Engineering Safety and Security through Simulation:

Fire, Evacuation, Terrorism and COVID19

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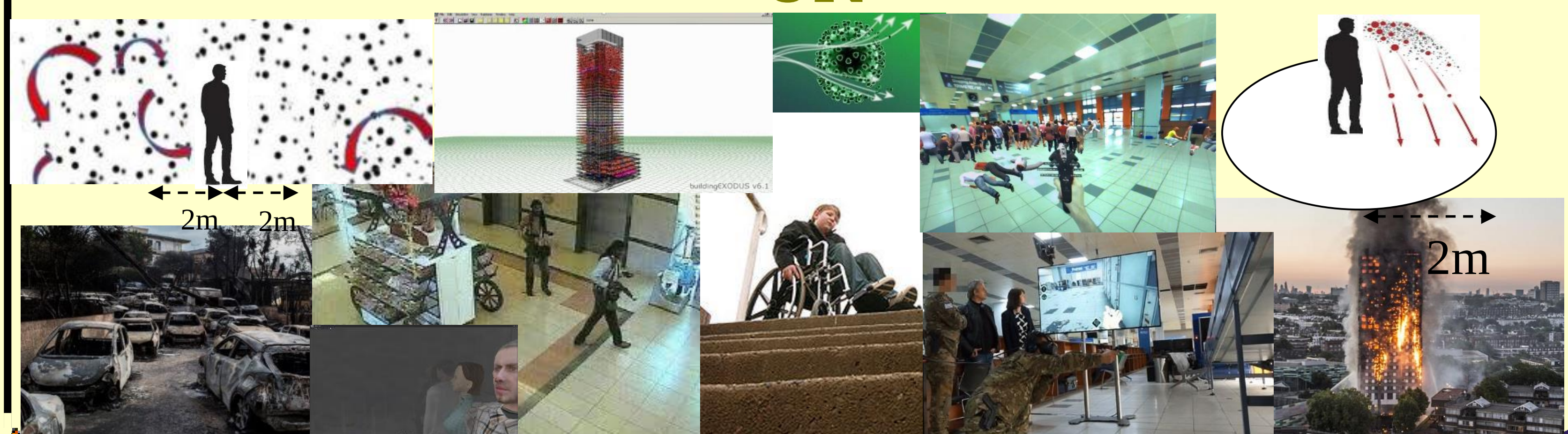

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Engineering Safety and Security through simulation

- PRM Evacuation

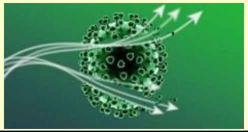
- Dynamic Signage

- High-Rise Construction sites

- Urban-Scale Evacuation

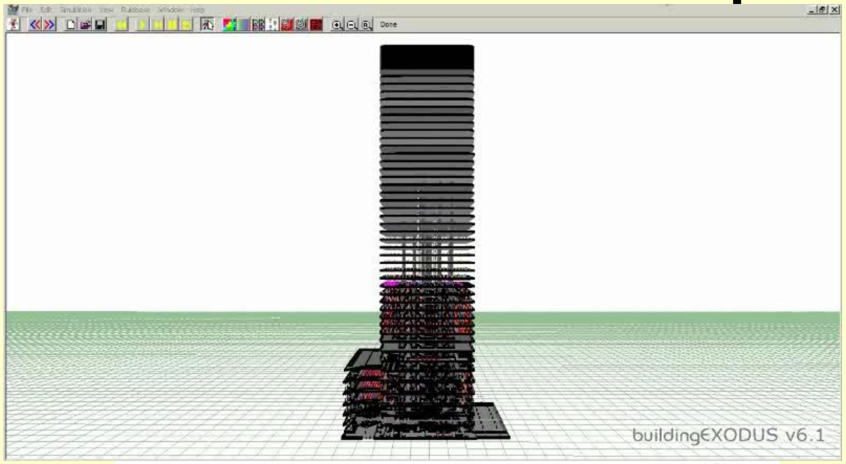
- Marauding Armed Terrorist

- COVID19



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 20 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:
  - aviation, buildings, maritime and rail.
- Developed EXODUS and SMARTFIRE tools
  - Both under continual development since 90s
  - Extensive validation history
  - Users in over 35 countries



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Movement Assist Devices

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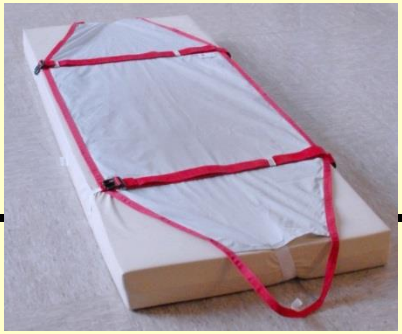
Assist devices for PRM

- In a fire, PRM may be required to wait in a safe refuge within the building to be rescued.
- In severe situations it may be necessary for other to assist in the evacuation of PRM.
- Assist devices are essential to aid in evacuation of PRM. But:
  - How long does it take to evacuate non-ambulant person using these devices?
  - How many people are required to use the device?
  - What impact do these devices have on the flow of other people down the stairs?

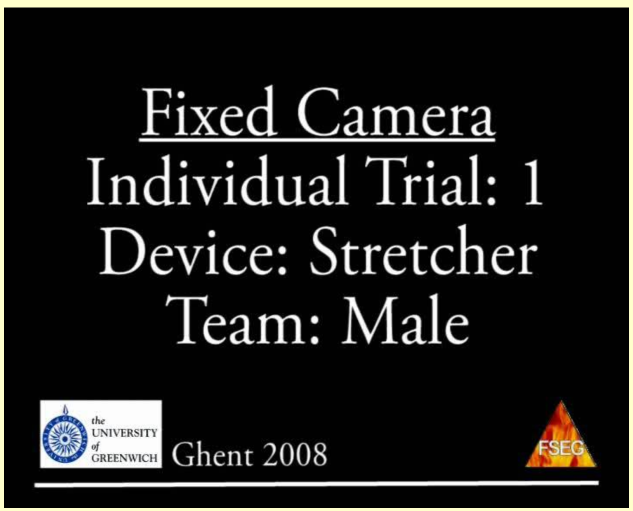
- To answer these questions and quantify the performance capabilities of these devices a series of 32 trials in an 11 floor building using four commonly used aids was conducted.



Assist devices for PRM

• Preparation time: females 31.2 s

• Horizontal speed: males 1.2 m/s



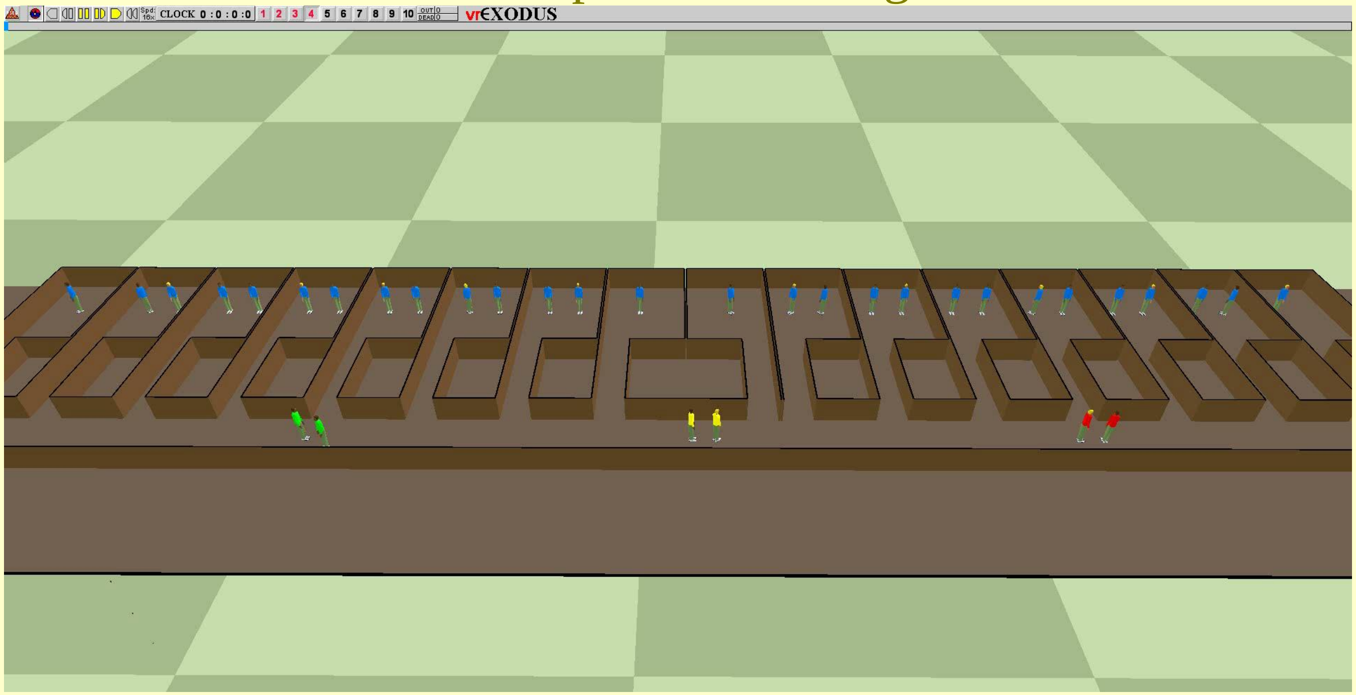
← minimum number physically required

	Stretcher	Evac Chair	Carry Chair	Rescue Sheet
Preparation Time	68 secs (63-74)	29 secs (24-32)	35 secs (32-40)	53 secs (46-60)
	88 secs (61-120)	36 secs (30-42)	48 secs (41-52)	78 secs (67-86)
Horizontal Speed	1.09 m/s (0.99-1.23)	1.55 m/s (1.51-1.65)	1.54 m/s (1.44-1.75)	1.16 m/s (1.08-1.23)
	0.99 m/s (0.91-1.09)	1.39 m/s (1.34-1.44)	1.46 m/s (1.41-1.51)	0.72 m/s (0.52-0.97)
Stair Descent Speed	0.63 m/s (0.59-0.66)	0.83 m/s (0.78-0.88)	0.50 m/s (0.40-0.61)	0.82 m/s (0.78-0.85)
	0.44 m/s (0.40-0.48)	0.82 m/s (0.79-0.85)	0.66 m/s (0.58-0.74)	0.52 m/s (0.50-0.55)

• Vertical speed: males 0.63 m/s

• Performance summary

buildingEXODUS simulation using PRM performance data – Implicit modelling



- 32 PRM
- 7 day staff
- 4 night staff

	Male Teams		Female Teams	
	Day (hrs)	*Night (hrs)*	*Day (hrs)*	*Night (hrs)*
Evacuation Chair	0.5	0.9	0.6	1.1
Rescue Sheet	1.1	1.6	1.5	2.1
Carry Chair	1.6	3.1	3.2	3.5
Stretcher	3.3	3.8	3.9	4.7

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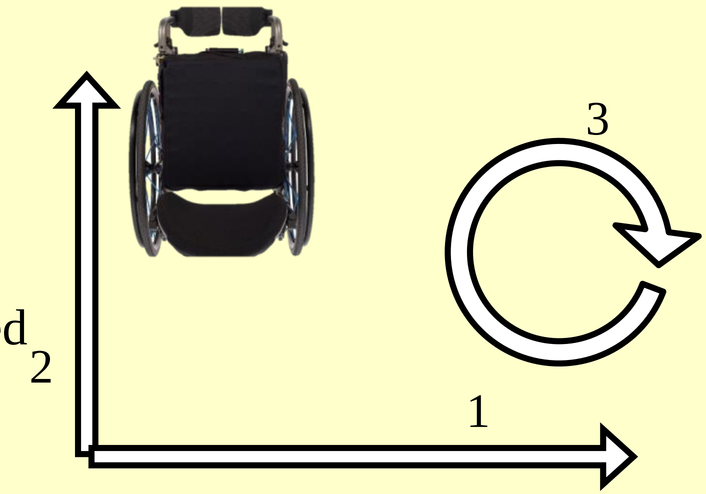
Explicit modelling of assist devices

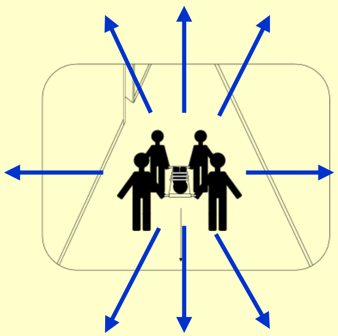
- Currently under development by FSEG PhD research student **Michael Joyce**
- When modelling a physical device, it is essential to represent its spatial and kinematic constraints e.g. turning radius.
  - Most software only consider speed while some also include spatial constraints e.g. size and shape.
- Kinematic constraints can be described by the device degrees of freedom (DOF).



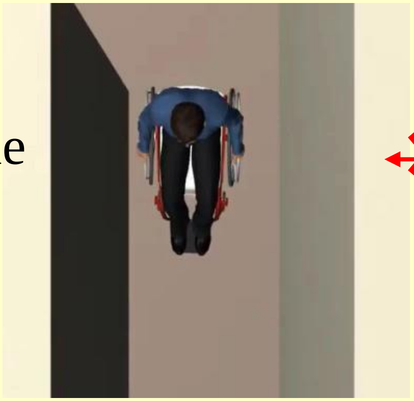
- Kinematic constraints dictate how the device is able to manoeuvre through space.
  - Inability to negotiate tight restrictions potentially restricts some available routes.
- Kinematic constraints that limit manoeuvrability are:
  - holonomicity and minimum turning radius.

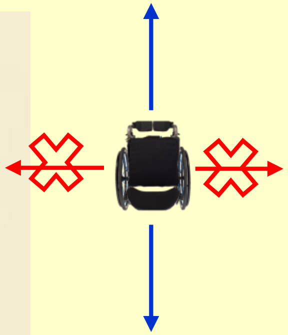
Device Kinematic Constraints

- A Holonomic device can move in any direction without first rotating.
  - **Stretcher is a Holonomic device**
  - **It can move in any direction without the need to rotate,**



  - **Wheelchair is a non-Holonomic device**
  - **It must rotate to change direction (other than reversing).**



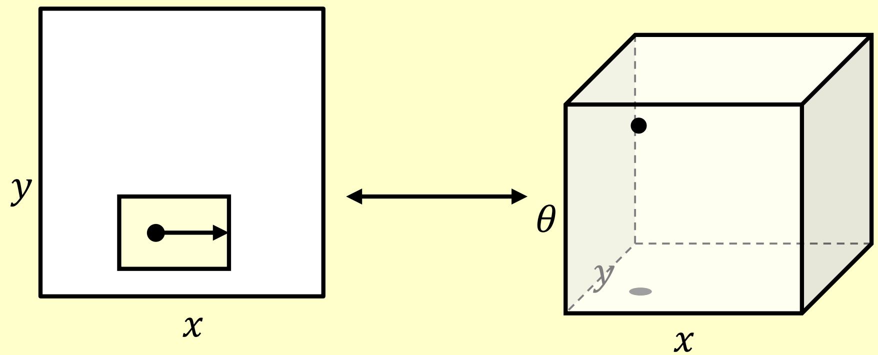


- Non-holonomic devices may not be able to traverse a 90-degree corner even if it's length and width suggest it can – dependent on turning circle.
- Evacuation models that ignore Kinematic Constraints may predict unrealistic routes for non-holonomic devices.

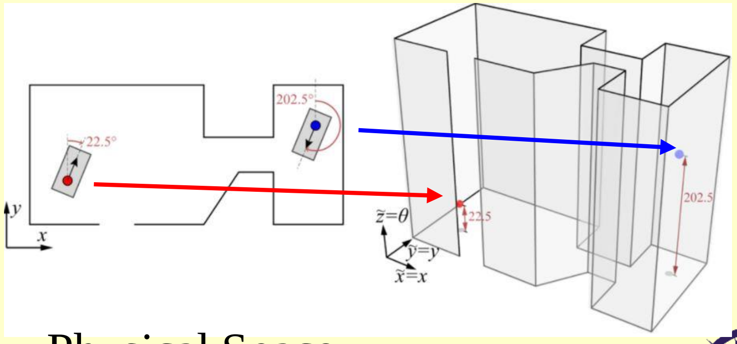
Configuration Space (C-Space)

- Each degree of freedom has its own dimension
- Object with 3 DOF represented in a 3D C-Space

Map from physical
space to C-Space



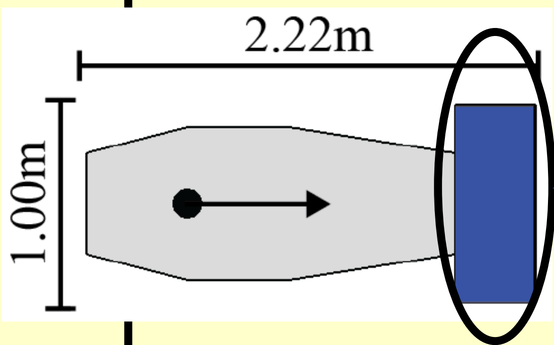
- The 3 DOF are:
  - (x,y) coordinates of a reference point on the device (2 DOF)
  - (θ) angular orientation around this point, measured clockwise in degrees from the positive y axis (3rd DOF).



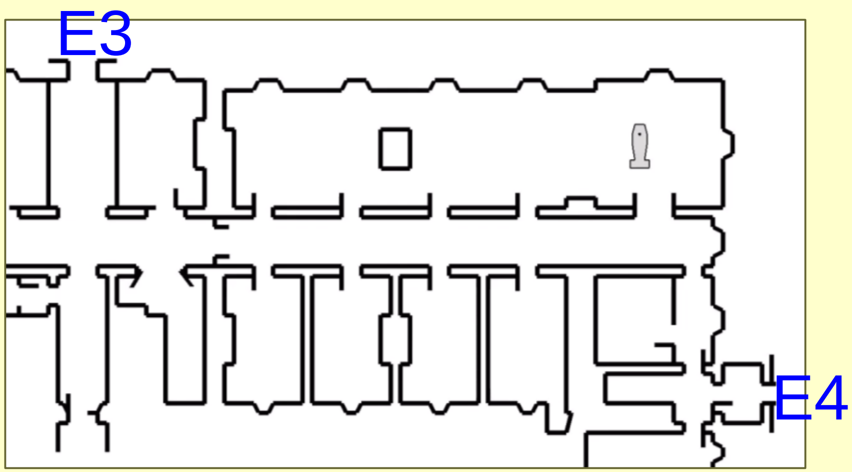
Physical Space

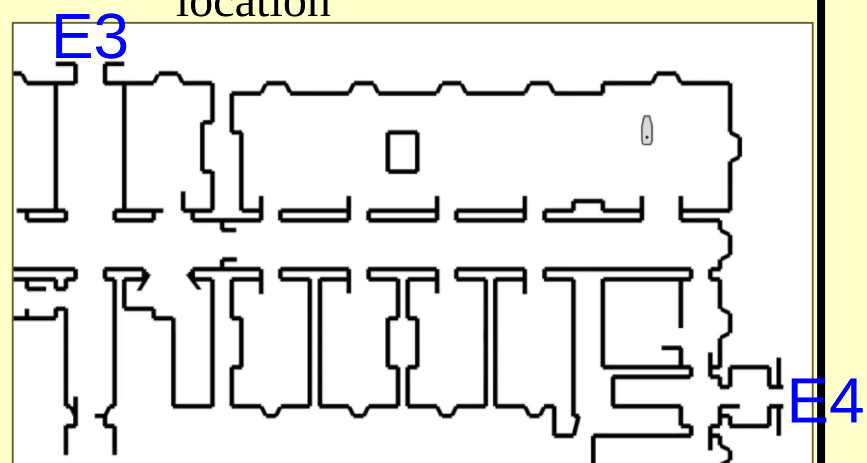
C-Space

Device Movement through complex space



- For each device must identify:
  - Location and # of handlers
  - Dimensions of device+handlers
  - Lateral and angular movement capabilities of device
  - Ability of handlers to adjust location



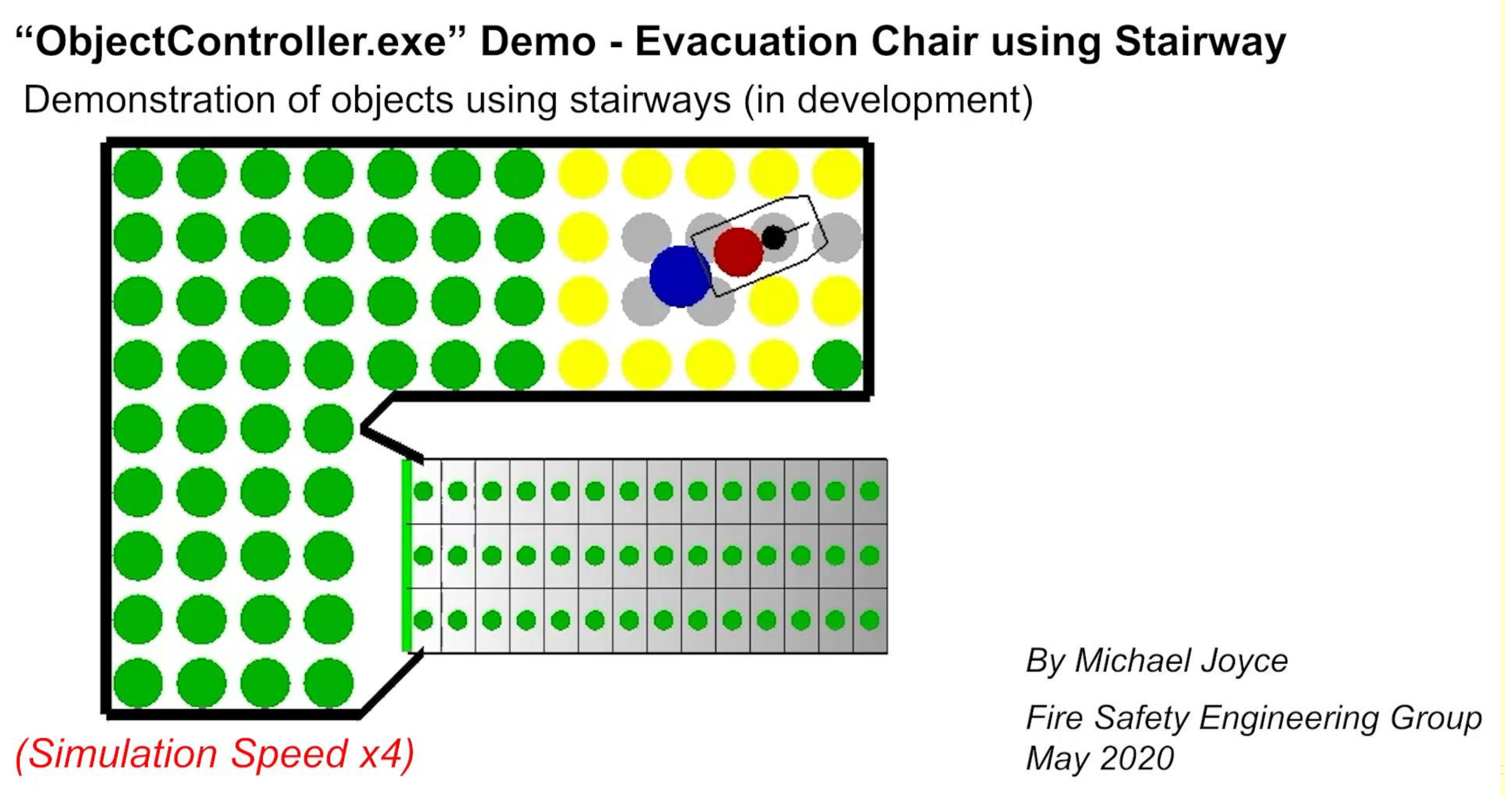


- **Drag sheet** cannot negotiate path to nearest exit E4
- Must take longer route to E3

- **Evac-Chair** can take the shortest exit path and so exits through E4

Stair Behaviour

- Yellow nodes “halo” nodes:
  - Used to identify to other agents presence of a device to enable them to navigate around the device.
  - Also used to alert the device as to whether it is blocking a corridor and so may need to change its behaviour.
- Objects can prefer the middle, inside, outside, left or right of stairways and landings.
  - In the case depicted, preference not set, so device follows the quickest route



DYNAMIC SIGNAGE

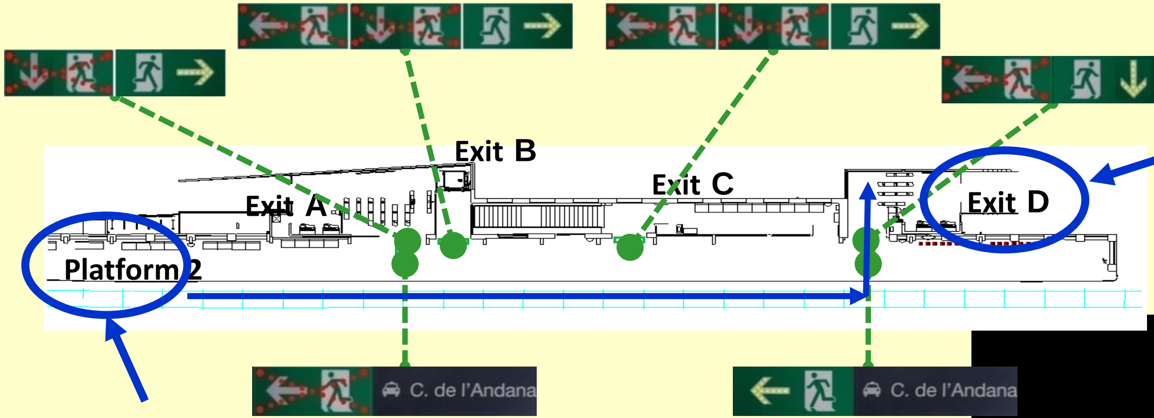
Active Dynamic Signage System (ADSS)

- Conventional emergency exit signs suffer from:
  - Poor detectability (low affordance)
  - Inability to adapt to an evolving hazard environment.
- In an emergency, every second counts!
- To address both issues the ADSS concept was developed
  - Through a series of experiments and surveys ADSS was shown to:

- Significantly improve detectability:
  - 39% "see" standard sign (SS).
  - 77% 'see' dynamic sign (DS)
- Significantly reduce average route decision time:
  - **5.6s don't see SS**, 2.6s 'see' SS, **1.8s 'see' DS**

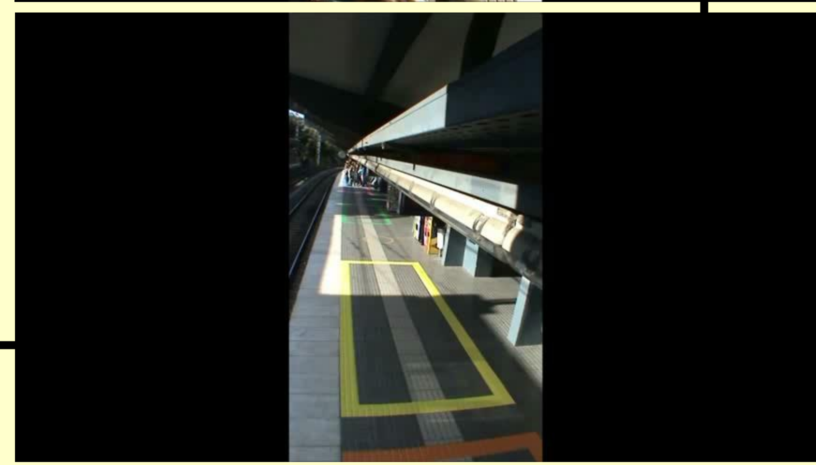
- 92% correctly interpret meaning of DS
- 0.5% critical confusion rate

Full-Scale Trial (Get Away project)



Only viable exit

Starting location of population



- **66% of participants by-pass exits A, B and C and utilise target exit.**

- **Only 34% of participants chose to use their nearest exit compared to 100% in trials with standard signs**

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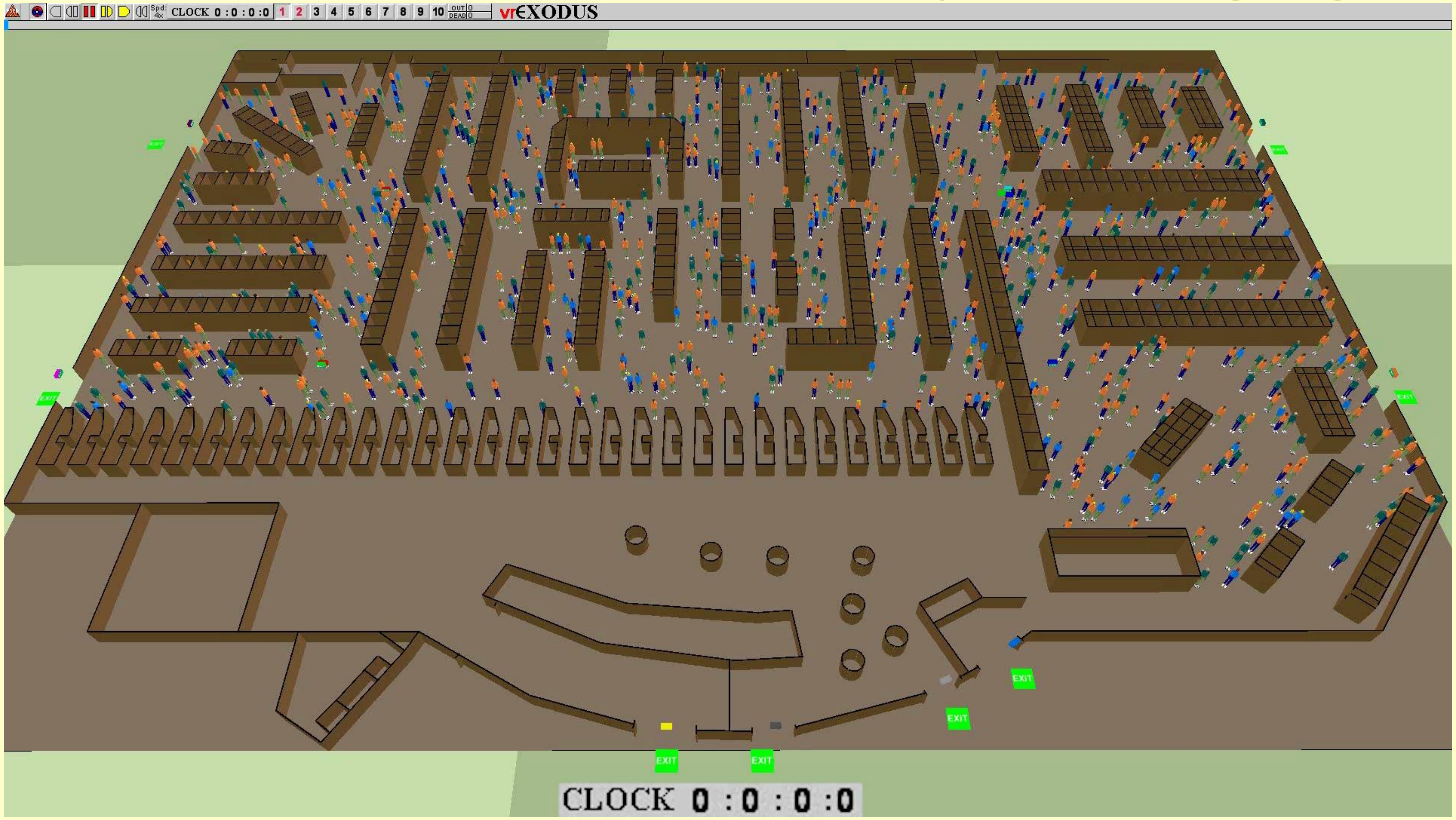
Demonstration: Standard Vs Dynamic Signage

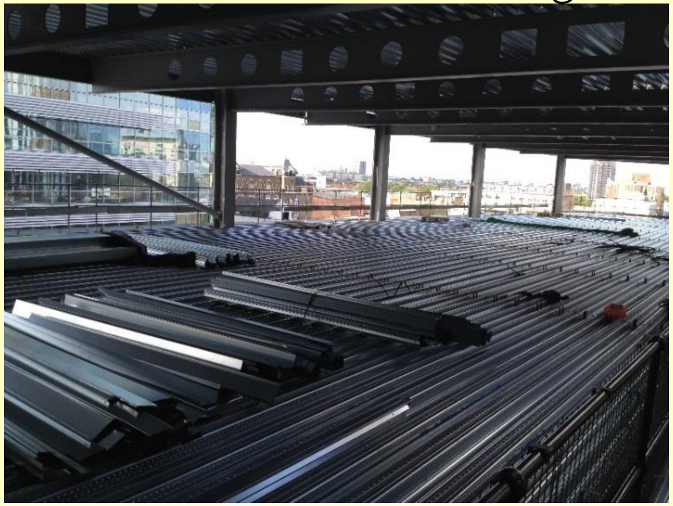


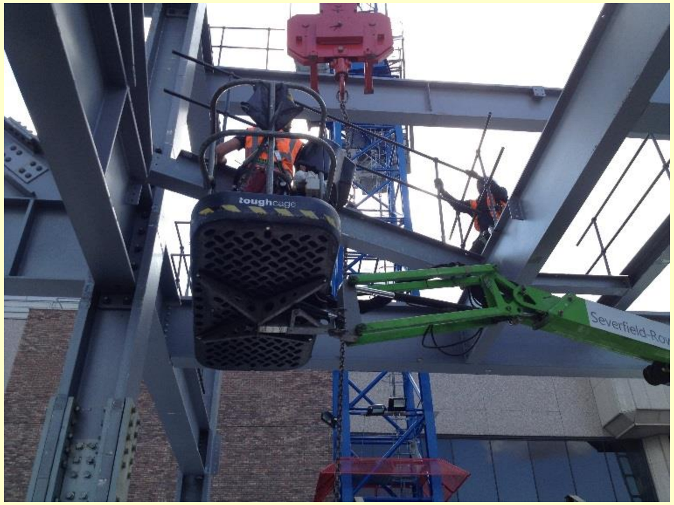
- Through better use of available exits, DS result in an average 36% reduction in time wasted due to congestion and 13% reduction in PET.
- Added benefit during COVID19 pandemic as it reduces exit congestion, time spent in close proximity to others and time spent evacuating.

Evacuating High-Rise Construction Sites

Construction Site Evacuation - Challenges

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





- 2 High-rise Construction sites
- 4 Evacuation Trials
- 5 Walking speed trials

iosh

MULTIPLEX
Built to outperform.

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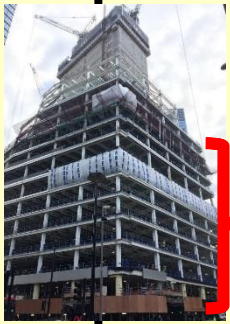
Selected data from trials

Response Time Main Building



- Lognormal
- Mean: 1.2 min, Max: 5.7 min
- 32% disengage > 60 sec

Speed on Temporary Stairs
Parallel Scaffold Stairs

Descending

74% of
stair average

Ascending

79% of
stair average

Speed on Temporary Floor Surfaces
Decking with Rebar

Experienced

78% of
Average walk speed

In-Experienced

72% of
Average walk speed

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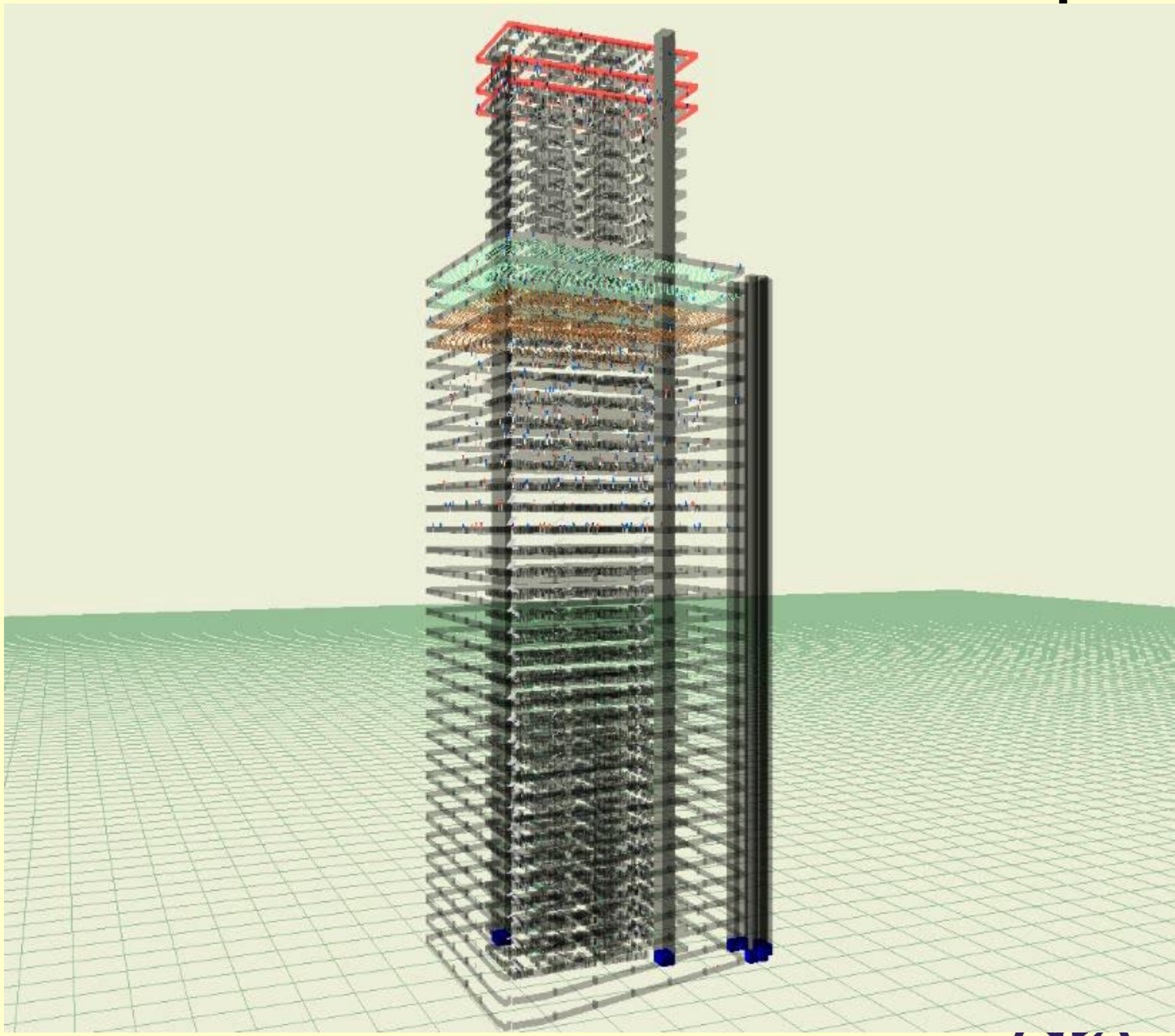
Use of Hoists for General Evacuation

- Two building heights considered, BM1 and BM2.
- Two hoist speeds considered, (1.5 m/s and 0.7 m/s)
- Two hoist capacities considered (40 and 30 occupants).
- Single dispatch scenario considered
  - 2 hoists serve FW
  - 6 hoists serve MB
- Two cases considered, 100% hoist usage and 50:50 hoist:stair usage



Use of Hoists for General Evacuation

- Findings are dependent on the nature of the dispatch strategy applied.
- Presented results apply only to the specific dispatch strategy used in study

- Fast hoists high capacity
  - Significant benefits
  - Regardless of height
  - Even partial use of hoists advantageous

- Slow hoists high capacity
  - Marginal benefit
  - Particularly for lower buildings

- Slow hoists low capacity
  - Do not use hoists
  - Especially for higher buildings

Fast Hoists with High Capacity			
Height of construction	Stairs Only	Hoist Only	50/50 Stairs/Hoist
23 Levels	615 s	25% (463 s)	23% (471 s)
43 Levels	852 s	30% (592 s)	19% (692 s)

Slow Hoists with High Capacity			
Height of construction	Stairs Only	Hoist Only	50/50 Stairs/Hoist
23 Levels	615 s	4% (589 s)	7% (570 s)
43 Levels	852 s	-26% (1078 s)	4% (821 s)

Slow Hoists with Low Capacity			
Height of construction	Stairs Only	Hoist Only	50/50 Stairs/Hoist
23 Levels	615 s	-37% (845 s)	8% (568 s)
43 Levels	852 s	-80% (1530 s)	-16% (991 s)

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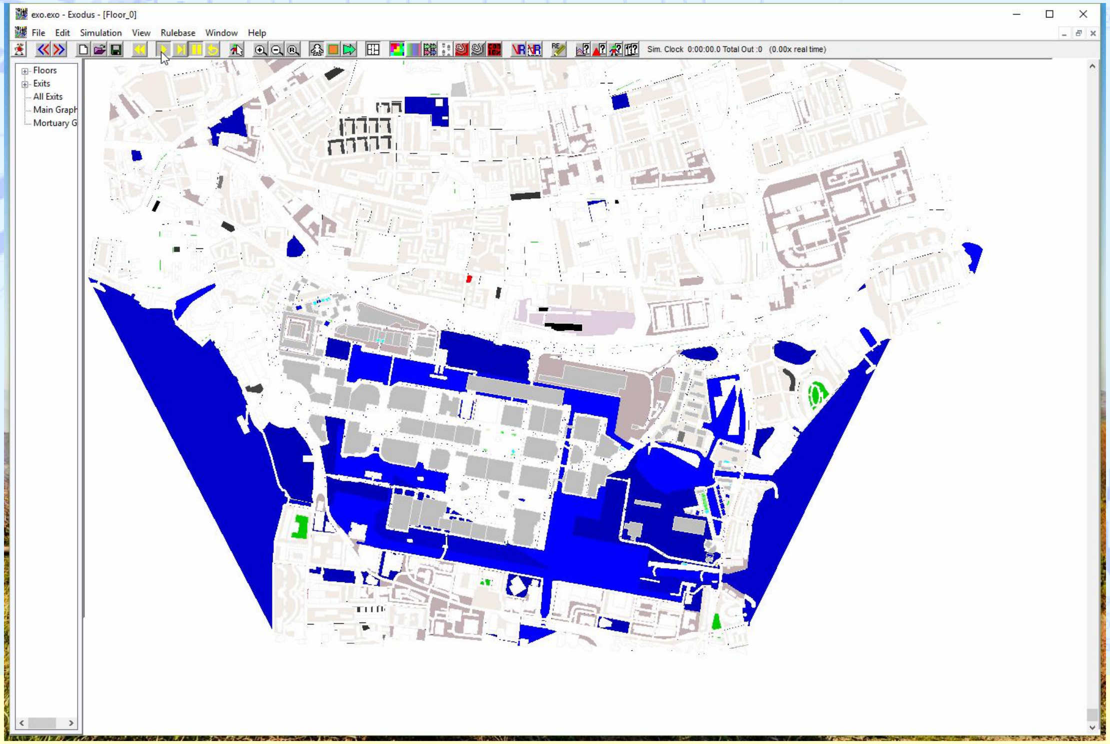
Urban Scale Evacuation and Crowd Dynamics



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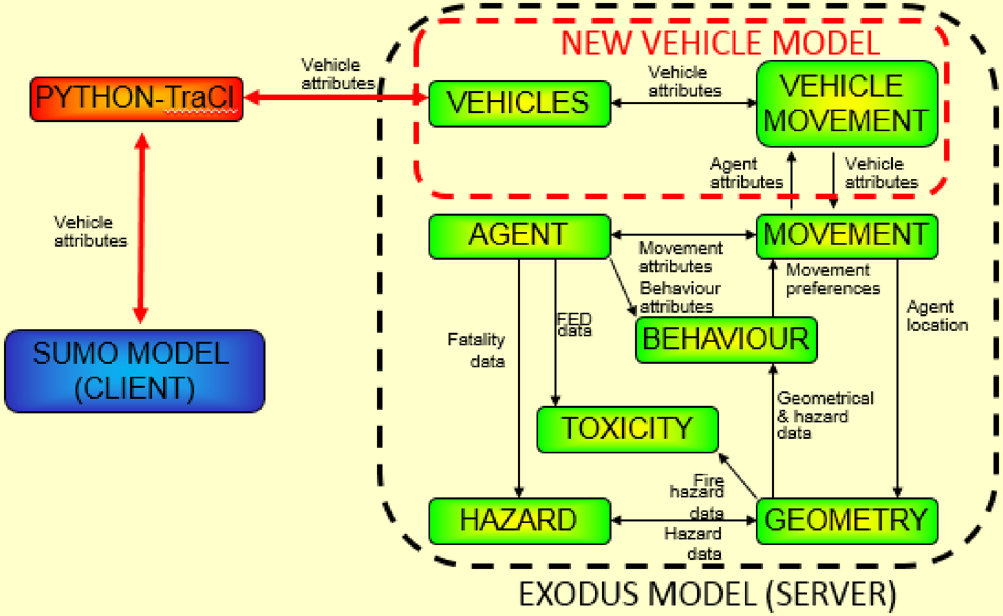
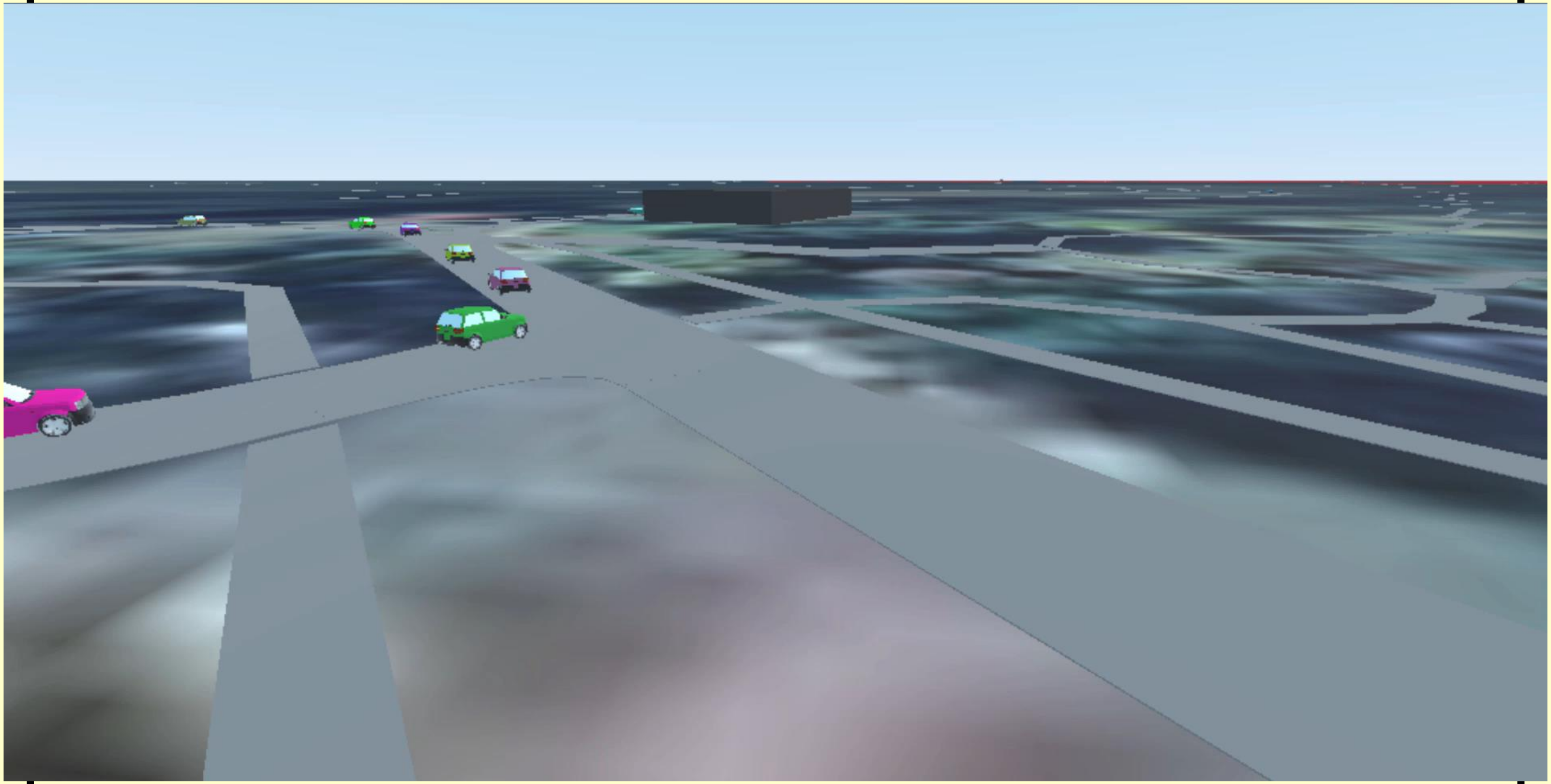
Large Scale Resilience Planning and Management

- **urbanEXODUS** has been developed for applications involving large-scale urban disasters, such as wildfires, floods, earthquakes, chemical spills, etc. .
  - planning urban-scale evacuation
  - enhancing local resilience through simulation aided training
  - real-time emergency management systems.
- **urbanEXODUS** can read street geometries from open source resources such as:
  - Googlemaps, Open Street Maps (OSM)
- **urbanEXODUS** also links to:
  - disaster management systems to provide situational awareness information for the COP
  - accepts terrain information from and DEM OS Terrain 50
  - Wildfire models such as ***PHOENIX, FARSITE, PROMETHEUS, SPARKS*** **AND** ***WILDFIRE ANALYST***
  - ***SUMO*** traffic model



- **First evacuation model to link pedestrian-vehicle-wildfire models**

urbanEXODUS vehicle-pedestrian interaction

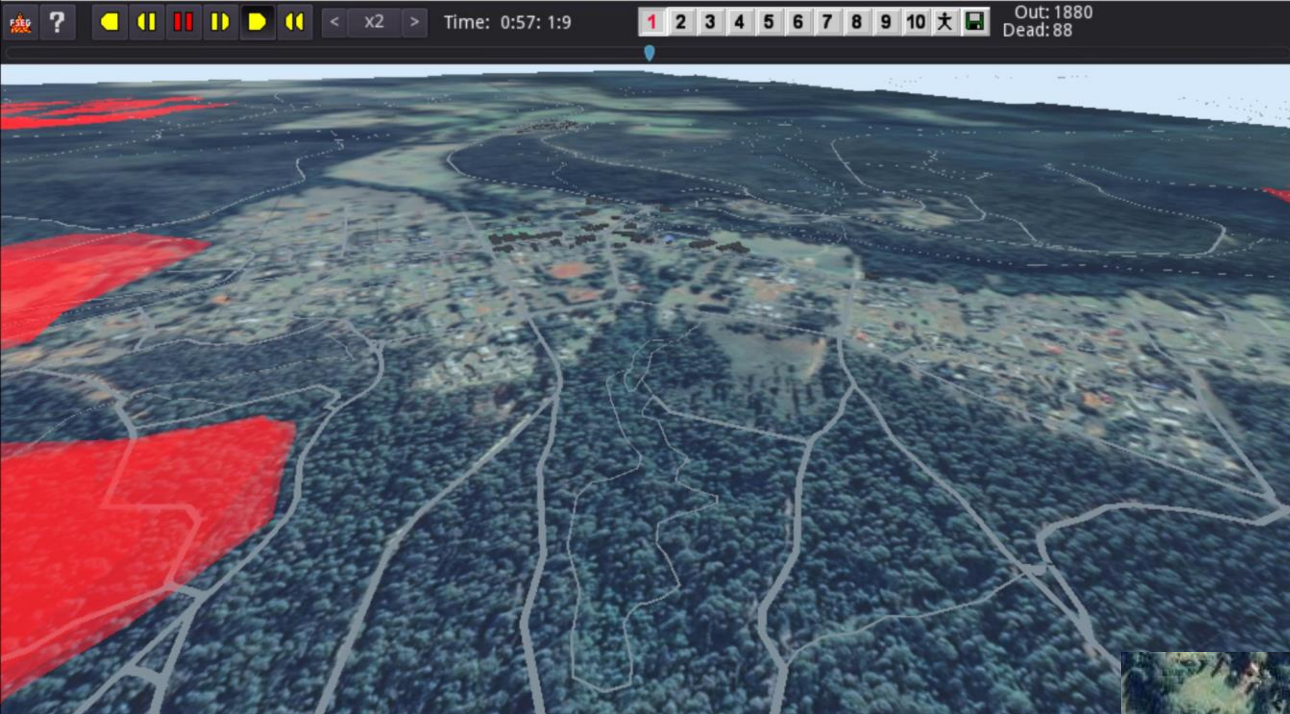


- Traffic flow controlled by SUMO.
- Pedestrians react to vehicles, do not cross in front of vehicles
- EXODUS applies brakes to vehicles when necessary to avoid collision with pedestrians.

urbanEXODUS: linked pedestrian-vehicle-wildfire simulation demonstration

- Demo loosely based on the Black Saturday (7 Feb 2009) **Murrindundi** fire that devastated Marysville, a town of approximately 500 people.
- There were 34 fatalities and almost 400 buildings destroyed (14 remained).
- Map, weather, terrain and fuel conditions and fire start location accurate.
- Fire simulations performed by Dr Thomas Duff of Melb Uni using PHOENIX
- Demonstration scenario involves:
  - 3633 people, 1035 vehicles, 397 people evacuate on foot and 3236 in vehicles.
  - Notification times explored: 1.75hr to 3.5hr after fire ignition.
  - RTs of agents 1 to 1.5hr after notification
  - Pedestrians attempt to shelter at the oval (large cleared patch of land)
  - Vehicles travel North on C508

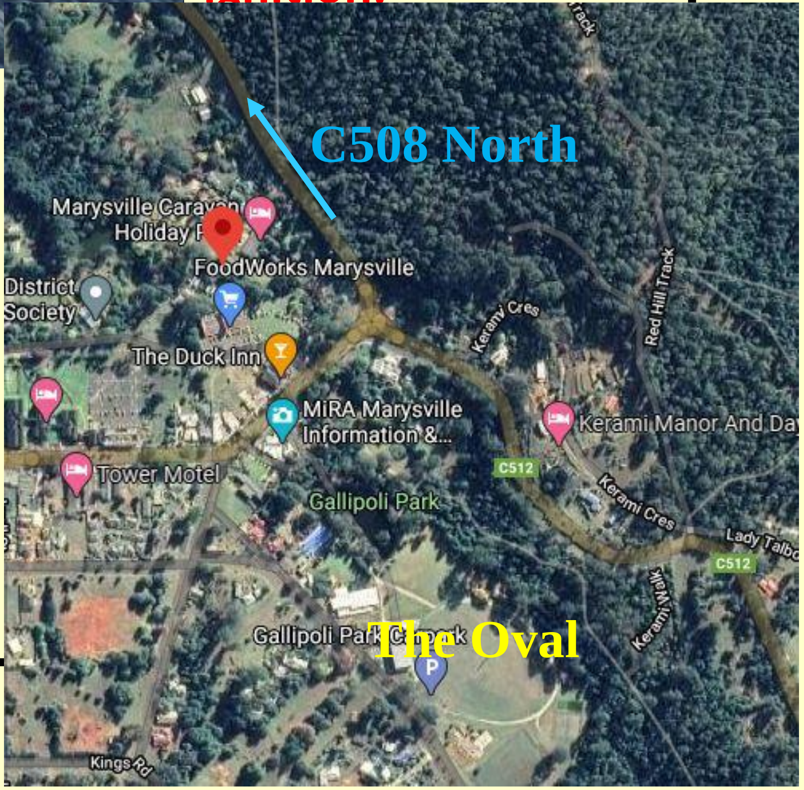
  - When C508 compromised by approaching wildfire at 05:04 (smoke or fire front), vehicles divert to oval. Road to oval compromised by 06:00.



- Cyan circle indicates vehicle exit point.
- Orange circle indicates the Oval.
- Results are average from 100 simulations
- **Notification time: 3.5hr after fire ignition.**

- 1hr 56 min for survivors to reach ‘safety’
- 1461 fatalities (40%): 1350 (42%) in cars, 111 (28%) pedestrians
- 437 cars (42%) lost, 211 (20%) redirected
- ***Waiting 3.5hrs to start evacuation TOO LATE!***

- **If notification time 1hr45min:** fatalities 0, 2hr15 min for population to reach safety.
- **If notification time 2hr:** fatalities 21 (in cars) 7.4 cars lost, 2hr15min to reach safety.



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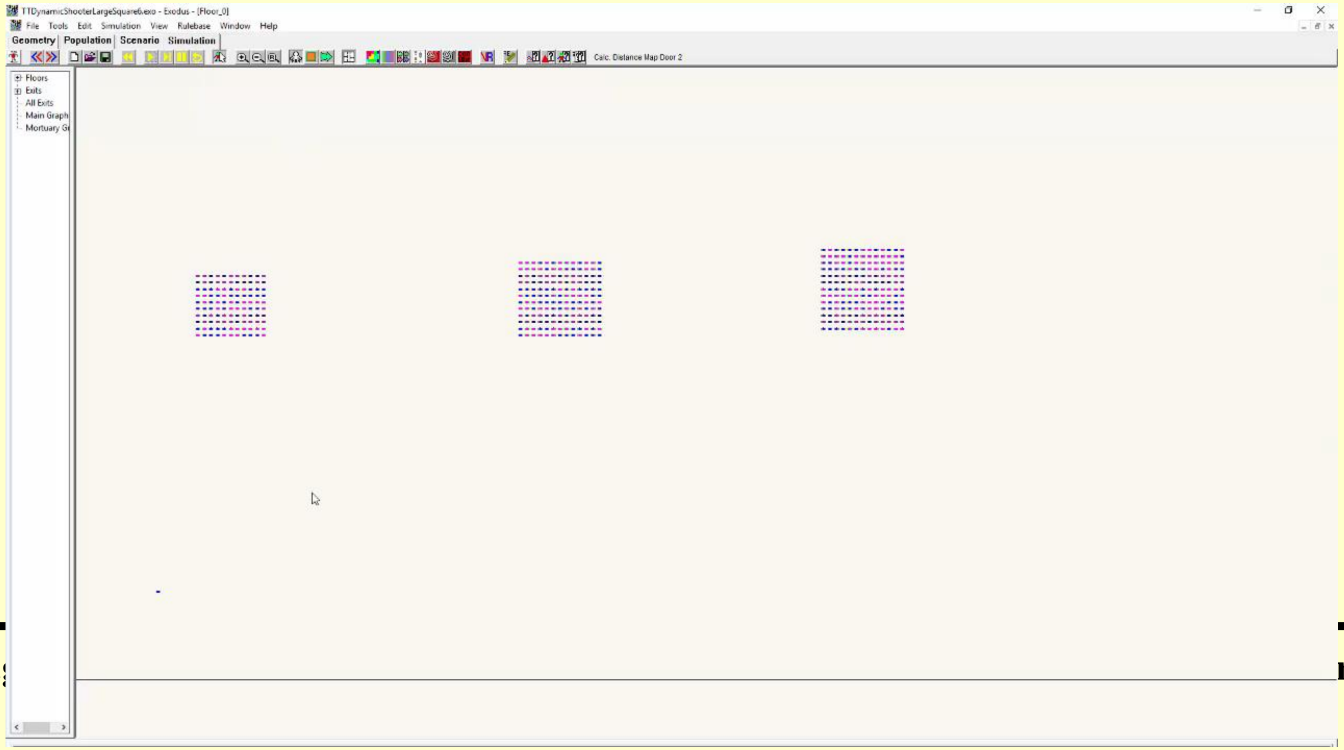
matEXODUS - Marauding Armed Terrorist Functionality

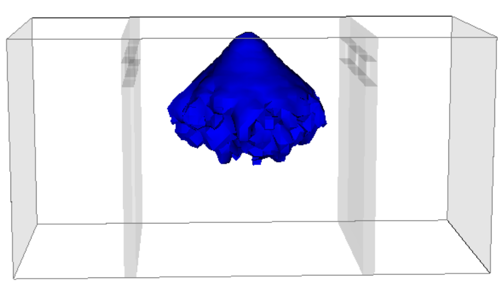



matEXODUS

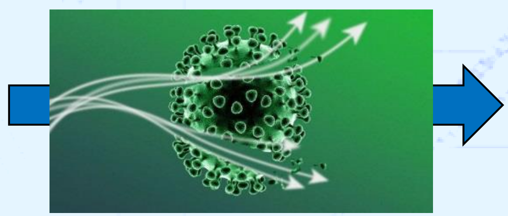
- matEXODUS: Simulates impact of Marauding Armed Terrorist in crowded places – currently under development with support from DSTL.
- Agents can respond to ‘MAT’ agent and attempt to flee or take cover.
- ‘MAT’ agent assigned a mission goal (e.g. maximise fatalities), follows a set itinerary, with a given weapon type, ammunition supply and proficiency
  - ‘MAT’ agent may go off pre-set itinerary to ‘hunt’ for targets of opportunity if too few available on set path.
  - Each round fired can hit or miss target, defined using a probabilistic approach.
  - If a target is hit, there are a range of outcomes which are defined probabilistically.

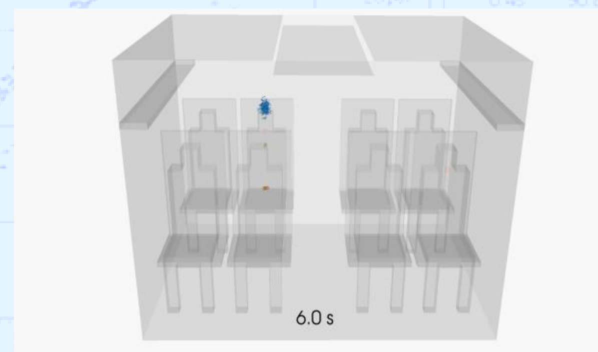


Using Agent Based Models and CFD Fire Simulation Models to address COVID-19 APPLICATIONS



SMARTFIRE water mist fire suppression simulation





SMARTFIRE respiratory aerosol dispersion simulation

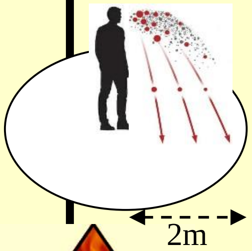
THREE ROUTES TO SARS-CoV-2 INFECTION

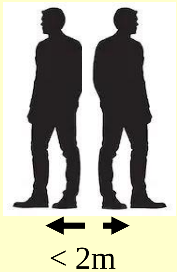
(1) Fomite infection: Associated with large droplets that fall onto surfaces contaminating them. Touching the surface and then your face, mouth or eyes causes infection.

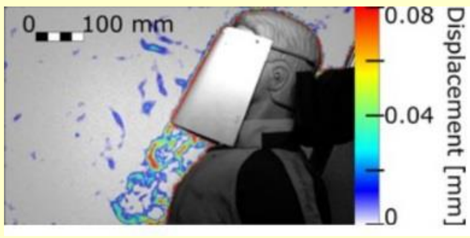
- Hence recommended: hand hygiene.
- However, CDC now claim only 0.001% IP

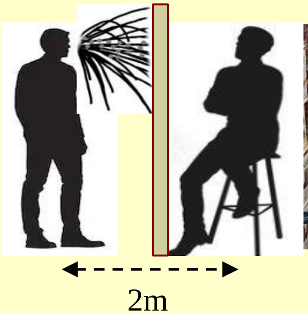
(2) Large Droplets: large respiratory droplets (> 100 µm) follow ‘cannon ball’ projectile trajectories and fall to the ground within ~ 2m in a few seconds – susceptibles within ~ 2m can inhale large falling droplets or they can impact eyes.

- Hence recommended: 2m physical distance, avoid directly facing someone in queues or seating in offices, face shields, partial screens and one way flows.



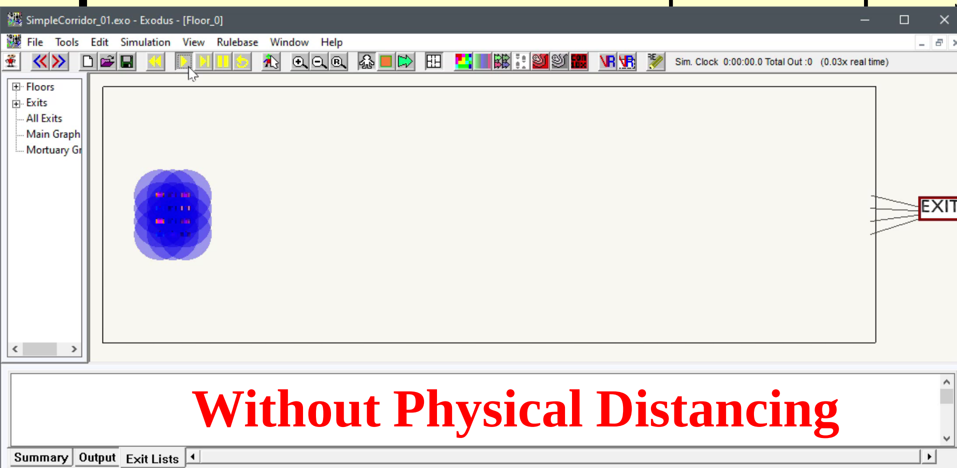




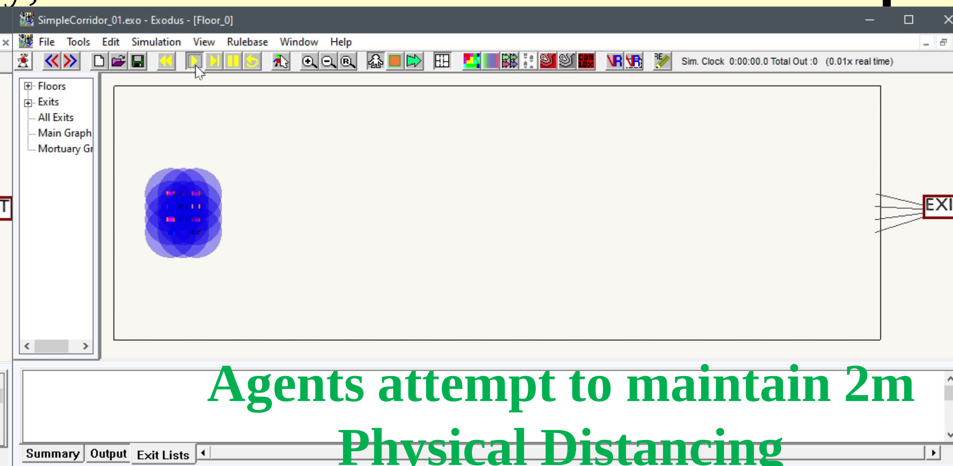


Simulating imposed physical distancing within EXODUS (ABM)

- EXODUS ABM has been modified to take into consideration agents efforts to maintain physical distancing, which is not always successful - circle radius = 1m.
- Results in less crowding at exit point, time to empty space increased by 19%.
- Can be used to assess impact on capacity, flow and level of service.



Without Physical Distancing

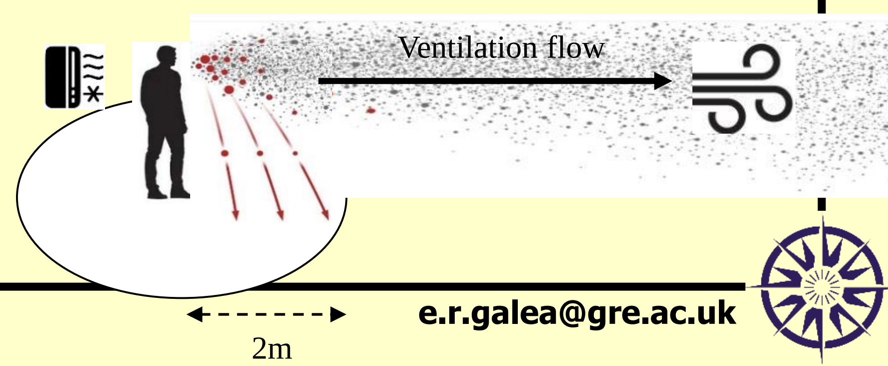


Agents attempt to maintain 2m Physical Distancing

(3) Airborne infection: small respiratory droplets (< 100 µm). These aerosols can be dispersed throughout the space, carried by thermal currents, ventilation AND wake flows Aerosols can remain suspended in the air for hours even after source has left.

- Hence recommended: face coverings and high ACH.

- ABMs, on a building scale, ignore aerosol dispersion, the impact of air-conditioning systems and the impact of agent generated wake flows – questionable value for assessing IP and mitigation strategies.

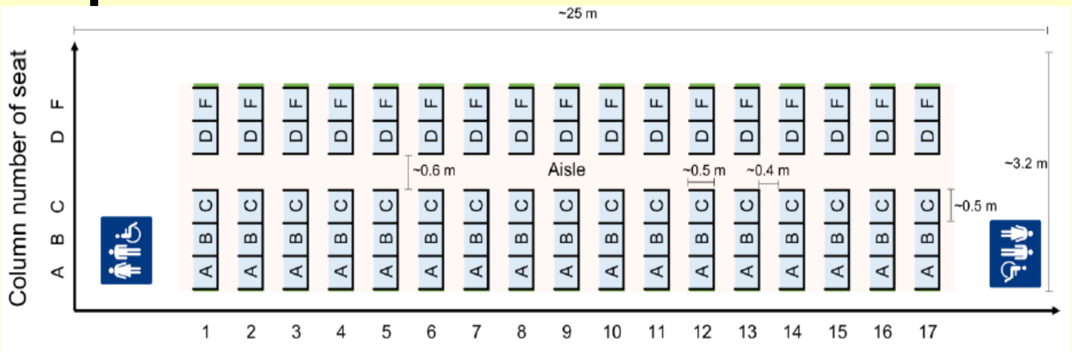


Aerosol dispersion using CFD - SMARTFIRE

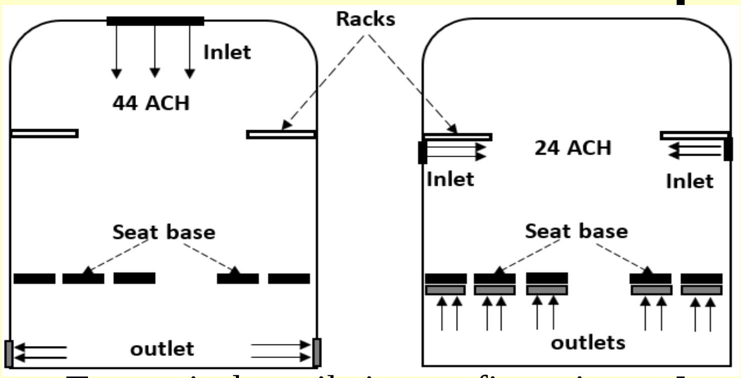
- Rapid prototype development of new modelling capabilities for aerosol dispersal based on core SMARTFIRE CFD fire simulation software;
  - RANS, with k-eps turbulence model, with Lagrange water mist model including particle/air momentum coupling, particle drag and evaporation.
- Enhancements include capability to:
  - Represent aerosol dispersion as evaporating particles or passive scalar.
  - Simulate recirculating HVAC with filtration and wake flows due to dynamic movement, through RNG K-eps and Immersed Boundary Method.
  - Couple CFD with Wells-Riley equation to determine infection probability (IP) based on CFD predicted aerosol dispersion, $p = 1 - e^{-Iqvt/Q}$
- Validate model using analysis of infection risk on Chinese long distance trains (G Train, M Hu et al., 2020) and explore mitigation strategies for trains.
  - Maogui Hu, et al, "The risk of COVID-19 transmission in train passengers: an epidemiological and modelling study," *Clinical Infectious Diseases*, no. https://doi.org/10.1093/cid/ciaa1057, 2020.

Validation Case: Actual COVID 19 Transmissions on G - Train

- Study by M Hu et al, 2020, involving 2,334 index patients and 72,093 close contacts (seated within three rows of index) with co-travel times of 0–8 hours from 19 Dec 2019 to 6 Mar 2020;



Floor configuration of typical G-train carriage



Two typical ventilation configuration

- The IP within 3 rows of index patient varied from 0 to 10.3%;
- Two vent configurations: 44 ACH - Inlet: ceiling, Outlet: floor-level side-walls. 24 ACH - Inlet: side-walls under racks, Outlet: seat bottoms.
- Mass ratio of recirculated to dumped air in Scenario 1 / 2 is 0.66 / 0.59
- Ventilation filtration efficiency: 20%;
- Note: ventilation rates for UK trains are much lower, 8-10 ACH.

G-train CFD Aerosol Dispersion Model

Methodology: Coupled CFD + Wells-Riley Model

- Respired aerosol droplets modelled using a *scalar gas release*;
- Predicted CFD scalar concentrations are converted to quanta concentrations, ***c*** ;
- Individual IP derived using modified WR model and simulated local quanta concentrations;

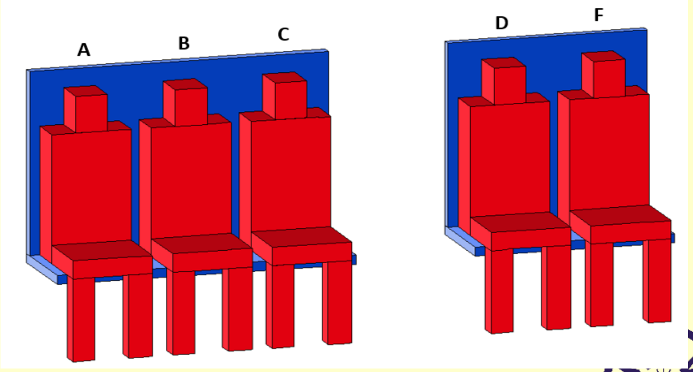
Modified Wells-Riley to take into consideration masks

$$p = 1 - (1-x)^2 e^{-cvt} - x(1-x)\left(e^{-(1-a)cvt} + e^{-c(1-b)vt}\right) - x^2 e^{-(1-a)c(1-b)vt}$$

- *Mask use, x*=40%; Index FE, *a*=50% and Susceptible FE, *b*=30%

CFD Simulations

- Seats/Paxs: represented as obstacles, paxs have 50 W/m^2 surface heat release rate;
- Quanta generation rate: 14 quanta/h. Representative of resting infectious individuals (Wang et al 2021)



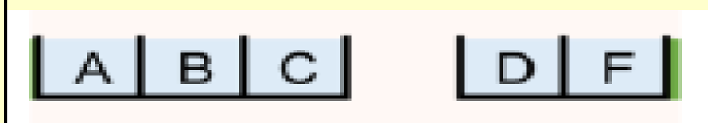
G-train validation study, estimation of COVID19 IP

Maximum infection probability

- 10.3% at seat locations adjacent to index patient as reported by M Hu, 2020;
- 14.7% predicted by simulations (average for 10 index cases in the two ventilation scenarios)

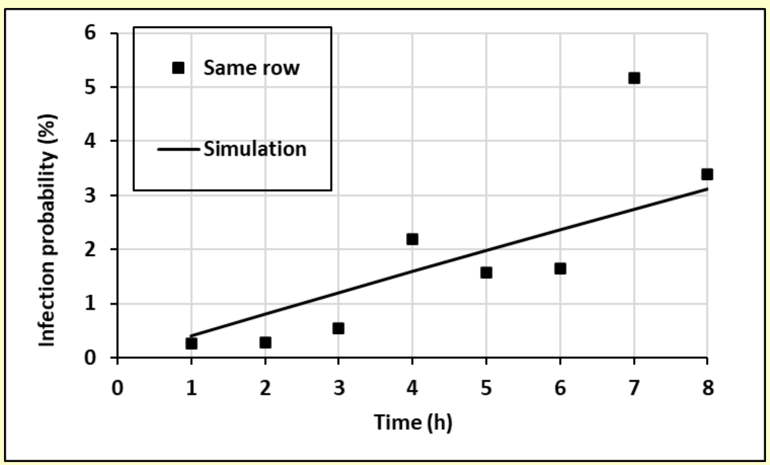
Highest/lowest infection probability (average travel time 2.1 hours)

Reported IP: 0.28% 0.41% 0.34% 0.34% 0.27%

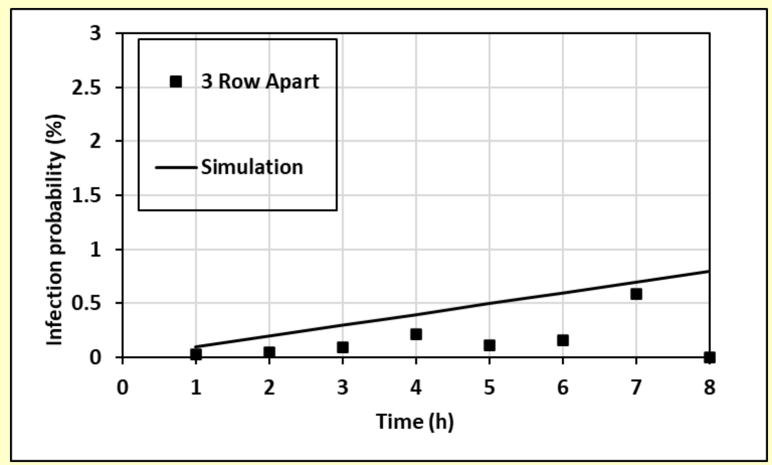


Predicted IP: 0.56% 0.70% 0.55% 0.63% 0.53%

- Infection probability as function of distance to index patient and exposure time.



Same seat row as the index patient (symbol: reported data)

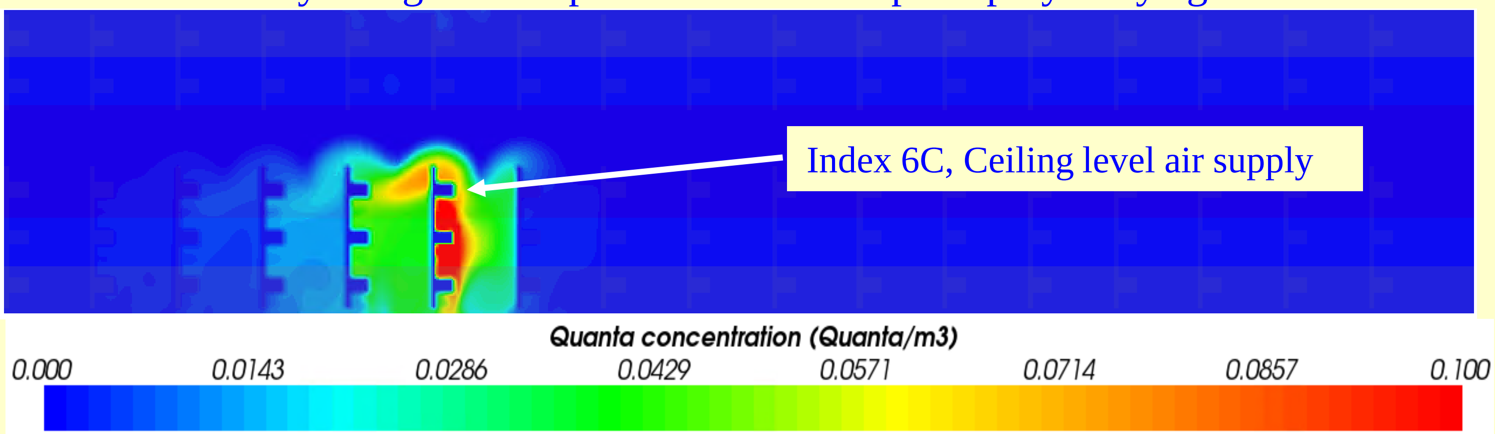


Three seat row away from the index patient

G-train – Estimation of COVID-19 Infection Risk

Asymmetry in quanta distribution and IP in Scenario 1 with index patient in 6C

- Very high quanta conc up to 2 seat rows behind index patient;
- Lower quanta conc in seat row ahead of index patient;
- Seat block with index patient has significantly higher quanta conc than seat block opposite;
- Asymmetry of quanta distribution results in asymmetry in IP.
- IP of 0.5% at locations far from the index patient is due to recycled quanta.
- Conventional WR model with well mixed assumption CANNOT reproduce these observations.
- Questionable validity of rigid 2m separation and concept employed by agent-based models.



Quanta concentration distribution excluding recycled background distribution

F	0.5	0.5	0.5	0.6	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D	0.5	0.5	0.6	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
C	0.7	0.8	1.6	3	10.4		1.1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
B	0.6	0.9	1.5	3.1	8.7	25.3	1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
A	0.6	0.8	1.3	2.8	7.6	12.1	0.9	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

IP (%) distribution for 8-hour G-train travel Scenario 1 (recycled quanta contributes 0.5%)

Exploring non-pharmaceutical mitigations

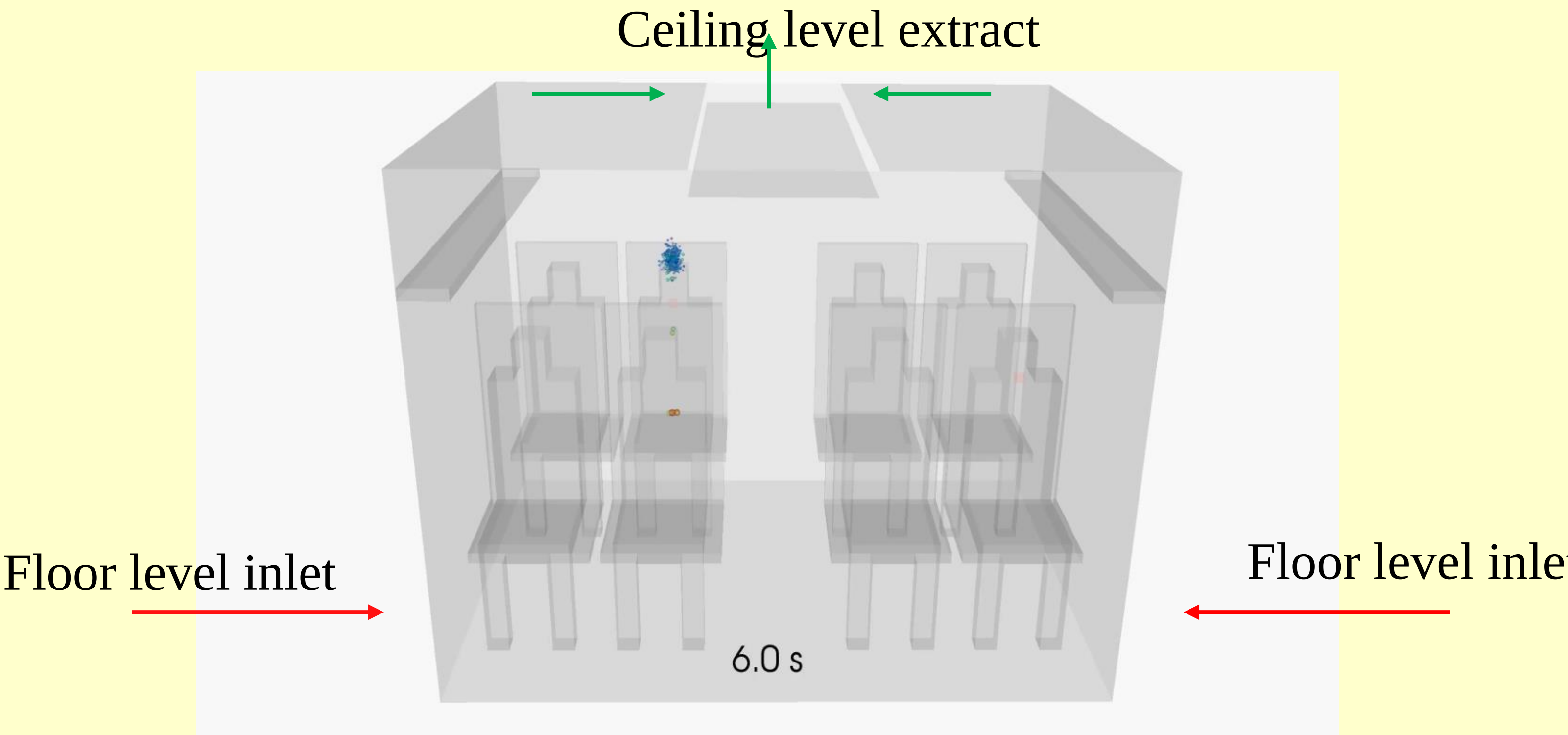
- **Assuming 20% Filtration Efficiency with 63% recycled air, and 8 hr exposure.**

- **Impact of Mask Wearing (MW) – average results for Scenario 1 and 2:**
  - With 40% passengers wearing surgical masks, average IP = **1.21%** resulting in Secondary Infections (SI) = **1.02**.
  - Increasing MW to 90% **reduces** average IP and average SI.
    - Average IP = **0.7%** and SI = **0.6**.
  - With 90% MW high efficiency masks (90% effective), average IP and SI **drop significantly.** Average IP = **0.06%** and Average SI = **0.05**.

- **Seat Blocking Strategies for Scenario 1: (assuming 1 Index per 85 paxs)**
  - 3 seat blocking strategies explored, reducing paxs from 85 to 51, 45 and 27.
  - Note: IP dependent on location of index patient.
  - Most effective involves only occupying A, C and F seats in odd rows
  - Reduces number of passengers per car from 85 to 27
  - Reduces average IP from **1.22%** to **1.05%** and SI from **1.03** to **0.27**.
  - However, must run 3.15x as many saloons.

- **Most effective strategy is to ensure 90% of passengers correctly wear high efficiency masks.**

Demonstration of SMARTFIRE Particle Model for Respiratory Particles



- 10 ACH, approximately 67% of air-conditioned air is recycled
- Train filtration system generally low quality i.e. not HEPA filters – 20% filtration efficiency
- Return air contains respiratory aerosols uniformly seeding the environment.
- The droplet/aerosol source is represented by a sinusoidal breathing model (Gupta et al, 2010)
- The respiratory droplets/aerosols follow the “BLO” size distribution of Johnson et al. (2011)

Immersed moving boundary condition with droplet dispersal

- Is 2m spacing adequate in corridors? ABM implicitly assume this is acceptable.
- Each figure is separated by 2m, height and walking speeds are identical.
- Lead figure is the Index Patient, 3 following figures are constantly bathed in aerosols.
- Staggered walking configuration significantly reduces exposure to respired aerosols
- Note the persistence of the aerosol cloud.

CONCLUDING COMMENTS

- Safety and 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.
- Advanced simulation tools such as EXODUS and SMARTFIRE can be used to assist in planning to ensure:
  - efficient throughput,
  - comfort,
  - safety
  - security and
  - Infection control.

Recent FSEG Publications

Assist Devices for PRM:

- Joyce, M.S., Lawrence, P.J., Galea, E.R., Hospital Evacuation Planning Tool for Assistance Devices (HEPTAD), Fire and Materials, 25 May 2020, https://doi.org/10.1002/fam.2856

Dynamic Signage:

- Lazaros Filippidis, Hui Xie, Edwin R. Galea, Peter J. Lawrence, Exploring the potential effectiveness of dynamic and static emergency exit signage in complex spaces through simulation, Fire Safety Journal, Vol 125, 2021, https://doi.org/10.1016/j.firesaf.2021.103404
- Xie H and Galea E R. A survey-based study concerning public comprehension of two-component EXIT/NO-EXIT signage concepts. Fire and Materials. 2021; 1-12. https://doi.org/10.1002/fam.3035

Covid-19:

- Wang Z, Galea ER, Grandison A, Ewer J, Jia F, "Inflight transmission of COVID-19 based on experimental aerosol dispersion data," Journal of Travel Medicine, Volume 28, Issue 4, May 2021, https://doi.org/10.1093/jtm/taab023
- Wang, Z., Galea E.R., Grandison A, Ewer J, Jia, F., A coupled Computational Fluid Dynamics and Wells-Riley model to predict COVID-19 infection probability for passengers on long-distance trains, Safety Science, 2021, https://doi.org/10.1016/j.ssci.2021.105572

Construction Sites:

- Deere, S., Xie, H., Galea E.R., Cooney, D and Lawrence P.J. An Evacuation Model Validation Data-Set for High-Rise Construction Sites, Fire Safety Journal, May 2020, https://doi.org/10.1016/j.firesaf.2020.103118
- Lynn M. Hulse, Steven Deere, Edwin R. Galea, Fire safety in construction: Site evacuation and self-reported worker behaviour. Safety Science, Volume 145, 2022, 105482, https://doi.org/10.1016/j.ssci.2021.105482