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

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ABSTRACT

Forest fires are an annual occurrence in many parts of the world causing evacuation of nearby residential areas and industrial facilities. The frequent occurrence of these events deems it necessary to develop appropriate evacuation plans for areas that are susceptible to forest fires. A well-established and well-validated evacuation model, buildingEXODUS, has been extended to model large scale urban/rural evacuations by including the road network and open spaces (e.g. parks, green spaces and town squares) along with buildings. The evacuation simulation results have been coupled with the results of a forest fire spread model and applied to the Swinley forest fire. Four evacuation procedures differing in the routes taken by the pedestrians were simulated and analysed providing key evacuation statistics such as time to reach the assembly location, the distance travelled and congestion experienced by the agents. In addition, the safety margins associated with using each evacuation route are identified. This is the time available between the safe passage of the pedestrians through the route and the route being considered no longer safe for pedestrian use. A key finding of this work is the importance of formulating evacuation procedures in response to wildfires by providing occupants timely evacuation notice and appropriate choice of routes to keep them at a safe distance from the fire even at the cost of taking longer evacuation routes.

INTRODUCTION

A large number of wildfires occur in Great Britain every year. In the past four years there have been on average 45,000 wildfires each year attended by the fire and rescue services in Great Britain[1]. Furthermore, warmer and drier conditions, and more frequent and longer-lasting heatwaves also raise the risk of wildfires. This risk is compounded by the UK's high population density, which means that fires are more likely to encroach into urban environments, posing a significant threat to life. Forest fires can spread rapidly affecting built-up areas in its path at different times depending on the speed and direction of the fire spread which depends on a number of factors such as the wind speed/direction, nature of terrain and available fuel in the path of the fire. When urban areas are threatened by wildfire, it is essential for civil protection authorities to manage large-scale evacuation of threatened populations.

When planning an evacuation due to wildfires, it is essential for civil protection authorities to know what areas will be affected due to a fire, when the areas will become untenable, how long it will take occupants in these regions to evacuate and how long it will take occupants to reach a designated place of safety. This information is essential to assess the level of risk associated with each region, how and when to warn the population appropriately, how to allocate available resources (first responders, fire fighters and staff at assembly locations) and most importantly to formulate an effective evacuation strategy which involves safe routes that occupants can take to the designated assembly locations. Urban scale agent based evacuation modelling tools offer the potential to address all of these issues, especially if they can be integrated with disaster management systems[5]. While several evacuation models[3,4] have been developed that attempt to simulate large scale evacuation situations resulting from floods, tsunamis and earthquakes, there are few, if any agent based evacuation simulation tools that address evacuation situations arising from wildfires. Coupling the agent based urban scale evacuation model to a wildfire simulation tool[2] enables the identification of the times at which the wildfire will threaten regions, making evacuation routes untenable and the time required to evacuate the region using the threatened routes. Thus safety margins associated with a particular evacuation strategy can be assessed.

Furthermore, current urban scale agent based evacuation modelling tools are not integrated with disaster management systems[5]. As a result, disaster managers do not have an easy means to test evacuation procedures during pre-incident planning or receive real time support on optimal evacuation procedures to adopt during an ongoing incident. Integrating evacuation simulation tools with disaster management systems provides valuable evacuation decision support functionality for disaster managers to assist in the co-ordination and management of disasters. While the CEMPS simulator[6] comes close to addressing this problem by coupling a traffic simulation model with ESRI's GIS-ARC/INFO, nothing currently exists that couples evacuation models with incident management systems.

The approach adopted in this paper differs from previous work by providing a loose coupling between the evacuation simulation tool and disaster management system with the focus being on pedestrian rather than traffic simulation in response to large scale disasters. The agent based evacuation simulation tool buildingEXODUS[7,8] is primarily used for building evacuation applications although it has also been used to simulate large crowds in external environments[8]. As part of the EU FP7 project IDIRA[9], the buildingEXODUS software was adapted to utilise GIS data to model large scale space involving real world objects such as roads, buildings, open spaces, etc. In addition, a set of open source web and GIS tools were utilised to develop a user friendly GUI that the strategic (command and control centres) and tactical (on-scene) commanders can utilise to specify input data for the EXODUS simulation such as; area to evacuate, refuge locations, non-traversable areas and distribution and attributes of pedestrian population. The GUI also enables commanders to run simulations and analyse the results in order to determine the efficiency of the various evacuation options available. In this way the EXODUS software was integrated within the disaster management system developed as part of the IDIRA project and was found to be a valuable decision support tool for the people/organisations involved in disaster management. Furthermore, as part of the work for this paper, the EXODUS software was loosely coupled to the output produced by the Prometheus wildfire simulation tool[2]. This paper provides an overview of the EXODUS large scale evacuation modelling system and describes the application of the system to a case study involving the Swinley Forest fire that occurred near Bracknell in Berkshire, UK on May 02, 2011.

THE EXODUS LARGE SCALE EVACUATION MODELLING SYSTEM

The EXODUS large scale evacuation modelling system is an agent based evacuation model capable of simulating the evacuation of large populations – measured in the hundreds of thousands - in large scale environments – measuring many square kilometres. It is based on the popular buildingEXODUS[7,8] software and consists of three components; urbanEXODUS, webEXODUS and the EXODUS engine. Each of these are briefly described in the following section.

urbanEXODUS

A desktop interface, urbanEXODUS, was developed to enable the EXODUS engine to easily represent large scale urban space. It is capable of receiving geospatial vector data from an OSM XML[10] file and converting it into a virtual representation of space that is suitable for modelling pedestrian evacuation. It is also capable of producing simulation output in the form of shapefiles that can be published to GIS servers thus aiding visualisation of simulation output on web based GIS interfaces. The main use of urbanEXODUS is pre-incident during the planning and preparation phase of a possible large scale evacuation by simulating various what-if evacuation scenarios.

webEXODUS

A portable GIS based web interface, webEXODUS, was developed to be utilised during an incident. It is connected to the evacuation simulation server over the Internet and can be accessed remotely via browsers on desktop PCs, tablets or smartphones. It can also be used during the planning and preparation phase similar to urbanEXODUS. However, it is primarily intended for use during an incident by strategic command in the command and control centre providing a generic data model to describe a variety of evacuation simulations and run these simulations on the remote evacuation server. By enabling the current tactical situation to be entered into the evacuation simulation and providing a set of tools to rapidly analyse the results the system assists strategic commanders decide which evacuation procedure to employ based on the situation as it unfolds.

EXODUS Engine

The EXODUS[7,8] engine receives simulation inputs from urbanEXODUS or webEXODUS, performs the simulations and returns the results. Within the EXODUS engine agents are represented as individuals with each agent being defined by a set of attributes. These attributes have the dual purpose of defining all occupants as individuals while allowing their progress and condition during the evacuation to be tracked. The EXODUS engine is a hybrid model capable of utilising coarse node, fine node and continuous spatial representations[7]. The coarse and fine node modes of the EXODUS engine have been utilised with the former providing quick preliminary results at a faster than real time rate and the latter providing more refined results at a slightly later time. The coarse node model employs ‘location estimation’ techniques by estimating the location and spread of agents within the region. This is to better improve upon inherent uncertainties with pure coarse node modelling thus improving the accuracy of the movement model, the produced results, and also by allowing for the calculation of population densities within sub-regions of the coarse nodes. The same technique is also utilised to record the number of agents in 6m X 6m grid cells which are used to produce a heat map showing population density contours. The coarse node model also employs varying walk speeds depending on whether the agent is traversing paved paths or off road paths. Junctions such as road junctions are modelled as special coarse nodes which can represent multi-directional flow.

System Overview

An overview of the utilisation of the three components - urbanEXODUS, webEXODUS and EXODUS engine during the preparation/planning and emergency response phases of disaster management is provided in Figure 1. Sometime before an incident, the spatial data and hazard simulation data are provided as inputs to urbanEXODUS. The spatial data is currently in the form of an OSM XML file. The OSM data includes the coordinates of the geospatial objects as well as their description. For example the OSM data includes the co-ordinates of an object and includes a description identifying the type of object such as a building, road or park. urbanEXODUS reads the OSM data and builds a virtual representation of space to model pedestrian movement in it. The output of fire spread models, such as Prometheus[2], can also be provided as an input to urbanEXODUS. In the current implementation this is used to identify the times at which critical areas in the modelled area became untenable due to fire. Other hazard simulation tools such as flood or chemical simulation tools can also be utilised in a similar manner. Further developments will involve a tighter coupling of the output from wildfire models and urbanEXODUS.

During the planning and preparation phase, end users can then configure an evacuation scenario by specifying population data and procedural data. Population data mainly includes the number of occupants, their attributes and manner of their distribution. Procedural data mainly includes the response times of the occupants and routes taken. The EXODUS engine receives the scenario input from urbanEXODUS and runs the simulation. During the simulation, the EXODUS engine stores the population density contours as the simulation progresses at pre-defined time-steps in the form of Shapefiles. Upon completion of the simulation, the simulation results are transferred to urbanEXODUS. The key results include the overall evacuation times, individual evacuation times of each agent in the simulation along with other results such as congestion times and safety margins. The Shapefiles are stored on a GIS server thus allowing the simulation progress to be overlaid on basemaps using webEXODUS.

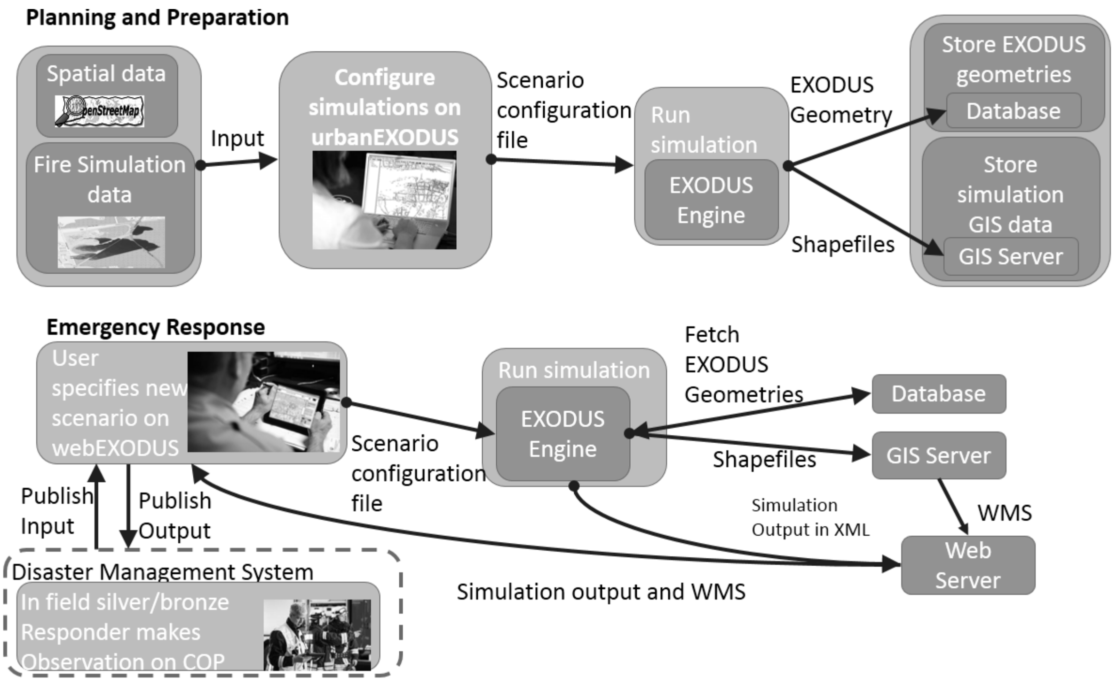


Figure 1: System overview depicting the usage of the EXODUS large scale evacuation modelling system during the planning/preparation and emergency response phases of a large scale incident.

During the emergency response phase, webEXODUS can be utilised by strategic level incident commanders to view the results of the simulations performed during the planning and preparation phase thus assisting them to decide what evacuation procedure to employ. However, not all eventualities can be tested prior to an incident and hence incident commanders can also modify scenarios using the latest tactical information reflecting the current situation and rerun the simulation. The web interface of webEXODUS has been simplified so it can be utilised by those who are unfamiliar with evacuation simulation tools. After analysing different evacuation procedures, the incident commanders can publish the most suitable evacuation procedure to a disaster management system such as the COP[9] which provides a Common Operational Picture in real-time, sharing disaster related information from all parties on strategic, tactical and operational levels. The evacuation simulation results published on the COP assists the tactical and operational commanders to manage the tactical implementation of the evacuation process by implementing a set of evacuation actions.

urbanEXODUS APPLICATION EXAMPLE – SWINLEY FOREST FIRE

The Swinley forest fire was contained within a 110 hectare region of the Swinley forest, directly threatening built-up areas. In this example the population within the built-up area is hypothetical and used purely for demonstration purposes. The threatened area consisted of, the Transport Research Laboratory (consisting of approximately 850 people of mixed working age), a large business estate (consisting of approximately 200 people of mixed working age and predominantly young), a pub (consisting of approximately 200 people of mixed age with a number of elderly and 10% having some form of minor moving disability) and 5 residential dwellings (each consisting of a family of two adults and two children). The fire also threatened near-by towns of Bracknell and Crowthorne, the Broadmoor High Security Hospital and the Royal Military Academy

Sandhurst. The fire, the largest in Berkshire's history, was attended at one point by 55 appliances from 12 brigades. Fortunately, a road running along the built-up area (B3348) acted as a fire break preventing the fire from spreading to the built-up area. Following this fire considerable analysis was undertaken to determine the impact on the built areas had the wind changed[11]. One scenario considered a wind change of 90^0 to the North West. This was modelled using the Prometheus fire spread modelling tool[12]. If these conditions had occurred during the fire it would have prompted the evacuation of the nearby built-up area (see Figure 2).

An overview of the area modelled in EXODUS is shown in Figure 2 (total area, 1.58 km^2). The fire simulations are based on real meteorological data (e.g. fuel maps and ignition locations/times) as recorded on 2 May 2011, however, with slightly different wind conditions (speed and direction). The output shows the simulated spread of the fire for over seven hours. The residents of the indicated buildings are evacuated to the assembly area at the Great Hollands recreation ground, located on the north east side of the built-up area. All the routes leading to the assembly area used by the agents in the simulations are shown in Figure 2.

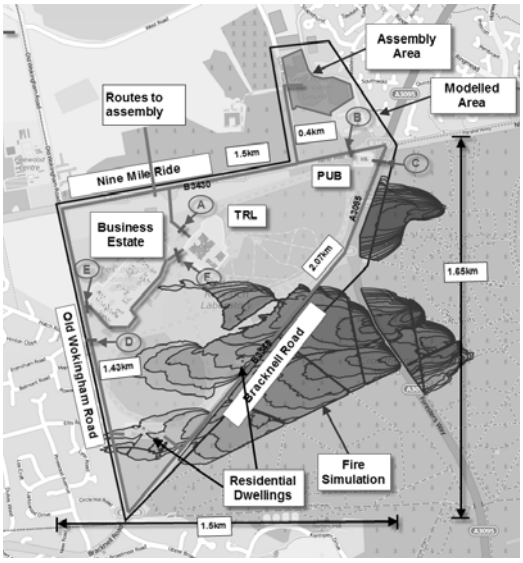


Figure 2: The simulated area in Bracknell which was affected by a real fire on May 02, 2011.

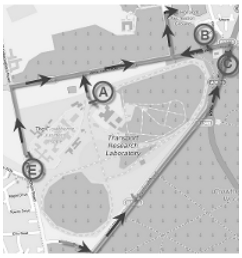
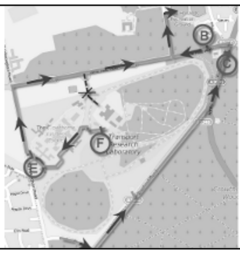
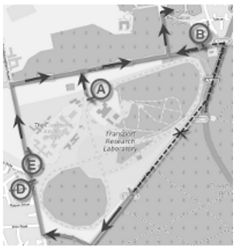
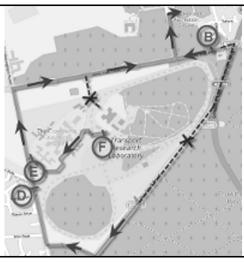
EVACUATION SCENARIOS

The evacuation process is undertaken on foot as it is assumed that the roads need to be kept free for use by emergency vehicles and road conditions are considered hazardous for vehicles due to reduced visibility resulting from smoke. A total of 1220 agents were distributed in the directly threatened locations (pub, TRL, business estate and residential dwellings).

During a wildfire affecting large areas it is essential for incident commanders to know which areas to evacuate first[13,14]. To do this they need to know when the fire will directly threaten the occupied area, when the fire will threaten proposed evacuation routes, how long it will take to clear the threatened areas and how long it will take for the evacuating population to pass through the threatened evacuation routes. Key locations on the evacuation routes, labelled A to F, are depicted in Figure 2. These represent 'safe locations' which the evacuating population must pass to be considered safe from the approaching fire. These locations were determined by analysing the fire progression within the fire simulation and represent the place of closest approach of the fire to the various evacuation routes. A region is considered to be untenable when the fire front is within 500 m of the location. At this point the smoke concentration, visibility and temperature are considered unsafe. The safety margin associated with each route is the difference in time between the time for the fire front to be within 500 m of the region and the time for the last person to pass through the region.

Four scenarios are investigated; they consist of a base case in which it is assumed that all evacuation routes are available and three other cases in which various evacuation routes are considered non-tenable. An overview of the four scenarios has been provided in Table 1
Table 1. In this table, the arrows indicate the direction of travel of the agents from the buildings. The dashed lines with a cross denote loss of routes.

Table 1: Overview of evacuation scenarios.

Scenario	Diagram	Description
1		Base case scenario assuming that all routes are available. Hence all agents take the shortest route to the assembly location. The safe locations A, B, C and E represent the locations at which the agents in the TRL, Pub, residential dwellings and Business Estate reach safety from the full extent of the fire.
2		Assumes the path out of TRL connecting to the Nine Mile Road (B3430) is closed/unusable due to use by emergency vehicles. The agents in TRL are thus forced to take a longer route through the business estate. The safe location for the agents in TRL is now F instead of A.
3		Assumes that a part of the Bracknell road is unsafe to use forcing the agents in the residential dwellings to take a slightly longer route via Old Wokingham Road - Nine Mile Road to the shelter location. The safe location for the agents in the residential dwellings is D instead of C. This part of the Bracknell road is the first route to be affected by the fire and hence this is an important scenario.
4		This scenario assumes that the route losses from scenarios 2 and 3 are merged in this scenario.

All the scenarios have the same initial conditions in terms of the number, nature, and distribution of agents, their response times and the location of the assembly area which is at the Great Hollands Recreation centre located in the north east. The four scenarios differ in terms of the routes taken by the evacuating population. The routes utilised by the agents in the four scenarios and the safe locations for the various establishments are shown in Table 1. The safe locations A to F differ for each scenario depending upon the routes taken by the agents. For example, in scenario 1, the agents located within the TRL building are considered to be safe after clearing safe location A. However, in scenario 2 a different path is adopted by the agents in TRL where safe location F is considered.

Within each scenario the agent response times were specified as follows:

- Pub: 30 - 60 s, proprietor alerted by phone call from police at t = 0 s.
- TRL: 60 - 120 s, building managers alerted by phone call from police at t = 0 s.
- Business Estate: 60 - 120 s, building managers alerted by phone call from police at t = 0 s.
- Residential Dwellings: 10 to 16 min, alerted by the police door knock. Each dwelling is visited in turn by a police patrol that informs residents to evacuate. The police reach the first

house at t = 300 s. The second house is visited 60 s later and so on. Each household has a 5 min response time once alerted.

Occupant response times for these types of situations are not known and so the values used in these simulations are intended for demonstration purposes. In reality it is likely that people would have much longer response times, especially for residential dwellings. Furthermore, the start of the evacuation (t = 0 s) occurs at the time of fire initiation. This is unlikely to be the case in reality as it will take some time for the fire to grow to a size that can be detected and then for the fire to develop to the point that it may be considered a threat. However for simplicity in this demonstration the evacuation process is considered to start at the start of the fire. Both these simplifications should be taken into consideration when assessing the results presented.

RESULTS AND DISCUSSION

Arrival Times and Distance Travelled

The assembly times and distance travelled by the agents from the different buildings in each scenario is shown in Table 2. The agents from the Pub are always the first to assemble. The agents in the Residential Dwellings (RD) are always the last to assemble in all scenarios and thus determine the overall assembly times for the entire population. A graph of the times at which the agents arrive at the assembly location for all four scenarios is shown in Figure 3.

Table 2: Times to assemble and distance travelled by agents in each scenario for each building

Scenarios	Assembly times (HH:MM:SS)				Distance travelled (km)			
	Pub	TRL	BE	RD/ALL	Pub	TRL	BE	RD
1	00:18:38	00:35:26	00:51:36	01:11:32	0.8	1.5	2.3	2.7
2	00:18:37	01:07:05	00:52:09	01:10:26	0.8	3.0	2.3	2.7
3	00:18:42	00:35:35	00:51:16	01:26:01	0.8	1.5	2.3	3.0
4	00:18:40	01:07:25	00:52:31	01:24:25	0.8	3.0	2.3	3.0

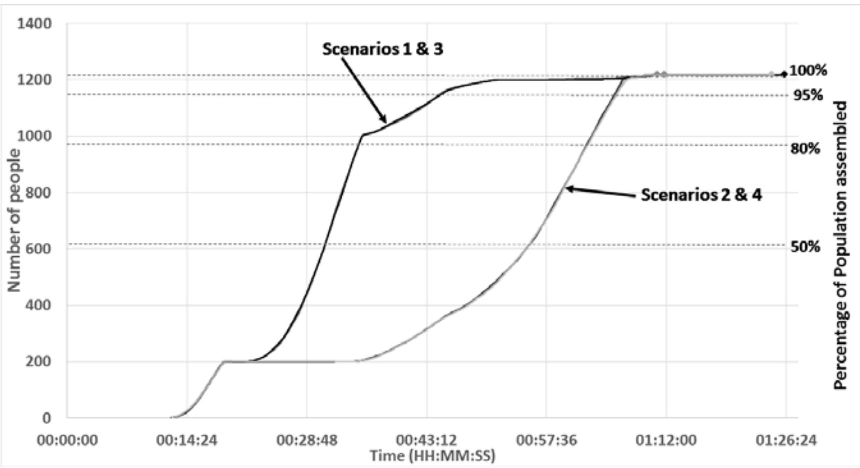


Figure 3: Comparison of arrival times at the assembly location. The times at which proportions (50%, 80%, 95% and 100%) of the entire population assemble is denoted by the horizontal dashed lines.

As can be seen in Figure 3, the evacuation dynamics for scenarios 1 and 3 are quite similar and the evacuation dynamics of scenarios 2 and 4 are quite similar, but both pairs exhibit quite different evacuation dynamics to each other. The evacuation dynamics in scenarios 1 and 3 are similar as the only difference between the two scenarios is that the agents from the RD take a slightly longer route in scenario 3 (2.7 km versus 3.0 km) compared to scenario 1. In these scenarios we note that there is a rapid build-up of people in the assembly area after approximately 21 min. This is due to the arrival of people from TRL. While the evacuation dynamics in these two scenarios are broadly similar, there is a large difference (14 min or 20%) in the overall assembly times between these two scenarios. This is a result of the agents from the RD travelling an additional 0.3 km to reach the assembly location in scenario 1.

The evacuation dynamics in scenarios 2 and 4 are quite similar as again, the only difference between these two scenarios is that the agents from the RD take a slightly longer route in scenario 4 (2.7 km versus 3.0 km) compared to scenario 2. In these scenarios we note that there is a slower build-up of people in the assembly area compared to that in scenarios 1 and 3. This difference is due to the occupants from TRL taking a longer route to the assembly location (3.0 km versus 1.5 km) in scenarios 2 and 4 compared to scenarios 1 and 2. This has a significant impact on the development of the arrival times. Indeed, as noted in Figure 3, after the arrival of the last occupants from the Pub into the assembly area there is a period of about 16 min when no further people arrive in the assembly location. While scenarios 2 and 4 have broadly similar evacuation dynamics, there is again a large difference (14 min or 20%) in overall assembly times between these two scenarios. As with scenarios 1 and 3, this is due to the slightly longer evacuation route taken by the occupants of the RD in scenario 4 compared to scenario 2.

The overall assembly times in scenarios 1 and 2 are similar as are those in scenarios 3 and 4. This is because the final assembly times are determined by the arrival times of the RD occupants. In scenarios 1 and 2 the occupants of the RD follow the same route (most direct route) while in scenarios 3 and 4 they follow the slightly longer route. Hence the overall assembly times for scenarios 1 and 2 are slightly shorter (71 min or 16%) compared to those for scenarios 3 and 4 (85 min).

Assembly Performance

The times at which various proportions (50%, 80%, 95% and 100%) of the population arrive at the assembly location is provided in Table 3. As already noted there is a rapid build-up of people in the assembly area in scenarios 1 and 3 compared to scenarios 2 and 4. This is due to the occupants from TRL taking the direct route to the assembly station. From Table 3 we note that within scenarios 1 and 3, not only do 50 % of the population arrive at the assembly location in just under 31 min (compared to just over 55 min in scenarios 2 and 4), but 95% of the total population have assembled in a shorter time than the time taken for 50% of the population to assemble in scenarios 2 and 4. Thus in scenarios 1 and 3 it is essential that the assembly locations are staffed and ready to handle the arrival of large numbers of people in a relatively short period of time – 30 min from the start of the evacuation process.

Furthermore, in scenarios 1 and 3 the arrival time curve has a long tail, the last 5% of the population requiring between 26 min (in scenario 1) and 41 min (in scenario 3). This is equivalent to the time required for the first 50% to arrive in the assembly in the assembly location. Indeed, in scenario 3, the last 5% of the population require almost 50% of the total assembly time.

Table 3: Times at which proportion of entire population assembled

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	01:06:11	01:24:38

Safety Margins

The safety margin associated with each route is here defined as the difference in time between the time for the fire front to be within 500 m of the region and the time for the last person to pass through the region. Presented in Table 4 are the safety margins associated with the various populations in each scenario. The smallest safety margins are 37 min for the occupants of the RD in scenarios 1 and 2 and 86 min for the occupants of the pub in scenarios 3 and 4. The longest safety margins are over 360 min and are associated with the population in the BE in all four scenarios.

The very short safety margins associated with scenarios 1 and 2 are due to the occupants in the RD taking the shortest route to the assembly location i.e. along Bracknell Road, which inevitably takes them quite close to the fire start location and directly in the path of fire spread. Given that the start of the evacuation process is associated with the start of the fire, this means that there could only be a maximum of 37 min delay between the start of the fire and the notification of the population in the RD before scenarios 1 and 2 would become non-viable.

In scenarios 3 and 4, the population in the RDs take the longest route to the assembly location, i.e. along Old Wokingham Road, which takes them effectively away from the fire and hence gives them a much higher safety margin of over 165 min (associated with clearing safe point D). Although the agents in the residential dwellings travel a longer route (0.3 km more) via the Old Wokingham Road, it is the route that offers them maximum safety and is the only viable route given the delay likely between starting the evacuation and detecting the fire. The occupants of the Pub also have a relatively small safety margin requiring them to start their evacuation within 86 min of fire initiation, regardless of which scenario is considered. The agents in the other establishments (TRL and Business estate) have more than four hours safety margin in all scenarios and hence can be considered to be quite safe in terms of warning time and time needed to reach safety locations.

Table 4: Safety margins (min)

	Pub	TRL	BE (and TRL for scenarios 2 and 4)	RD
Scenario 1	87	290	379	37
Scenario 2	87	261	365	37
Scenario 3	87	290	379	166
Scenario 4	87	261	365	166

Thus of all four scenarios, scenario 3 offers the greatest margin of safety for most people, even though it results in the longest assembly time and the longest travel distance for the population of the RD. Without the use of coupled fire and evacuation modelling this result may not have been immediately apparent as it is somewhat counter intuitive i.e. preferred option involves longest assembly time and greatest travel distance for RD residents.

The safety margins also provide a basis on which to prioritise the warning sequence for the occupants in the various establishments. In the preferred scenario 3, the population with the shortest safety margin are the occupants of the Pub followed by the occupants of the RD and TRL and finally the BE. Thus if resources are low, it would be essential to warn the occupants of the Pub first followed by the RD.

Congestion on Evacuation Routes

Relatively small amounts of congestion was experienced on the evacuation routes in all scenarios. Since the evacuation took place on roads which were at least 4 meters wide, there was not much congestion experienced by the agents in any of the scenarios. Furthermore, the agents from the different establishments reached the main exit routes at slightly different times reducing the likelihood of generating high congestion levels. The percentage of time spent by the agents in congestion compared to their overall evacuation time for all scenarios is shown in Table 5.

Table 5: Percentage of the time agents spent in congestion compared to their overall evacuation time

	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)	Scenario 4 (%)
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

The agents from TRL experience the greatest levels of congestion for all scenarios with scenarios 1 and 3 producing the most severe conditions when they take the direct route to the assembly area. However, when they use the path that takes them through the BE the levels of congestion they encounter are lower due to the fact that their evacuation takes longer and have longer time to spread on the evacuation route. However, in the worst cases of scenarios 1 and 3 they only waste 7.2% of their travel time in congestion. The agents from the Business Estate experience very low levels of congestions 1.2% for scenarios 1 and 3 and 1.3% for scenarios 2 and 4. This is due to the fact that the relatively fewer agents (200 in total) are distributed in several buildings within the estate. Therefore, there is little chance for congestion to build up along the evacuation route. Conversely, the same number of agents that are located in the Pub experience higher levels of congestion at 5.7% for scenarios 1 and 3 and 5.6% for scenarios 2 and 4. This is due to these agents exiting from one small building and utilising a single short path (0.8 km) to the assembly area. The agents originating from the RDs did not experience any congestion in any of the scenarios.

Reviewing simulation results in webEXODUS during emergency response

The version of EXODUS used in the above analysis, which is equivalent to the planning and preparation phase of an emergency was urbanEXODUS. During the emergency response phase, the incident strategic commanders require a more mobile and easier to use version of the evacuation simulation tool. In these applications the webEXODUS interface can be used by operators with little or no knowledge of evacuation simulation software to analyse evacuation procedures during a developing incident. webEXODUS can be accessed over the internet allowing field commanders to specify simulation inputs using a browser, run simulations on the EXODUS engine located on a remote server and view the simulation results. A single aspect of the webEXODUS functionality namely the ability to replay the simulation results on a web browser is shown in Figure 4. The main purpose of this functionality is to allow the user to step through the simulation to gain an understanding of how the pedestrian evacuation is projected to progress during the incident.

A snapshot of the webEXODUS interface used to view the simulation progress as a time stepped animation is shown in Figure 4. There are three main sections in this interface. The main body consists of the base map and the population density overlays. The base map shown in Figure 4 is the OpenStreetMap. However, other base map layers can be selected including various versions of Google Maps. The population density contour is seen as dots at the assembly location and the South Road leading to the Great Hollands Recreation Ground. The dots are cells measuring 36 m^2 (6 X 6 meters). The reason behind the selection of this size is based upon the assumption that group behaviour is best observed at this size [8]. The safe locations A - F are shown as lines on the map labelled accordingly. These lines or safe locations are interactive in that they can be clicked on to bring up a popup showing the total number of agents that have cleared the location during the entire simulation and the number of agents that have cleared them at the current time. The polygon on the east shows the fire progress at 1 hour. The footer of this interface contains the controls to step through the simulation. The simulation time is also displayed. The number of agents that have reached the assembly location and that are still evacuating is also shown. If there are any predicted fatalities or agents trapped in the simulation due to a loss of viable escape route they can also be depicted. In Figure 4, a snapshot of the simulation at 30 min 10 sec is shown. At this time, the agents in the simulation have cleared the safe locations A, B, C and E. At this time step 1200 agents out of the total 1220 agents have reached the assembly location.

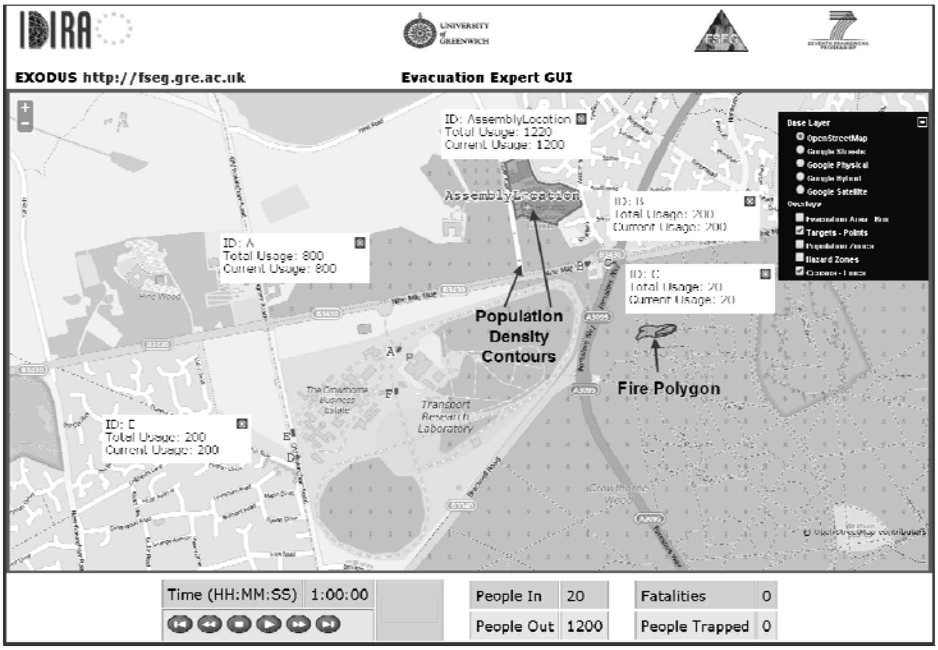


Figure 4: Viewing the simulation progress on webEXODUS

CONCLUSIONS

This paper presents a software system that has been developed to evaluate evacuation procedures during the preparation and emergency response phases of a large scale incident such as a wildfire. The work demonstrates that the integration of fire simulation with evacuation simulation enables the estimation of safety margins associated with alternative evacuation strategies and thereby assists incident managers in planning phased evacuation strategies. Through the use of a web based interface, the tool also has a role in real time applications where it can be used by incident commanders, making use of live tactical information to update and modify planned evacuation strategies during an actual incident. The system can be extrapolated to other emergencies such as those associated with floods and earthquakes or manmade terrorist situations.

The software was demonstrated by simulating the evacuation of part of Bracknell which was affected by the Swinley fires of 2011. The software, coupled with the output from wildfire simulation, was used to evaluate four possible evacuation scenarios associated with hypothetical wind changes that could have impacted the fire development during the actual fires. The analysis determined the time required to evacuate the threatened population to a place of safety, the distances travelled by the population, levels of congestion incurred during the evacuation and the safety margins associated with each population centre in each scenario. The analysis identified that two of the scenarios would result in very small safety margins associated with the evacuation of occupants from threatened residential dwellings. The optimal scenario, which resulted in maximum safety margins for all threatened sub-populations was counter intuitive in that it resulted in the maximum assembly time and the longest travel distances for the occupants of the residential dwellings. Use of the software also confirmed the viability of the identified assembly area, prioritised the alerting of the at-risk populations and assisted in prioritising the tasks of the emergency services.

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