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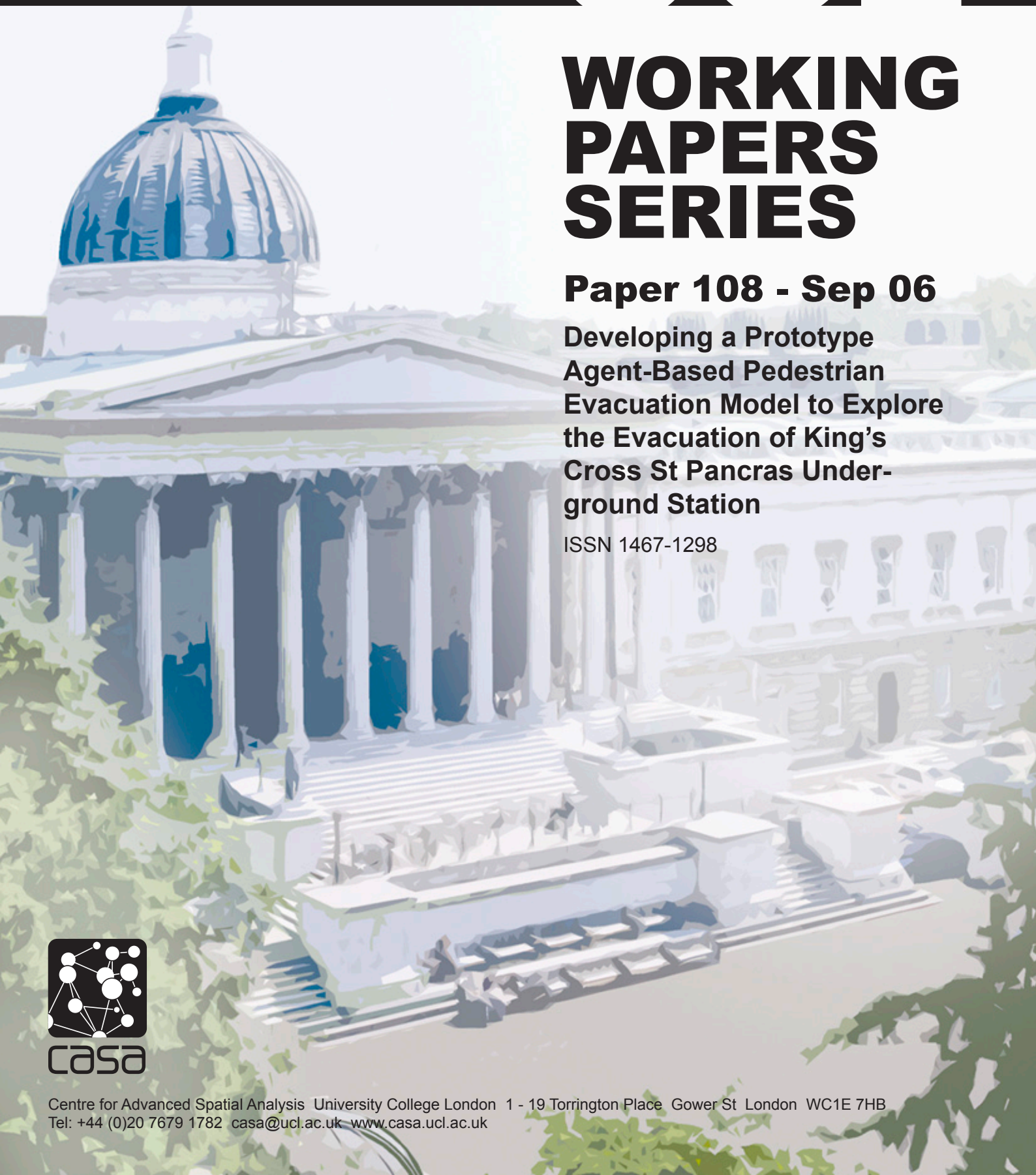

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Developing a Prototype Agent-Based Pedestrian Evacuation Model to Explore the Evacuation of King's Cross St Pancras Underground Station*

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Abstract

London's King's Cross St. Pancras underground station has been the unfortunate location of two major incidents within the last twenty years. A fire in November 1987 and the terrorist bombing in July 2005 both resulted in the loss of lives, and the injury of many people. The implementation of measures to mitigate or neutralise the effect of all possible future incidents at this site is unrealistic. The adoption of preparedness measures is crucial for the emergency services to limit the loss of life and property, and to improve the response phase of an incident. King's Cross St. Pancras underground station is currently being redeveloped, partly to mitigate the remaining few operational and safety issues identified after the 1987 fire, and also to allow for a predicted increase in passenger use. Despite these modifications and improvements, both the surrounding built environment and the station will necessarily remain complex structures. The local emergency services have several duties placed upon themselves in the event of a major incident at this site, and a computer based model capable of examining the effects of different incident assumptions or contingencies has been identified as potentially beneficial to the local National Health Service (NHS) resilience planning department.

The specific aim of this paper is to provide the reader with an overview of this research project. To begin, the aims and deliverables are identified. In light of these, principles of pedestrian evacuation modelling are presented, highlighting a shift in approaches: from aggregate movement, to individual-level movement and behavioural models. The feasibility of using a proprietary pedestrian evacuation model to achieve the research goal is discussed. This is followed by an agenda for developing an agent-based pedestrian evacuation model using the Repast toolkit. This paper concludes with progress of the prototype model to date.

Keywords: Pedestrian evacuation modelling, Agent-Based Modelling, Repast toolkit, London's King's Cross St. Pancras underground station.

Introduction

London's King's Cross St. Pancras underground station has been the unfortunate location of two major incidents within the last twenty years. On November 18th 1987, a fire within the station resulted in 31 fatalities, more than 60 severe injuries, and serious structural damage to the station (Hallén and Kulling, 1990). On Thursday July 7th 2005 one of four terrorist bombs to explode on London's public transport network occurred on a train leaving King's Cross St. Pancras underground station (BBC News, 2005). Twenty six people lost their lives and many more people were injured in this incident.

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During a major incident such as the King's Cross fire or the London bombings, people within an enclosure, the enclosure itself, and the immediate environment (i.e. at the street level) are affected in ways that considerably reduce the speed of incident response (Kwan and Lee, 2005). The complex internal structure of buildings and limited number of access points at street level render speedy escape and rescue particularly difficult. During any major incident a matter of minutes may lead to significant changes in the environment within which evacuees need to escape and rescue personnel have to operate. In this respect, the efficiency and effectiveness of the emergency services is critical, and directly related to their major incident management.

Preparedness is a key component of major incident management, which can play a significant factor in the event that emergency response efforts become necessary (Castle and Longley, 2005). Unfortunately, information from comparable incidents is usually unavailable and the way that some incident scenarios evolve is unknown. Nakanishi *et al.* (2003) state that robust incident preparedness plans should incorporate the results of available computer simulation models. These models are especially useful in estimating the impacts of incident characteristics and response strategies, on response and evacuation times. The principles advocated by Nakanishi *et al.* (2003) provide the wider context in which this thesis is set.

The remainder of this paper provides the reader with further information regarding this research. The following section identifies the specific aims and objectives, highlighting the impact of the King's Cross redevelopment on pedestrian egress from the underground station. Consequently, an overview of principles relating to the modelling of pedestrian evacuation is presented, identifying a shift in modelling endeavours. The penultimate section of this paper discusses the feasibility of using a proprietary pedestrian evacuation model to fulfil the research goal. This is followed by an agenda for developing an agent-based pedestrian evacuation model using the Repast toolkit. This paper concludes with progress of the prototype model to date.

Research Aims and Deliverables

This research is a direct response to the Department of Health's (DoH, 2004a; b) request for the National Health Service to assess, and where necessary, make adjustments to their plans for coping with their responsibilities during a major incident. In particular, resilience planners within the local NHS department (Camden Primary Care Trust, PCT - the research sponsors) have identified the need to evaluate resources after the completion of the King's Cross redevelopment.

An estimated £4 billion of investment has been allocated to redevelop the King's Cross area of London, which is set to become Europe's largest integrated transport hub. The redevelopment started in 2000 as is due to be completed in 2015[‡]. One of the four main development projects entails the upgrade of King's Cross St. Pancras underground station, one of London's oldest and busiest stations. In part, the upgrade will address several of the remaining operational and safety recommendations identified by the Fennel investigation into the 1987 King's Cross fire (Fennell, 1988). In addition, the station must cope with future passenger demand. The station is part of a major interchange between two national rail stations (St. Pancras and King's Cross, FIGURE 1), which contributes to heavy passenger congestion during peak periods. At present an estimated 65,000 passengers traverse the station during the morning peak (7:00-10:00am). By 2011, with domestic and international high-speed rail services operating from St Pancras, 92,000 passengers will pass through the underground station during the morning peak, rising to 105,000 during the Olympics in 2012 (London Underground Limited, LUL, 2006).

[‡] King's Cross St. Pancras underground station is due to be completed in 2009.

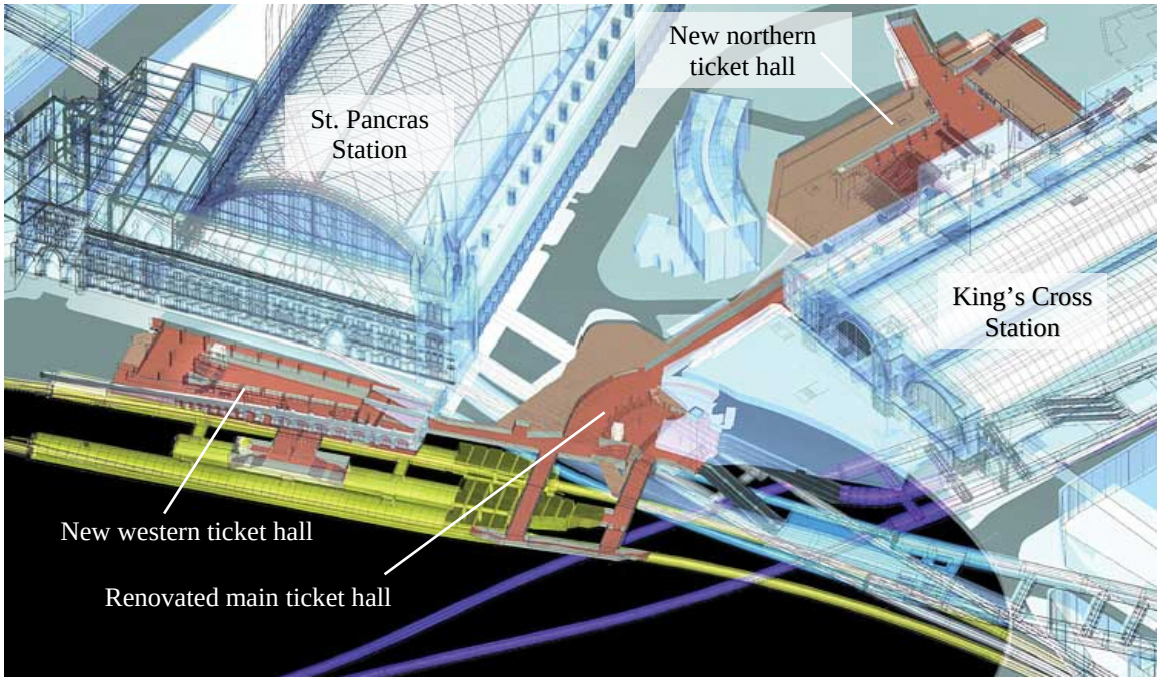

FIGURE 1: Renovated King's Cross St. Pancras underground main ticket hall, and new northern and western ticket halls (Allies and Morrison, 2004).

In light of the significant layout changes and increased passenger numbers, a main aim of this research is to develop a prototype pedestrian evacuation model for Camden PCT to evaluate their resources in the event of an incident within King's Cross St. Pancras underground station. In particular, Camden PCT are interested in the appraisal of pedestrian egress from the study area to determine the allocation and positioning of key emergency functions and facilities (e.g. ambulance loading point(s), casualty clearing station(s) to which the injured can be taken, etc), in the event of a future incident. Local emergency service administrators, medical and public health professionals, and other community policy makers and planners who must prepare for future incidents at King's Cross St. Pancras underground station have been actively involved in determining deliverables through the research advisory panel (see http://www.casa.ucl.ac.uk/kxsdsses/advisory.htm).

Pedestrian Evacuation Modelling

The evacuation of occupants from a building during an emergency can be evaluated in several ways. Firstly, a building can be assessed by a full-scale evacuation demonstration, involving an exercise using a representative target population within the structure. However, this approach can pose ethical, practical, and financial limitations, which undermine its viability. Alternatively, before the construction of a building has started, an architect can design the layout based on prescriptive building codes; designed to accept or reject a proposed design on the basis of its compliance. Gwynne and Galea (1997) note, that in order to fully assess the potential evacuation efficiency of an enclosure, it is essential to address the configurational, environmental, behavioural, and procedural aspects of the evacuation process.

Configurational considerations are those generally covered by traditional building codes and involve building layout, number of exits, exit width, etc. In the event of an incident, environmental aspects need to be considered. These include the potential effects on building occupants as a result of heat, toxic and irritant gases, travel speed due to smoke density, and way-finding capabilities. Procedural aspects relate to staff actions, level of occupant evacuation

training, occupant prior knowledge of the enclosure, emergency signage, etc. Finally, and what Gwynne and Galea (1997) perceive as the most important consideration, is the likely behavioural responses of occupants (e.g. initial response to evacuation, travel speeds, family / group interactions, etc).

The aforementioned traditional methods of building design and evaluation fail to address these issues in a quantitative manner, preferring to rely almost totally on judgement and prescriptive rules. Prescriptive rules tend to have a dependency on configurational considerations (e.g. travel-distance and exit width), which can prove too restrictive. Moreover, these traditional methods are insensitive to human behaviour or varying emergency scenarios. Computer based models offer the potential to evaluate the evacuation of occupants from a building during an emergency; overcoming these limitations.

Modelling Human Movement and Behaviour

In the building industry, research into quantifying and modelling human movement and behaviour has been underway for at least 30 years. This work has progressed down two routes: movement of people under emergency and non-emergency conditions. Early work was concerned with movement of people under non-emergency conditions (e.g. Fruin, 1971, and Predtechenskii and Milinskii, 1978). Their research mainly focused on the movement capabilities of people in crowded areas and stairs, and led to the development of initial pedestrian movement models such as PEDROUTE / PAXPORT. Attempts to simulate emergency pedestrian movement are somewhat more recent. One of the first publications was produced by Stahl (1978), which focused on modelling emergency egress during fires. Similarly, initial models only considered movement, although more recent models incorporate behaviour as well. Galea (2004) has subsequently classified the development of evacuation models into five generations: 1) manual calculations; 2) computer based flow or hydraulic models; 3) ball bearing models; 4) rule based models; and, 5) models sensitive to local conditions (i.e. attempting to reproduce behaviours based on the conditions experienced and information available.

Models classified within each of these pedestrian modelling generations have adopted a different approach. Each approach can be distinguished by the way the enclosure, population, and behaviour of the population are represented. The plethora of approaches has led to the development of more than thirty models, designed for simulating the evacuation of pedestrians from buildings alone[§]. Consequently, a review was conducted to determine the feasibility of using a proprietary model for achieving the aims and deliverables of this research.

Simulating the Evacuation of Pedestrians: Proprietary Models

Based on the advice of Nelson and Mowrer (2002), and the findings of the feasibility review, there were several reasons why the use of a proprietary model was considered undesirable to the research sponsor. For instance, many proprietary models only provide limited information as to how the model works. Essentially black box, accompanying literature also provides little or no evidence to support the validity of the results they produce. Furthermore, the design of these models, to some extent, reflects the purpose for which they were originally intended, the nature of the model developer (e.g. engineer, physical scientist, psychologist, architect), and the computer power available to the developer at the time. Additionally, accessibility to some of these proprietary models is limited to a consultancy basis only. Invariably, in these circumstances, the client is limited to results and analysis published in the final

[§] Excluding models designed for aviation or maritime evacuation scenarios.

report. Moreover, they are unable to explore results further, or reuse the model to explore a specific scenario at a later date. In light of these limitations, the development of a pedestrian evacuation model was identified as a viable option for this research.

Developing an Agent-Based Pedestrian Evacuation Model with Repast

Amongst other developments, the evolution of pedestrian evacuation modelling demonstrates a noticeable transition from aggregate to individual-level modelling. In part, increased computer power and storage capacity has only made individual-level modelling practicable in recent times. Essential to the progression of individual-level modelling has been the development of automata approaches, which have been at the forefront of computer modelling research (see Benenson and Torrens, 2004). Two classes of automata tools, cellular automata (CA) and agent-based modelling (ABM) have been particularly popular; their use has dominated the research literature. Both classes of tool offer significant development opportunities for pedestrian modelling (see Castle and Crooks, in press). Of particular interest to this research is the agent-based approach, which is capable of representing attributes of individual agents (or groups) and their behaviour within a given system. For example, entities could be programmed to have varying degrees of prior knowledge regarding the building layout (e.g. commuters vs. tourists), or different mobility speeds (e.g. children, adults, mobility impaired, etc). Agents may interact with each other and / or with the environment, of potentially varying conditions (e.g. a smoke filled enclosure). A computer model also allows for a model to be re-run many times, altering parameters to evaluate different situations. Helbing *et al.*, (2000) have developed a model which illustrates these possibilities. The model simulates panicking pedestrians evacuating an enclosure, representing evacuees as thinking and reacting individuals rather than identical particles. The output of their model generates some interesting results. Moreover, in the context of pedestrian evacuation modelling, the agent-based paradigm will permit the development of a model that is adaptive (i.e. pedestrians can be sensitive to local conditions and have the ability to react to information and options available to them).

The recursive porous agent simulation toolkit (Repast) has been identified as a suitable medium for the development of the agent-based pedestrian evacuation model for this research project. One of several reasons for choosing Repast was due to its abstraction of key conceptual requirements involving agent-based models. The toolkit provides suitable functionality to easily create, run, display, and collect data from an agent-based model. In addition, Repast provides template components. For example, representational elements are already provided, such as the environment in which agents interact (e.g. grid, torus, network, etc). This functionality allows modellers to spend more time developing the specifics of their model (e.g. agent interactions and their behaviours) rather than setting up the basics of a simulation (e.g. scheduling events to occur, developing a visual display, etc).

Current State of Research

At the time of writing, the prototype model is still in its early stages of development. The model is being developed iteratively, in accordance with general advice regarding the development of agent-based models (e.g. Gilbert and Troitzsch, 2005). At present a baseline model has been completed in which pedestrians traverse the underground station using a cost surface as a means of determining the shortest path to available exits. The underground station layout and cost surface are imported as .ascii files (ESRI format i.e. as two-dimensional grids). FIGURE 2 is a screen capture of pedestrians evacuating the Piccadilly line underground platform at King's Cross St. Pancras underground station.

Subsequent versions will build upon this model, developing more sophisticated pedestrian attributes, behaviours, and interaction rules. In this sense, the final model will evolve analogously to the generations of pedestrian evacuation models identified earlier. At present, the baseline model would be classified as a third generation, or 'ball-bearing' model. Individuals are represented, but only the movement of pedestrians is considered. The model lacks behaviour associated with decision making processes. Subsequent versions will become more advanced. For instance, a rich diversity of behaviours will be incorporated, and pedestrians will be adaptive (i.e. sensitive to conditions around them, reacting to information and options available to them). Further iterations of the model will be posted on the research project website (http://www.casa.ucl.ac.uk/kxsdsses), as and when they have been developed.

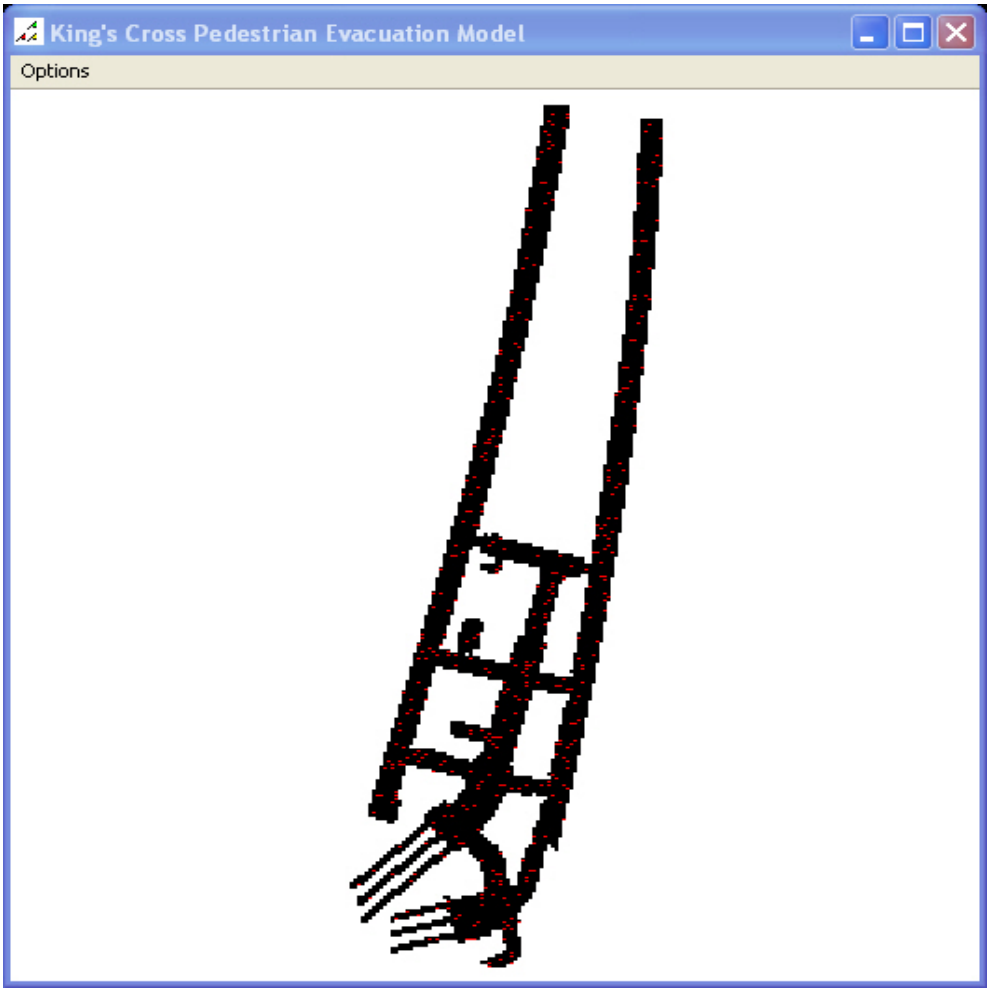

FIGURE 2: Pedestrian evacuation model of the Piccadilly line platform at King's Cross St. Pancras underground station.

Conclusion

This paper has provided the reader with information regarding the progress of this research project to date. The aims and objectives were identified; specifically the evaluation of pedestrian egress from King's Cross St. Pancras underground station. After the redevelopment passenger numbers will have increased and the layout of the enclosure will have significantly altered. Consequently, principles of pedestrian evacuation modelling were presented, highlighting a shift in modelling strategies: from aggregate movement, to individual-level movement and behavioural models. The penultimate section of this paper discussed the

feasibility of using a proprietary pedestrian evacuation model to achieve the research goal. However, this was deemed as an undesirable option by the research sponsor. The development of agent-based pedestrian evacuation model using the Repast toolkit was chosen as a viable alternative. The paper concluded with a progress update of the prototype pedestrian evacuation model so far.

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Author Biography

Christian Castle is a second year Ph.D. student at the Centre for Advanced Spatial Analysis (CASA, University College London) under the supervision of Professor Paul Longley. His Ph.D. is entitled 'A GIS-Based Spatial Decision Support System (SDSS) for Emergency Services: London's King's Cross Redevelopment'. Some of his main research interests include pedestrian evacuation modelling, agent-based modelling, and GIS for emergency evacuation management.

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