The Simulation of Urban-Scale Evacuation: The Swinley Forest Fire

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Wildfire Event - Greenwich UK
10 April 2015

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Evacuation in Large Scale Emergencies

- **Due to global warming, extreme weather events in the UK are increasing:**
  - **with this comes an increased threat of floods, an estimated 3.6 million people will be at risk of flooding by 2050.**
  - **warmer and drier conditions and more frequent and longer-lasting heat waves also raise the risk of wild fires.**
- **In the past 4 years there have been on average 45,000 wildfires each year attended by the fire and rescue services in Great Britain.**
- **The fire risk is compounded by the UK's higher population density, which means that fires are more likely to encroach into urban environments posing a threat to life.**
- **These events will increase the frequency with which communities will need to be evacuated.**
- **To improve population resilience it is necessary to make appropriate plans for large-scale population evacuation resulting from natural or manmade emergency situations.**

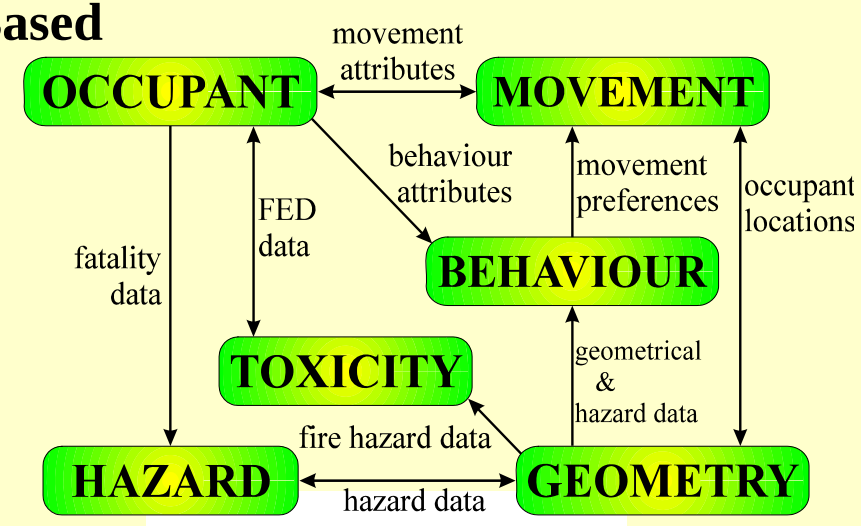
Evacuation in Large Scale Emergencies

- As part of planning, for a given range of scenarios it is necessary to:
  - Estimate the time required to evacuate a region,
  - Determine optimal evacuation routes,
  - Identify the best locations for refuge areas, and,
  - Prioritise evacuation regions - deployment of emergency services.
- Incident managers must also be able to quickly adapt emergency plans in light of real-time developments such as:
  - Actual or forecast loss of evacuation routes,
  - Changing hazard development,
  - Availability of resources
- Urban-scale evacuation simulation using multi-agent models offers:
  - Emergency planners a means to develop and test evacuation procedures before an emergency,
  - Incident managers real-time support to determine the best evacuation procedures to adopt during an on-going emergency.

EXODUS Software

- **Developed by FSEG and under constant development since 1989**

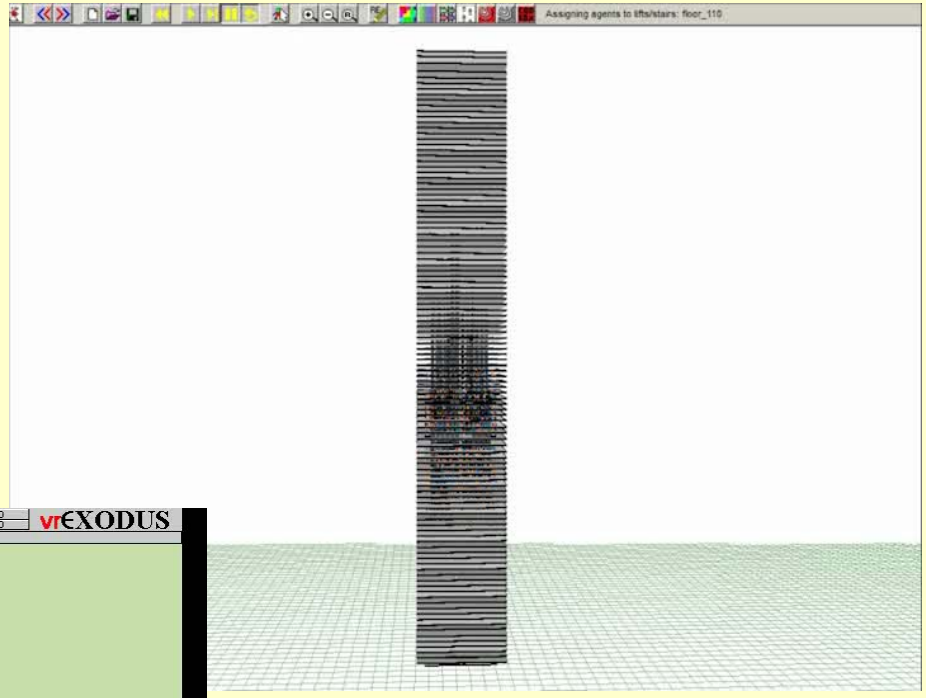
- **Agent based model with Rule Based Behaviour.**
  - **Behaviour is adaptive**
  - **Some rules stochastic.**
- **Behaviour model considers:**
  - **People-people**
  - **People-fire**
  - **People-Structure**

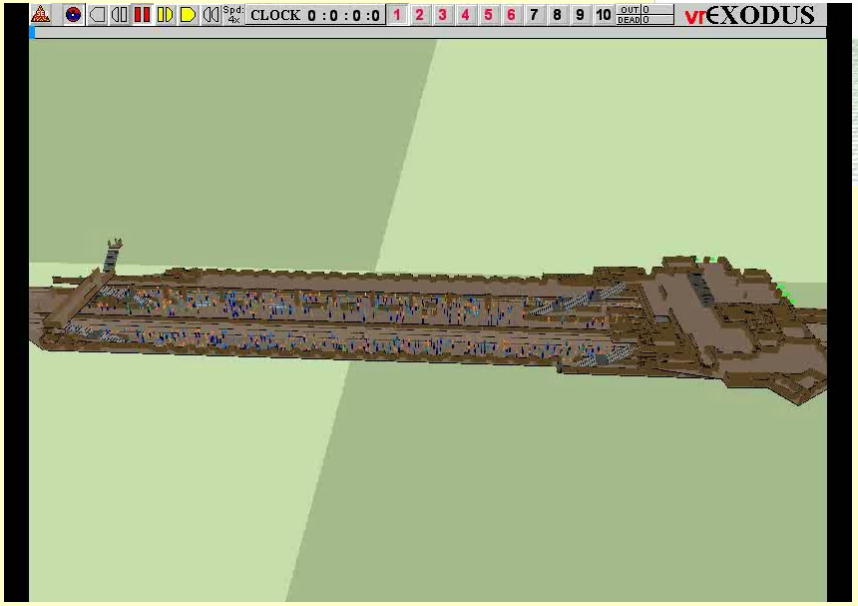


- **EXODUS unique features include:**
  - **ability to simulate impact of heat, smoke and toxic gases on evacuation capability of individuals**
  - **ability to include interaction of authorities with population**
  - **extensive validation history**

Typical buildingEXODUS Applications

- **High-Rise building evacuation using lifts.**
- **Underground station evacuation.**
- **Software routinely used for design applications.**





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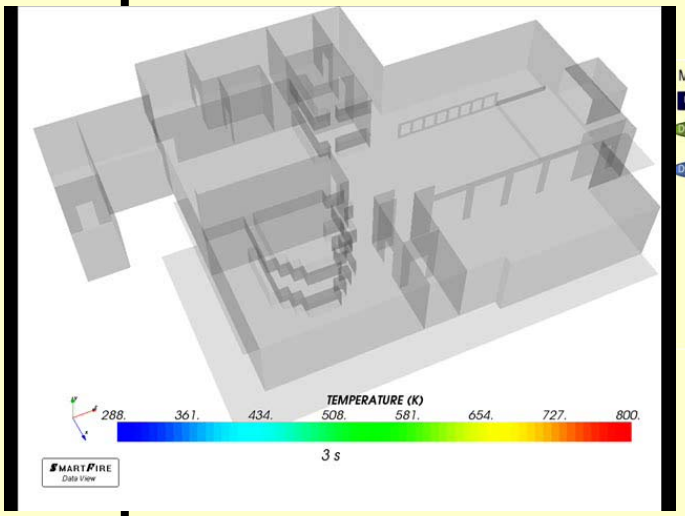
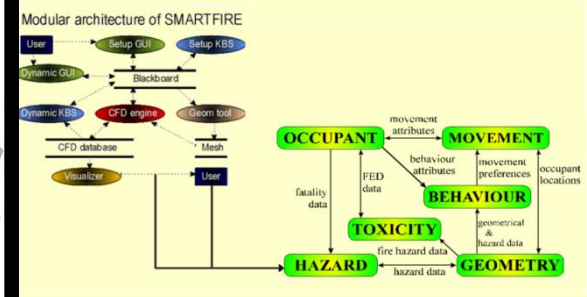
buildingEXODUS and SMARTFIRE simulation of Station Nightclub fire

- 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.

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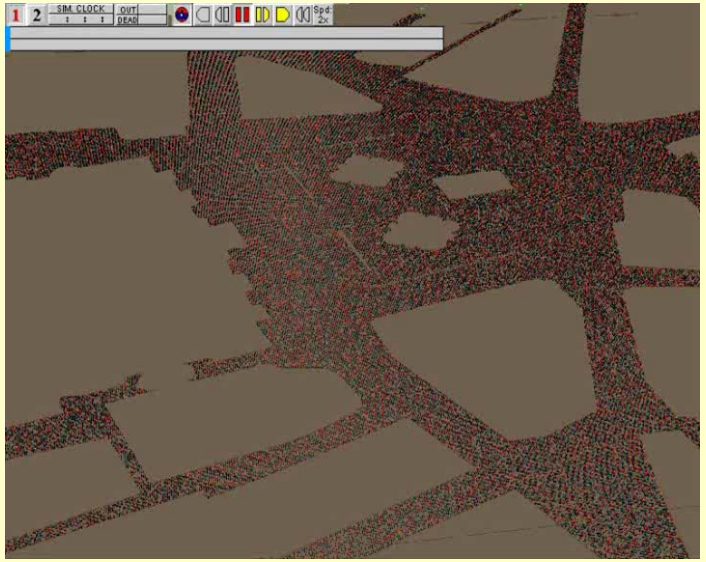
Large external crowd simulation

- **Hypothetical incident in Trafalgar Square: 125,000+ people simulation**



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

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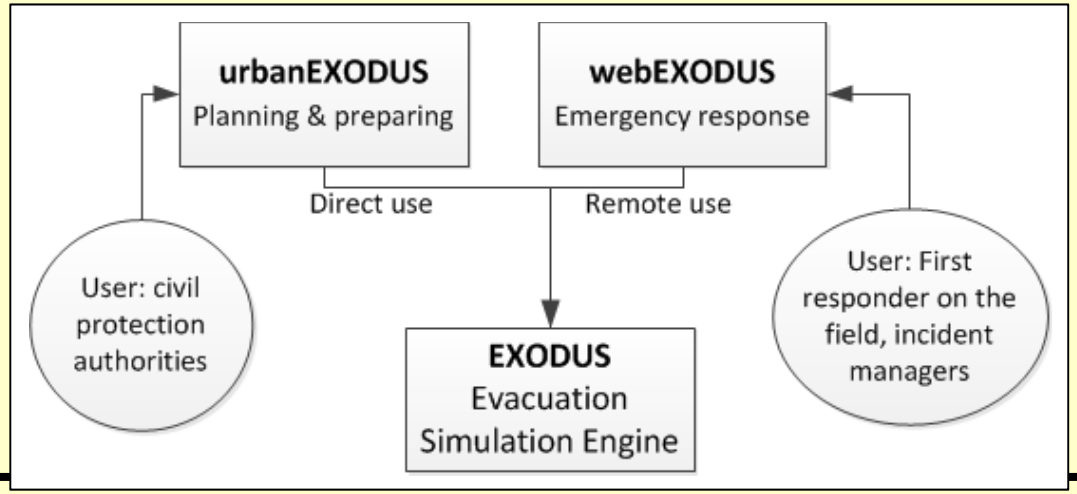
Large Scale Emergency Planning and Management

- As part of an EU FP7 project called IDIRA, a prototype version of the EXODUS software was developed for use in large-scale urban emergency applications.
- Intended applications include: wildfire, floods, tsunami, earthquakes, etc.
- Software is intended to assist in planning large-scale movement of people and for real-time use to assist in management.
- Two versions envisaged:
  - urbanEXODUS for use in planning applications
  - webEXODUS for use in real-time incident management applications

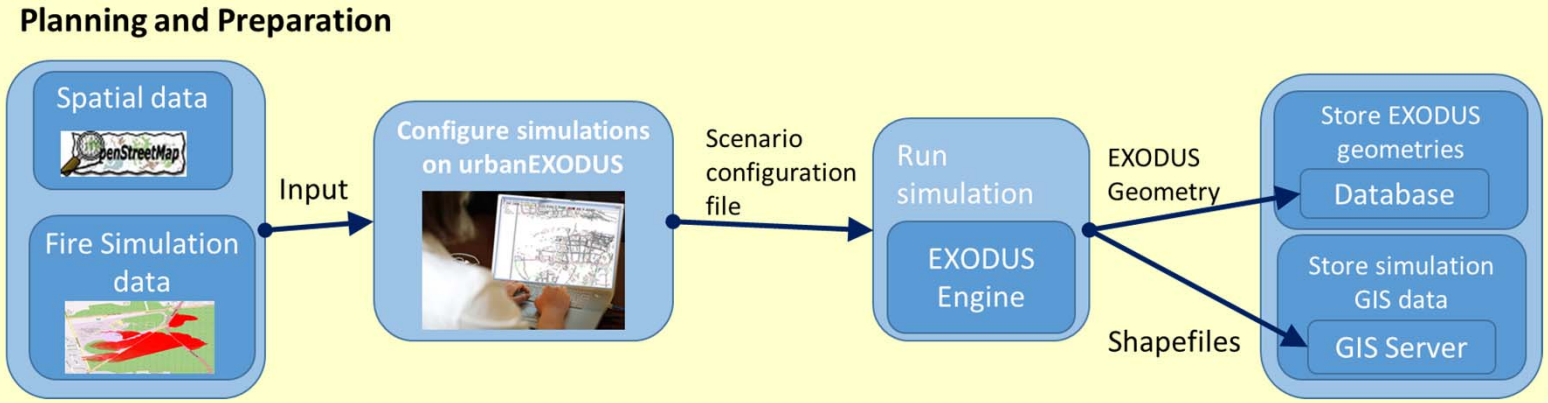


Proto-Type Features Developed as part of IDIRA

- EXODUS extended to incorporate GIS data (e.g. maps from OSM) and GIS data formats (e.g. shapefiles storing population distribution and density)
- Established a semi-automatic method of converting geospatial vector data (Open Street Maps) to EXODUS geometry data
- Extended fine network spatial representation within EXODUS to include: Course Nodes and Continuous Spatial representations.
  - Enables more efficient representation of very large urban spaces.
- Developed a Web UI allowing non-expert users to:
  - Enter scenario data and configure scenarios
  - Remote management of EXODUS simulations
  - Automatically analyse evacuation simulation results with ability to identify regions that developed critical congestion
  - Ability to integrate with modern web based GIS Crisis Management systems to provide support for real-time incident management.

urbanEXODUS prototype

- Define and explore evacuation scenarios for planning purposes
- User defines:
  - evacuation region, refuge locations, populations, evolving hazards.
- The evacuation region and scenario is constructed.
- Explore various what-if scenarios including:
  - variations in population characteristics and distribution, route availability, hazard locations, evacuation procedures, etc
- Establish evacuation efficiency for a given scenario.
- Save configurations and scenarios for real-time use



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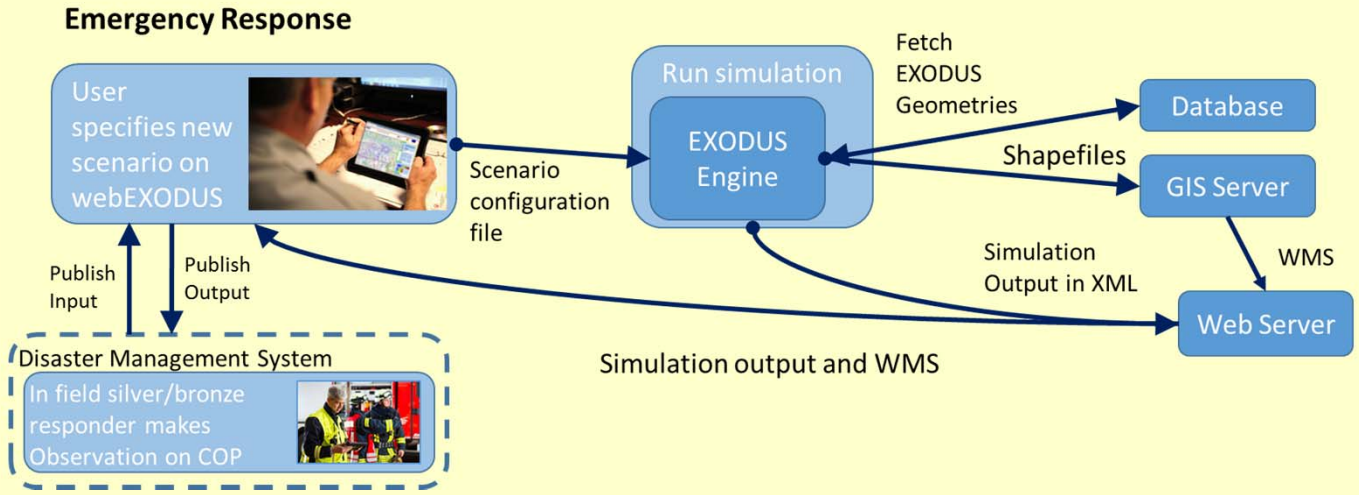
webEXODUS prototype

- **Pre-incident**: urbanEXODUS used to define procedures for a range of scenarios, create libraries of physical region and scenarios.
- **During-incident**: webEXODUS retrieves most similar library case.
- Incident managers can quickly modify an existing scenario or set up a new scenario
- First responders in the field can dynamically update route availability, hazard spread, population distribution.
- Changes to the planned scenario dynamically updated to determine impact on procedures – faster than real time.

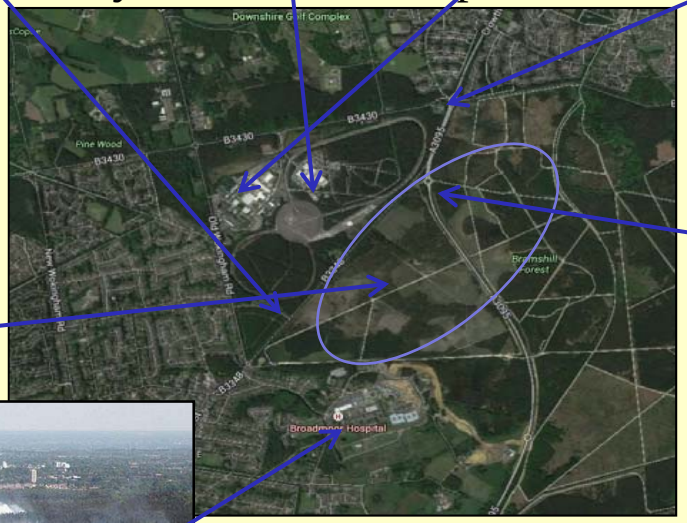


Swinley Forest Fire

- uEX used to simulate hypothetical evacuation associated with the Swinley forest fire.
- Fire simulation based on real incident but assumed slightly different weather conditions to assess the danger to nearby built up area
- Fire simulation based on real meteorological data on 2 May 2011 (fuel maps, ignition locations, wind direction)
- Four evacuation scenarios were examined simulating different evacuation routes adopted by the at-risk population.
- Purpose of study to assess the available safety margins associated with each of the possible evacuation routes.

SWINLEY 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

SWINLEY 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**

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Simulated Fire evolution – from ignition to 273 minutes

- Criteria used to define safety margin:
  - Region assumed to be unsafe when fire front is within 500m.
  - Safety margin = time for fire front to be within 500m of region - time at which last person passes through region

Milestone	Fire (minutes)	Location
1	91.00	Fire close to NE section of A3095, RD occupants must clear A3095 before this time
2	126.00	Fire reaches A3095, the affected section of A3095 cannot be used,
3	210.00	Fire reaches middle section of B3348 therefore B3348 cannot be used
4	245.00	Fire crosses B3348
5	273.00	Fire approaches House 5 Fire approaches TRL
6	301.00	Fire reaches House 5 Fire approaches TRL
7	336.00	Fire consumes House 5 Fire reached TRL
8	364.00	Fire approaches Houses 1-4 Fire expands in area between TRL and houses
9	392.00	Fire consumes Houses 1-4 Fire expands towards BE
10	420.00	Fire reached BE Fire reached Old Wokingham Road





Simulated Fire evolution – from 301 minutes to 420 minutes

Milestone	Fire (minutes)	Location
1	91.00	**Fire close to NE section of A3095, RD occupants must clear A3095 before this time**
2	126.00	Fire reaches A3095, the affected section of A3095 cannot be used,
3	210.00	Fire reaches middle section of B3348 therefore B3348 cannot be used
4	245.00	Fire crosses B3348
5	273.00	Fire approaches House 5 Fire approaches TRL
6	**301.00**	**Fire reaches House 5** **Fire approaches TRL**
7	**336.00**	**Fire consumes House 5** **Fire reached TRL**
8	**364.00**	**Fire approaches Houses 1-4** **Fire expands in area between TRL and houses**
9	**392.00**	**Fire consumes Houses 1-4** **Fire expands towards BE**
10	**420.00**	**Fire reached BE** **Fire reached Old Wokingham Road**

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Evacuation Sequence

- For simplicity, assume evacuation and fire spread start at the same time.
  - In reality, evacuation initiation starts some time after fire starts
  - This delay should be considered when evaluating size of safety margin.

- TRL Evacuation: Initiated by phone call at t=0s, RT=1–2min

- BE Evacuation: Initiated by phone call at t=0s, RT=1–2 min

- Pub Evacuation: Initiated by phone call at t=0s, RT=0.5–1 min

- RD Evacuation: Initiated by police door to door, requires
  - 5 min for police to reach first house,
  - 1 min required for police to reach next house, etc.
  - Once alerted, occupants require 5 min to get ready.

Evacuation Scenario 1

Evacuation Scenario 1: Most Direct Routes adopted

TRL:

- Main exit, turn right onto B3430, go to Assembly Area

Business Estate:

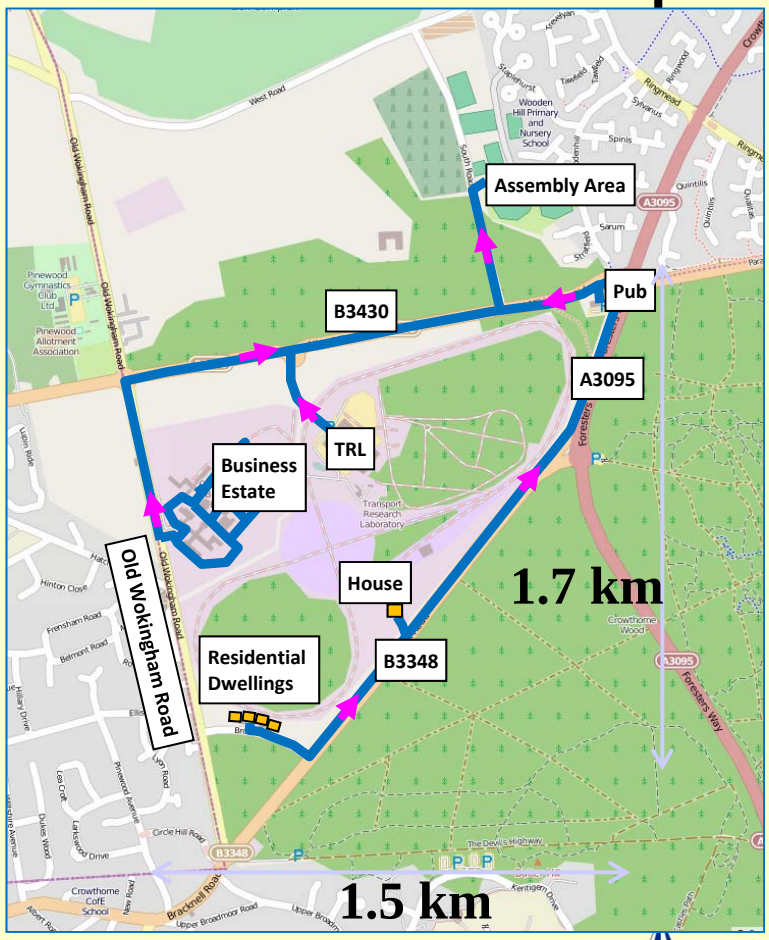
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:

- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:

- Follow B3348 and then A3095 towards the pub, turn left onto B3430, go to Assembly Area.



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Evacuation Scenario 2

Evacuation Scenario 2: TRL avoids using main entrance to allow emergency vehicles access

TRL:

- Main exit, left onto path towards and through Business Estate, follow then same path as Business Estate

Business Estate:

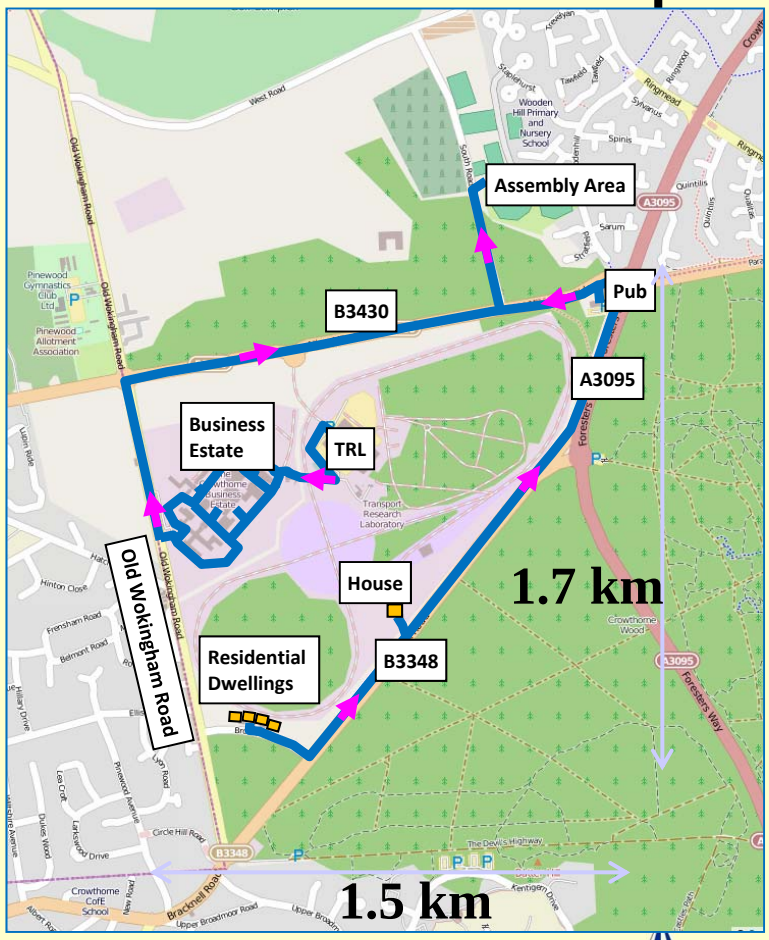
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:

- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:

- Follow B3348 and then A3095 towards the pub, turn left onto B3430, go to Assembly Area.



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Evacuation Scenario 3

Evacuation Scenario 3: Most direct route adopted EXCEPT RD who take Old Wokingham Road due to advance of fire front threatening B3348.

TRL:

- Main exit, turn right onto B3430, go to Assembly Area

Business Estate:

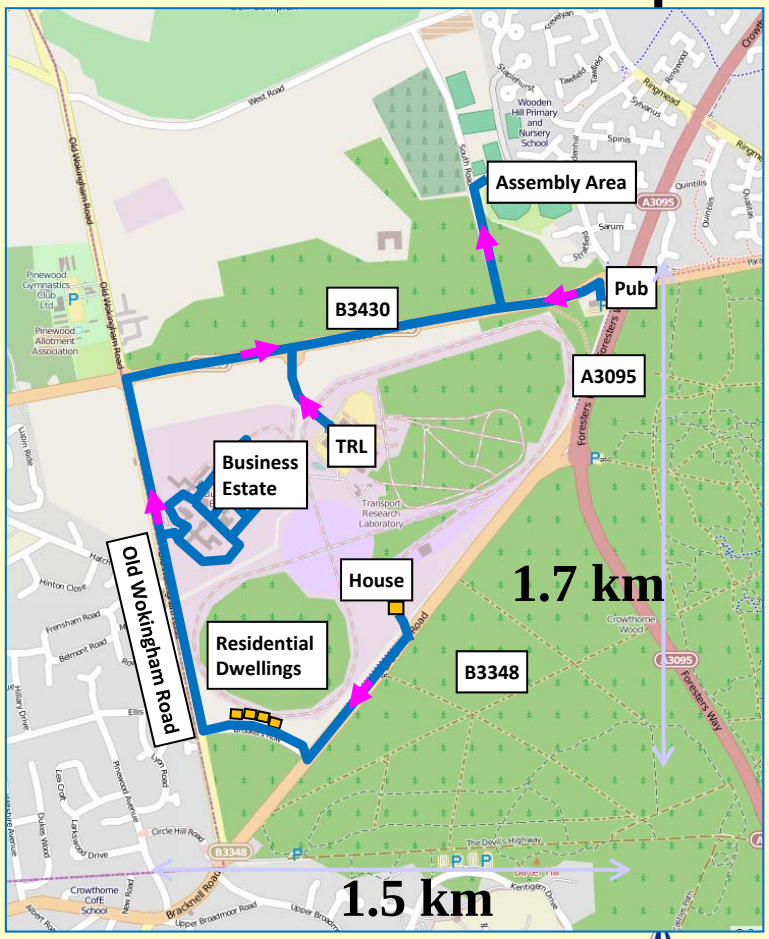
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:

- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:

- Follow B3348 (only isolated house) and then Old Wokingham Road towards the Business Estate, turn right onto B3430, go to Assembly Area.



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Evacuation Scenario 4

Evacuation Scenario 4: TRL avoids using main entrance to allow emergency vehicles access AND RD take Old Wokingham Road due to advance of fire front threatening B3348.

TRL:

- Main exit, left onto path towards and through Business Estate, follow then same path as Business Estate

Business Estate:

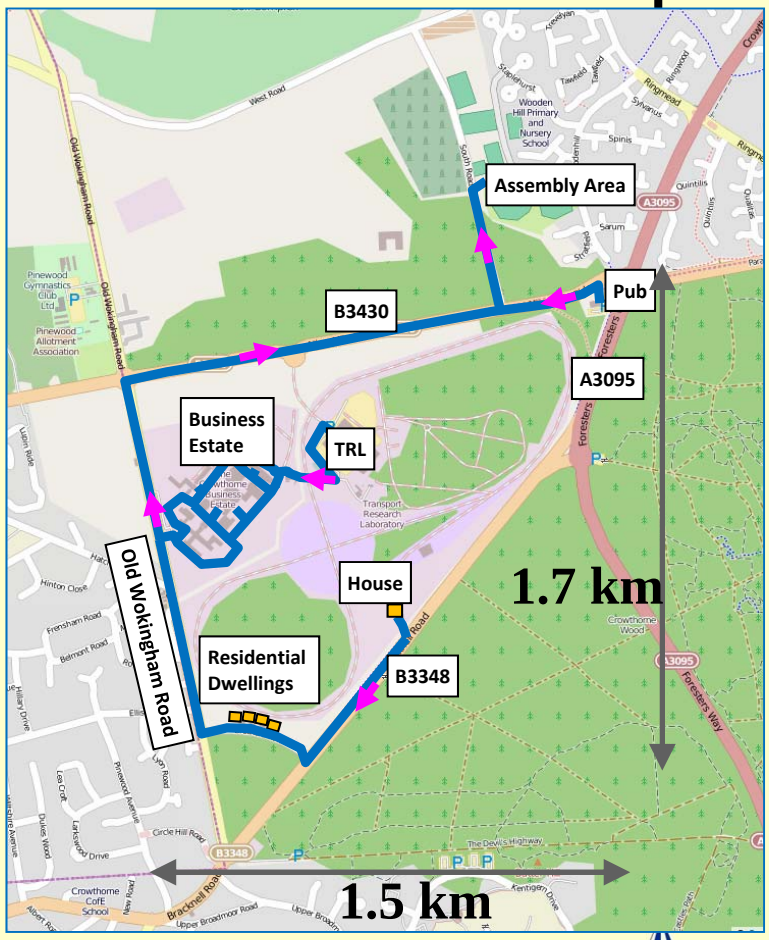
- Main exit, turn right and right onto B3430, go to Assembly Area.

Pub:

- Exit, turn left onto B3430, go to Assembly Area.

Residential Dwellings:

- Follow B3348 (only isolated house) and then Old Wokingham Road towards the Business Estate, turn right onto B3430, go to Assembly Area.



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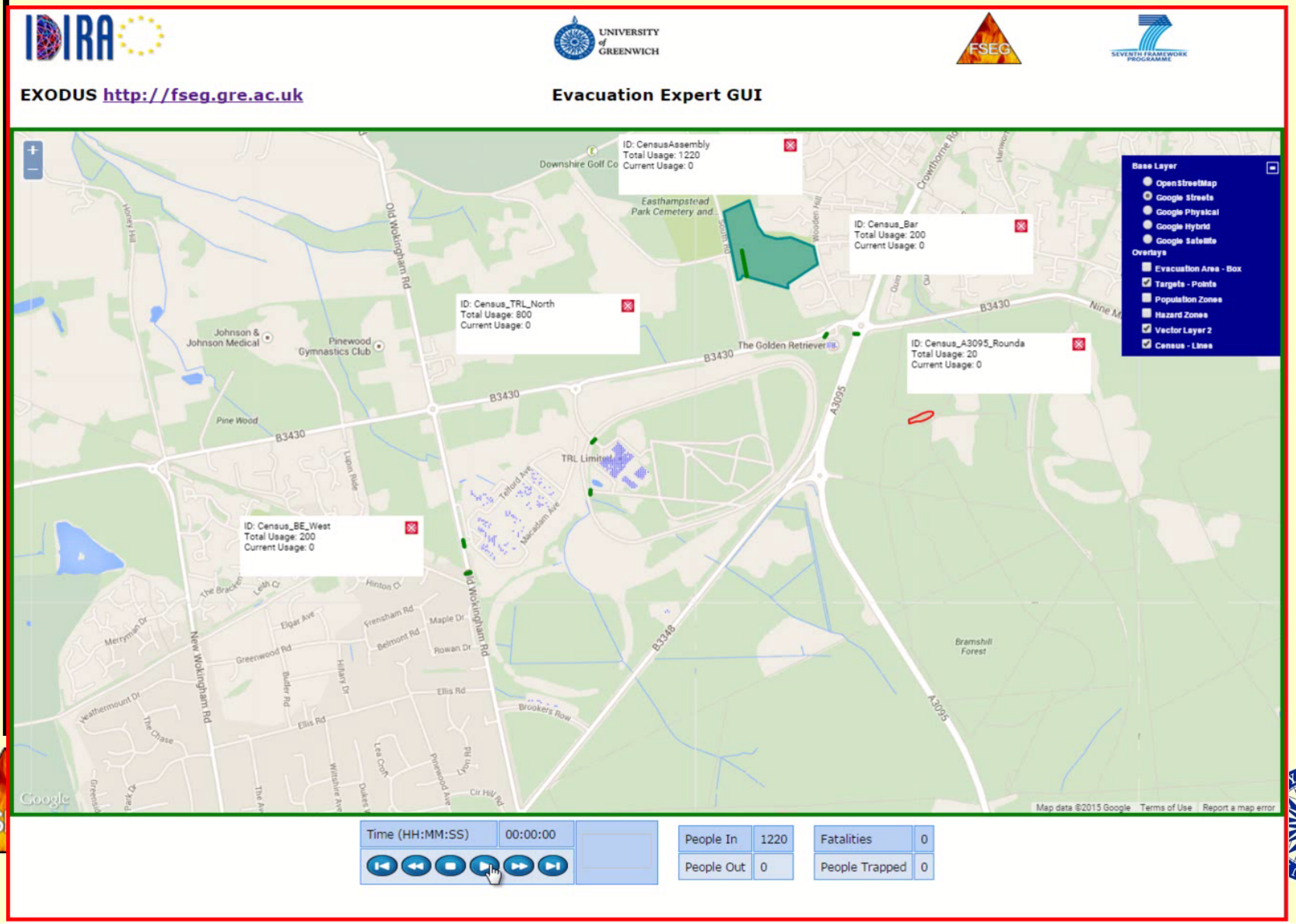
Assembly Simulation – Scenario 1

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



Safety Margins – Scenario 1

Safety of Pub

- Pub clears point (B) at 4 min 28 sec.
- Pub assembles at 18 min 38 sec.
- Fire approaches A3095 at 91 min (**milestone 1**).
- **Pub has safety margin of 86 minutes.**

Safety of TRL

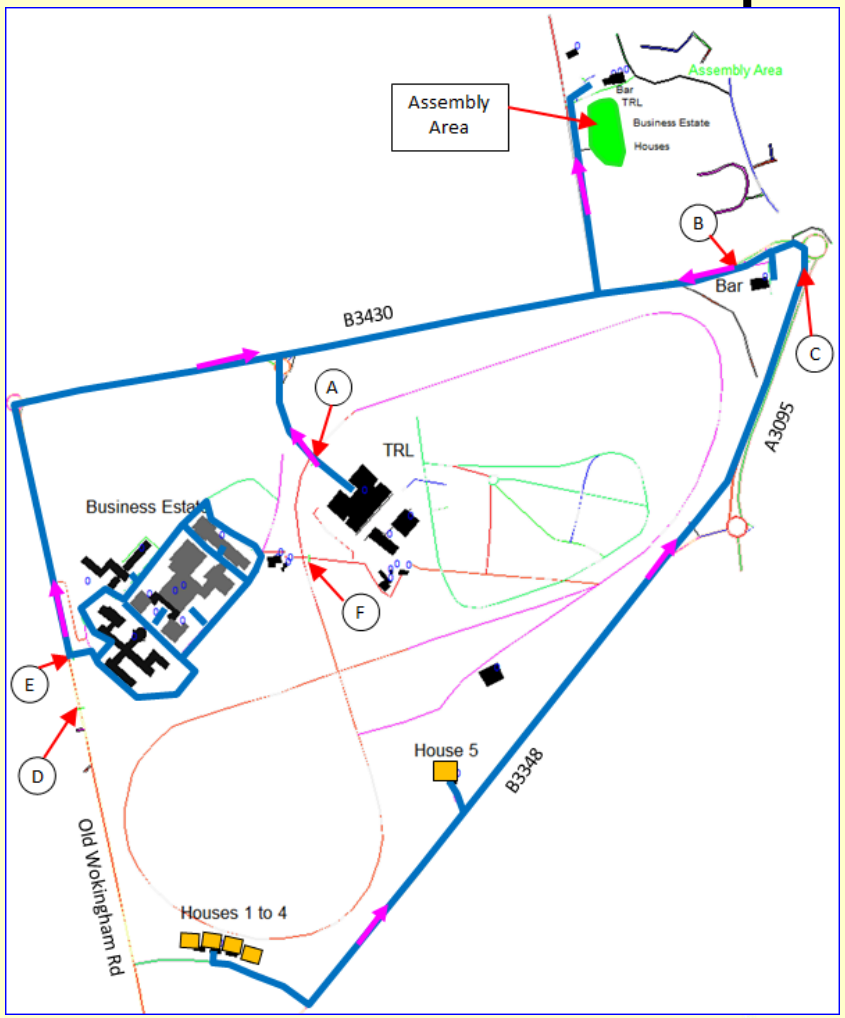
- TRL clears point (A) in 10 min 48 sec.
- TRL assembles at 35 min 26 sec.
- Fire approaches TRL at 301 min (**milestone 6**).
- **TRL has a safety margin of 290 min.**

Safety of Business Estate

- BE clears point (E) at 13 min 11 sec.
- BE assembles at 51 min 36 sec.
- Fire approaches BE at 392 min (**milestone 9**).
- **BE has a safety margin of 378 min**

Safety of Residential Dwellings

- RD clear safe point (C) at 53 min 52 sec.
- RD assemble at 1 hr 11 min 32 sec.
- Fire approaches A3095 at 91 min (**milestone 1**).
- **RD have a safety margin of 37 min.**
- Fire reaches A3095 at 126 min, a critical point deeming that section of the road is unusable.



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Congestion on Evacuation Routes

CWT/PET	Sc1 (%)	Sc2 (%)	Sc3 (%)	Sc4 (%)
TRL	7.2	5.7	7.2	5.7
BE	1.2	1.3	1.2	1.3
Pub	5.7	5.6	5.7	5.6

- Relatively small amounts of congestion experienced on evacuation routes
  - Congestion is not an issue in any of the scenarios.
- TRL pop experienced greatest levels of congestion in SC1/3 when they take the direct route to the assembly area.
  - However, only waste 7% of travel time in congestion.
- BE pop experience marginally greater levels of congestion in SC2/4
  - Occurs when the TRL join them on their evacuation route.
  - However, BE waste less than 2% of evacuation time in congestion.

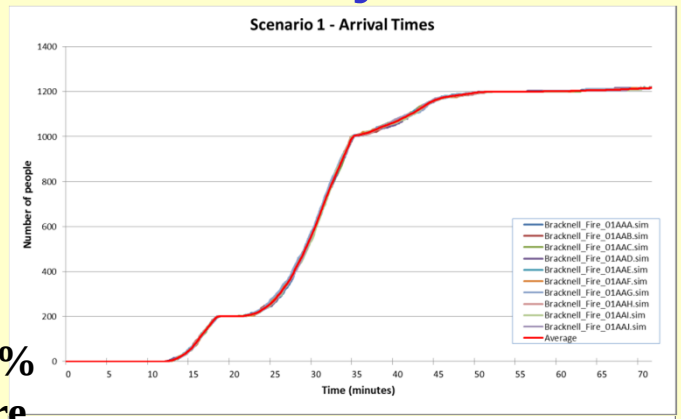
Assembly Performance

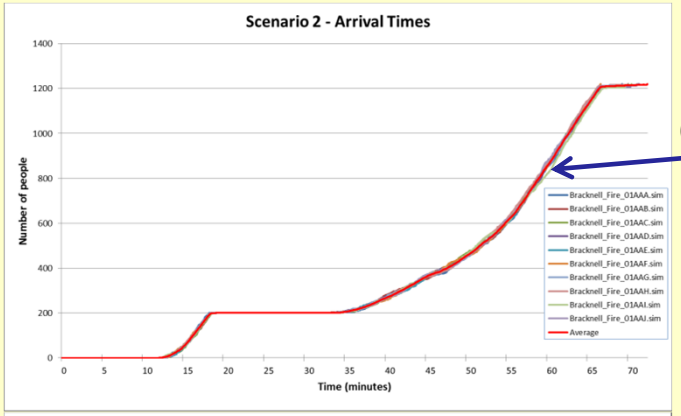
Proportion Assembled	50% (610)	80% (976)	95% (1159)	100% (1220)
Scenario 1	00:30:56	00:35:05	00:45:19	01:11:45
Scenario 2	00:55:22	01:02:30	**01:05:58**	**01:10:54**
Scenario 3	00:30:55	00:35:06	**00:45:29**	**01:26:14**
Scenario 4	00:55:20	01:02:40	00:59:00	01:24:38

- In SC 3:
  - 50% of the population arrive in 30min – must be prepared asap.
  - 95% of the population are assembled in just over 45 min.
  - Last 5% require 50% of the total assembly time.

- In SC2:
  - 50% of the population arrive in 55min – more time to prepare.
  - 95% of the population are assembled in 1hr 6 min.
  - Last 5% require just 5 min or 7% of the assembly time.

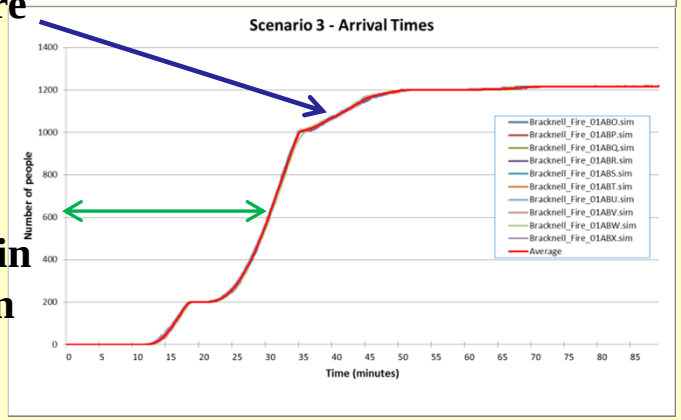
Assembly Times – Scenario 1, 2, 3 and 4



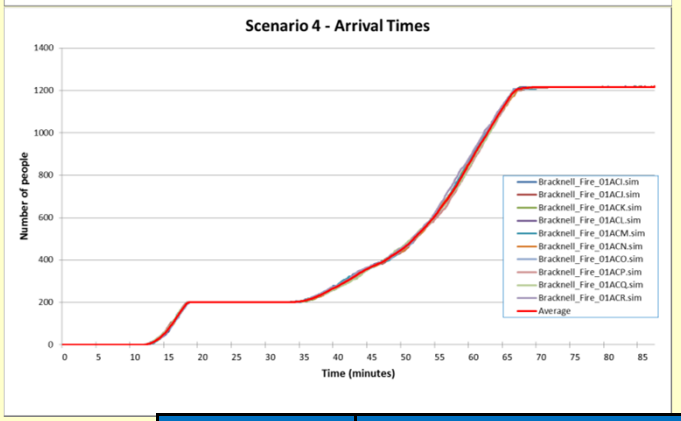


Constant stream

Last 5% require 50%



50% arrive in 30 min



RD: SC1,2 Average distance travelled: 2.7km
RD: SC3,4 Average distance travelled: 3.0km
TRL: SC1,3 Average distance travelled: 1.5km
TRL: SC 2,4 Average distance travelled: 3.0km
PUB: Average distance travelled: 0.8km
BE: Average distance travelled: 2.3km

	Assembly (hh:mm:ss)			
	Pub	TRL	BE	RD
Scenario 1	18:38	35:26	51:36	1:11:32
Scenario 2	18:37	1:07:05	52:09	1:10:26
Scenario 3	18:42	35:35	51:16	1:26:01
Scenario 4	18:40	1:07:25	52:31	1:24:25

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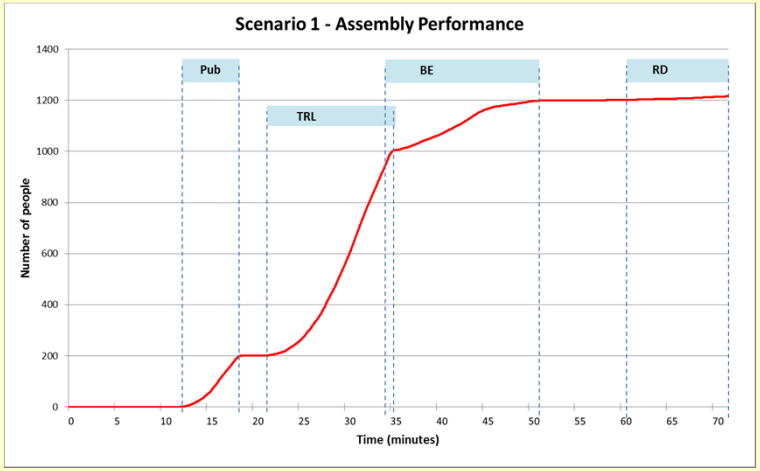
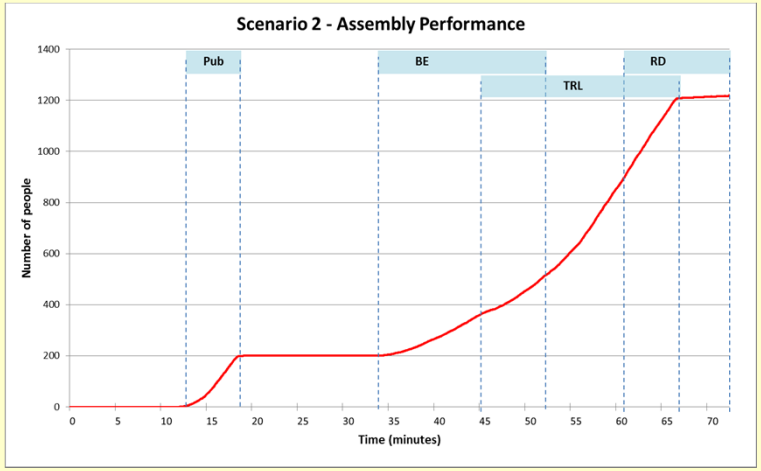
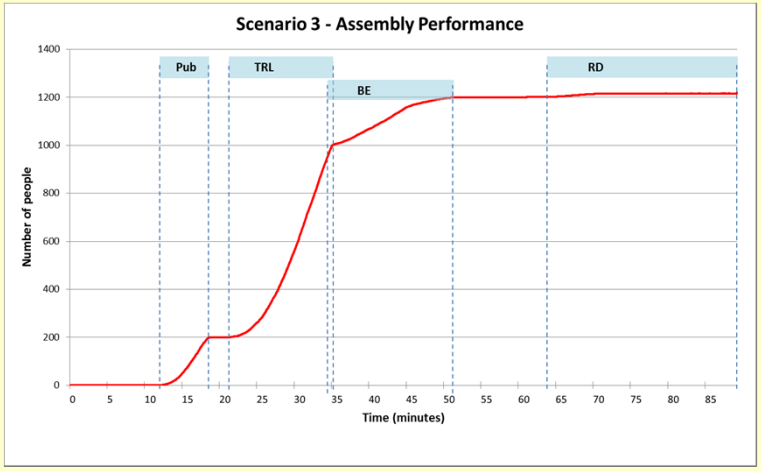
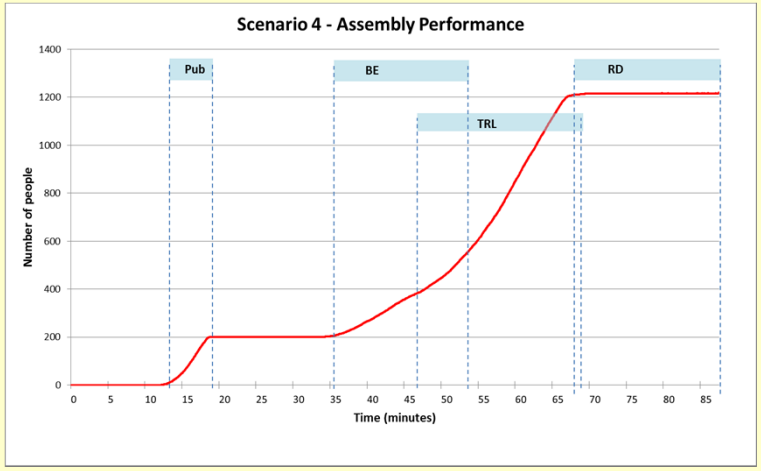
Assembly Performance – Scenario 1, 2, 3 and 4



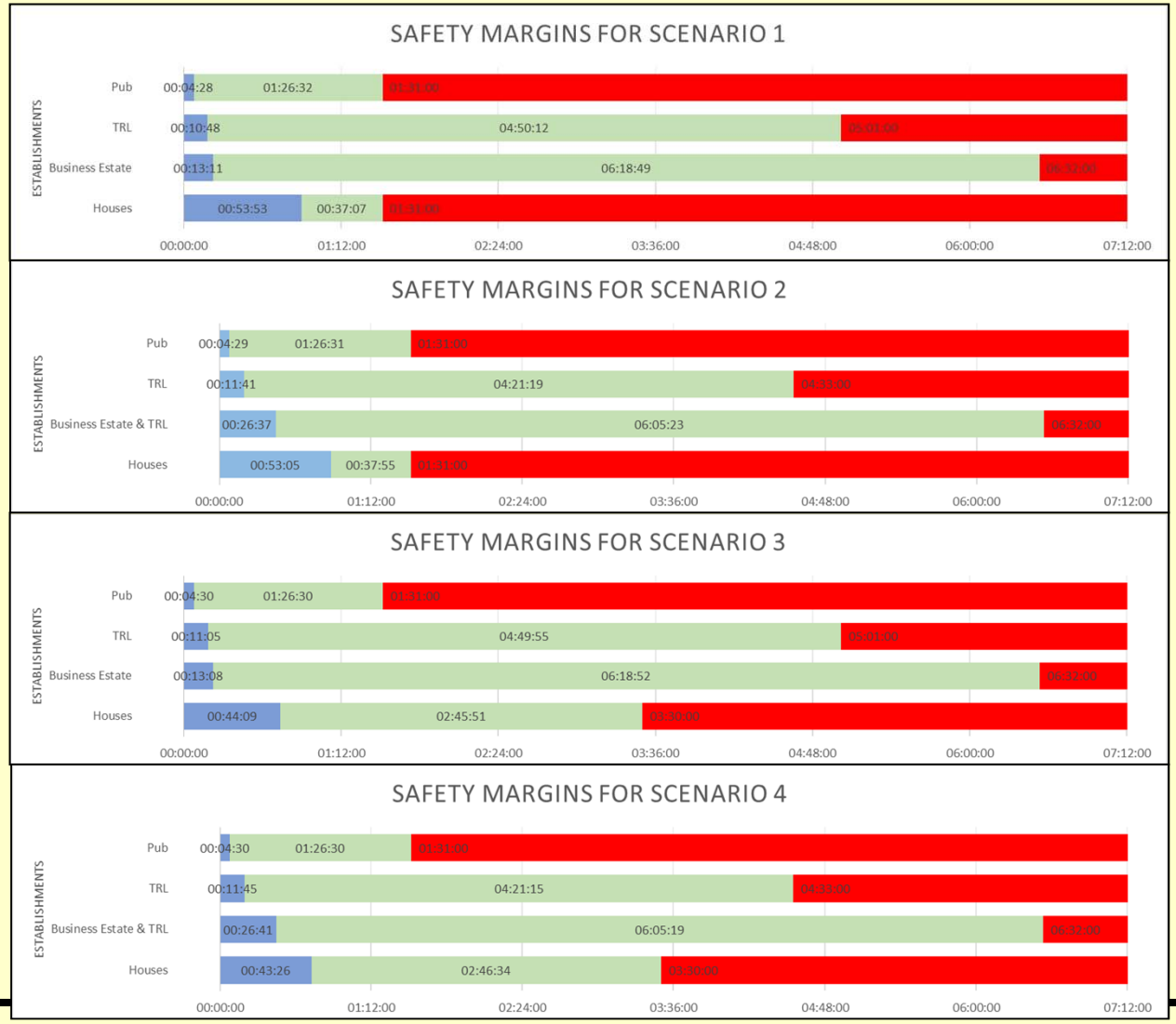






	Assembly average first and last use (hh:mm:ss)			
	Pub	TRL	BE	RD
Scenario 1	12:27 - 18:38	21:36 - 35:26	34:34 - 51:36	1:00:43 - 1:11:32
Scenario 2	12:18 - 18:37	45:11 - 1:07:05	34:09 - 52:09	1:01:09 - 1:10:26
Scenario 3	12:17 - 18:42	21:30 - 35:35	34:15 - 51:16	1:04:09 - 1:26:01
Scenario 4	12:23 - 18:40	45:12 - 1:07:25	34:13 - 52:31	1:05:36 - 1:24:25

Swinley Forest Fire – Safety Margins – Scenario 1, 2, 3 and 4



Clearance time

Safety Margin

Fire Approach

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Evacuation Scenario Comparison

	Assembly (hh:mm:ss)				Safety Margin (min)			
	Pub	TRL	BE	RD	Pub	TRL	BE	RD
Scenario 1	18:38	35:26	51:36	1:11:32	86	290	378	**37**
Scenario 2	18:37	1:07:05	52:09	1:10:26	86	261	365	**37**
Scenario 3	18:42	35:35	51:16	1:26:01	**86**	289	378	165
Scenario 4	18:40	1:07:25	52:31	1:24:25	**86**	261	365	166

- Longest distance travelled is 3.0 km, by:
  - RD occupants in SC3,4
  - TRL occupants in SC2,4
- FIRST to assemble always from PUB, LAST always from RD
- Minimum safety margins are :
  - 37 min incurred by the RD in SC1&2
  - 86 min incurred by the Pub in SC3&4
- Maximum safety margin always for BE, always greater than 365 min
- SC3 is the best option as it provides the maximum safety margin for each population group, even though it also produces:
  - LONGEST assembly time and MAX travel distance for RD

Evacuation Scenario Comparison

- Due to the likely delay between fire initiation and start of the evacuation, SC1&2 unlikely to be viable due to small safety margin.
    - Unlikely to be possible to alert the RD in time to make this a viable evacuation strategy.
- SC3 provides the largest safety margins for the entire population, but results in the RD having to travel the greatest distance and will result in the longest overall assembly time.
- In SC3,
    - PUB should be prioritised to be alerted first as they have the shortest SAFETY MARGIN – 86 min.
    - Next at risk group are the RD – they have a safety margin of 165 min.
- If unable to use the main entrance road to TRL (SC2&4), diverting the TRL population through the BE:
    - Doubles travel distance for TRL from 1.5km to 3.0km
    - Doubles assembly time for TRL from 35min to 67min
    - Decreases TRL safety margin by 30 min to 260min
    - Marginally increases congestion experienced by BE population

CONCLUSIONS

- Use of urban-scale evacuation modelling tools allow ‘WHAT-IF’ scenarios to be examined prior to an incident occurring.
  - Enhances population resilience by enabling authorities to plan and evaluate possible evacuation procedures.
- Provides insight into:
  - Timeframes required to get population to safety.
  - Safety margins available for various at risk groups.
  - Viability of designated safety refuges.
  - Prioritise alerting of at-risk groups.
  - Assist in prioritisation of tasks for emergency services.
- Integration with crises management systems enables:
  - Unforeseen events to be taken into consideration during the incident in real-time.
  - Formulation of new procedures to accommodate real situation as opposed to planned situation.
  - Confirmation of command decisions.