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Discussion

Why model evacuee decision-making?

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ABSTRACT

The purpose of this article is to outline the theoretical and practical benefits of representing the evacuee decision-making process within an agent-based simulation tool. This rationale is important as the development of a comprehensive representation of evacuee decision-making will be expensive, requiring a great deal of time, expertise and effort. However, the theoretical and practical benefits are such that this effort is considered warranted.

In previous work, Gwynne et al. demonstrated advances in the representation of evacuee performance and the potential for representing evacuee decision-making. Here, we show that realising this potential is critical to progressing future analysis and, in turn, the field. The paper concludes the following:

- Current understanding of evacuee performance suggests a decision-making process often in response to a complex, ambiguous and dynamic environment. This process connects the conditions experienced by an agent and the actions taken. Representing this is important if we are interested in what evacuees do and when they do it.
- Agent-based models have the potential to represent evacuees, their decision-making process, their subsequent actions and the resultant interactions between agents and entities in their environment.
- Generative Social Science (GSS) employs ABM (agent-based models) to produce subject matter insights using retrodiction and prediction. These approaches will help us enhance our subject matter understanding and the computational tools available to quantify evacuee performance, in turn aiding theoretical and practical efforts.

The specific benefits of this approach to our understanding and quantification of evacuee performance are described in this paper, which include the expansion of the explanatory value of the tools available and the refinement of theoretical explanations of evacuee behaviour.

1. Introduction

A number of computational models are used to calculate egress times. These models offer the *potential* for representing evacuee performance, specifically the evacuee decision-making process, in a more refined manner. This potential is rarely realized. In reality, any egress model is a simplification that involves a representation of theory, data, and the judgment of developers and users. Even the most sophisticated of current egress models have tended to over-simplify some areas of the evacuation process (particularly evacuee decision-making), while focusing on others (e.g. the representation of physical movement); primarily due to the lack of a comprehensive conceptual model (CCM) describing evacuee decision-making during fire emergencies, and scepticism that such a representation is even possible (Gwynne et al., 2016).

Models of evacuee performance vary considerably: ranging from conceptual models, to analogous models, to cellular automata, to agent-based simulation models. Within various approaches, the evacuee decision-making process might be represented: implicitly, i.e. assumed to be represented by some other aspect of the model; statistically, i.e. ahistorical probabilities applied when certain external/scenario conditions are met; empirically, i.e. data-sets used to represent the aggregate impact of actions; directly, i.e. using a stimulus-response relationship between agents' actions and cues perceived; specifically, i.e. agent response is determined by the user; or explicitly, i.e. a deliberate attempt to represent the evacuee decision-making process. It should be noted that this last explicit approach is rare, and currently only used on a small-scale, to reflect singular/specific aspects of evacuee behaviour. The variety in model approaches reflects their different origins, objectives and the state of the field at the time of their development. Given

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that each approach has limitations it is imperative that the behavioural assumptions on which each model is based is understood, allowing the user to discriminate between them and either take compensatory actions or consider the confidence that they have in the results produced.

Models have continued to be developed in response to our increased understanding of the subject matter at hand, computational power available, and access to data. However, the evacuee decision-making process itself is not yet explicitly and comprehensively defined (nor is the sensitivity of this process to external environmental or social cues), largely because of the immaturity of our understanding of evacuee behaviour, the lack of sufficient theoretical structures and our field's late adoption of 'generative' approaches to simulation. To further the simulation of evacuee decision-making, a CCM is required that describes the decision making process and encapsulates our current knowledge of evacuee behaviour. It is proposed here that the inclusion of such a model within a simulation tool (in this instance, an ABM) will add to the credibility and the capabilities of egress tools available.

The current, immature conceptual model of evacuee behaviour is a composite of existing theories and data, each representing some portion of evacuee performance (Kuligowski, 2011). As it continues to be developed, this will represent the key factors that are known to inform decision-making during an evacuation. Once it is sufficiently advanced, the CCM of evacuee behaviour will be embedded (e.g. into a computational egress model) to better represent egress behaviour and aid in the quantification of egress performance. For instance, it would drive the response of an evacuating agent who might interact with other aspects of the host model, such as other agents, the procedure, the structure, etc., given the situation faced and the information available (Kuligowski, 2011, 2009).

In this paper, we outline the theoretical and practical benefits for simulating the evacuee decision-making process within an agent-based tool, using current understanding from the generative social sciences. These benefits are both theoretical and practical. It is contended that the representation of evacuee decision-making as a process within computational tools is critical in two ways. Firstly, to the generation of useful insights for current model users – expanding the explanatory value of the tools available, to add to the descriptive insights typically provided. And secondly, to the further refinement of theoretical explanations of evacuee behaviour and the continued development of a behavioural framework ready for anticipated rich and vast data sources in the future (Gwynne et al., 2016; Kuligowski, 2011, 2009; Templeton et al., 2015; Kuligowski et al., 2016). We certainly do not underestimate the scale of the task; however, we recognize the fundamental importance of this task to the future credibility and applicability of our field.

The purpose of this article is therefore to

- Present the benefits of adopting an agent-based approach when representing evacuee performance.
- Introduce a generative approach to enhancing our theoretical understanding and practical modeling capabilities that is reliant on the use of an ABM.
- Present the practical and theoretical benefits of representing the evacuee decision-making process during the simulation of evacuee performance.

The intention is to support our ongoing efforts in producing more credible, representative and insightful egress tools.

2. Theoretical benefits of agent-based simulation

In the next sections, parallels are drawn between the core elements of evacuee performance (Gwynne et al., 2016; Kuligowski, 2011, 2009, 2015; Templeton et al., 2015; Kuligowski et al., 2016; Klein, 1999; Simon, 1956; Mileti and Soresen, 1990; Tversky and Kahneman, 1974) and the fundamentals of ABM (Gilbert et al., 2012; Gilbert and Troitzsch, 2015); supporting the suitability of ABM for representing both individual actions and the evacuee decision-making processes. The importance of representing the decision-making process to reliably simulate evacuee performance is discussed in subsequent sections.

2.1. Theories of evacuee behaviour

Human behaviour in fire (HBiF) is relatively immature, only being a recognizable area of research for about 50 years (since the pioneering work of Prof. Bryan (Kuligowski, 2015). HBiF came out of an established area of engineering (fire safety/fire protection) that was hungry for numerical tools that aided engineering practice, as opposed to tools that provided a qualitative understanding of evacuee response. *This immediate need dominated long-term understanding.* This somewhat skewed research to the (admittedly laudable) pursuit of empirical data suitable for immediate use in engineering calculations. The need for this empirical data accelerated with the introduction and proliferation of performance-based design (PBD), as PBD is more directly reliant upon the quantification of evacuee performance. The work presented here in no way diminishes this vital and fundamental work – or diminishes the importance of PBD. Quite the opposite: the models developed in response to this need provide the foundations for the on-going development of the field and have opened up enormous potential for the ideas presented herein.

As PBD has continued to be employed, third party scrutiny has also evolved, requiring greater insights and more detailed explanations of the causal factors underlying the results presented. In response, desired outputs now extend well beyond the time for the evacuation of an entire structure and include more refined results; for instance, the time to clear specific internal locations, the numbers using certain routes, the performance and experience of sub-populations, etc. In order to inform an iterative design process, third parties also want greater insights into the factors that influence this performance.

2.2. Evacuee decision-making

An evacuation is a social process that involves the movement of an individual from an initial location to another (ideally safer) location in response to a potential threat. The evacuee objectives, the tasks performed to meet these objectives and the manner in which they are performed will be reliant upon the information available, the (social and physical) conditions faced, and the capabilities of the individual evacuee to process the information and respond in the required manner; all of these factors involve sensory, cognitive and social processes.

A large body of behavioural research has shown that occupants, either individually or in groups, engage in a decision-making *process* during an evacuation (Kuligowski, 2011, 2009, 2015; Klein, 1999; Simon, 1956; Mileti and Soresen, 1990). This process may be iterative, imperfect, variable, partial, unconscious in parts, and inconsistent; however, it can be considered as an attempt by the evacuee to produce a sequence of actions in order to satisfice a set of short-term and long-term objectives (Simon, 1956; Mileti and Soresen, 1990).[1] Individuals perceive certain cues; interpret the situation given the information available combined with prior knowledge and experience; assess their personal risk; update their objective(s); and then make a decision as to what to do in order to meet their updated objective(s) in concert with the physical and social situation faced. Depending on their training, experience and the perception of the time available this process may be truncated (Klein, 1999; Tversky and Kahneman, 1974). There are a number of conceptual models presented in the literature that either: provide a simple overview of evacuee behaviour, focus on one aspect of it, or are derived from a specific incident (Kuligowski, 2009, 2015; Templeton et al., 2015; Kuligowski et al., 2016). Full conceptual models

[1] Goal-driven behaviours.