EVACUATION MODELLING BIASES: RESEARCH, DEVELOPMENT, AND APPLICATION

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ABSTRACT

Human behavior in fire research, the number of evacuation models being developed, and the complexity of the models themselves, has dramatically increased in recent years. This has led to a proliferation of evacuation model usage within the building design process. The vast majority of research within the evacuation modelling community is focused on how people behave during emergencies and how this can be represented. Relatively little attention has been given to how research is conducted, how developers design/implement the evacuation models, or how engineers/consultants use the models to inform the building design process. The complexity of these areas and relative immaturity of the engineering field risks associated stakeholders having more unconstrained decisions to make which can make them more susceptible to human errors in this decision-making. Errors in decision-making may be caused by a lack of resources (e.g. time, information available, etc.) or over focus on certain information through cognitive biases. This paper provides an overview of general decision-making theory including heuristics and cognitive biases with examples of cognitive biases which may exist within evacuation modelling research, model development, and use within the building design process. An online evacuation model user survey was conducted to ascertain to what extent cognitive biases may occur when using evacuation models. Results from the survey provide empirical basis for supporting that cognitive biases do occur in evacuation model usage. The paper is intended to prompt consideration of how decision-making may be improved within evacuation modelling research, model development, and model usage.

INTRODUCTION

Increased computer processing power [1] in the latter half of the 20th century enabled computers to be used for more complex simulation processes - eventually allowing evacuation models to be developed [2]: models simulating people during the evacuation process. Such models were initially developed by university researchers for highly focused specific applications [2, 3, 4]. In the 1990s, computational evacuation models were increasingly used commercially in the building design process by fire engineers. This saw an increase in the number of model development teams within the commercial sector. Currently a number of evacuation models are developed by businesses in the commercial sector [13,14]; however, the large majority of human behavior in fire research which underpins such models is still predominantly conducted by universities. The most prolific users of such models are fire engineers [13,14]. This separation of evacuation model researchers, model developers, and users coupled with an increase in complexity of such models increases the potential for errors in decision making in each associated area. Such errors may be caused by a lack of resources (e.g. insufficient knowledge, time to process such information, mental ability) or an over focus on certain information at the expense of more relevant information though cognitive biases. This paper initially proposes potential cognitive biases which may occur in evacuation model research, model development, and usage. To provide empirical basis and gauge the extent some of the evacuation modelling cognitive biases may occur, an online survey was developed and conducted. The survey invited evacuation modelling users to answer a series of questions about a hypothetical evacuation modelling project. An analysis of results of the survey are presented.

DECISION-MAKING & COGNITIVE BIASES

Research in decision science proposes that decision-making can be thought of as if employing two separate, though interacting, systems of thinking: an automatic system and a reflective system [5,6,7,8,9]. The key differences between the two types of processing is that the latter occurs consciously and requires the use of working memory, whereas the former occurs nonconsciously and does not require working memory [8,9].

The reflective system allows people to address situations in a more deliberative manner. It is more effortful to use, relatively slow and limited by working memory. In comparison to the automatic system, it requires more information, cognitive resources, and focus to complete the decision-making process. It is frequently adopted in unfamiliar situations (e.g., wayfinding in an unfamiliar building, etc.), where a task requires reflection or requires a systematic process (e.g., solving/approximating a long mathematical calculation, identifying the appropriate strategy to attack a fire in a complex scenario, etc.), and/or where time is not considered a limiting factor in an decision [5,6,7,8,9].

The automatic system occurs without a person being directly aware of it. It is used for most decisions, is relatively quick, and is based on a person recognizing given situations or types of situation and associating it with a stored response – effectively pattern matching the scenario with stored examples and then identifying associated stored responses. Commonly it is adopted in familiar situations or where a quick response is required. It is possible to train the automatic system to identify suitable responses when given patterns in a context/situation are identified (e.g. in the form of heuristics). Such training may be received formally (e.g., in the classroom), or may be developed over time through repeated experience (e.g., through repeatedly attending fire incidents). It allows experts (e.g., firefighters, etc.), to competently operate in complex situations under time pressure. Where information is lacking or ambiguous, the automatic system extrapolates, potentially giving the illusion of validity to a decision where it might not be justified.

Neither the automatic or reflective system is guaranteed to produce correct or incorrect response. Irrespective of which system of decision-making is used, the process is bounded in terms of the information available, time available, and an individual's mental resources to process such information. To compensate for such limitations and manage uncertainty or complexity with a decision, people may employ heuristics in the decision-making process.

Heuristics are defined as rules of thumb [9] which can be applied to complex decisions that can result in a suitable response. Such rules of thumb may be developed by creating associations between a given situation and past experience of a learned response, which results in the adoption of a given action based on the association, shortcutting the reflective aspects of decision-making. The development of a rule of thumb involves substituting the decision being made for a similar simpler decision which can be used to produce an outcome. It may also be possible to deliberately prime an individual to adopt heuristics through training to enable speedy responses to a situation; however, the heuristics may not be appropriate if used outside of the intended set of scenarios, placing greater importance on the pattern matching capability of the individual and the quality of the information available. Heuristics are extremely common and can be used in a variety of situations. This type of decision-making process may be labelled as 'expert intuition', which in part demonstrates the nonconscious nature in which it occurs [5]. However, if heuristics are employed inappropriately (e.g. due to incomplete information) systematic errors can inadvertently be produced. This can be made worse through the existence of cognitive biases, where information is inappropriately processed or overly focused upon at the expense of more relevant information in the decision-making process.

EVACUATION MODELLING COGNITIVE BIASES

Based on a review of literature and the authors experience in the field of evacuation modelling research, model development, and usage, the table below lists potential examples of cognitive biases that might affect decision making in each respective area. The list of cognitive bias examples is not exhaustive and not based on empirical data specific to evacuation modelling but is instead derived from general biases identified within decision science and the authors experience with evacuation modelling. The frequency and impact of cognitive biases in evacuation modeling and the building design process is unclear. The potential for their existence warrants attention given the safety critical nature of evacuation modelling.

Table 1: Evacuation modelling cognitive biases

#	Cognitive Bias Type	Application to Evacuation Modelling
		1. Evacuation Research
1.1	Availability bias [9,10]	Overly focusing on aspects of human behavior or modelling which the researcher has past experience at the expense of more relevant human behavior.
1.2	Incentive bias [11]	Having a funding source that develops or has a vested interest in a given approach / product causing the researcher to overly focus on the benefits of the approach/ product.
1.3	Authority Bias [9,10]	Choosing to follow the guidance of an experienced practitioner because they are in a position of authority giving little/less consideration to the validity of the guidance.
1.4	Confirmation Bias [9,10]	Focusing on data that that supports currently held views. Only presenting results which are statistically significant whilst ignoring other data which may still give insights into understanding a given type of human behavior.
1.5	Availability bias [9,10]	Collecting data from an easily available demographic sample (e.g. university students etc.), whilst applying the results to a wider demographic group in an evacuation modelling analysis.
1.6	Availability bias [9,10]	Overly citing the authors own past papers whilst giving less attention to other relevant material.
1.7	Confirmation Bias [9,10]	Focusing on all the reasons why a given research study/finding/model is valuable whilst paying insufficient attention to its limitations.
		2. Evacuation Model Development
2.2	Availability bias [9,10]	Putting undue resources on developing the naturalistic visual output of an evacuation model (as this is what a user sees) whilst giving less attention to developing the underlying behavioral model.
2.3	Optimism Bias [9, 12]	Representing a behavior implicitly (e.g. probability of occurring), while not addressing the underlying mechanisms which produce that behavior explicitly, and then promoting that such behavior as being 'predicted'.
2.4	Confirmation Bias [9,10]	Developing a component of an evacuation model and then searching for research that supports the model development giving little/less consideration to alternate apposing research or appreciation there is insufficient research to develop such a component which can be used with confidence. Developing a component of an evacuation model and then justifying it as being visually realistic despite there being insufficient

		data/understanding to develop a model component with sufficient confidence.
3. Evacuation Modelling Application		
3.1	Default bias [9]	Using default model parameters/settings without consideration of the suitability or underlying limitations for a specific application.
3.2	Availability bias [9,10]	Selecting an evacuation model based on familiarity rather than suitability for a specific application.
3.4	Halo Effect [9, 10]	Believing an evacuation model must be suitable to use for a given application because 'it has been validated/verified' without consideration of the specific nature or details of the validation/verification process in relation to the application.
3.5	Halo Effect [9, 10[	Believing because the visual graphical representation of people in an evacuation model appears realistic, the underlying behavior which governs the people's movement is also realistic.
3.4	Optimism Bias [9, 12]	Assuming that a model that has been used successfully for one application can be used for another application, giving little/less consideration to the differences between the projects or the suitability of the models features/validation/verification for the specific application.

EVACUATION MODELLING COGNITIVE BIASES SURVEY

An online survey was conducted to examine the potential for biases in evacuation modelling usage. This approach provided access to a wide range of evacuation model users. The survey was aimed at evacuation model users, posing a hypothetical evacuation modelling project then asking them what decisions they would make. Participants were informed that they were employed to conduct an evacuation modeling assessment as part of an engineering performance-based analysis and that they should answer a series of questions about their decision-making. Participants were time constrained to prompt more naturalistic responses. The intention of the survey was to identify if cognitive biases existed and how frequently they occur within the evacuation modelling process.

The survey consisted of 21 questions which was split into five sections including: evacuation model selection, scenario specification, model configuration, results analysis and presentation, and user details. The survey was disseminated through online social media networks (e.g. LinkedIn and Twitter) and made available over a period of two months (June 2020 – July 2020). The briefing page of the survey requested that only those involved or have experience in evacuation modelling in a commercial setting should complete the survey.

Participant characteristics and experience

60 participants completed the survey: two-thirds (65%) were male and approximately one third female (28.3%), with the rest preferring not to state their gender. Most participants were aged between 20-39 years old (78.4%). Participants came from a variety of global regions located in Europe (53.3%), Australasia (20%), Asia (11.7%), North America (11.7%), and Middle East/South America (3.3%).

When asked about evacuation model training, most participants stated they received more than one form of training: Interestingly, two-thirds (66.7%) either received informal training or were self-taught. Just under a third (28.3%) reported having attended a university course and under a half also received some in-house training within their company. Almost one half (45%) of participants stated they were proficient with two evacuation models with 38.3% stating they could use only one evacuation model with 16.7% stating they could use 3 or more evacuation models (see Figure 1A).

The sample represents a broad range in terms of user experience, yet over half of participants (58.3%) stated they had less than 5 years' experience (see Figure 1B). Taken together, these statistics reflect that evacuation modelling users commonly come from a relatively young age range with limited years experience.

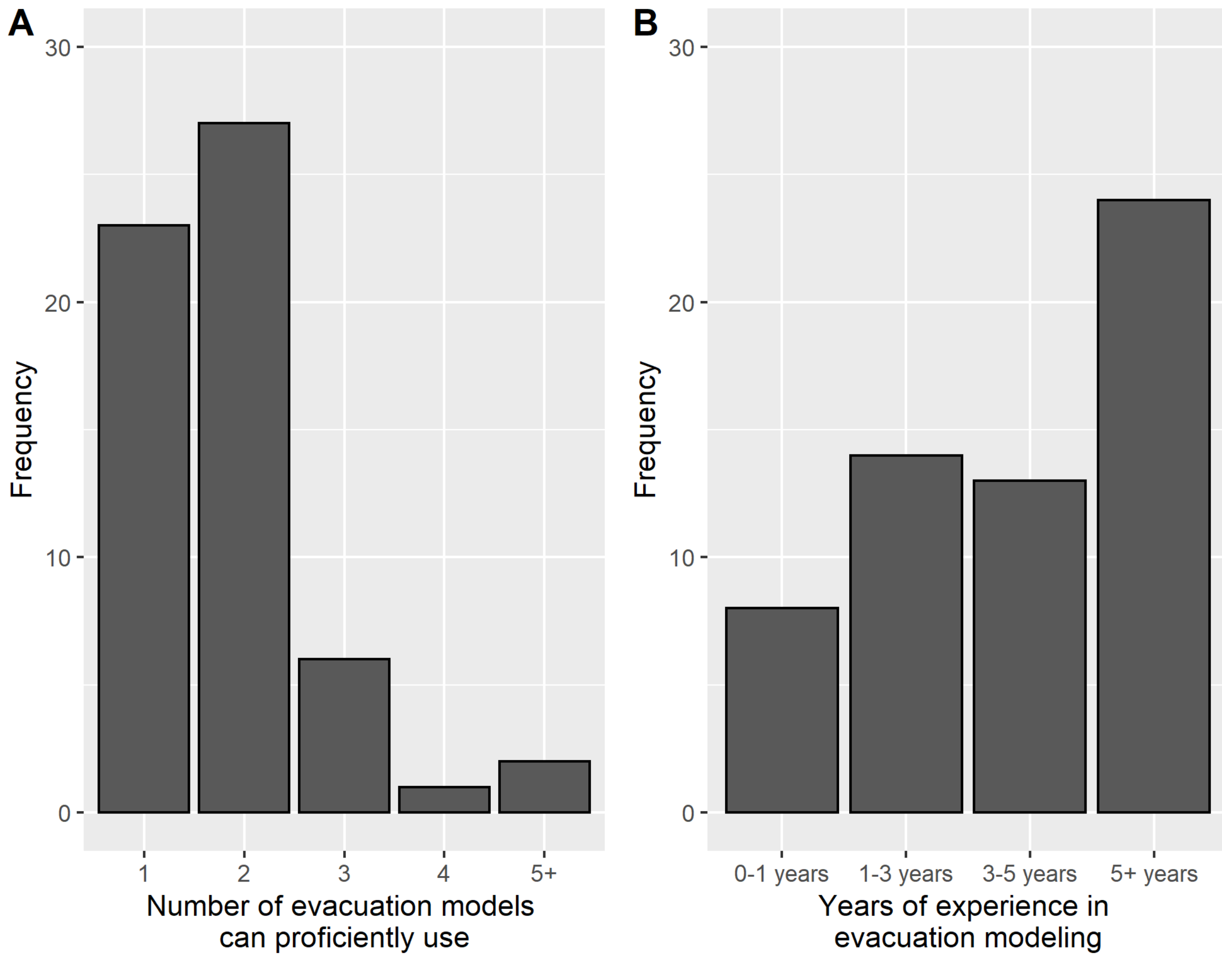

Figure 1: Participant proficiency (A) and experience (B) in evacuation modeling

Evacuation model selection

Participants were asked what tasks they would typically perform before conducting the evacuation modelling analysis. The intention was to elicit if participants considered alternatives when selecting an evacuation model to use. Just over a half (58.3%) of participants stated they would consider which evacuation model to use.

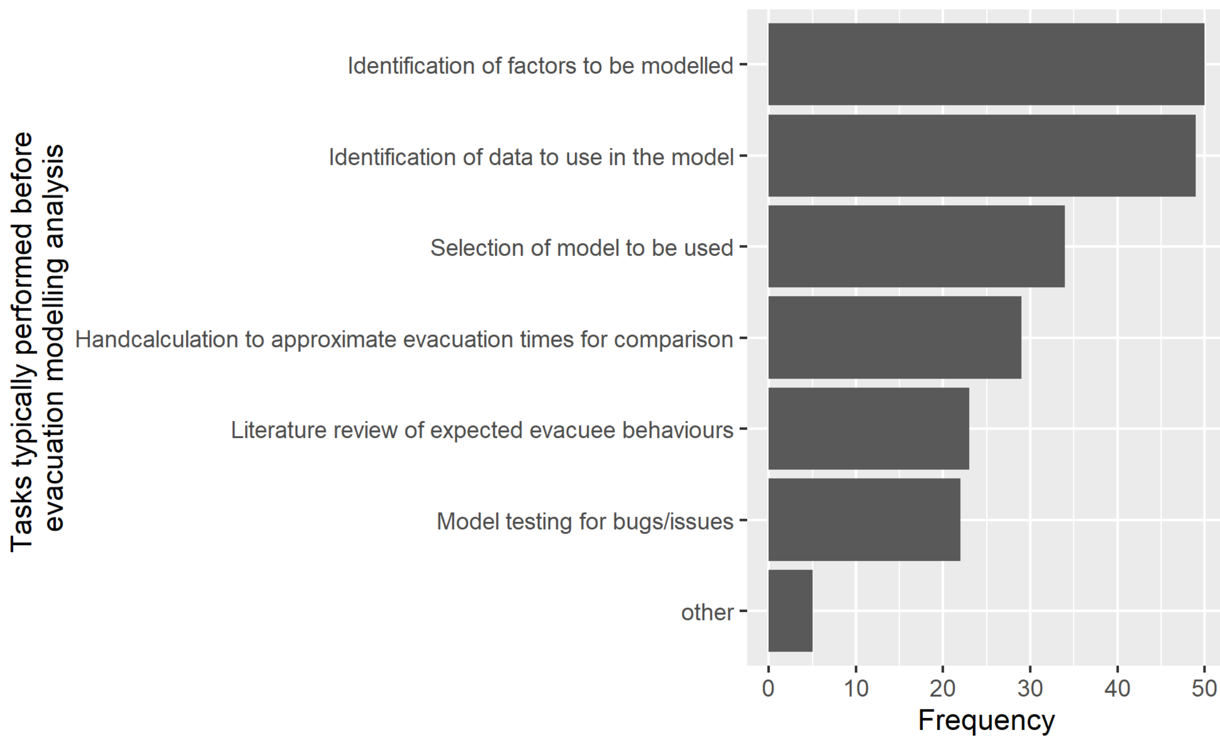

Figure 2: Tasks participants would typically perform before conducting the evacuation modelling analysis

A series of follow up questions were asked to establish why participants may select a given evacuation model. Participants were asked how many evacuation models they could access to conduct the analysis (i.e. their organization has software licenses and they are proficient users). Just over a half (58.2%) of participants have access to one evacuation model. Just over a third (38.2%) of participants have access to 2-3 evacuation models. Considering company resources are limited for software licenses and associated costs regarding training, it is not surprising that model access is limited. Evacuation model selection, for many users, may not necessarily occur due to ignorance/oversight of information (or an nonconscious bias) but instead imposed on users by commercial constraints. However, of those participants who stated that they only had access to one evacuation model (n = 32), still 18% stated that model selection was a task they performed prior to their analysis – potentially showing some tension in this part of the modelling process.

The participants who had access to more than on evacuation model were asked the reasons for selecting an evacuation model. 34.8% stated they would use the model which was most suitable for the project. Around a half (52.1%) stated they would either use the evacuation model they most frequently use on past projects (21.7%) or they would choose the model that have most experience/expertise in. This implies that model familiarity rather than suitability for a given application is a factor in over a fifth of participants who had a choice.

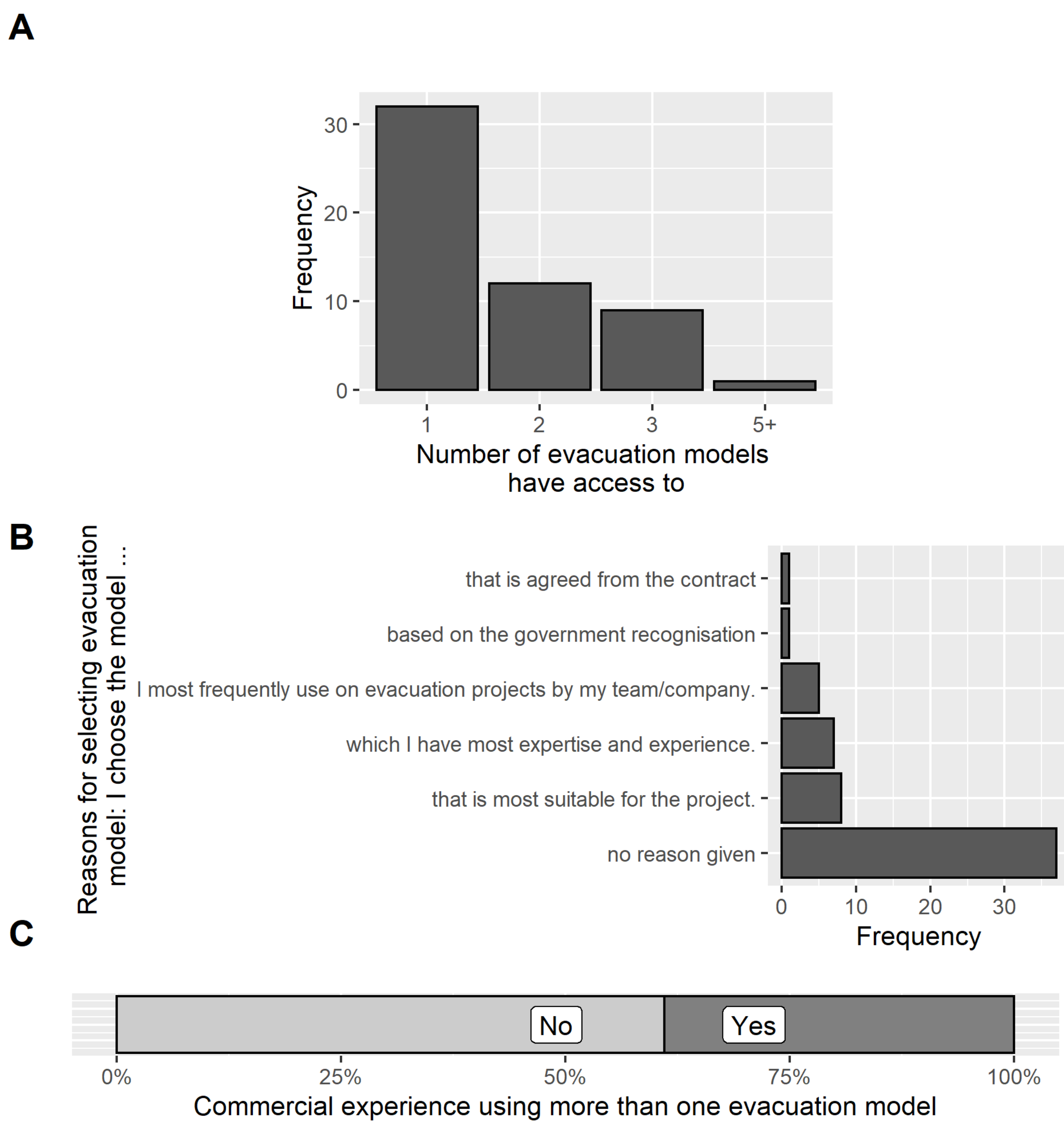

Figure 3: Evacuation model selection reasons: Access (A), User (B), Experience (C)

Scenario specification

The next section of questions was focused on understanding the scenarios participants would conduct- to identify any trends in the selection of scenarios and/or potential biases in the process. 86.8% of participants stated they would likely run more than one evacuation scenario. This suggests there is widespread understanding of the need to consider multiple evacuation scenarios, although there is a small minority that would only consider running a single evacuation scenario. Of the 86.8% who would run more than one scenario, three factors were most frequently identified: doors/stairs being blocked by fire/smoke (88.5%), different demographics groups (69.2%), and different pre-evacuation time distributions (61.5%) (see Figure 4). The results suggest that, for people that decide to consider multiple evacuation scenarios, generally there are range of factors they would consider which are expected to potentially impact the modelling results.

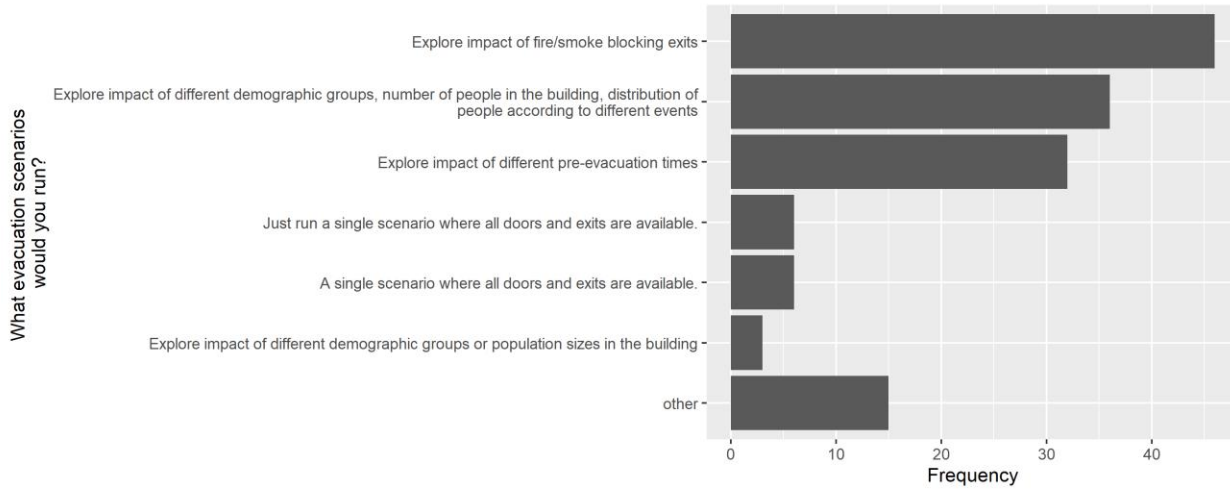

Figure 4: Evacuation scenarios participants would run

Model configuration

Model configuration requires specifying input parameters/settings to reflect a scenario. This section of the survey explored whether these parameters were set to best reflect the scenarios or influenced by other factors (e.g. using default settings irrespective of their suitability). Participants were initially asked if they would use the default walking speeds within the model, of which over a third (36%) stated they would always or most of the time use the default speeds. The remaining participants stated they would sometimes, rarely or never use the default walking speeds. Participants were then asked if they were aware of the source the default walker speeds used, of which over a third (38.3%) stated they did not know. Of those participants which stated they did know the default speed source (61%), they were asked to name the study or reference. From the responses, almost half (46.7%) could not name the study or reference . Of those they did provided the source, 27% stated Fruin, 12.7% stated SFPE Handbook, and 12.7% stated another source. Participants which had 5+ years' experience were more likely to state the source compared to those with less experience. The motivations for selecting the default walker speeds is unclear from the results and the suitability of this data may vary depending on which model is used. However, the results suggest that a sizeable proportion of evacuation model users will adopt the default walker speeds regardless of the application. There also appears to be some overconfidence with participants stating they know the source but then not actually be able to name the study or reference. It is suggested that if these individuals cannot state the study or reference then they will be unaware of details about the associated data, its limitations or its suitability for a given application.

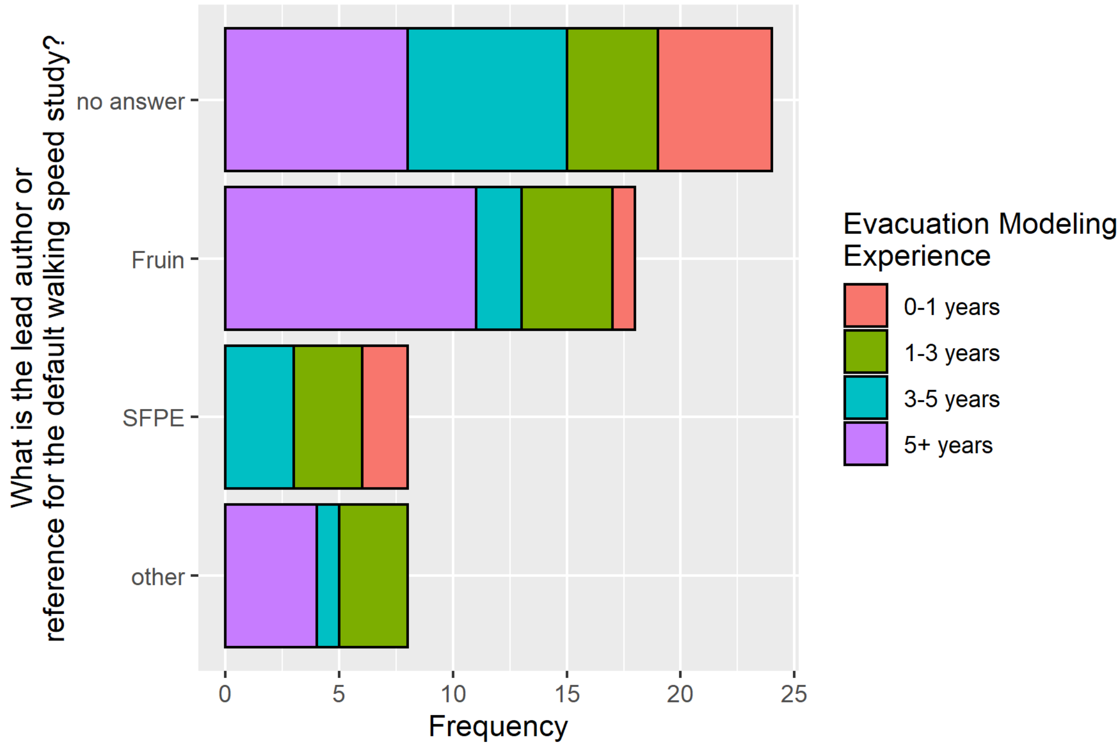

Figure 5: Knowledge of walking speed reference

Participants were asked more generally if they would use the default settings within an evacuation model for other aspects of model configuration: 51.1% stated they would very likely do so. This broadly correlates with the walking speed results with a sizable proportion of participants electing to the use the default settings within an evacuation model.

Participants were asked if they would run repeat simulation runs (i.e. to account for stochastic elements /pseudo random sampling within an evacuation model). 86.9% stated they would run multiple repeat simulation runs. Participants were then asked how they would determine the number of repeat simulation:

- 44.2% would measure some output variable(s) or series for variance and repeat simulation runs until the level of variance stabilized.
- 17.3% would run a predefined fixed number of repeat simulation runs based on standard guidance recommendations.
- 17.3% would run a predefined fixed number of repeat simulation runs as this is what they normally did.

The results highlight that almost a fifth (17.3%) would generally adopt default behavior in selecting the number of repeat runs without consideration of variability in the results produced or recommendations from standard guidance.

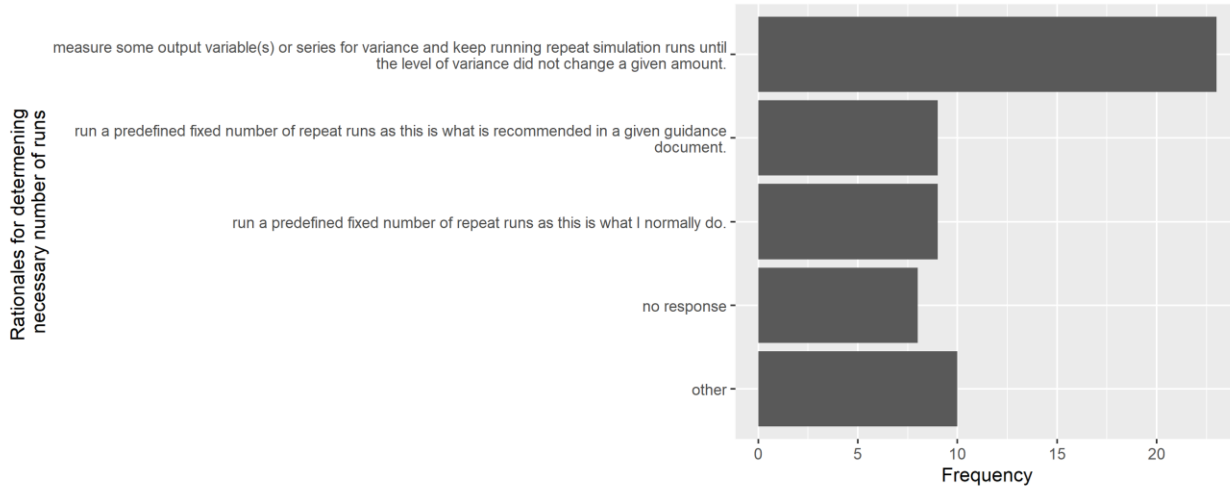

Figure 6: Rationales given for determining the number of evacuation modeling runs needed

Evacuation modelling results analysis

The analysis of the results forms a key aspect of the evacuation modelling process. This section of the survey attempted to establish if any biases existed regarding the graphical realism and implied reliability of the results. Many evacuation models employ visually realistic looking graphical representation of people evacuating which may cause halo-bias (9, 10) - where realistic graphical representation is assumed to imply representative modelling. 81.7% of participants stated that evacuation models allow them to produce convincing and visually realistic looking animations of people evacuating. These participants were asked if they believed that visual realism implies simulated behaviours are also realistic. Over two thirds of participants (69.3%) stated either it did not give them confidence (46.9%) or they were not sure if it gave them more confidence (22.4%). Almost a third (30.6%) of participants stated because the simulation looks visually realistic then it gives them confidence that the simulated behavior is also realistic. Results suggest that a sizable proportion of participants were biased by the graphical realism of the model output without specific reference to the underlying behavioural assumptions made in the model.

LIMITATIONS

The presented study has several limitations. First, data collected in online surveys relies on the honesty of participants in their responses. Several respondents stated that they knew that the reference for the walking speed data, but did not specify the author of that source in a follow-up question. Respondents may simply have forgotten the name, but it is also possible that they were not honest in their initial response. Second, surveys rely on the ability of participants to interpret questions in the way the authors intended. Although, the authors tested the survey prior to data collection, it is possible that at least some participants did not interpret items as intended. Third, data was collected from a convenience sample or a limited size, limiting the generalizability of the results. Fourth, the survey items were not evaluated regarding their reliability or any other psychometric performance benchmarks. To address such limitations, it suggested trials could be conducted under experimental conditions of actual evacuation model usage to demonstrate biases occurring in practice rather than being based on self-reported behavior in a hypothetical scenario.

CONCLUSION

The paper presents a general description of decision-making and potential sources of cognitive biases. Potential evacuation modelling cognitive biases are presented in research, model development and usage. These are based on a review of general decision science literature, observations within the general evacuation modelling field based on the authors' experience. Results from an online survey of evacuation model users is presented which provides empirical basis for the existence of certain evacuation modelling cognitive biases along with the extent they occur. The key objective of this article is to promote awareness of the existence of potential evacuation modelling cognitive biases with the intent that this in turn may promote development of associated mitigation measures. Those that may benefit from awareness of such biases include not only evacuation modelling researchers, model developers, and users but also approving authorities and students involved in evacuation modelling.

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