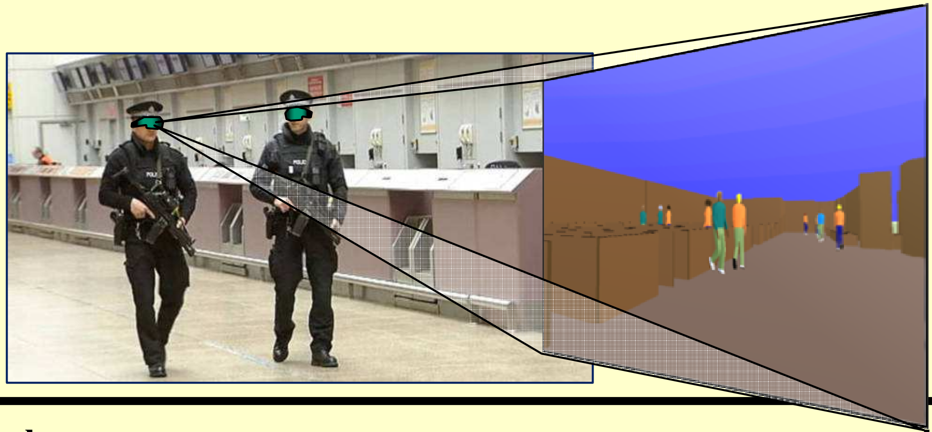


FSEG's Main Contribution

FSEG Developments for AUGGMED:

•Users will be able to:

- Select a particular simulated *blue* team member and assume control of that agent
- All actions of selected agent are now dictated by real player rather than EXODUS
- In VR user is within the VR environment playing the scenario sitting in a desk
- In MR user is located in the targeted installation viewing the real structure through head mounted display and viewing virtual people (civilians, *red* team members) as participants in the scenario



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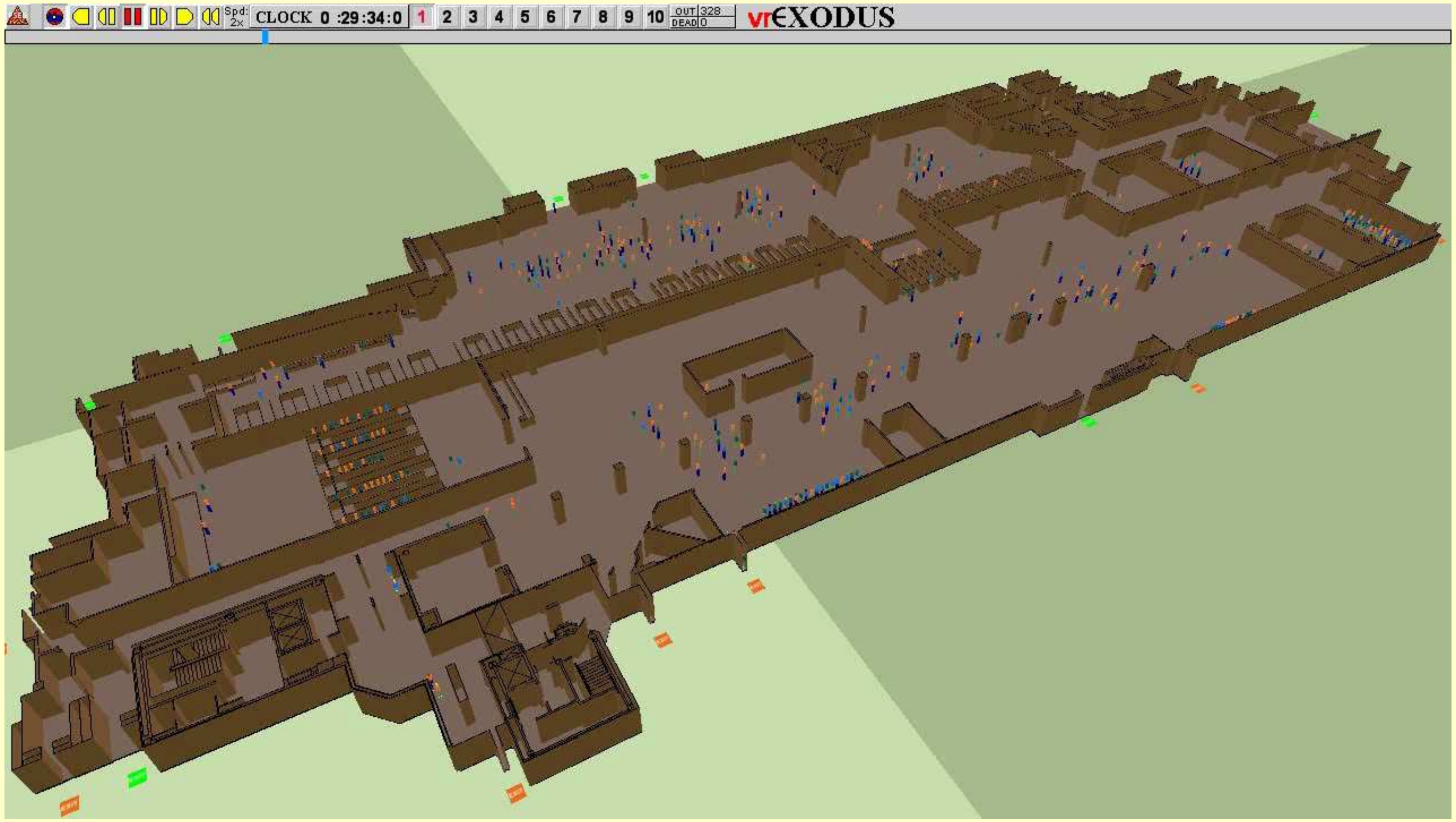
Pilot 1 Geometry: The Airport Terminal

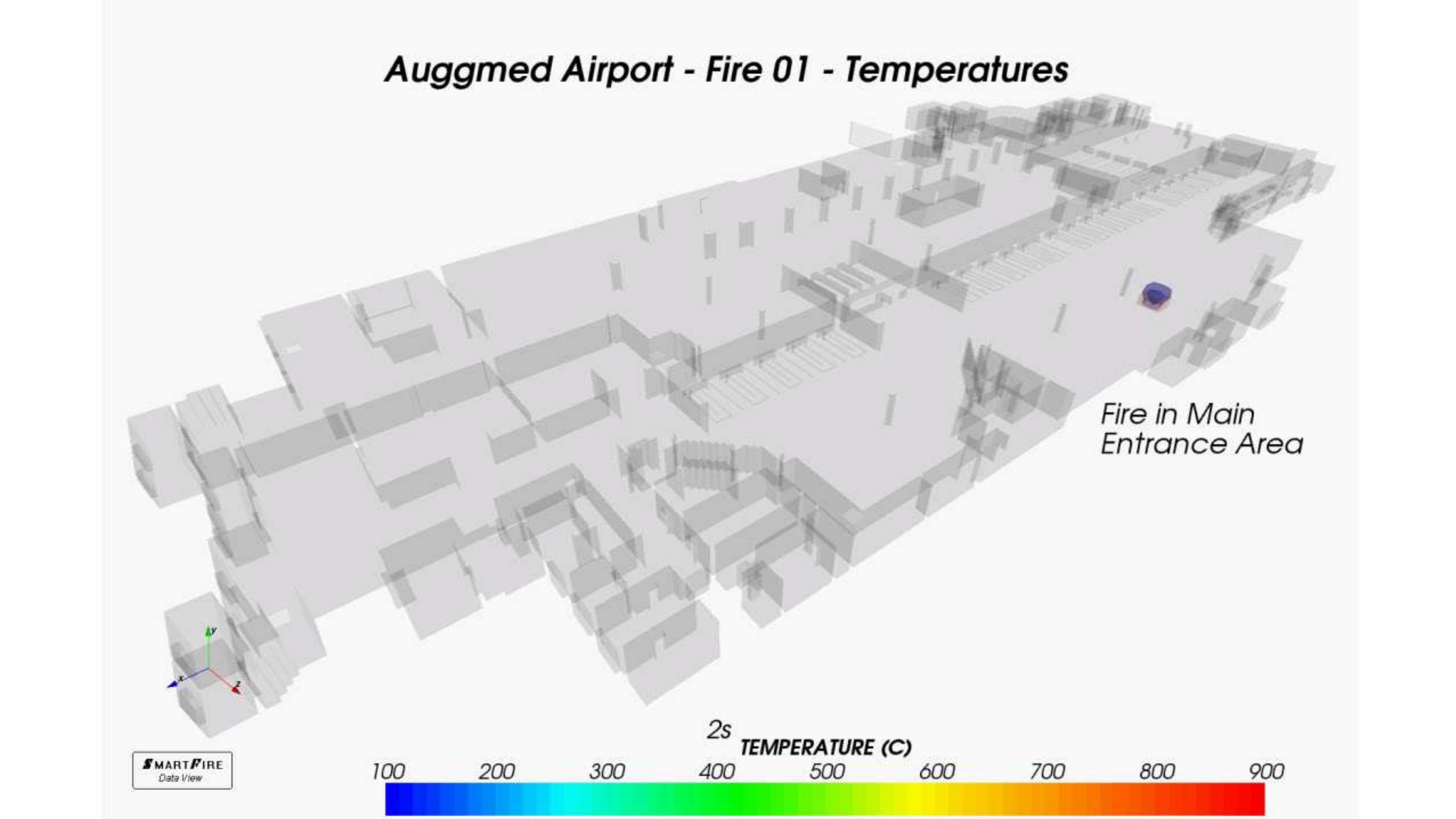
Generic Airport Terminal Model: vrEXODUS representation

•Circulation example imported into vrEXODUS



Environmental Conditions – Fire

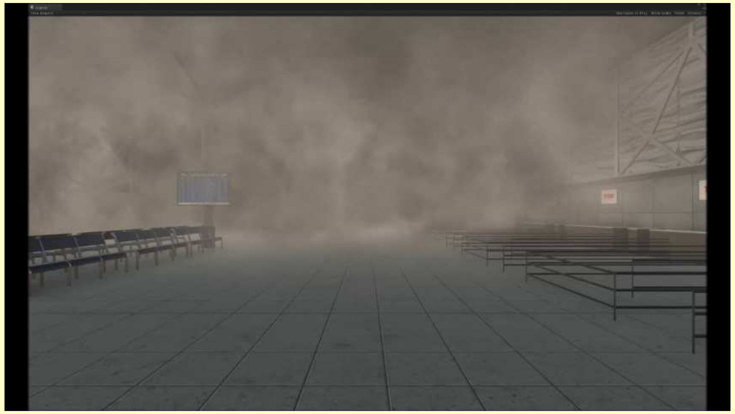
Fire Simulations – SMARTFIRE



Pilot 1 Geometry: The Airport Terminal

Generic Airport Terminal Model: Unity3D representation

- EXODUS model exported and represented within Unity3D for VR+MR applications
- Simulated fire causes visual obscuration to both simulated agents and real users
- Fire hazards affects simulated civilians causing disorientation, reduction in movement ability, incapacitation



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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.