Simulating the Interaction of Occupants with Signage Systems

LAZAROS FILIPPIDIS, PETER J. LAWRENCE, EDWIN R. GALEA and DARREN BLACKSHIELDS
Fire Safety Engineering Group
The University of Greenwich
30 Park Row, Greenwich, London SE10 9LS

ABSTRACT

This paper describes the introduction of chained signage systems into evacuation simulation models. Signage systems are widely used in buildings to provide information for wayfinding, thereby providing exiting information during emergencies and assisting in navigation during normal circulation of pedestrians. Recently a system was developed to introduce simple signs into egress models. The system, known as Visibility Catchment Area or VCA, allowed simulated agents to interact with signs which point directly to an exit and signs which are located directly above the exit. However, this approach was not able to represent the more general situation of a sign network within an arbitrarily complex building. In this paper we extend the method to include chained signage systems which provides simulated agents that are unfamiliar with the structure a means by which to navigate to an emergency exit. The model includes the associated navigation behaviours exhibited by occupants that rely on a signage system for navigation including: Searching behaviours, Backtracking behaviours, Lost behaviours and Communication behaviours. The new features are demonstrated through a series of demonstration cases and are shown to produce plausible results.

KEYWORDS: human behaviour, egress, modelling

INTRODUCTION

Signage within complex building spaces is intended to provide occupants with information relating to wayfinding. A successful signage system can reduce the apparent complexity of an enclosure thereby improving wayfinding under both general circulation and emergency conditions. While inefficient signage may contribute to loss of commercial earnings in general circulation situations, it has more serious consequences in emergency situations. It has been known for many years [1,2] that in emergency situations occupant unfamiliarity with exit routes can significantly contribute to the resulting casualties [3-6], a relatively recent highly prominent example of this is the Station Night Club fire [7].

Evacuation and pedestrian circulation models have generally ignored the interaction of occupants with the wayfinding system; the implicit assumption in most of these techniques is that the occupants “know” the route. While this may be appropriate in many situations, it is clearly a simplification of reality. In order to produce realistic representations of evacuation and circulation in arbitrarily complex structures, it is necessary to represent the interaction between occupants and signage systems.

Recently, the ability to represent the interaction of people with signs was introduced into the buildingEXODUS evacuation and pedestrian dynamics model [8,9] through the concept of the Visibility Catchment Area (VCA) [10]. The VCA of a sign is defined as the region from where it is physically possible to visually receive and discern information from the sign. In this early model, the maximum viewing distance or the VCA termination distance was arbitrarily set as the distance specified in regulations. This concept was then extended through a theoretical and experimental analysis that established the relationship between observation angle, sign size and maximum viewing distance [11].

These early signage system computer model implementations were restricted to zero and first order systems. The order of the signage system is a classification system, developed by the authors, that identifies the level of redirection that is implied by an individual sign within a wayfinding system. The system identifies signs as having a redirection requirement of zero, first or higher order. A ***zero order*** level of redirection refers to signs that are located immediately above the object they are intending to identify, such as an exit sign located above a door. A ***First order*** sign refers to signs that directly point to the target object. To be effective, it is preferable that these signs lie within the VCA of the object they are pointing to.

FIRE SAFETY SCIENCE–PROCEEDINGS OF THE NINTH INTERNATIONAL SYMPOSIUM, pp. 389-400

Finally, ***higher order*** signs refer to signs that do not directly point to the target object but lead the observer to another sign in the signage system (see Fig. 1.).

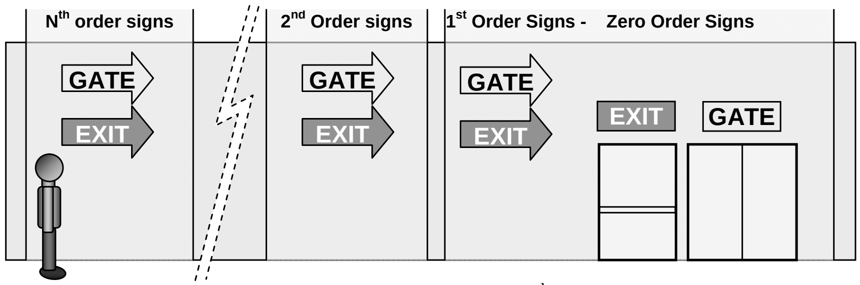


Fig. 1. Signage system involving zero, 1st, 2nd, and higher order signs.

In this paper we extend the representation of signage systems in evacuation and pedestrian circulation models to include the concept of higher order signage systems. The signage system is used by occupants within the simulation that do not have knowledge of the structure and hence do not know where their target is located. In evacuation simulations this may be an emergency exit while in pedestrian circulation simulations this may be a departure gate at an airport. The model includes the associated navigation behaviours exhibited by occupants that rely on a signage system for navigation. These behaviours include searching and backtracking and behaviours to represent being lost.

THE CORE EVACUATION MODEL

The core software used in this paper is the buildingEXODUS V4.0 evacuation model. The basis of the model has frequently been described in other publications [8-11] and so will only be briefly described here with emphasis given to model capabilities required by the new developments and used in this paper.

EXODUS is a suite of software tools designed to simulate the evacuation of large numbers of people from complex enclosures. The version of the software used to simulate evacuation from the built environment is known as buildingEXODUS. The software takes into consideration people-people, people-fire and people-structure interactions. The model tracks the trajectory of each individual as they make their way out of the enclosure, or are overcome by fire hazards such as heat, smoke and toxic gases. The software has been written in C++ using Object Orientated techniques utilising rule base technology to control the simulation. Thus, the behaviour and movement of each individual is determined by a set of heuristics or rules. For additional flexibility these rules have been categorised into five interacting submodels, the **OCCUPANT, MOVEMENT, BEHAVIOUR, TOXICITY** and **HAZARD** submodels. These submodels operate on a region of space defined by the **GEOMETRY** of the enclosure.

The spatial and temporal dimensions within the software are spanned by a two-dimensional spatial grid and a simulation clock (SC). The spatial grid maps out the geometry of the building, locating exits, internal compartments, obstacles, etc. The building layout can either be specified using a DXF file produced by a CAD package or be constructed using the interactive tool provided. The grid is made up of nodes and arcs with each node representing a small region of space and each arc representing the distance between neighbouring nodes. Individuals travel from node to node along the arcs.

The Occupant submodel allows the nature of the occupant population to be specified. The population can consist of a range of people with different movement abilities, reflecting age, gender and physical disabilities as well as different levels of knowledge of the enclosure’s layout, response times etc. On the basis of an individual’s personal attributes, the Behaviour submodel determines the occupant’s response to the current situation, and passes its decision on to the Movement submodel.

The Behaviour submodel functions on two levels, Global and Local. Global behaviour involves implementing an escape strategy that may lead an occupant to exit via their nearest serviceable exit or most familiar exit. The desired global behaviour is set by the user, but may be modified or overridden through the dictates of local behaviour, which includes such considerations as determining the occupants initial response, conflict resolution, overtaking, etc. In addition a number of localised decision-making processes are available to each individual according to the conditions in which they find themselves and the information available to them. This includes the ability to customise their egress route according to levels of congestion around them, the environmental conditions and the social relationships within the population. Individual agents may also communicate information concerning the location of exits if they pass within a predefined distance of each other. In real evacuation situations, individuals may react to a signage system and follow directions to an otherwise unknown exit or object. In the current implementation of the software only zero and first order signs are catered for. Thus occupants will only be able to detect otherwise unknown exits in which the exit sign is either directly above the exit or pointing directly to the exit. Occupants may detect the sign only if they fall within the VCA of the sign [10,11]. The VCA takes into consideration the following attributes; the location of the sign, the height of the base of the sign above the floor, the location and height of floor mounted obstructions, the height of a representative observer and a termination distance that is dependent on the size of the sign lettering and the observation angle of the observer [11]. Once the agent is within the VCA of the sign they are able to physically see the sign. Whether or not they actually see and detect the sign is based on a probability distribution which is dependent on their relative orientation to the sign [10]. Thus, the agent is provided with an ability to make route finding decisions according to their knowledge level of the environment and the visual cues provided by the signage system. In the current implementation the decision making process has been simplified to represent the ideal situation in which if the sign is observed by the agent the information will be correctly interpreted and acted upon [10,11].

Two other important features of the Behaviour submodel are the Itinerary List (IL) and Redirection node. Using the IL it is possible to assign occupants a list of tasks to perform. The nature of the task can be to visit a pre-defined location and remain at the location for a pre-defined or random period of time. The Redirection node is a location within the geometry which contains several different ILs. When an agent visits a Redirection node they adopt, based on a probability distribution, one of the ILs provided by the Redirection node. In this way it is possible to randomly change an agents IL – and hence the tasks that they will perform - during a simulation. As certain behaviour rules, such as conflict resolution, are probabilistic in nature, the model will not produce identical result if a simulation is repeated.

The Hazard submodel controls the atmospheric and physical environment within the enclosure, such as the developing of fire hazards and the availability of exits. The Toxicity submodel determines the impact of various hazards defined in the Hazard submodel upon occupants, and passes the effect through communication with the Behaviour submodel. These five submodels work integratively to simulate the evacuation and movement of a population specified within structures.

THE HIGHER ORDER SIGN MODEL

Initial Concepts – Interacting with signage systems

Zero and first order signs provide direct information of an available exit or location within the geometry. Conversely, higher order signs link a network of signs in a chain that eventually leads to the desired target. The information relayed to an observer by a higher order sign amounts to the general direction where another sign is located that in turn is either another higher order sign in a continuous chain of signs or a 1st order sign pointing directly towards the desired target. Thus observers discover the direction in which they must travel in order to reach their desired destination without however gaining exact knowledge of the location of their target.

By utilising higher order signs an occupant can be continuously directed until the final destination is achieved. In effect the directed occupant "hops" from sign to sign until the desired (final) location is achieved. This concept is depicted in Fig. 2. where an individual P wishes to reach end point F without knowing the direction to the desired location. The occupant receives navigational information from the signage system. Assuming that the occupant observes the signs and understands the relayed information, the occupant can move from the vicinity of sign A to all subsequent signs (i.e. B, C, D, and E) until the zero order sign F is reached. The process is made more efficient if the VCAs of the various signs overlap as shown in Fig. 2.

A well designed signage network consists of a series of signs in appropriate locations directing and at the same time reinforcing the observer's confidence, while the occupant moves from sign to sign until a first or zero level sign is reached. In this way, occupants who are otherwise unfamiliar with the structure can reach their desired location without having a priori knowledge of the internal layout of the structure.

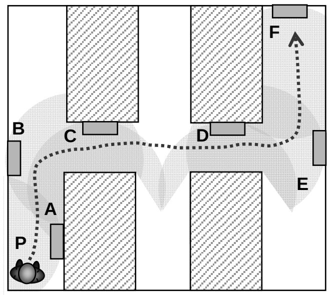


Fig. 2. N^{th} order signs (with VCAs highlighted) guide occupant P from starting location/sign A to desired target location/sign F

Due to the occupants unfamiliarity with the structure, their movement from sign to sign may not follow an optimal path but rather a sub optimal path that is influenced by the effects of navigating and actively seeking appropriate signs. A broken signage system, one that has gaps in the signage continuity or has signs that are conceived by the occupants to be placed too far apart can lead to time being wasted wayfinding or worse, to occupants being lost. Such a system might also have a negative psychological effect on the occupants making them lose faith in the reliability of the signage system. Poorly designed signage systems may force occupants to backtrack towards the previously seen sign, altering, perhaps with a negative effect their direction of travel. This type of behaviour may also occur in well designed signage systems if the occupant fails to detect the required sign. Occupants may also seek further information from fellow occupants or members of staff or might eventually miss their target location. In circulation scenarios this can lead to wasted time and occupant frustration, but in an emergency situation it may impact survivability.

Representing Higher Order Signs within the model

Signs used for circulation purposes often convey simultaneously information about more than one target destination, with the occupant consciously selecting the required information. A method therefore must be devised to incorporate the capability of signs to direct occupants to multiple targets. The method described here utilises the concept of the Redirection node in conjunction with the signage object to define the higher order sign object. The combination of signage objects and Redirection nodes allows the implementation of high order signs that provide directions to multiple target locations. The model is quite simple in concept. When an occupant enters the VCA of a sign and *the occupant detects the sign*, the Redirection node associated with the higher order sign conveys to the observer the required directional information leading to the next sign in the signage chain, this in effect updates the occupant's IL with the required target information (see Fig. 3). It is important to note that even if an occupant enters the VCA of a sign they may not detect the sign due to their relative orientation to the sign.

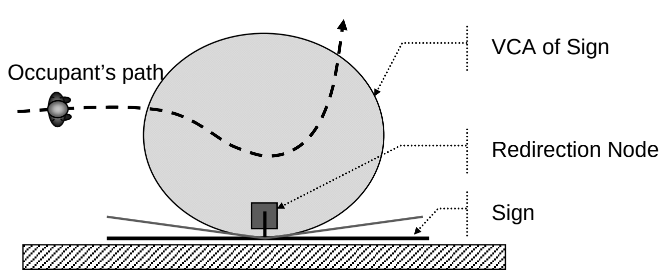


Fig. 3. Higher order sign consisting of sign object and associated Redirection node.

When an occupant using the signage system to navigate enters the VCA of the n^{th} sign *and detects the sign* they begin moving in the direction of the next sign in the signage system i.e. the $(n-1)^{th}$ sign, as indicated by the Redirection node. They continue moving until they enter the VCA of the $(n-1)^{th}$ sign at which point, if they again detect the sign, they pick up information relating to the next sign in the system i.e. the $(n\text{-}2)^{th}$ sign. This continues until they reach the zero order sign and their destination.

Thus, in a well designed signage system the occupant will be directed from sign to sign until the target location is attained. However, not all signage systems are well designed and occupants relying on a signage system may get confused, lose track of the next sign or get lost. If the occupant fails to detect the next sign in the signage system some or all of the following non optimal behaviours may be activated; Searching Behaviour, Backtracking Behaviour, Lost Behaviour and Fail Safe Behaviour.

Searching Behaviour

A person enters “signage searching behaviour” once they have travelled a distance of two thirds of the value of the *Expected Distance between the Signs* and failed to find the next sign or target exit. For the purposes of this demonstration, the initial value for this distance is set to 15m. During a simulation the *Expected Distance between the Signs* is continually updated as the occupant successfully detects signs and is replaced by the actual distance between the last two signs that were detected. During this mode of behaviour the simulated individual continues moving in the general direction of travel in accordance with the information received from the previously observed sign. This behaviour represents the fact that an individual expects to see a sign within a reasonable distance from the previously detected sign.

Backtracking Behaviour

When a person has entered “signage searching behaviour” and has travelled a distance of twice the value of *Expected Distance Between Signs* and failed to detect the next sign or target exit then “signage backtracking behaviour” is enabled. A person entering this behaviour will backtrack and head towards the location of the last known sign for a travel distance of twice the *Expected Distance Between Signs* or start location. This behaviour represents a verification stage in the person’s behaviour. The occupant goes back to the last location where they received information from the last detected sign and tries again to navigate towards the target.

Lost Behaviour

A person who has backtracked and returned to their previously encountered sign or start location and has failed to acquire further information regarding their target is assumed to be lost and so enters “signage lost behaviour”. This behaviour is triggered if the occupant has travelled 3.5 times the *Expected Distance Between Signs* or has returned to their last known sign or start location. At this stage the person who is lost will once again head towards the location directed to by the last encountered sign.

Additionally, the person will try to obtain information on the target’s location from the surrounding population. This behaviour utilises the normal communication capabilities within the software. The individual will target building staff in preference to other building occupants if they are available. Through this communication the person might acquire knowledge of the location of another sign or the final target. If direct information is provided as to the location of the target the person will ignore the signage system and head directly towards the target.

Fail Safe Behaviour

If a person has travelled a distance of four times the *Expected Distance Between Signs* and still has found neither their target nor another relevant sign or acquired information from the surrounding population they will enter “fail safe behaviour”. Under these circumstances in non-emergency circulation simulations, the individual will give up the search for their target and carries out the next task in their IL or exits the structure via the nearest available known exit. In evacuation simulations, the occupant will attempt to exit the structure via their nearest known exit – this may be the exit with which they entered the structure.

DEMONSTRATION SCENARIOS

The higher order sign capabilities described in this paper will be demonstrated through a range of scenarios utilising an arbitrary test geometry. The cases are simple in nature but are intended to highlight the nature of the implemented behaviours.

Test Geometry Description

The test geometry used in these demonstration scenarios is depicted in Fig. 4. The geometry consists of a large wide corridor that terminates to a cross corridor which in turn has an emergency exit located on the east side. Along the east wall of the structure a set of three high order signs have been placed. On the north wall a first order sign has been placed and a zero order sign above the Emergency Exit. The signage system has been designed to relay information regarding the location of the Emergency Exit. For all four scenarios a single occupant will utilise the signage system. The single occupant is placed in the south west corner of the structure and instructed to evacuate via the Emergency Exit.

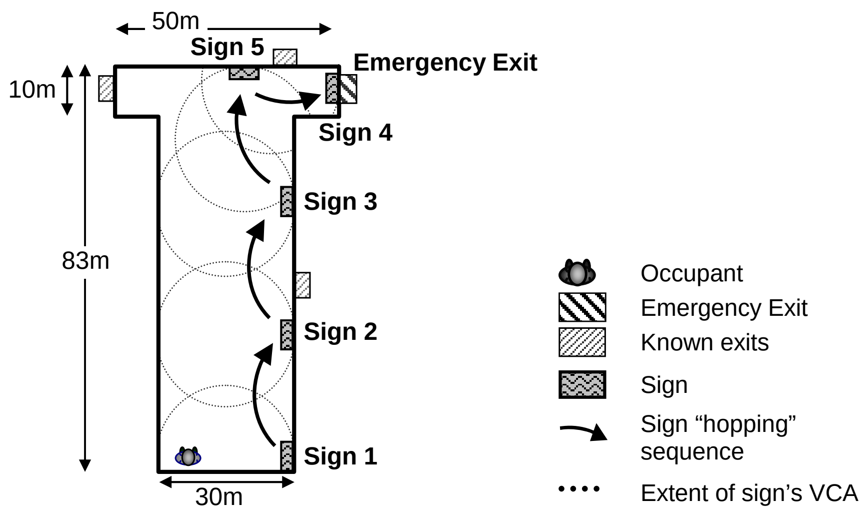


Fig. 4. Layout of demonstration geometry

For the purposes of this demonstration three alternative exits have been provided and are known to the occupant. One exit is placed on the East wall, one on the North wall and one opposite the Emergency Exit. These exits will enable the "Fail Safe" behaviour to be demonstrated if the test subject fails to find the target Emergency Exit.

Test Scenario Description

To demonstrate the model capabilities four test scenarios are considered. These scenarios demonstrate the higher order sign to sign navigation capabilities of the model in situations where the occupant is unaware of the location of the targeted external exit and so must be guided through the structure using the signage system. For the purposes of this demonstration a single occupant is initially located in the south west corner of the structure. The occupant has been instructed to exit the structure via the Right Emergency Exit however, the location of the exit is unknown to the occupant who is therefore forced to use the signage system to assist in wayfinding.

In the first three scenarios the VCAs of the signs are progressively reduced in order to demonstrate the impact of signage efficiency on wayfinding (see Fig. 5.). In the fourth scenario, the impact of communication between occupants on wayfinding is demonstrated. These scenarios will demonstrate the **Searching**, **Backtracking, Lost and Fail Safe** behaviours. In evacuation simulations, if a simulated occupant cannot find information regarding the targeted exit the Fail Safe behaviour is to exit via the nearest known exit. For simplicity of the demonstration several additional "known exits" have been placed in the geometry providing a convenient means of escape. In practice, the fail safe exit may be a distantly located entrance to the structure.

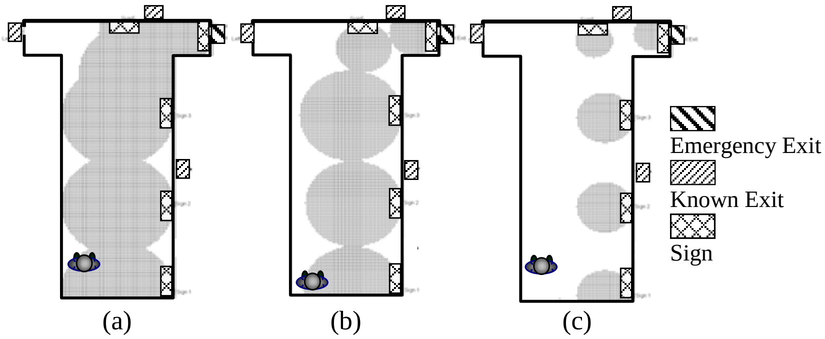


Fig. 5. Extent of VCAs used in the various scenarios; (a) Overlapping (b) Touching (c) Independent

MODEL RESULTS

As some of the behaviours within EXODUS are stochastic in nature, the software will not produce the same outcome if the simulations are repeated. In order to derive a better representation of the outcome of the demonstration scenarios, each scenario is repeated 10 times and the results for each of the 10 simulations are presented.

Scenario 1: Overlapping VCAs

In this scenario the lettering on each exit sign is 15.2cm in height generating VCAs with a maximum extent of 30m [12]. The VCAs created for these signs cover 82% of the floor area and are overlapping, therefore they provide an almost complete coverage of the enclosure floor space. Thus virtually no matter where occupants are located within the enclosure they are highly likely to be within the VCA of a sign and are highly likely to intersect the VCA of the next sign before they leave the VCA of the current sign (see Fig. 5a.). This scenario is intended to represent a well defined signage system that should be capable of leading occupants to the intended exit. Thus the most likely behaviour to be exhibited by the agent in this scenario is a smooth transition from one VCA to another with the agent managing to follow the sign chain to the target destination. While Backtracking or Lost behaviour is not expected to be observed some Searching behaviour may occur.

The paths taken during the 10 simulations are depicted in Fig. 6. In each of the 10 simulations the occupant successfully found the emergency exit. On three occasions in each of the 10 simulations the occupant entered the Searching behaviour (path sections 1, 2 and 3 in Fig. 6.) but was able to locate the next sign, with the second Searching segment being the longest of the three. While in the VCA associated with sign 3 the occupant detects sign 5 and almost immediately diverts towards the emergency exit, taking the shortest route to the exit, cutting the corner of the geometry (path section 4 in Fig. 6.).

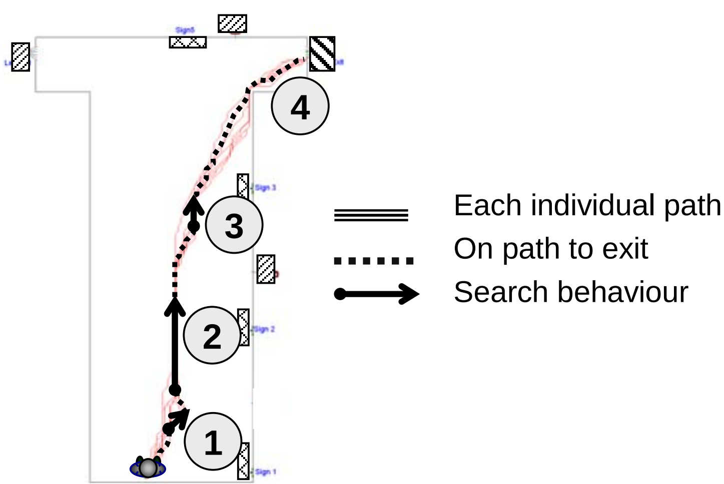
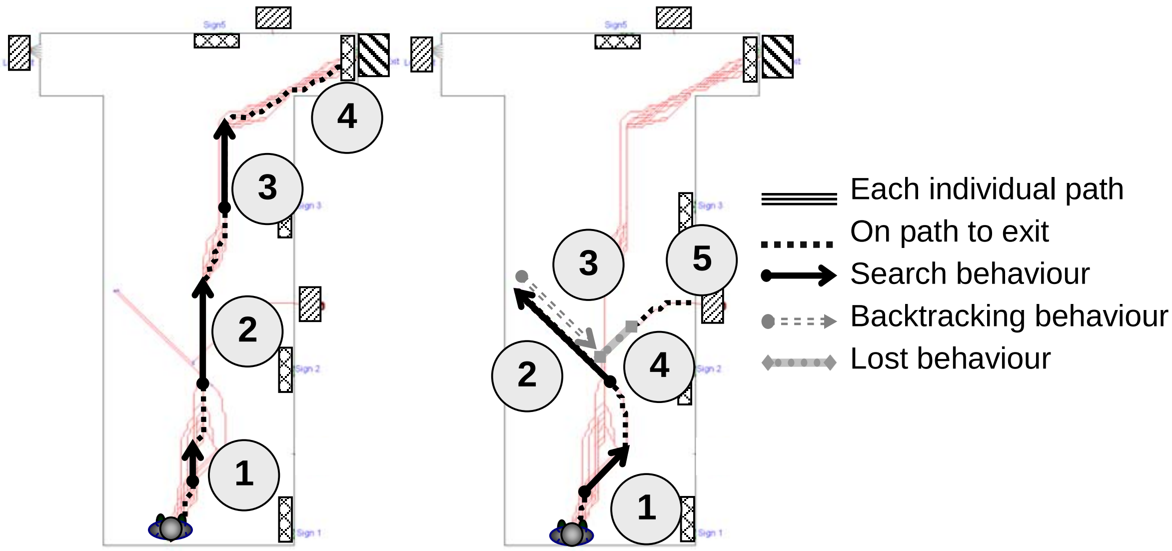


Fig. 6. Paths taken by occupant during 10 simulations in Scenario 1.

The very large VCAs associated with each sign, producing a floor coverage of 82%, results in a 100% success rate in locating the emergency exit.

Scenario 2: Touching VCAs

In this scenario the VCAs for each sign have been reduced (by decreasing the size of the lettering) to such an extent that they are tangent to each other (see Fig. 5b.). The floor space covered by the VCAs of the sign represents 65% of the total floor area.



(a) (b)

Fig. 7. Paths taken by occupant during 10 simulations in Scenario 2, (a) nine paths taken to emergency exit and (b) one path during fail safe behaviour.

In this scenario we are more likely to observe Searching behaviour, Backtracking and possibly Lost behaviours. The paths taken during the 10 simulations are depicted in Fig. 7. In nine of the 10 simulations the occupant successfully found the emergency exit (see Fig. 7a.) and in only one simulation was the occupant lost and failed to find the emergency exit and resorted to the Fail Safe Behaviour and exited by an known exit (see Fig. 7b.).

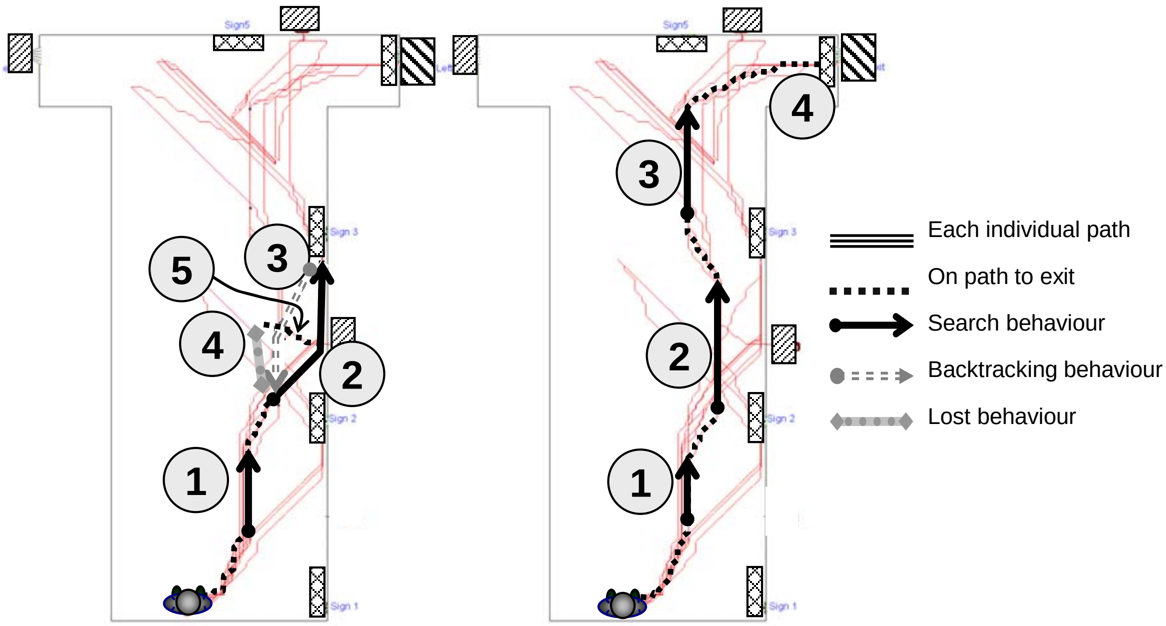
In each of the nine cases in which the emergency exit was found, the occupant entered the Searching behaviour on three occasions (path sections 1, 2 and 3 in Fig. 7a.). This is similar to behaviour exhibited in Scenario 1. However, unlike Scenario 1, the third period of Searching behaviour lasts considerably longer as the occupant attempts to locate sign 5. This longer search behaviour is a result of the smaller VCA associated with sign 5. Eventually sign 5 is detected and the occupant moves towards the emergency exit. We also note that the path taken to the exit in the final portion of the journey (path section 4 in Fig. 7a.) is not as optimal as that in Scenario 1. This is because the occupant takes longer to detect sign 5 and so must travel further towards the North Wall before making the turn towards the emergency exit.

In the one simulation in which the occupant fails to find the emergency exit (see Fig. 7b.) the occupant fails to see sign 2 even though he is within the VCA for the sign. He enters Searching behaviour (path section 2 in Fig. 7b.) and fails to see the sign and then enters Backtracking behaviour (path section 3 in Fig. 7b.). After failing to find a sign the occupant enters Lost behaviour (path section 4 in Fig. 7b.) and eventually enters Fail Safe behaviour and exits the structure via the nearest available known exit (path section 5 in Fig. 7b.).

Thus the smaller signs producing in VCAs which cover 65% of the floor area results in a 90% success rate in locating the emergency exits, a 10% decrease compared with the large VCAs found in Scenario 1.

Scenario 3: Independent VCAs

In this scenario the VCAs for each sign have again been reduced (by further decreasing the size of the lettering) to a point that the VCAs are independent and cover only 23% of the floor space (see Fig. 5c.). In this case large portions of the geometry are not covered by the VCA of a sign and so we expect occupants to have difficulty in navigating through the geometry. We are therefore likely to find a larger proportion of Backtracking and Lost behaviours and unsuccessful attempts at locating the emergency exit.



(a) (b)

Fig. 8. Paths taken by occupant during 10 simulations in Scenario 3, (a) one lost path leading to an exit on the East Wall (b) one of the four successful paths to the emergency exit.

The paths taken during the 10 simulations are depicted in Fig. 8. The paths appear more complex than in the previous cases as the occupant is often forced to enter Searching and Backtracking behaviours. In six of the 10 simulations the occupant was lost and unable to find the target emergency exit; in four of these cases the known exit on the North Wall was used as the fail safe exit, in one case the occupant elected to use the fail safe exit on the North Wall and then "accidentally" found and used the emergency exit, and in one case the occupant used the known exit on the East Wall (see Fig. 8a.). In four of the 10 simulations the occupant successfully navigated to the emergency exit (see Fig. 8b.).

In one simulation in which the occupant fails to find the emergency exit (see Fig. 8a.) the occupant is between the VCAs for sign 1 and 2 when they enter the Searching behaviour (path section 1 in Fig. 8a.). After travelling a short distance they again enter the Searching behaviour (path section 2 in Fig. 8a.) and fail to detect sign 3 and so eventually adopt the Backtracking behaviour (path section 3 in Fig. 8a.). Having failed to detect the sign they enter Lost behaviour (path section 4 in Fig. 8a.) and fail to find the emergency exit, leaving the geometry via the known exit on the East wall (path section 5 in Fig. 8a.). Depicted in the top part of Fig. 8a. are a number of paths where the occupant fails to detect the 1st order sign (sign 5 located on the North wall) pointing directly to the emergency exit and exit via the known exit located on the North wall.

In each of the four cases in which the emergency exit was found, the occupant entered the Searching behaviour on three occasions (path sections 1, 2 and 3 in Fig. 8b.). This is similar to behaviour exhibited in Scenarios 1 and 2. The third period of Searching behaviour lasts considerably longer than that in Scenarios 1 and 2 as the occupant attempts to locate sign 5. This longer search behaviour is a result of the considerably smaller VCA associated with sign 5 in this scenario compared to the other scenarios. Eventually sign 5 is detected and the occupant moves towards the emergency exit. We also note that the path taken to the exit in the final portion of the journey (path section 4 in Fig. 8b.) is the least optimal of the three scenarios. As in Scenario 2, this is because the occupant takes longer to detect sign 5 and so must travel further towards the North Wall before making the turn towards the emergency exit.

As expected, the extremely small VCAs associated with each sign – covering only 23% of the floor space - resulted in the highest proportion of lost individuals and unsuccessful attempts at navigating to the emergency exit. In total 60% of the exit attempts failed to locate the emergency exit.

Scenario 4: Independent VCAs with Occupant Communication

In this Scenario the same geometry is used as in Scenario 3, however, the geometry is populated with a variety of occupants, three of which have knowledge of the location of the emergency exit. These occupants are located adjacent to the known exit on the East Wall.

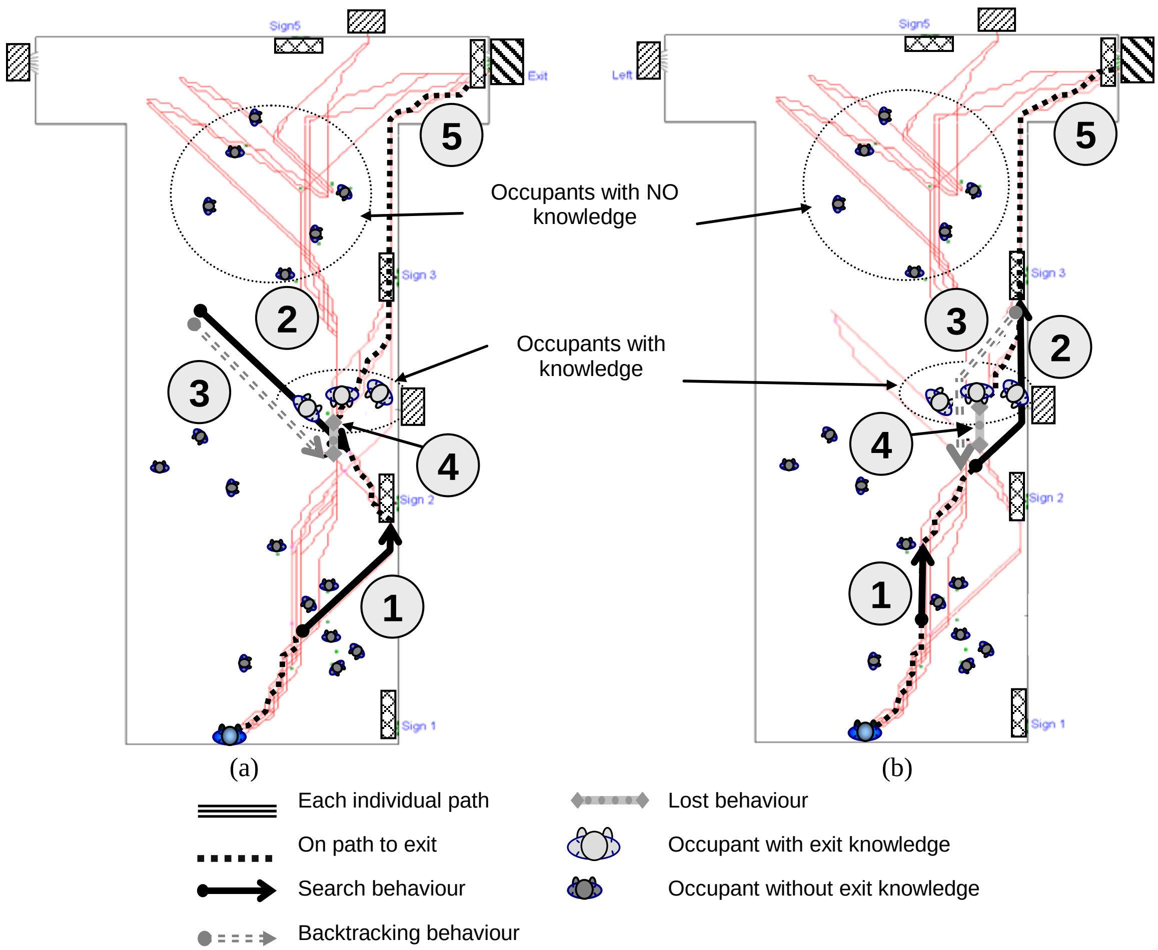


Fig. 9. Paths taken by the occupant during 10 simulations in Scenario 4, highlighted paths indicate path guided by information provided by other occupants.

The paths taken during the 10 simulations are depicted in Fig. 9. In six of the 10 simulations the occupant successfully navigates to the target emergency exit; in three of these cases the occupant navigates to the emergency exit using the signage system and in the other three cases relies on information relayed to him by the three knowledgeable occupants. Two of the three cases in which the occupant relies on communication are depicted in Fig. 9a. and Fig. 9b.

The path highlighted in Fig. 9a. depicts a situation in which the occupant fails to find sign 2 and enters the Searching behaviour (path section 1 in Fig. 9a.). After detecting sign 2 and continuing for a brief period the occupant again enters the Search behaviour after failing to find another sign (path section 2 in Fig. 9a.).

The occupant continues searching and then enters the Backtracking behaviour (path section 3 in Fig. 9a.) and returns to the vicinity of the known exit on the East wall at which point he enters the Lost behaviour (path section 4 in Fig. 9a.). After a brief period in the Lost behaviour mode the occupant successfully communicates with occupants who have exact knowledge of the location of the emergency exit. The occupant then takes a direct route to the emergency exit (path section 5 in Fig. 9a.). The path depicted in Fig. 9b. is a similar situation in which the occupant relies on directional information from other occupants. As with the case shown in Fig. 9a., once the occupant has been given information as to the exact location of the targeted emergency exit, they adopt the most optimal route to achieve their target.

Even with a poorly designed signage system (in this case consisting of extremely small signs), the probability of finding the targeted exit is greatly improved by the introduction of the communication capability allowing occupants to exchange exit location knowledge. Here we find that 60% of the attempts to locate the emergency exit were successful, with half of these successes being due to communications.

In reviewing the results of the above four scenarios, it must be remembered that in the current implementation the decision making process has been simplified to represent the ideal situation in which if the sign is observed by the agent the information will be correctly interpreted and acted upon [10,11]. Thus, the success rate presented above should be considered optimistic. In reality, even though a person may be within the VCA of a sign and may also be facing in the direction of the sign – and thus physically able to see the sign - they may not actually see the sign. Furthermore, even if they do see the sign, they may not react to the sign. This situation can be represented by introducing a probability that the sign will be seen and the information correctly interpreted and acted on. The authors are currently investigating this aspect through a series of experiments. It should also be noted that while the above examples did not include complications associated with visual obstacles obscuring the view of signs, the VCA approach can readily accommodate such complications. Finally, the key distances at which decisions are made to search, backtrack, etc are currently set globally as fixed multiples of the *Expected Distance Between Signs.* These factors are likely to be individually based and so future versions will incorporate this as an individual rather than a global parameter.

CONCLUSIONS

Whether building occupants are involved in evacuation activities or normal circulation activities, their wayfinding abilities can be enhanced through interaction with the structure's signage system. When modelling evacuation and circulation within an enclosure it is therefore important to represent the ability of the occupants to interact with the signage system. In this paper we have extended the VCA concept that allowed the representation of single isolated signs, to incorporate the more general situation involving chained signage systems. In addition to the system for representing the sign network, the behaviour sub-model of the egress model was extended to include the types of human behaviours associated with using a signage system for navigation, including: Searching, Backtracking, Lost and Communication behaviours. Thus, the simulated agents were provided with an ability to make decisions according to their knowledge level of the environment, the visual cues provided by the signage system and communications with other agents within the simulation.

In the current implementation the decision making process has been simplified to represent the ideal situation in which if the sign is observed the information will be correctly interpreted and acted upon. In future implementations, a factor representing less ideal behaviour will be introduced allowing the engineer to set a likelihood that the information will be followed. Ideally, this percentage should be based on data collected from experimentation. In addition, the key distances at which decisions are made to search, backtrack, etc are more likely to be individual preferences and so should be represented as individual parameters rather than global parameters. It would also be desirable to obtain survey data from actual complex environments where occupants make use of signage systems as a form of verification and calibration of the model. While the results generated using the implemented signage behaviour are based on an idealised model, they can offer useful insight into to engineering analysis. The use of such a capability augments the standard engineering practice of bracketing evacuation performance between the extremes of assuming that everyone will exit via their means of entrance (i.e. the upper limit of evacuation performance) and everyone will use their nearest exit (i.e. the lower limit of evacuation performance). Indeed, the assumption that occupants will follow the signage system provides a more reasonable lower limit to evacuation performance than assuming that everyone has perfect knowledge of the structure i.e. they move towards their nearest exit.

Including the chained sign functionality within evacuation simulations allows for a more reasonable and potentially more realistic investigation of the evacuation capabilities of a particular enclosure. The system can also be used to assist in the layout of signage systems within complex structures.

ACKNOWLEDGEMENT

The authors are indebted to the EU Framework 6 programme for funding this work through project AVATARS (TST4-CT-2005.012462) and to their AVATARS partners (BMT, FGC, ATM, University of Salford and Buro Happold) for their co-operation and support.

REFERENCES

[1] Sime, J., Escape Behaviour In Fire: ‘Panic’ Or Affiliation?, PhD Thesis, Department of Psychology, University of Surrey, Guildford, Surrey, UK,1984.

[2] Gwynne, S., Galea, E.R., Owen, M. and Lawrence, P.J, *Escape As A Social Response*, Published by the Society of Fire Protection Engineers, 1999.

[3] Weinspach, P.,M., Gundlach,J., Klingelhofer,H.,G., Ries, R. And Schneider, U., *Analysis Of The Fire On April 11th, 1996, Recommendations And Consequences For Dusseldorf Rhein-Ruhr-Airport*, Staatskanzlei Nordrhein-Wstfalen, Mannesmannufer 1 A, 40190 Duss, Germany, 1997.

[4] Report of the Tribunal of Inquiry on the Fire at the Stardust, Artane, Dublin, 14th Feb 1981

[5] Best, R.,L., Reconstruction Of A Tragedy: The Beverly Hills Supper Club Fire, Southgate, Kentucky, May 28, NFPA, 1977

[6] *Summerland Fire Commission Report*, Douglas: Isle Of Man Fire Report, 1974.

[7] Grosshandler W., Bryner N., Madrzykowski D. And Kuntz K., “Report of the technical investigation of the station nightclub fire”, NIST NCSTAR 2: Vol. I-II , National Institute of Standards and Technology, Gaitherburg, MD., USA, 2005.

[8] Gwynne S, Galea E R, Owen M, Lawrence P J and Filippidis L, Adaptive decision-making in buildingEXODUS in response to exit congestion, Fire Safety Science 6: 1041-1052. doi:10.3801/IAFSS.FSS.6-1041

[9] Gwynne, S., Galea, E.R., Lawrence, P.J. and Filippidis, L., ‘‘Modelling Occupant Interaction with Fire Conditions using the buildingEXODUS Evacuation Model,’’ Fire Safety Journal, Vol. 36, Issue 4, 327–357, 2001. DOI:10.1016/S0379-7112(00)00060-6

[10] Filippidis L., Galea E.R., Gwynne S., and Lawrence P., *Representing the Influence of Signage on Evacuation Behaviour with Evacuation Models*, Journal of Fire Protection Engineering, Vol 16, No1, 37-73, 2006. DOI: 10.1177/1042391506054298.

[11] Hui X, Filippidis L, Gwynne S, Galea E.R., Blackshields, D., and Lawrence P., “Signage Legibility Distances as a Function of Observation Angle”, Journal of Fire Protection Engineering, Vol 17, No1, 41-64, 2007. DOI: 10.1177/1042391507064025.

[12] NFPA, *Life Safety Code Handbook*, National Fire Protection Association, Quincy, MA, 1997