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IMPLEMENTATION OF COGNITIVE MAPPING, SPATIAL REPRESENTATION AND WAYFINDING BEHAVIOURS OF PEOPLE WITHIN EVACUATION MODELLING TOOLS

ANAND VEERASWAMY, PETER J. LAWRENCE AND EDWIN R. GALEA
Fire Safety Engineering Group
The University of Greenwich, London SE10 9LS, UK

ABSTRACT

Within the building evacuation context, wayfinding describes the process in which an individual located within an arbitrarily complex enclosure attempts to find a path which leads them to relative safety, usually the exterior of the enclosure. Within most evacuation modelling tools, wayfinding is completely ignored; agents are either assigned the shortest distance path or use a potential field to find the shortest path to the exits. In this paper a novel wayfinding technique that attempts to represent the manner in which people wayfind within structures is introduced and demonstrated through two examples. The first step is to encode the spatial information of the enclosure in terms of a graph. The second step is to apply search algorithms to the graph to find possible routes to the destination and assign a cost to the routes based on their personal route preferences such as "least time" or "least distance" or a combination of criteria. The third step is the route execution and refinement. In this step, the agent moves along the chosen route and reassess the route at regular intervals and may decide to take an alternative path if the agent determines that an alternate route is more favourable e.g. initial path is highly congested or is blocked due to fire.

INTRODUCTION

Within the building environment, wayfinding describes the process by which an individual located within a complex enclosure decides on a path or route in order to reach a goal location. Within the building evacuation context, wayfinding describes the process in which the individual attempts to find a path which leads them to relative safety, usually the exterior of the enclosure.

The process of wayfinding requires the individual to have a cognitive or mental map of the space. Cognitive mapping has been defined as the process by which an individual acquires, stores, recalls and decodes spatial information[1]. According to the Landmark, Route, Survey (LRS) model[2], cognitive mapping involves individuals first extracting key landmarks from the environment. Within the built environment, these landmarks may be internal exits, external exits, rooms, escalators, stairs, lifts, sculptures, etc. Route knowledge then develops as the individual associates landmarks with routes and a mental map of the required route is formed. Survey or configurational knowledge is said to have been attained when the map is more complete and the person can find a path from any point in a building to any other point even though he/she may not have traversed that path.

In most evacuation modelling tools, the process of wayfinding is either ignored or grossly simplified. In a recent review of 30 evacuation models wayfinding features were only mentioned in context of two models[3]. On the whole, evacuation models assume that the simulated agents have complete knowledge of the structure and so follow a potential or distance map to their nearest exit. Some models may even assume that a proportion of the occupants have partial knowledge of the structure and so are familiar with only some of the exits[4]. At least one model incorporates agent interaction with signage allowing agents completely unfamiliar with the structure to follow a signage chain leading to an exit[5].

This paper provides a framework for representing wayfinding within evacuation models. As part of this work the paper describes an approach to representing Spatial Recognition – or the connectivity of the building space - and cognitive mapping within the "mind" of the agent and how this is used for wayfinding. The wayfinding approach is then implemented within the buildingEXODUS[4, 5] model and demonstrated through several simple evacuation scenarios.

WAYFINDING

Wayfinding has been defined by Passini as a cognitive process comprising of three distinct abilities: a cognitive-mapping or information generating ability that allows us to understand the world around us, a decision making ability that allows us to plan actions and to structure them into an overall plan of action; and a decision executing ability that transforms decisions into behavioural actions[6]. However, this definition does not include the possibility of modifying the initial plan of action based on new information gained during the execution of the plan. In an evacuation situation this may result from the original path being blocked by fire hazards or a segment of the original route being heavily congested, or may simply be the result of noticing an emergency exit sign pointing in a different direction. Downs and Stea have an alternative view of wayfinding which comprises four distinct stages[1]. These are; spatial orientation which is the identification of the self location and target location within the environment; the selection of the initial route from the starting location to the target; continuous monitoring of the route taken, modified by estimates of self location and target location and reassessment or confirmation of route choice; and finally, the ability to recognise when the target has actually been reached.

In his study of urban based wayfinding, Golledge[7] devised a series of hypothetical maps and asked test subjects to plan a route from point A to point B. The 32 test subjects were then asked to rate the various wayfinding criterion they used in determining their path using a 7-point scale with 7 being the most important. The selected criteria, in order of priority, as being the most important in influencing an individual's route selection or wayfinding decisions; shortest distance(4.2), least time(4.1), fewest turns(3.6), most scenic/aesthetic(3.5), first noticed(2.5), longest leg first(2.3), route involving many curves(2.3), route involving many turns(1.8), route different from the previous one(1.8) and shortest leg first(1.7). The numbers shown in the brackets next to each criterion is the mean rating achieved by each criterion. Distance and time thus form the most important criteria affecting human wayfinding in urban environments. Golledge's work provides a basis for implementing a wayfinding algorithm within evacuation software. However, some of the Golledge's criteria are not appropriate for building evacuation applications, being more suited to urban based wayfinding, for example, "most scenic/aesthetic routes" and "the first noticed route". In addition, some of the criteria are opposites to other criteria, for example, "longest leg first" and "route involving many turns" are opposite to "shortest leg first" and "route involving fewest turns".

In this work the criteria used by the agents in wayfinding, or selecting an appropriate route, in order of importance, from most to least important are; total distance, total time, total number of turns, longest leg first, angle of turns and total number of decision points. The additional criterion "angle of turns"

has been added as Ruth Conroy has shown that people tend to follow the route with minimum angular deviation as long as it is in the direction of their final destination[8]. Furthermore, the additional criterion "total number of decision points" has also been added as it has been demonstrated that the more choice points people have to pass through along their path the more complex the path appears to be and people have a tendency to minimise complexity when it comes to wayfinding[9]. We call this collection of criteria the "building wayfinding criteria" or BWC.

IMPLEMENTATION OF WAYFINDING ALGORITHM

The wayfinding algorithm implemented within the buildingEXODUS software involves a three stage process. The first step is to encode the spatial information of the enclosure in terms of a graph. The second step is to apply search algorithms to the graph to find possible routes to the destination and assign a cost to the routes based on their personal route preferences such as "least time" or "least distance" etc. The routes which offer the least cost or within 10% of the least cost and hence which most closely matches the agent's preferences is selected. The third step is the route execution and refinement. In this step, following the concept of Downs and Stea[1], the agent moves along the chosen route and reassess the route at regular intervals and may decide to take an alternative path if the agent determines that an alternate route is more favourable e.g. initial path is highly congested or is blocked due to fire.

Spatial Representation

Spatial representation of the enclosure is achieved by creating a mathematical graph the connectivity of which is representative of the enclosure. The key elements of the enclosure are the rooms (and corridors), the internal exits and the external exits. Each of these elements is considered a node in the graph. These nodes are linked by arcs which represent the actual connectivity between the enclosure elements. A sample building is shown in Figure 1. The connectivity graph for the building is shown superimposed on the original building in Figure 2.

Cognitive Mapping

The second task requires the agents to possess a cognitive map in order to find optimal and sub optimal routes. The connectivity graph is converted to a tree to enable a faster search of viable routes. The exit nodes form the root nodes of the tree. Nodes are then added in the following order; exit nodes to room nodes to internal exits. This order is followed as people will tend to move from their present room to an internal exit to another room and so on until they are in the final room from which they exit the enclosure. The final tree produced using this method is an example of an acyclic graph[10]. A property of this type of graph is that any specific path cannot involve cycles and hence a room cannot be visited more than once on any particular path. For large complex buildings the tree produced using this method can be rather large requiring long computational times to search the paths of the tree. To address this problem, heuristics[11] can be applied in order to prune the tree thereby reducing the size of the tree at the cost of eliminating possible routes. However, heuristics can be devised to eliminate high cost routes. Each agent will only have access to a subset of the tree based on their familiarity with the enclosure. For example an agent who is familiar with only one of the building exits will be allowed to search only that part of the tree which is connected to that exit.

A cost function is associated with each path in the tree. The cost function is determined by taking a weighted sum of the normalised route preference criteria (RPC) associated with an agent. Before the cost function can be determined the route preference criteria e.g. travel distance, travel time, number of turns, etc must be determined.

The RPC for each route are determined using appropriate data associated with each route. In the work presented here, the route preference criteria are determined using exact values associated with each route. In real life individuals will not be able to determine these values with certainty and so fuzziness should be introduced into the estimation of these parameters. For example, population sub-group 1 will have perfect knowledge of the building and so will be able to determine the parameters precisely; sub-group 2 may be less familiar with the enclosure and so a certain amount of fuzziness will be introduced into the determination of the parameters, while sub-group 3 will be unfamiliar with the enclosure and so a more significant degree of fuzziness will be introduced into their estimation of the parameters.

The various RPC used in this analysis were identified above and are determined as follows:

- **Distance - RPC_1 :** Distance of the path is the sum of the lengths of all the links in a path.
- **Time – RPC_2 :** The time taken to traverse the path is the sum of the time taken to traverse the distance of the path and the time spent in congestion at each internal exit node along the path. As the congestion at each internal exit is not known at the start of the simulation an arbitrary level of congestion is assumed, with parameters such as agent speed, door width, queue size kept constant for all agents and all paths (see equation (1)).

$$\text{Time} = D/S + (N*Q) / (UFR*W) \qquad [1]$$

D	= Distance of the path in meters
S	= Agent walk speed in m/s = 1.35 m/s
N	= Number of doors along the path
Q	= Size of the queue at each door = 20
UFR	= Unit flow rate of the doors = 1.33 occ/m/s
W	= Width of the door in meters = 2 m

- **Average angle – RPC_3 :** The average angle of the path is defined as the sum of the angles made at each intersection in the path. This angle is always the non reflex angle at the intersection. The angle is between 0 and 180, with turning back taken as 0 and going straight taken as 180[8]. The higher the angle the more straight the path is and hence the more preferable.

- **Turns – RPC_4 :** At each intersection of the path, the angle of intersection is calculated and the number of turns is increased by one for each intersection making an angle less than 175°. An intersection with an angle between 175 and 180 is almost straight and hence is not considered a turn. Routes with more turns are estimated to be longer than routes with less turns as shown by Sadalla and Magel[12]. Hence the more turns in a route the less preferable the route is.

- **Length of First Leg – RPC_5 :** This is the length of the first link of each path. The longer the first leg of the path, the more preferable the path is.

- **Decision Points – RPC_6 :** A room node is considered to be a decision point if there is more than 1 internal exit in the room. An internal exit is considered to be a decision point if there are more than 2 internal exits connected to it. The sum of the decision points along a path is the total number of decision points in the path. The more the number of decision points along the path the less preferable the path. Presently a T intersection with no internal exits is not considered as a decision point. The ability to recognise such intersections as a decision point will be incorporated in future.

Each RPC is then normalised by identifying the largest value of RPC_k, for route preference criteria k, for all the identified routes i.e. MAX RPC_k and dividing all the other RPC_k values by MAX RPC_k. This process is repeated for all the RPC with the exception of RPC_3 and RPC_5. Unlike the other criteria which are inversely related to the preference value, RPC_3 and RPC_5 are directly related to the preference value of a route. That is, the higher the angle of a route or the longer the length of the first leg the more preferable the route is. These RPC are normalised by identifying the largest value of RPC_k for all identified routes, subtracting MAX RPC_k from all RPC_k and dividing the difference by MAX RPC_k. For RPC_3, MAX RPC_3 is taken as 180 since that is the largest possible angle.

Having determined the normalised values for the route preference criteria i.e. $\overline{RPC_k}$ the cost associated with route "i" for agent "j" with route preference weightings $W_{k,j}$ for route preference criteria "k" is given by:

$$\text{Cost}_{i,j} = W_{1,j} * \overline{RPC_{1,j}} + W_{2,j} * \overline{RPC_{2,j}} + W_{3,j} * \overline{RPC_{3,j}} + \ldots + W_{6,j} * \overline{RPC_{6,j}} \qquad [2]$$

Where;
$W_{k,j}$ stands for the personal weightings associated with $RPC_{k,j}$ for agent "j". The sum of all the weights for agent "j" adds to 100.

In this way a route cost is determined for each route based on the personal wayfinding preferences of each agent. The route with the lowest route cost provides the best match with the agent's personal wayfinding preferences.

Route Execution and Refinement

The third step in the process involves the agent moving along the selected path. Here we have two approaches, non-sequential wayfinding (NSW) and sequential wayfinding (SW). In NSW, all agents make a route decision from their initial position and maintain their chosen path throughout the simulation. Using this approach there is no refinement of the exit route. In SW, the agent is able to modify their route based on congestion or fire conditions they encounter on their way to an exit. Here we simply include modifications to the selected path based on congestion. Congestion impacts the route preference criteria RPC_2 i.e. the estimated time required to travel along the chosen path. There are two approaches which can be used to take this into account:

- **Local-Prescribed (LP):** Using this approach equation 1 is used to estimate the time penalty at each door along the path with the exception of the door in the room the agent is currently in. The agent is assumed to have access to all the information in their current room and so knows the size of the crowd at each internal exit, the size of each door and the flow rate for each door. All the other doors along the various routes are assumed to have the previously defined default values. This information is used to re-evaluate the route options from the current location (using equation 1).

- **Local-Local (LL):** This approach is similar to the previous approach however, rather than using the default values to estimate the time required to pass through all the other doors, the agent assumes that all the other doors along the various routes will have similar conditions to the local doors in their current room.

Finally, in the current research implementation of this methodology, the wayfinding decision making is implemented using a coarse node model which passes the route information to the agents in the fine node buildingEXODUS evacuation model.

DEMONSTRATION CASE 1:

In this section a simple building is considered and the steps involved in creating a tree or a cognitive map of the building are outlined. The demonstration geometry is a simple enclosure with three rooms R23, R24 and R25 connected via internal doors and two corridors R21 and R22. Each of the rooms is also connected to corridor R22. The room R23 and corridor R22 are connected to corridor R21. The corridor R21 is connected to the only external exit (see Figure 1). The connectivity graph for the enclosure is shown in Figure 2. Note that the logical paths are determined by the sequence; room to internal exit to room to internal exit .... to room to external exit. However, within the coarse node model, the agent's paths are simply internal exit to internal exit to internal exit .... to internal exit to external exit. In this example, all the agents are initially located in room R25 for simplicity.

Each agent searches a subset of the main tree connected to the known exit based on the agents exit familiarity. Consider room node R25 (see connectivity graph in figure 2), there are seven paths (acyclic paths which does not involve visiting the same room more than once) from the room node R25 to the (only) exit node E0; these paths are:
Path 1: R25 I11 R22 I1 R21 E0
Path 2: R25 I18 R24 I13 R23 I4 R21 E0
Path 3: R25 I11 R22 I7 R23 I4 R21 E0
Path 4: R25 I18 R24 I10 R22 I1 R21 E0
Path 5: R25 I11 R22 I10 R24 I13 R23 I4 R21 E0
Path 6: R25 I18 R24 I10 R22 I7 R23 I4 R21 E0
Path 7: R25 I18 R24 I13 R23 I7 R22 I1 R21 E0

A similar collection of paths is constructed from each room to the external exit and stored in each of the room nodes. As agents enter each room they are given this route knowledge. This approach is more efficient than requiring each agent to search the tree for paths.

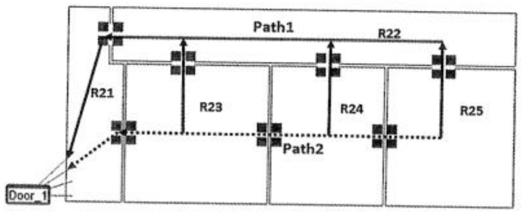

Figure 1: Building 1 containing three rooms (R23, R24 and R25) and two corridors (R21 and R22) having an area of 108.50m^2.

The values for the various RPC for each path originating from R25 are presented in Table 1. From these values the normalised values are determined and the normalised values are combined with the personal weights associated with each criterion to produce the total score for each path. While it is possible for each agent to have their own unique weight distribution, for simplicity, in all the cases presented here, the weight distribution for each agent is identical. Several different scenarios were investigated using different weight distributions. Here we present the results for two scenarios. In Scenario 1 the following weight distribution was used for the BWC; total travel distance (45%),

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estimated travel time (40%) with the other four parameters sharing the remaining 15%. This particular weight distribution biases the total travel distance with the greatest weight and hence we expect that the preferred path will be one in which the total travel distance is small. This weight distribution is suggested by the authors as possibly being a realistic representation of how people plan routes. We call this distribution when applied to the BWC the "realistic weight distribution" (RWD).

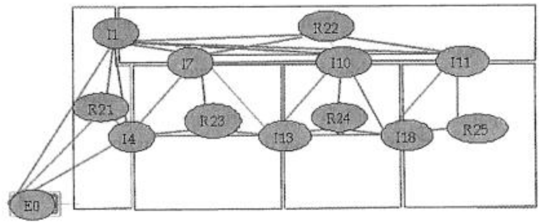


Figure 2: Connectivity graph of Building 1 overlaid on the Building 1 geometry.

Table 1: Values of the RPC for each path from room R25

Paths	Distance(m)	Time(s)	Turns	Average angle (degrees)	Length of first leg (m)	Decision Points
Path 1	21.72	38.65	1	105.55	12.01	3
Path 2	16.29	42.14	1	167.75	4.00	4
Path 3	20.44	45.22	2	126.88	8.99	4
Path 4	20.85	45.52	2	116.78	3.35	4
Path 5	20.44	52.74	3	124.65	3.99	5
Path 6	19.56	52.08	3	129.52	3.35	5
Path 7	20.42	52.72	3	138.75	4.00	5

The total score and for each path is: Path 1, 79.5; Path 2, 71.7; Path 3, 84.2; Path 4, 86.8; Path 5, 93.3; Path 6, 91.0; Path 7, 92.9. The path with the lowest score is considered to be the path that most closely matches the route preference criteria of the agent. All paths with a score within 10% of the minimum score are considered viable. Within the simulation, the agents are randomly assigned the viable paths which they follow to the exit. In this example the following paths are considered viable:
Path 1: R25 I11 R22 I1 R21 E0
Path 2: R25 I18 R24 I13 R23 I4 R21 E0

These paths are the most direct paths, with Path 2 being the most direct. Path 2 produced the lowest score and Path 1 was 9.8% larger than Path 2 and so was also considered acceptable. It is interesting to note that Path 2 was the shortest distance path, while Path 1 was the greatest distance path. As the distance travelled is the most important RPC it maybe surprising that Path 1 was considered. However, we also note that Path 1 produced the shortest time estimate as it only involved passing through two internal doors. As the time RPC had almost the same weight as the distance the penalty incurred for high travel distance was balanced by the benefit gained by the short travel time. The worst path is path 5 which requires the agent to visit R25, R22, R24, R23 and R21 prior to exiting and so the agent must pass through many internal doors incurring high time penalties.

Path 5: R25 I11 R22 I10 R24 I13 R23 I4 R21 E0

For Scenario 2 a different weight distribution was investigated. This involved using a weight distribution which corresponded to Golledge[7] criteria which are applicable to wayfinding within buildings. In this case weights for the angle and decision points are ignored as these criteria were not part of the Golledge criteria. In Scenario 2 the following weight distribution was used; total travel distance (29.5%), estimated travel time (28.8%), number of turns (25.4%), longest leg (16.2%) and is referred to as the "Golledge weight distribution" (GWD). As with Scenario 1, this weight distribution biases the total travel distance with the greatest weight and hence we again expect that the preferred path will be one in which the total travel distance is small. The total score and for each path is: Path 1, 59.2; Path 2, 64.5; Path 3, 73.5; Path 4, 81.9; Path 5, 92.8; Path 6, 92.1; Path 7, 92.8. Path 1 is selected as the optimal path with Path 2 being within 10% of Path 1, so both Paths 1 and 2 are considered viable paths. The weighting used in Scenario 2 results in the same two paths being selected as in previous scenario. However, the path with the minimum score is maximum travel distance minimum time path. While the two viable paths are the same in each scenario, this analysis does demonstrate that it is possible to generate different optimal paths depending on the nature of the weight distribution selected. As Scenarios 1 and 2 have the same two viable paths, the results generated from the buildingEXODUS simulations are expected to be similar.

To examine the implication of the selected paths on an evacuation simulation the viable paths were implemented in a buildingEXODUS evacuation simulation involving Building 1. The building was populated with 50 agents in room R25 half the agents were given Path1 as their optimal path and half the agents were given Path 2 as their optimal path. The simulation was run 20 times and the average results presented in Table 2. In Table 2, the average CWT is the average cumulative wait time (time spent in congestion) for the whole population, the average PET is the average personal elapsed time (the time spent by each agent in the simulation till they exit), the average distance is the average distance travelled by the whole population. For comparison purposes an additional scenario (scenario 3) was run in which the agents simply followed the standard distance map to the exit, thereby selecting the path of minimum travel distance, Path 2. As can be seen from Table 2, using the wayfinding algorithm, the total evacuation time (40.8 s) is considerably lower than in the standard evacuation case (59.0 s) where everyone uses the minimum distance path. This is primarily due to reduced congestion experienced by the population on the way to the exit through the use of two exit paths.

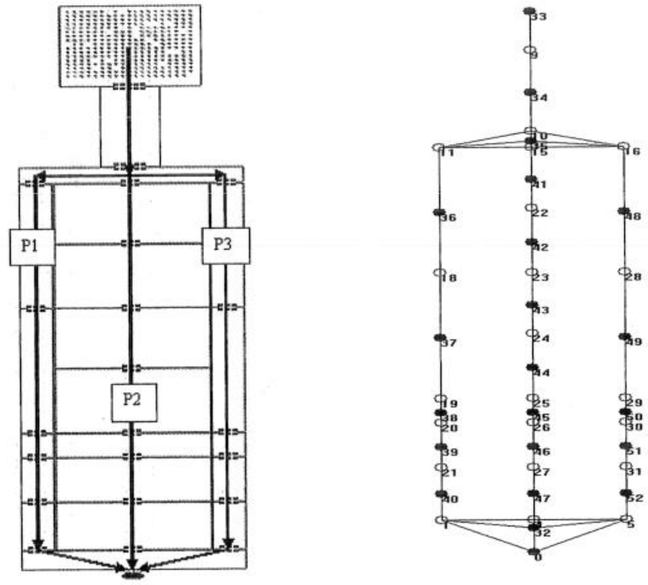
Table 2: Average evacuation simulation statistics for 20 repeat simulations of each scenario for Demonstration case 1 using non-sequential wayfinding.

	Average CWT(s)	Average Distance(m)	Average PET(s)	Number of people Using Path1	Number of people Using Path2	Total Evacuation Time (s)
Scenario 1/2	10.9	19.0	27.5	25	25	40.8
Scenario 3	22.0	16.3	37.0	0	50	59.0

DEMONSTRATION CASE 2:

Presented in Figure 3 is the geometry for Demonstration Case 2. This consists of an assembly room (top room of Figure 3a) with a population of 300 agents, connected via a wide corridor to a horizontal corridor leading to three connections to the other part of the structure; a long vertical corridor on the left, a central collection of seven rooms lined vertically from top to bottom and another long vertical corridor on the right. Each room within the central section is connected to the next room via a set of doors. The two long vertical corridors flank the vertical collection of the rooms, one to the left and one to the right. Each corridor is separated into five compartments with six internal doors. The final exit to the geometry is at the bottom of Figure 3a. There are three different

paths to the exit; P1, P2 and P3. The most direct path to the exit is P2 which is the path from the assembly room to the exit via the central section. The two alternate exit paths are; P1 which is the path via the left corridor and P3 which is the path via the right corridor. The shortest path is P2 which requires the agents to pass through 10 internal doors prior to exiting, two more than encountered on paths P1 and P3. Within this demonstration case, agents have knowledge of all three P1, P2, P3. Note while other paths are possible, they require the agent to revisit at least one compartment on the exit path and hence are not considered (cyclic graph).



(a) (b)

Figure 3: Geometry of Demonstration case 2 showing (a) three exit paths (P1, P2, P3) from assembly room and (b) connectivity graph for case 2 (filled black circles are room nodes, open circles are internal exits and the grey filled circle is the exit external exit).

Several cases are examined. In Scenario 1 the standard distance map approach is used in which the agents select the shortest path. In Scenario 2 NSW is considered, similar to Case 1. Two weight distributions are examined, the RWD (Scenario 2a) and the GWD distribution (Scenario 2b). In Scenario 3 SW is applied using the RWD with Local-Prescribed and Local-Local time estimation (Scenario 3a and 3c respectively) and the GWD with Local-Prescribed and Local-Local time estimation (Scenario 3b and 3d respectively). The results from the evacuation simulations for these scenarios are presented in Table 3.

In Scenario 1, using the distance map approach, all the agents take the shortest route which is P2, straight down the centre and through the seven rooms. This results in a total evacuation time of 212.2 s, an average distance travelled of 64.7 m and an average CWT of 59.2 s. From a realism perspective, these results may be considered questionable as all the agents have used a single path, ignoring the other two routes completely. In Scenario 2a the non-sequential wayfinding algorithm is used with the "realistic" weight distribution. Here we find that all three routes are viable with Path2 producing the lowest cost and the other two paths being within acceptable cost limits. As in Case 1, we have simplified the analysis by providing the entire population with the same weight distribution, this means that the entire population can select any one of the three routes. As a result, to simplify the analysis, we simply allocate one third of the population to each path. Here we find that the total evacuation time decreases to 143.2 s, a decrease of some 33% while the average distance travelled becomes 71.8 m, an increase of 11%. While the average distance travelled has increased, the total evacuation time has decreased due to the reduction in average time spent in congestion. This has decreased by some 63%. In Scenario 2b the Golledge weight distribution was used. This resulted in only Path2 being selected as the only viable path and hence the results are identical to Scenario 1. Here we note that the difference in the nature of the weight distribution has made a significant difference in terms of the identified viable paths and hence the overall results of the evacuation simulation. It is important to note that even though the relative weighting of the two main RPC – distance and time – are similar using the two different weight distributions, the relative weighting of the minor RPC and the nature of the minor RPC included in the cost function are quite different and for this problem this resulted in significantly different outcomes.

Table 3: Average evacuation simulation statistics for 20 repeat simulations of each scenario for Demonstration case 2 using non-sequential and sequential wayfinding

	Wayfinding Criteria	Average CWT (s)	Average Distance (m)	Number of people Using Path1	Number of people Using Path2	Number of people Using Path3	Total Evacuation Time (s)
Scenario 1	Distance Map	59.2	64.7	0	300	0	212.2
Scenario 2a	NSW, RWD	21.6	71.8	100	100	100	143.2
Scenario 2b	NSW, GWD	59.1	64.7	0	300	0	212.2
Scenario 3a	SW, RWD, LP	22.8	71.1	91	119	90	143.8
Scenario 3b	SW, GWD, LP	59.1	64.7	0	300	0	212.2
Scenario 3c	SW, RWD, LL	22.9	71.0	85	122	93	144.0
Scenario 3d	SW, GWD, LL	25.2	70.5	86	136	78	149.3

In Scenario 3 we consider sequential wayfinding (SW). In non-sequential wayfinding (NSW), the agent makes a decision as to which path to follow from their starting location and maintains the selected path until they have successfully evacuated. In SW we allow the agents to reassess the viability of their selected path each time they enter a new compartment. As discussed above, in the current implementation, the only RPC which changes during the simulation is the time criterion. This is based on the congestion at the doors of the compartment the agent is currently occupying. As described earlier, the time analysis can be based on the Local-Prescribed (LP) and Local-Local estimations (LL).

When evaluating the paths, only acyclic paths are considered potentially viable i.e. paths which do not have compartments that are revisited. However, the path determination does not include "memory" and so viable paths may include compartments that were visited at an earlier time, thus backtracking is possible. For example consider an agent in compartment (node) 48 (see Figure 3b) When the agent re-evaluates the paths from room 48, the available paths are:

Path1: 48, 28, 29, 30, 31, 5, 0
Path2: 48, 16, 11, 18, 19, 20, 21, 1, 0
Path3: 48, 16, 15, 22, 23, 24, 25, 26, 27, 4, 0

It should be noted that in all the simulations presented in this paper backtracking was not observed and hence only the three core paths were considered viable. Furthermore, future versions of the

model will include a contra-flow penalty for agents who backtrack as part of the cost function evaluation.

The results for Scenario 3a and 3b concern the cases with using the LP time estimation with the RWD and GWD respectively are presented in Table 3. Using the RWD we note that 91 agents use Path1, 119 use Path2 and 90 use Path3. Initially all three paths were considered viable, with Path2 producing the minimum cost, but unlike Scenario 2a we do not have an equal distribution of agents to all three paths. Using the SW we note that fewer occupants eventually decided to take Path1 and 3. The agents decided to ignore these paths when they entered the horizontal corridor and were faced with the three different route options. When the agents recalculate the viability of the paths, they take into account the congestion that occurs at the three internal exits at the start of each of the three paths. This will be different for each agent as they encounter the exits at different times in the simulation. Using the LP time estimation, they will only use the local conditions for the local exit and use the prescribed conditions for all the other exits. While Path2 has more internal exits and hence will be at a disadvantage with the time calculation, Path2 is also the shortest route and so will have a time (as well as a distance) advantage. The advantage/disadvantage of the various paths will change during the simulation, but at the end of the simulation Path2 is favoured by the majority of the agents. This only results in a small time increase when compared with Scenario 2a using non-sequential wayfinding and the RWD. Using the GWD, Path2 is considered to be the only viable path, as with the NSW (scenario 2b).

The results for Scenario 3c and 3d concern the cases with using the LL time estimation with the RWD and GWD respectively are presented in Table 3. Initially all three paths were considered viable (Path2 again producing the lowest cost) however, using the RWD we note that even fewer agents elect to use Paths 1 and 2 with an average of 122 electing to use Path2. Using this time estimation method agents assume the number of agents and hence the congestion at the other exits based on the congestion that they experience at the local conditions. This may be a poor assumption and lead to sub-optimal path selection, but it may be a more realistic situation. Using this weight distribution and the LL time estimation we again note that the time increases slightly over the time for the non-sequential wayfinding with the RWD. Finally, using the LL time estimation and the GWD we find a different trend to that found using the RWD. In this case even more agents elect to utilise the central path resulting in a slightly greater increase in the total evacuation time.

CONCLUSIONS

If agents within evacuation simulations are simply permitted to select the shortest exit path, unrealistic evacuation dynamics may result leading to over use of particular paths with associated predicted evacuation times being unreliable. The introduction of wayfinding into evacuation simulation potentially overcomes this problem by generating more complex exiting behaviours with resulting added complexity in occupant flow dynamics. The wayfinding approach adopted here, based on widely accepted environmental psychology theories, demonstrates the impact that wayfinding can have on evacuation simulation. Even the introduction of somewhat simplistic non-sequential wayfinding produces significantly more complex exiting behaviour and route selection when compared to situations in which agents simply follow a shortest exit route path. The more sophisticated sequential wayfinding algorithm, in which agents are capable of reassessing their exit routes and effectively "change their minds" as to which path they adopt offers far greater realism. In the current implementation, redirection decisions are based on congestion, with time estimations for congestion at remote internal exits along the exit path being based on either fixed default values (Local-Prescribed) or on local experienced conditions (Local-Local). The later approach producing more dynamic, and arguably more realistic results. The sequential wayfinding algorithm is currently being expanded to take into consideration other factors such as fire hazards along the exit path. In addition, fuzziness is being introduced into the cost function to represent lack of familiarity with particularly routes. Finally, additional effort is also to be used to explore; additional RPC such as for example agents preferring paths which are initially straight[13] and contra-flow time penalties; plausible and realistic weight distributions for the various RPC and more efficient tree algorithms to handle very large and complex structures.

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