MEASURING HUMAN BEHAVIOUR USING A HEAD-CAVE

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Abstract. In this research funded by NSFC (50408038), an agent-based simulation model is developed for the human evacuation behaviour determined by a list of so-called architectural clues in the environment. A research method is introduced with an application for one of these clue types called Doorway. A six-variable model and a related set of virtual scenes were constructed and implemented in a Head-CAVE system, in which 102 subjects were tested as in an evacuation game. With the binary logit regression analysis a utility function is estimated indicating how these variables affect human choice on any pair of doorways in a scene. Evidence was found that the distance from the decision point to the doorway is not always the most important factor as it is assumed in the other evacuation models.

1. Introduction

As many mega cities in China, Shanghai is entering a period of booming underground space development, Figure 1, in the next 20 years. As the government planned, the subway system will increase from 82 km to more than 400 km by the year 2010, and the daily passengers will increase from 1.3 million to 6 million. With the big step of the underground space development, the security problem on how the public space evacuates people in an emergency is coming to the surface.

Building performance research with regard to hazard situations resulted in simulation models of human movements. These models are based on social force methods (e.g. Helbing et al. 2000) and cellular automata methods (e.g. Nishinari et al. 2004).

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Figure 1. The crowded underground space in Shanghai

Performance-based evaluation methods together with some commercial evacuation simulation models for underground space design were introduced to the government of China. However, due to the limited background knowledge, most of the evaluation models were found too complex to be used by architects. Actually these models are used by the experts in the fire security department to check the evacuation problems in the most critical situations.

In this research an agent-based simulation model is developed for the behaviour of humans determined by the public architectural space of the underground environment. All the other factors investigated in the existing models such as fire, smoke, toxic gases, alarm, signalling, etc. (Kuligowski and Peacock 2005) are excluded from this model. The focus is on architectural clues that drive the movement through the space. A set of experiments in virtual architectural spaces is designed and implemented with the assumption that "If a setting works well under normal conditions, it will have a better chance of working well in emergency conditions." (Arthur and Passini 1992)

The outline of the paper is as follows: First we will describe the list of architectural clues and the related evacuation strategies. Next the research method is explained, followed by the analyses of the data. We will finish with preliminary conclusions and outlooks.

2. Architectural-based Model for Underground Space Evacuation (AMUSE)

From previous research (Sun and Vries 2006) a list of so-called architectural clue types was deduced, namely Outdoors, Exits, Stairs, Slopes, Escalator, Raised Ceilings, Columns and Doorways. Based on these architectural clue types, 3 evacuation strategies are introduced ordered in a priority from high to low.

Strategy I**.** *Go to the safety*

Any architectural clue indicating itself as a safety termination of the evacuation such as Outdoors and Exits in the subject's view will be picked as a target to approach.

Strategy II. *Go to the higher floor*

Any architectural clue indicating itself useful to get the subject closer to the ground level such as Stair, Escalator, Slope in the subject's view will be picked as a target to approach.

Strategy III. *Try the more likely*

Any architectural clue indicating that it might lead to a probable way out such as Columns / Doorways leading to other spaces with lower/higher Ceilings in the subject's view will be picked as a target to approach.

The assumption is that from the set of architectural clues in sight, the human selects the one with the highest priority and performs a related strategy (Lawson 2001). If there are several clues with the same priority, for example three Exits in the same view, the subject has to pick the most probable one by a choice mechanism through pair wise comparison. In Table 1, we summarized how the architectural clue types are divided into three groups for the three strategies.

TABLE 1. Evacuation strategies and Architectural Clue Types

Evacuation Strategy	**Architectural Clue Type**
Go to the safety	Outdoors
	Exits
Go to the higher floor	Stairs
	Slopes
	Escalator
Try the more likely	Doorways with or without various Ceiling
	Columns

The agent uses its vision to perceive the environment and recognize the above clues in the 3-dimensional space to support the decision making during the evacuation simulation. The pixel-based recognition algorithm of the clues in the agent's vision will be presented in another publication. In the following section the research method is described to determine the decision-making parameters that lead to the selection of a specific evacuation strategy.

3. Research Method

The agent interpretation method raises a lot of questions, such as: are the priorities right, what about the preference between architectural clues with the same priority and finally, does the interpretation leads to valid behaviour of the agents? In this paper we will focus on the second question and on one priority level, namely the Strategy III 'Try the more likely', because the research methodology here is basic to the rest of the research project.

For all types of Doorways in Strategy III the following variables and corresponding attributes are defined (see Figure 2):

Distance from the entrance to observation point, defined as **D,** assumption is that a longer distance decreases the importance;

Width of the doorway, defined as **W,** assumption is that a wider doorway increases the importance;

Height of the doorway, defined as **H,** assumption is that a higher doorway increases the preference;

Angle between the direction of the view direction and the doorway, defined as **A1,** assumption is that a narrower angle increases the importance;

Angle between the direction of the view direction and the doorway axis, defined as **A2,** assumption is that a narrower angle increases the importance;

Besides the above variables, the left-right preference will be considered as another variable **LR,** assumption is that there is a cultural determined importance.

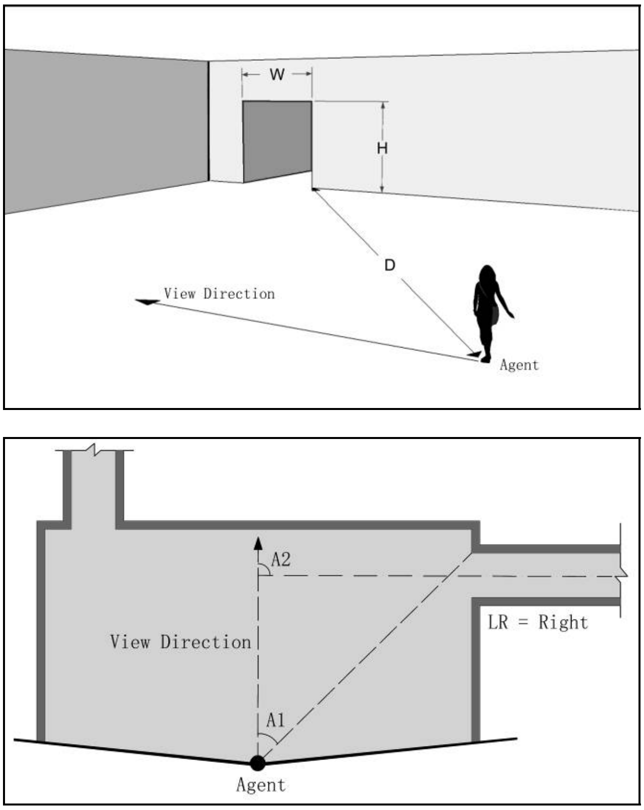

Figure 2. The definition of the variables of Doorway.

A statistic choice model Binary Logit is chosen to measure the relative importance of attributes influencing subject's choices. Hereby, subject's responses on choices are observed in hypothetical situations designed under controlled experiments in such a way as to satisfy the assumptions of statistical choice models.

To maximize statistical efficiency, attribute profiles and choice sets are constructed according to the principles underlying the design of statistical experiments. The main objective is to determine the contribution of predictor variables (attribute levels) to the overall preference or satisfaction. In the case of the choice task, in addition to estimating the utility function, the goal is to estimate the parameters of the choice model. In the Binary Logit model it is assumed that the probability that an individual will choose alternative a_i of the two alternatives from the choice set C is given by Equation 1.

$$p(a_i \mid C) = \frac{\exp[U(a_i)]}{\sum_{j=1}^{2} \exp[U(a_j)]} = \frac{\exp(x_i \beta)}{\sum_{j=1}^{2} \exp(x_j \beta)} \quad (1)$$

Where:

$p(a_i \mid C)$ is the probability that choice alternative a_i is chosen from set C;

$U(a_i) = \beta_0 + \beta_1 D + \beta_2 W + \beta_3 H + \beta_4 A1 + \beta_4 A2 + \beta_5 LR$

β_0 is a constant, β_i is the parameter for every variable.

In the experiment, choice sets of two alternatives are recorded. One alternative is chosen, the other not. Therefore, $p(a_i \mid C) = 1$ if alternative a_i is chosen otherwise $p(a_i \mid C) = 0$. The sample of the recorded dataset is shown in Table 2.

TABLE 2. A sample of the recorded choice for one scene in the experiment.

Scene ID	p	*D*	*W*	*H*	A1	A2	LR
00024	0	0	1	1	0	1	0
00024	1	1	0	0	1	0	1
Etc.							

4. Experiment

From previous experiments we learned that the scenes with a wide angle view presented on a flat screen have a big distortion on the subject's depth perception, which plays an important role in the measurement of the human behaviour (Sun, de Vries and Dijkstra 2007). There are precedents of research on human behavior in built environment done in virtual environment. To provide the subjects with a nearly 170 degree view (Turner and Penn 2002), such experiments generally use CAVE systems (Achten, Jessurun, and de Vries 2004). In this research, the authors built a Head-CAVE system with three LCDs, as shown in Figure 3.

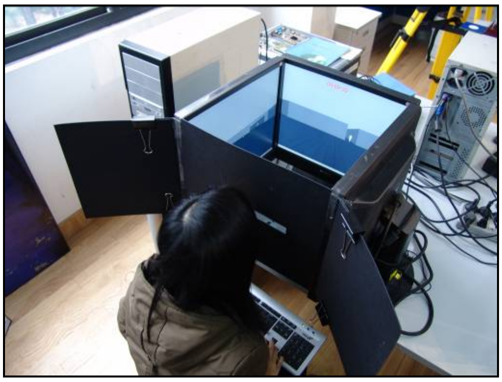

Figure 3. The Head-CAVE system.

In this experiment, two scene sets (A and B) were prepared, each set containing 32 scenes, each with two doorways, but with different attributes values, see Table 3.

TABLE 3. The two scene sets

Scene Set A

Scene ID	Left Doorway						Right Doorway				
	A1	**A2**	**W**	**D**	**H**		**A1**	**A2**	**W**	**D**	**H**
1	5	0	2.5	30	3		30	45	5	45	4
2	30	45	5	45	4		5	0	2.5	30	3
…	…	…	…	…	…		…	…	…	…	…
31	5	45	5	45	4		30	0	2.5	30	3
32	30	0	2.5	30	3		5	45	5	45	4

Scene Set B

Scene ID	Left Doorway						Right Doorway				
	A1	**A2**	**W**	**D**	**H**		**A1**	**A2**	**W**	**D**	**H**
1	5	0	2.5	30	3		55	90	7.5	60	5
2	55	90	7.5	60	5		5	0	2.5	30	3
…	…	…	…	…	…		…	…	…	…	…
31	5	90	7.5	60	5		55	0	2.5	60	3
32	55	0	2.5	30	3		5	90	7.5	45	5

The subjects observed two doorway options in every scene according to the above table through the T-window as showed in Figure 4. All the choices were recorded in the format indicated in Table 2.

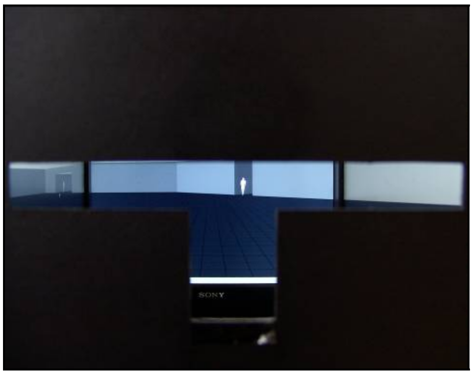

Figure 4. The scene with two doorway options through the HEAD-CAVE.

Altogether 102 subjects took part in the evacuation experiment, which was designed to be something like a first person shooting game, such as DOOM. Each subject can see a timer on the screen and hear from his earphone a heartbeat as well as an alarm urging him to evacuate. In the Head-CAVE system, the subject is faced with scenes from the two sets of experiments by random. He is required to imagine himself in an underground space and to get out of there as soon as possible by choosing either the left or the right doorway in each scene. He is also required to act on instinct. The subject who escapes the building in the least time wins. Every subject experiences all 64 scenes in one experiment. From the experiment we found that under the effect of the sound, the timer, and the dramatic game, the subjects were all rather absorbed in the experiment.

5. Analyses

In each scene there were only two escape options, a single choice of a subject brings about two statistical samples, each concerning one doorway. Each sample contains one dependent variable (**p**) and six independent variables (**D, W, H, A1, A2, LR**), also see Table 2. When a doorway is chosen, **p** is recorded as 1, or else 0. When the left doorway is chosen, LR is recorded as 1, or else 0. For weighting comparison, the smaller values of the other five independent variables are recorded as 0, and the larger as 1. Thus, for D,W,H,A1,A2 two distinct values were used. The experiment was conducted with two scene Sets. In Scene Set A the ratio of the distances from the two doorways to observer equaled to 1:1.5; whereas in Scene Set B, when the ratio of distances rose to 1:2. Binary Logistic Regression (forward

Stepwise LR) in the SPSS was applied to analyze the results. The most significant variables (Sig. equals 0.000), are shown in Table 4, from which we can conclude that in a model of the six variables mentioned, A1, W, D are the three main factors that effect the inducement of a doorway in evacuation.

TABLE 4. The result of Binary Logit analyses (B=β from equation (1), S.E.=Standard Error, Wald=$(B/S.E.)^2$, df= degrees of freedom)

Scene Set A

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	A1	-.352	.057	38.060	1	.000	.703
	W	2.058	.059	1236.418	1	.000	7.834
	D	-.992	.058	288.605	1	.000	.371
	Constant	-.357	.054	44.392	1	.000	.700

Scene Set B

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	A1	-.779	.057	188.635	1	.000	.459
	W	1.564	.058	722.204	1	.000	4.776
	D	-1.472	.058	641.336	1	.000	.229
	Constant	.344	.053	41.480	1	.000	1.410

From the experiment we observed: In Scene Set A, the main variables that effect induced evacuation behavior and their weights in order are: W (2.058), D (-.992), A1 (-.352); In Scene Set B: W (1.564), D (-1.472), A1 (-.779). A positive weight means that the larger variable value the higher chance the doorway being chosen, while a negative weight means the larger value the less chance. From the data above, the we found that the result of the two sets of scenes indicates the same main factors (W, D, A1), although the weights of the factors vary as the variable values change.

6. Preliminary Conclusion

From the results of experiment above, we conclude that the assumption in other existing evacuation models that people evacuate to the nearest doorway is inaccurate, or at least tenable only under certain circumstances. We discovered that, in the experiment of Scene Set A, the width of the doorways had a crucial effect on the observer's decision (with a weight twice that of the distance and making up 60% of the total weight); whereas in the experiment of Scene Set B, the effectiveness of the width and distance of doorways became rather the same (their weights close, each 26% of the total weight). From this trend, we deduced that when the ratio of the distances from the two doorways to observer is higher than 1:2, the weight of the distance will continue increasing while the weight of width will fall, which means that the distance of the doorway from the observer will play a crucial part in effecting the evacuation behavior. Therefore, only then the "nearest-doorway assumption" is tenable.

This conclusion can be used to modify the judgment on the pedestrian flow made by architects in designing a plan. It is obvious that when the ratio of the distances from the two doorways to the evacuees is lower than 1:2 the architect can guide evacuation by widening one of the entrances, as show in Figure 5. Otherwise, the misusing of the "nearest-distance assumption" and neglect of the significance of the width of the doorways can cause problems in evacuation, as shown in Figure 6.

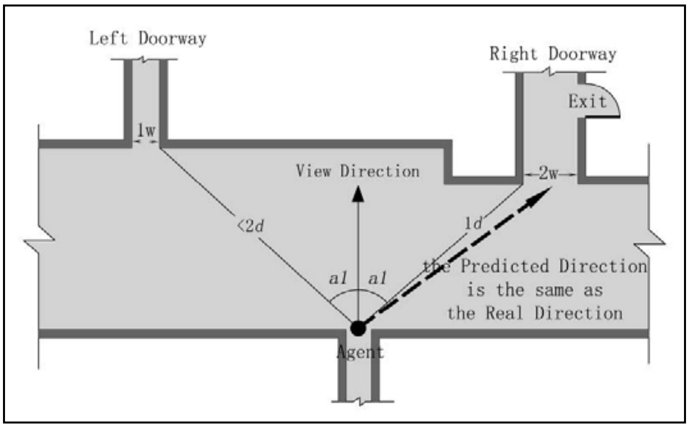

Figure 5. Correct prediction considering on the width factor.

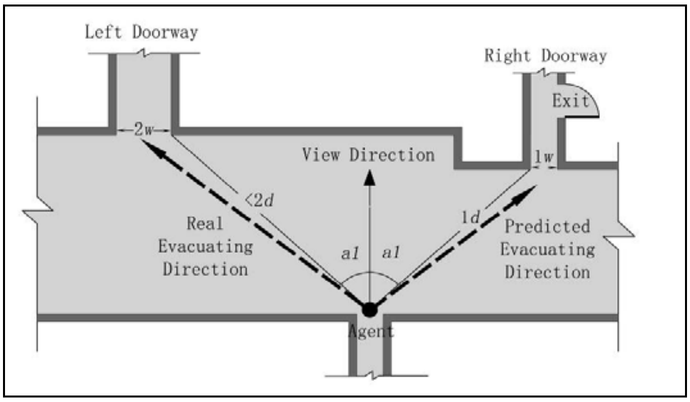

Figure 6. Wrong prediction ignoring the width factor.

7. Summary and Outlook

In this paper, a Head-CAVE-based experiment on measuring the human's evacuation behavior in front of two doorway options was introduced. The research method has proven that a doorway-oriented evacuation decision model can be constructed through Binary Logistic Regression. According to the preliminary model the nearest-doorway assumption in other evacuation models is questionable in some circumstances. Moreover, the relative critical value of the distances' ratio is discovered.

The next step in this research project is to conduct experiments for the other architectural clues, using the same methodology. After that a digital model of a complete underground space will be constructed including all architectural clues. The movement pattern of the agents in the simulation model AMUSE, based on architectural clue guidance, will be compared with real movement of humans in a Virtual model of the underground space. Finally AMUSE will be integrated into a CAD system to support architects in analyzing their architectural design of underground stations with regard to evacuation performance.

Acknowledgements

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