# A DECISION MAKING MODEL OF THE DOORWAY CLUE FOR THE AGENT'S EVACUATION SIMULATION

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## ABSTRACT

In this research funded by NSFC (50408038), an agent-based simulation model AMUSE is being developed for the evacuation behaviour of humans induced by the architectural characteristics of the environment. From previous research the architectural characteristics are interpreted as a list of so-called architectural clue types, which are related to three groups of evacuation strategies with a different priority. The Doorway clue is taken as an example of all the clue types to be investigated. With it a basic research method is explained. With an initial six-variable decision making model, a 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 Logistic Regression the utility function of the model is estimated indicating how these variables affect human choice on any pair of doorways in a scene. Finally, as a sub-model of AMUSE, the decision making model of the Doorway clues is setup, from which 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.

## INTRODUCTION

As many mega cities in China, Shanghai is entering a period of booming underground space development 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.

In our previous paper (2006), an architecture-based model for underground space evacuation simulation (AMUSE) was introduced, in which the focus is located on the architectural clues that drive the agent's movement through the space. All the other factors investigated in the existing evacuation simulation models such as fire, smoke, toxic gases, alarm, signalling, etc. (Kuligowski and Peacock 2005) are excluded.

The outline of this paper is as follows: First, we will describe the developing AMUSE including the list of architectural clues and the related evacuation strategies. Next, the Doorway clue is taken as an example of all the clue types to be investigated. With it a basic research method is explained, followed by the analyses of the data. Finally, as a sub-model of AMUSE, the decision making model of the Doorway clues is setup altogether with some preliminary conclusions.

## DEVELOPING AMUSE

From previous research a list of so-called architectural clue types was deduced, namely Outdoors, Exits, Stairs, Slopes, Escalator, Raised Ceilings, Columns and Doorways (Sun and Vries 2006). 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 or higher Ceilings in the subject's view will be picked as a target to approach.

The assumption is that from all the architectural clues in sight, the agent 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 the following table, we summarized how the architectural clue types are divided into three groups for the three strategies.

TABLE 1: Grouped Architectural Clue Types by Strategies

| **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.

## RESEARCH METHOD

The developing AMUSE 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.

We initially set up a six-variable decision making model for the pair choice of the Doorway clues according to the geometry definition from the view of an agent. The variables are in the following and illustrated in Figure 1.

Distance from the entrance to observation point, defined as **D**;

Width of the doorway, defined as **W**;

Height of the doorway, defined as **H**;

Angle between the direction of the view direction and the doorway, defined as **A1**;

Angle between the direction of the view direction and the doorway axis, defined as **A2;**

Besides the above variables, the left-right preference will be considered as another variable **LR**.

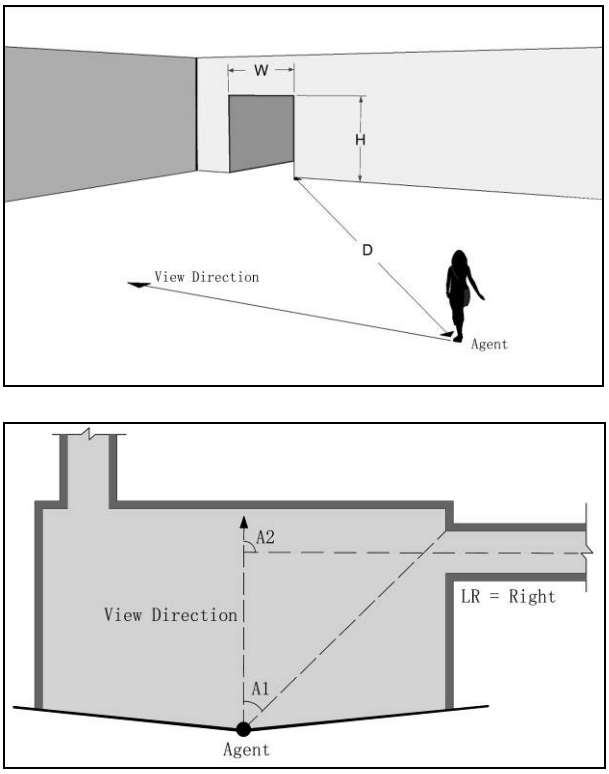

Figure 1: The Definition of the Variables of Doorway.

The pair choice mechanism enables the agent to choose the more likely doorway among the several doorways in the same view to escape to, which depends on the probability predicted for each doorway option 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 $a_i$ (a specific doorway) is chosen from set C (several doorways in the same view).

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

$\beta_0$ is a constant, $\beta_i$ is the parameter for every variable.

The above equation is based on the statistic choice model Binary Logistic Regression, which is used as a model in the following experiment design. Through it we can measure the relative importance of attributes influencing human's choices on the doorways. Hereby, human's responses on the doorway options are observed in hypothetical situations designed in controlled experiments in such a way as to satisfy the assumptions of the statistical choice model. To maximize statistical efficiency, attribute profiles and choice sets are designed according to the principles underlying the design of statistical experiments. It results in two sets of 32 scenes as indicated in Table 2.

Table 2: The Two Scene Sets

Scene Set A

| Scene ID | **Left Doorway** | | | | | **Right Doorway** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **A1** | **A2** | **W** | **D** | **H** | **A1** | **A2** | **W** | **D** | **H** |
| 01 | 5 | 0 | 2.5 | 30 | 3 | 30 | 45 | 5 | 45 | 4 |
| 02 | 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** |
| 01 | 5 | 0 | 2.5 | 30 | 3 | 55 | 90 | 7.5 | 60 | 5 |
| 02 | 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 |

In the experiment, the subject's choices in every scene will be recorded and used as statistic samples for Binary Logistic Regression. According to the pair choice mechanism, two doorway options in a scene are recorded into two samples as in Table 3, in which $p(a_i \mid C) = 1$ if the doorway is chosen otherwise $p(a_i \mid C) = 0$.

TABLE 3: Two Samples of One Choice in A Scene.

| Scene ID | *p* | D | W | H | A1 | A2 | LR |
|---|---|---|---|---|---|---|---|
| 01 | 1 | 30 | 5 | 4 | 5 | 45 | 0 |
| 01 | 0 | 45 | 2.5 | 3 | 30 | 0 | 1 |
| Etc. | | | | | | | |

With enough such samples, Binary Logistic Regression could help us to figure out all the parameters in Equation 1, which can tell us the different importance of the six variables in the initial decision making model and explain how they influence the human's choice when the escaper faces with any two doorway options in the view. Then we can build the decision making model of the Doorway clue as a sub model of AMUSE.

## EXPERIMENT

To measure all the parameters from human behaviour, a Head-CAVE system was setup, on which an experiment is designed and carried out.

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, we built a Head-CAVE system with three LCDs, as shown in Figure 2.

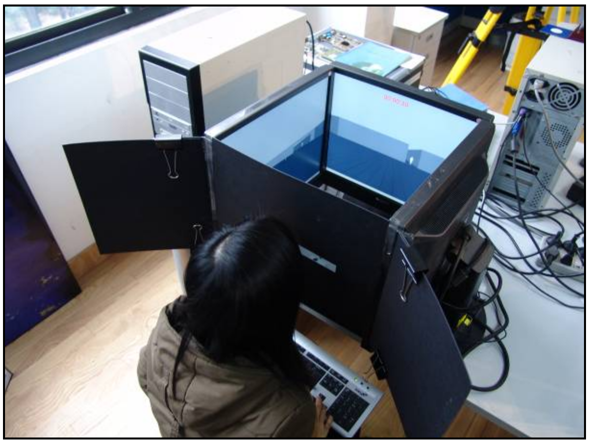

Figure 2: The Head-CAVE System.

According to the previous scene configurations in Table 2, two scene sets (A and B) were constructed in virtual space, each set containing 32 scenes. Every scene has two doorway options on the sides, each with different attributes values. The subjects observed two doorway options in every scene through the T-window as showed in Figure 3. All the choices were recorded in the format indicated in Table 3.

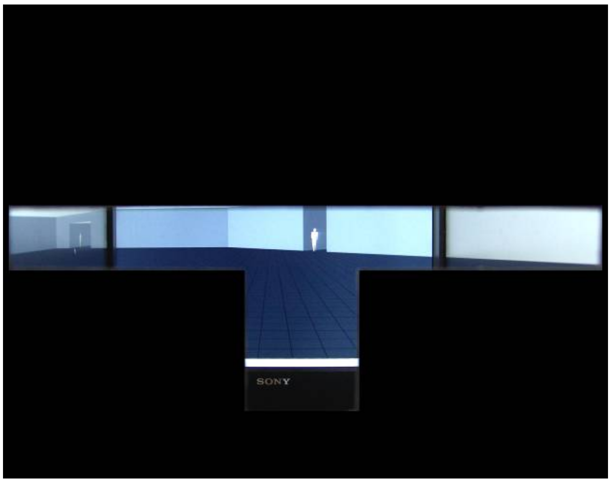

Figure 3: The Observed Scene with Two Doorway Options through the T-window of the HEAD-CAVE.

Altogether 102 subjects took part in the evacuation experiment, which was designed to be something like a first person shooting game, such as DOOM. Every 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 experiment 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. He is also required to act on instinct. The subject who escapes the building in the least time wins. Actually, every subject experiences all 64 scenes no matter how he makes his choices. So every subject is required to go through the experiment only once. We found that under the effect of the sound, the timer, and the dramatic game, the subjects were all rather absorbed in the experiment.

## ANALYSES

In every scene there were only two doorway 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**), as in Table 3. When a doorway is chosen, **p** is recorded as 1, or else 0. If the doorway is on the left, LR is recorded as 1, or else 0. For the reasonable comparison among the six variables' weights, the smaller values of the other five independent variables are encoded into 0, and the larger ones into 1. As an example, Table 3 was encoded into Table 4.

TABLE 4: The Encoded Samples of One Scene.

| Scene ID | *p* | D | W | H | A1 | A2 | LR |
|---|---|---|---|---|---|---|---|
| 01 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| 01 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |

We used Binary Logistic Regression (Forward Stepwise LR) in SPSS to analyze the results. The most significant variables (Sig. equals 0.000) are shown in Table 5, from which we can find that in the initial six-variable model, A1, W, D are the three main ones, which correlate to the subjects' decision making process of the Doorway clues strongly.

TABLE 5: The Main Variables of the Model

Scene Set A

| | B | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|
| 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) |
|---|---|---|---|---|---|---|
| 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 |

The experiment was conducted with two scene sets. Between the two sets, the ratio of the two levels of the same variable is different, which is used to indicate if the ratio itself will influence the weight. In Scene Set A the ratio of the variable D is 1:1.5, the ratio of the variable W is 1:2 and the ratio of the variable A1 is 1:6; whereas in Scene Set B, the ratio of D rose to 1:2, the ratio of W rose to 1:3 and the ratio of A1 rose to 1:11.

We observed: In Scene Set A, the main variables 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). Here, 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.

## PRELIMINARY CONCLUSION

From the data above, we found that the decision making model of the Doorway clues has three main variables, namely D, W and A1. And the ratio of the two levels of the variable influences its weight in the model.

Based on the different weights of the model, we also discovered that the assumption in other existing evacuation models that people always evacuate to the nearest doorway is inaccurate, or at least tenable only under certain circumstances. In 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 scene set B, the weights of the width and the distance became rather the same (each 26% of the total weight). From this trend, we deduced that when the ratio of the distances from the two doorways to the observer is higher than 1:2, the weight of the distance will continue increasing while the weight of the width will fall, which means that the distance 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 correct 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 doorways, as show in Figure 4. Otherwise, the misusage of the nearest-distance assumption and the neglect of the significance of the width of the doorways can cause problems in evacuation, as shown in Figure 5.

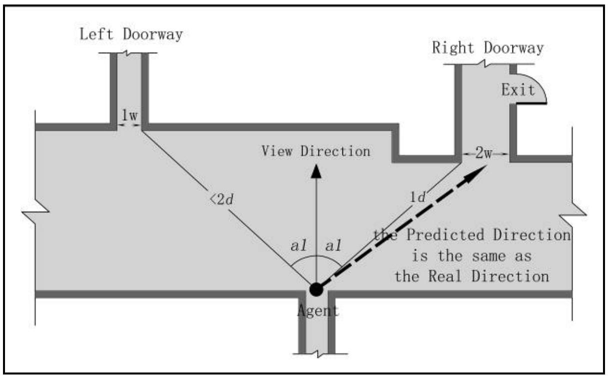

Figure 4: Correct Prediction with the Width Factor.

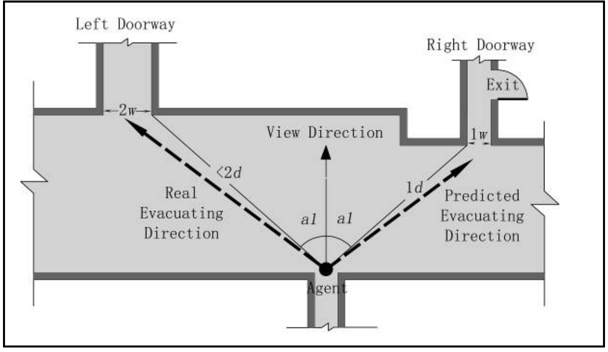

Figure 5: Wrong Prediction without the Width Factor.

## SUMMARY AND OUTLOOK

In this paper, we raised an initial six-variable decision making model of the Doorway clues, and introduced a Head-CAVE-based experiment on measuring the human's evacuation behavior in front of any two doorway options. The parameters of the model were figured out from the experiment data by Binary Logistic Regression. Finally the six variables were reduced into three main ones. A design application of such a result was also introduced, in which we indicated the nearest doorway assumption in other evacuation models is questionable in some circumstances. Moreover, the relative critical value of the distance ratio is discovered.

Through this study, many new questions are raised: how to carry out a more complete research on the weights of the Doorway variables as they vary with different ratio of the variable levels; how to build experiments to investigate the other architectural clues with this basic research method; how to make use of the advanced VR technology to improve the experiment environment to increase the reliability of the interior architectural space researches. The authors will carry out further research in the future concerning these questions, believing that such a series of investigations will lead to AMUSE for the prediction of the architectural inducement on human behavior in the emergency.

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