Collective Dynamics

Pilot Study of Mental Simulation of People Movement During Evacuations

Kinsey, M.J[1] · **Gwynne, S.M.V**[2]

[1] Ashton Fire, Birmingham, UK,
[2] Movement Strategies, London, UK,

E-mail: Michael.Kinsey@AshtonFire.com

E-mail: Steve.Gwynne@ghd.com

Received: 29 October 2023 / Last revision received: 5 Mai 2024 / Accepted: 7 June 2024
DOI: 10.17815/CD.2024.175

Abstract Mental simulation of people movement forms a core and important component of pedestrian/evacuation analysis and planning, albeit one that is rarely addressed. It can be defined as the process by which a practitioner imagines or develops a narrative story of how people within a built environment may move to inform a decision-making process regarding architectural or procedural design. There are a range of contexts in which a practitioner may use mental simulation. These can include assisting with identifying problems associated with architecture/procedural design and comparing with pedestrian/evacuation modelling results to suggest if these are in line with expectations. Little research has been conducted exploring the process by which practitioners mentally simulate people movement, its efficacy, what factors influence this process, and how accurate are practitioners conducting mental simulation. The pilot study presented in this paper is intended to provide initial insights regarding this process. Results from an online survey (N=10) are presented where expert practitioners were asked questions about a range of hypothetical evacuation scenarios with increasing complexity regarding what they expected the total evacuation time to be and how many people they expected to use each exit if they were simulated in a pedestrian/evacuation model. Participants were also asked how confident they were with their results. The survey data was then compared with results with evacuation model results of the same scenarios. Key findings from the study highlight that as the floor plan layout and behavioural complexity increase in a scenario, the greater the level of variation in responses between practitioners along with decreasing levels of accuracy and levels of confidence in their perceived ability for performing mental simulation of people movement. Floor plan and exit symmetry appear to influence a practitioner's ability to mentally simulate people movement in terms of estimating evacuation times and exit usage when layouts/exit locations change.

Keywords Mental simulation; people movement; evacuation; modelling

1 Introduction

A range of tools are used in the design of the built environment to understand and assess how people move within a space including hand-calculations and computational pedestrian/evacuation models. Such tools are used in a range of applications including as part of performance-based design where prescriptive requirements are not followed or for quantitatively assessing the impact of different factors on people movement during a range of scenarios e.g. the impact of exits being blocked due to fire/smoke, the impact of increasing the number of exits in a building, etc [1].

These tools provide a means for practitioners to outsource the quantitative assessment of the people movement process to an external electronic computational architecture to gain insights. Expertise and competency of the practitioner to appropriately set-up the tool for execution and then interpreting the results: it is the practitioner coupled with the tool being used which determines the results and how these should be interpreted. A core part of this is ensuring the practitioner can imagine how people maybe expected to move within a given environment and see if this is consistent with what the results from the tool provide. As part of this process a practitioner may mentally simulate how people move within an environment or part of an environment to develop benchmarks for comparison with the tool results. Little research has been conducted regarding the extent/credibility a practitioner can mentally simulate people movement with confidence and what factors influence this process. This paper will begin to address some of these challenges. In order to better understand how expert practitioners conduct mental simulation of people movement and identify some of its limitations, data has been collected via an online survey to assess accuracy and variability of expert judgement associated with a series of hypothetical evacuation scenarios which have been compared with evacuation modelling results of the same scenario. As part of this, the impact of floor plan layout complexity and exit location symmetry on practitioners accuracy to perform mental simulation has been explored.

2 Mental Simulation

Research into mental simulation has occurred for over half a century. In 1946 Adriaan de Groot [2] explored the use of mental simulation through the thought processes of chess masters that anticipated a given number of moves ahead to determine their next move. In the 1980s Kahneman and Tversky [3] proposed the ‘simulation heuristic’ which is based on the premise that people, being given the outcome of an event, use mental simulation to test out different hypotheses with varying input parameters to suggest reasons for the event. This relied on participants ability to use counterfactual thinking for proposing a range of possible alternatives to an event then assessing the validity of each. Findings from the study suggest that the easier it was a person to construct the mental simulation the higher the likelihood it is perceived to be accurate. Klein [4] similarly proposed that the assessment of credibility for the mental simulation is of key importance in determining the extent it will inform a given decision making process. This assessment of mental simulation credibility may consider a range of factors, including [4, 5]:

- Plausibility (the elements are believable, likely, and explainable)
- Consistency (the stages of the mental simulation fit in with each other and have low levels of variability)
- Economy (it is not too complex such that it not possible to be envisaged by the practitioner and communicated with key stakeholders in the design process).
- Uniqueness (we prefer communications which are not open to alternate explanations)

Where a mental simulation does not consider or violates these factors then the harder it is to explain alternate/conflicting information and the less confident a people will have in the process.

Later in the 1990s Klein and Crandall [6] proposed that people build mental simulations in a similar fashion analogous to building a 'machine'. Initially a person starts with an idea which is then built on trying out different options and dynamically discounting those options which do not yield suitable results as the 'machine' progressively gets bigger considering more factors. In this study it was observed that the mental simulation participants constructed was typically not very complex and only involved a small number of influencing factors (typically less than four) and involved no more than six transition states (i.e. where something in the system changes). The study proposed such limitations may potentially occur due to limitations of a person's working memory or perceived time limitations for conducting the mental simulation.

It is proposed that mental simulation in the context of people movement comprises a practitioner developing a narrative based on a causal chain of events of how people move within an environment in the future. This includes taking an initial set of assumptions regarding a built environment and its population, then abductively inferring how people may move within it at a given time. The process may be repeated for considering different conditions/influences for multiple scenarios. This process may be conducted visually i.e. a practitioner mentally picturing people physically moving around a given environment within working memory, etc., or in a more abstract/simplified manner which does not use visualisation of people moving. In this sense, practitioners do not perform mental simulations of people movement in the same way as computational pedestrian/evacuation models. Practitioners do not have the capacity to run through large numbers of interdependent rules and keep track of vast quantities of variables of a complex system as do computational models. What an practitioner can do is search for patterns based on a limited number of influencing factors using a their past experience of how they expect people to move in a given space. It is proposed that the more relevant experience, knowledge, and expertise a practitioner has for a given built environment type or people movement scenario, the increased likelihood of them being able to develop more clearly defined expectancy's of how people may move as part of a mental simulation.

3 Survey

Participants were requested to complete the survey if they have at least five or more years' experience in human behaviour in fire and evacuation modelling. The purpose of this is so that the results are reflective of the more highly experienced/proficient practitioners in the field and close to what is feasible in terms of mental simulation of people movement.

The survey presented participants with a series of evacuation scenarios to be developed within an evacuation model along with associated assumptions for the model. Participants were asked for each scenario how long they expected the total evacuation of all people to take and how many people they expected to use each exit within the evacuation model. Participants were requested to not conduct any egress hand-calculation or evacuation modelling to inform their responses. Results from the survey have been compared with the evacuation modelling results for each scenario using the MassMotion pedestrian/evacuation modelling software. Participants were recruited to complete the survey via direct email by the authors of potential suitable candidates and advertising on LinkedIn.com. Due to the requirements for participants to have a relatively high number of years' experience and project time constraints, the total number which completed the survey was 10 participants.

A series of three evacuation scenarios were developed. The first scenario comprised a single 10 m x 10 m square room with 100 people located inside randomly located. The second scenario comprised a series of eight rooms (with two people initially located in each) connected via a central corridor. The third scenario was identical to the second scenario but spanning multiple floors. The three scenarios represent relatively increasing levels of architectural and behavioural complexity, from a single room/single floor (Scenario 1), multiple rooms/single floor (Scenarios 2), and multiple rooms/multiple floors (Scenarios 3). Each scenario was then used to create a series of 3 cases (A, B, C) which progressively increase in size and/or complexity of the scenario itself. Case A represents the base case for comparison in each scenario (the simplest of a given scenario in terms of floor plan layout complexity). Case B increases the floor plan layout complexity by increasing the number of external exits or number of floors. Case C increases the floor plan layout complexity by increasing the number of external exits or number of floors further and locating the external exits in asymmetrical positions of the building footprint. Fig. 1 describes the floor plan layouts, exit locations, and initial starting locations of people in each scenario for each case.

Participants were informed at the start of the survey that people in the evacuation model were specified as having a number of characteristics parameters associated with size, speed, wayfinding, not being in a group and response time. These broadly reflect the input parameters and agent behaviour within the associated MassMotion model used for

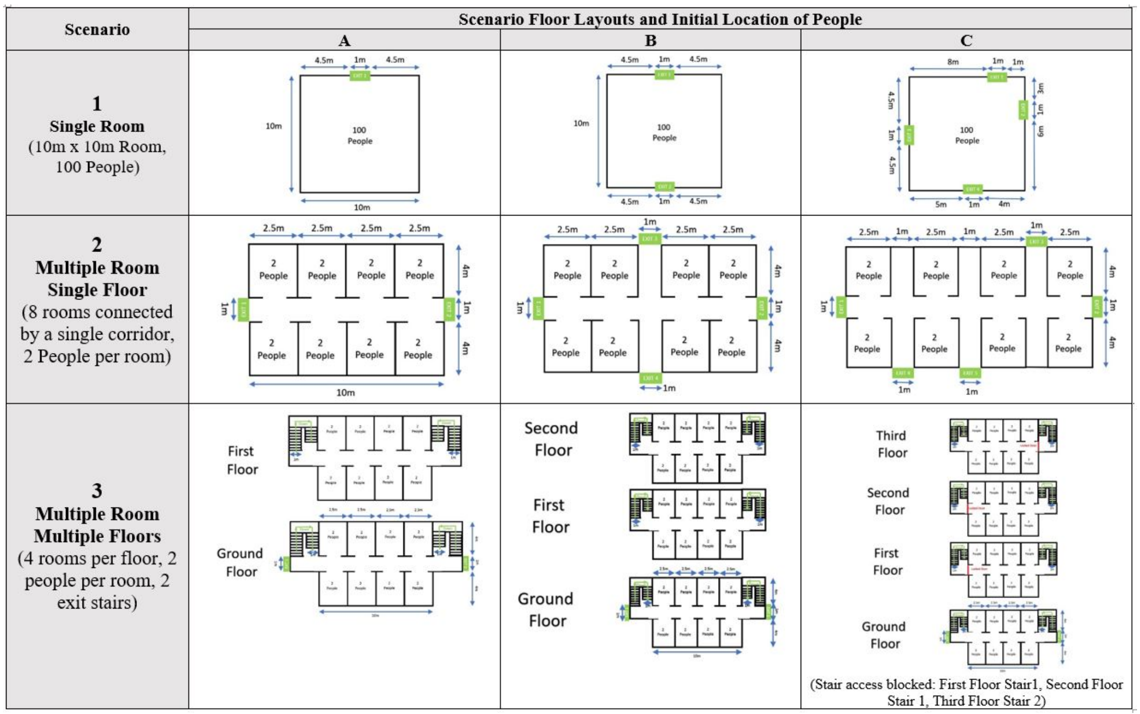

Figure 1 Evacuation Scenarios - Floor plan layouts, dimensions, and populations.

comparison with the participant results. For each question, participants were asked how confident they were with their answers.

4 Results and Analysis

A total of 10 participants completed the survey all of whom had five or more years' experience in human behaviour in fire and evacuation modelling. Just over half (54.5%) of participants had 5-10 years experience. Results from the questions in the survey (i.e. participant estimated evacuation times and exit usage) and from the MassMotion evacuation modelling along with a comparison of the two are shown in the table below Tab. 2.

The single room scenarios involved a single square room with 100 people randomly located within it. For Case A involving a single exit, participants on average overestimated the total evacuation time (98.8 seconds) by 26.1% compared to the modelling results (73 seconds) and, unsurprisingly, correctly stated all people would use the only available exit. It is worth noting that one participant overestimated the evacuation time by over double (150 seconds) and one underestimated the evacuation time by 70% (22 seconds) which highlights the potential for high variability by some participants.

The multiple room single floor scenario involved a central corridor connected to eight rooms with a rectangular footprint with two people initially located in each room with a total of 16 people. For Case A involving two exits, on average participants approximated the total evacuation time was 14 seconds which is almost identical to that in the model of 16 seconds. Similarly, the estimated proportion of people which used each exit (50% /

Case	Results	Survey Results Avg. [Min-Max]			Modelling			Avg. Difference Comparison (%) (+ overestimation, - underestimation)			Range of Proportional Difference For All Scenarios (%)
		Scenario 1 Single Room	Scenario 2 Multiple Room Single Floor	Scenario 3 Multiple Room Multiple Floors	Scenario 1 Single Room	Scenario 2 Multiple Room Single Floor	Scenario 3 Multiple Room Multiple Floors	Scenario 1 Single Room	Scenario 2 Multiple Room Single Floor	Scenario 3 Multiple Room Multiple Floors	
A	Evacuation Time (Sec)	98.8 [22-150]	14 [7-30]	38 [20-80]	73	16	39	+26.1	-12.5	-1.0	-1.0 to +26.1
	Confidence Rating (%)	33.3 – Totally 33.3 – Very 33.3 - Somewhat	10 – Totally 50 – Very 40 - Somewhat	20 – Totally 50 – Very 30 - Somewhat							
	Exit 1 Usage (%)	100 [100-100]	50 [50-50]	50 [50-50]	100	50	50	0.0	0.0	0.0	No difference
	Exit 2 Usage (%)		50 [50-50]	50 [50-50]		50	50		0.0	0.0	No difference
	Confidence Rating (%)	33.3 – Totally	40 – Totally 50 – Very 10 - Somewhat	30 – Totally 50 – Very 10 – Somewhat 10 - Not							
B	Evacuation Time (Sec)	51.1 [13-90]	12.2 [7-30]	25.2 [15-45]	43	17	56	+15.9	-28.2	-55.0	-55.0 to +15.9
	Confidence Rating (%)	20 – Totally 60 – Very 20 - Somewhat	10 – Very 90 - Somewhat	10– Very 70 – Somewhat 10 – Not 10 – Don't know							
	Exit 1 Usage (%)	50 [50-50]	33 [25-50]	50 [50-50]	51	50	50	-2.0	-34.0	0.0	-34.0 to -2.0
	Exit 2 Usage (%)	50 [50-50]	33 [25-50]	50 [50-50]	49	44	50	+2.0	-25.0	0.0	-25.0 to +2.0
	Exit 3 Usage (%)		17 [0-25]			6			+64.7		+64.7
	Exit 4 Usage (%)		17 [0-25]			0			+100.0		+100.0

Figure 2 Results – Survey, modelling and comparison of average difference for Case A, B, and C for Scenario 1 (Green), Scenario 2 (Blue), and Scenario 3 (red)

50%) was identical in the survey result for all participants and the modelling.

The multiple room multiple floor scenario was identical to the previous scenario with the addition of two stairs at either end of the corridor connecting the floors above. For Case A involving a total two floors (Ground + 1 floor above) and all exit routes being available, the average evacuation time estimated by participants (25.2 seconds) was 35.4% lower compared to the model results (39 seconds). Like the previous scenarios, a large range of responses regarding the evacuation time was evident with one participant stating an evacuation time which was 61.35% (24 seconds) lower compared to the modelling results. As with the other scenarios, all participants accurately estimated that half of all people would use each of the two exits.

5 Discussion

Analysis of the results highlight several findings regarding expert practitioners' ability to use mental simulation for people movement, which include:

- There may be sizeable variability in estimated evacuation times between practitioners using mental simulation and modelling results. Despite this, when responses from multiple practitioners are combined into an average, this can lead to increased accuracy: potentially representing the "wisdom of the crowd" – assuming all were available for a single project.

- There may be sizeable variability in estimated evacuation times between different practitioners using mental simulation.

- Practitioners may be able to use mental simulation in simple cases (e.g., involving small number of exits, symmetrical floor plan layouts, etc.) to estimate with reasonable accuracy the number of people which will use each exit and proportional impact of additional exits on evacuations times.

- Where there is no symmetry of exit locations and/or routes, this can increase the potential for inaccuracy in estimation of evacuation times and exit usage by practitioners in some cases.

- Practitioner's confidence in their ability to estimate evacuation times and exit usage decreases with increasing complexity and asymmetry of floor plan exit layouts.

Findings suggests practitioners would not likely be able to use mental simulation alone to accurately estimate with confidence how large numbers of people move in buildings in evenly moderately complex scenarios. However, results do suggest that some practitioners have the capability to accurately estimate the impact of small, localised changes in terms of the addition of exits and route availability given certain conditions. These findings from this pilot study should be considered in light of the small sample size of participants involved in the study and the subsequent limited statistical analysis which can be performed on such a sample. This limits the confidence in the results being representative of the general expert practitioner population. The findings should be considered suggestive in nature of potential trends regarding mental simulation of people movement. Further research is required with a larger sample size to enable more detailed statistical analysis and support findings with increased confidence.

6 Conclusion

The paper presents results from a pilot study where practitioners with a high level of expertise in understanding human behaviour in fire and evacuation modelling were requested to estimate, give a range of scenarios, how long they expected people to evacuate and how many people would use each exit if the same scenario was run using a pedestrian/evacuation model. There are several limitations regarding the study including the small sample size of participants, inclusion of a limited number of scenarios, potential past scenario response influence, and the use of modelling results as a comparison instead of actual physical experimental trials. As such, findings from the study are considered suggestive in nature: care should be taken when considering generalising. The level of accuracy regarding a practitioners' ability to conduct mental simulation requires further investigation to address the identified limitations of the study along with gaining further insights regarding what factors influence this process.

References

[1] of Fire Protection Engineers, S.: SFPE Handbook of Fire Protection Engineering, 5th edn. Springer (2015)

[2] De Groot, A.D.: Thought and Choice in Chess. Mouton Publishers, The Hague (1965)

[3] Kahneman, D., Tversky, A.: The simulation heuristic. In: Daniel Kahneman Paul Slovic, A.T. (ed.) Judgment under Uncertainty: Heuristics and Biases. Cambridge University Press, Cambridge (1998)

[4] Klein, G.A.: Sources of Power: How People Make Decisions. MIT Press (1999)

[5] Bloom, B.S., Broder, L.J.: Problem-solving processes of college students. Supplementary Educational Monographs **109** (1950)

[6] Klein, G., Crandall, B.W.: The role of mental simulation in problem solving and decision making. In: Local Applications of the Ecological Approach to Human Machine Systems. CRC Press (1995)