HUMAN BEHAVIOUR IN FIRE – MODEL DEVELOPMENT AND APPLICATION

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ABSTRACT
The purpose of this article is to introduce a conceptual model of human behaviour in fire. This model is based upon a theoretical framework of individual decision-making and response to emergencies, and from this foundation, is populated with behavioural statements or mini-theories predominantly from human behaviour in fire. These behavioural statements are extracted from articles and authoritative reports describing incidents, observations from within the field of evacuation analysis and human behaviour in fire. These statements are used to guide the model developer and model user in their attempts to better represent the evacuee decision-making process.

INTRODUCTION
The design of buildings is commonly informed by the use of prescriptive and performance-based (PBD) methodologies to ensure a certain level of safety. These methodologies attempt to ensure a sufficient degree of life safety within buildings by defining a set of viable design alternatives for the designer to employ or by assessing the life safety level reached. Prescriptive approaches rely on the application of a predetermined set of rules that, if employed, limit the risk of the design to an acceptable level[1]. The performance-based methodology requires the quantification of both available safe egress time (ASET) and required safe egress time (RSET) to determine the degree of life safety provided. This article focuses on the RSET component which a fire engineer would calculate using some type of egress modelling technique, by addressing human behaviour in fire.

For certain applications, simple engineering equations are applied to estimate the RSET value. These equations are typically based on a simplification of expected evacuee behaviour. For complex applications, more sophisticated computational tools are now frequently used. These tools offer the *potential* for representing evacuee behaviour in a more refined manner.

In reality, any egress model is a simplification that involves a representation of theory, data, and the knowledge and judgment that a developer or user brings. However, egress models have tended to over-simplify some areas (e.g. evacuee decision-making and situation awareness) while focusing on others (e.g. the representation of physical movement). Irrespective of the approach adopted, appropriate and accurate representation of human behaviour in fire within these approaches is currently limited, due mainly to the lack of a comprehensive conceptual model of evacuee decision-making and subsequent behaviour during fire emergencies.

A conceptual behavioural model is a composite of existing theories and data that has been drawn together to represent some portion of evacuee behaviour. In this instance, a conceptual model would be developed to represent the key decision-making process that influences response during a building evacuation, given the situation faced and the information available[2]. Once developed, the comprehensive conceptual model of evacuee behaviour would be embedded into computational egress models to better represent egress behaviour.

Currently, no conceptual model exists that is sufficiently comprehensive to reflect even our current (albeit immature) understanding of egress behaviour, although recent advances have been made[3]. In the meantime, what does exist is a set of micro-sociological theories or behavioural statements (previously referred to as behavioural facts) that describe specific aspects of evacuee response during fires. These statements, although are by no means universally appreciated or adopted[2], occasionally find their way into the design and application of evacuation models.

The purpose of this article is to present a preliminary conceptual model of human behaviour in fire that encompasses behavioural data and theory from various types of emergencies, including fire incidents. This model is constructed based upon a theoretical framework of individual decision-making and response to emergencies, and from this foundation, is populated with behavioural statements or mini-theories specific to human behaviour in fire. These behavioural statements are extracted from articles and authoritative reports describing incidents, observations from within the field of evacuation analysis, and human behaviour in fire[3-4].

In the second half of this paper, guidance is provided on how these behavioural statements might be incorporated:

- By the model developer into an evacuation model such that a more credible representation of the evacuee decision-making process is viable; and
- By the fire engineer into an evacuation model, in order to represent human behaviour in fire within a life safety analysis.

This article attempts to (a) identify the components required by evacuation models to represent current understanding of human behaviour in fire and (b) to provide some impetus to the development, implementation and representation of such models in current practice.

THEORIES OF EVACUEE BEHAVIOUR

A large body of behavioural research has shown that occupants, either individually or within groups, engage in a decision-making *process* before evacuating. Occupants perceive certain cues, interpret the situation, establish the risk to them based on those cues combined with prior knowledge and experience, and then make a decision as to what to do (i.e., select an action) based on these interpretations. There are a number of conceptual models presented in the research literature[3,4,5,6]. These models tend to focus on the overall process (e.g., Canter[7,8,9,10]) providing limited detail regarding the application of the decision-making process in any circumstance, an aspect of the decision-making process[11,12], or refer to a specific situation (e.g., Kuligowski[3]). Therefore, each type would need to be coupled with other data and theories to support the development of an overall conceptual model for implementation within a computational egress model.

Research into disasters, based on methods from the social sciences, has led to the development of theories and perspectives that can be related to building fire emergencies. In the first theory, Emergent Norm Theory (ENT)[13], individuals are required to make a concerted effort to create meaning out of new and unfamiliar situations, often under time pressure. From this meaning, a set of actions, different from those that have become routine, must be created. ENT explains the process of meaning-making in the face of uncertain conditions, stating that in situations where an event occurs that creates a normative crisis (i.e., an event where the institutionalized norms may no longer apply), such as a building fire, individuals interact collectively to create an emergent situationally-specific set of norms to guide their future behaviour. Milling is a communication process whereby individuals come together in an attempt to define the situation, propose and adopt new appropriate norms for behaviour, and seek coordinated action to find a solution to the shared problem at hand[14]. In another theory, a decision-making model has been developed that extends and applies ENT's explanation of the meaning-making process in crises to disaster situations. The Protective Action Decision Model (PADM), which is based on over 50 years of empirical studies of hazards and disasters[15, 16, 17, 18, 19], provides a process that describes the information flow and decision-making that influences protective actions taken in response to natural and technological disasters[20].

PADM posits that cues from the physical environment (e.g., the sight of smoke) and the social environment (e.g., emergency messages or warnings), if perceived as indicating the existence of a threat, can interrupt normal activities of the recipient. For this to happen, the individual must first receive the cue(s), pay attention to the cue(s), and then comprehend the cue(s). These three steps are known as "pre-decisional processes". After the three pre-decisional processes are completed, the core of the decision-making model consists of a series of five questions[20]:

- 1) *Is there a real threat that I need to pay attention to?* [If yes, then the individual/group believes the threat and that an action may be required]
- 2) *Do I need to take protective action?* [If yes, then the individual/group decides to take protective action given the personal consequences of the perceived situation]
- 3) *What can be done to achieve protection?* [The individual/group begins searching for possible protective action strategies – to protect themselves against the perceived threat]
- 4) *What is the best method of protection?* [The individual/group chooses one of the action strategies developed in the previous stage and develops a protective action strategy or plan]
- 5) *Does protective action need to be taken now?* [If yes, the individual/group follows the plan developed in the previous stage]

Individuals must "answer" each question in order to proceed through the perceptual-behavioural sequence, in which the outcome of the process is the performance of a behavioural action. If, at any time, they cannot answer a question, they engage in actions to seek additional information – asking themselves or others: a) what information do I need? b) where and how can I obtain this information, and c) do I need this information now?

Overall, ENT and the PADM provide the framework from which a conceptual model of human behaviour in fire can be developed. While the PADM outlines the steps or stages in which an individual/group has to go through to achieve safety, it does not address the specifics related to building fires: i.e., the factors that would influence various stages of the process, the types of behaviours that are likely to be performed at various stages, and the nuances unique to building fires (i.e., smoke from a fire can vary by optical density as well as levels of toxicity). For that reason, fire-related behavioural statements, described in the following section, are used to "populate" the previously described theoretical framework, in order to initiate the development of a conceptual model of human behaviour in fire.

BEHAVIOURAL STATEMENTS OF HUMAN BEHAVIOUR IN FIRE

In this section, 27 behavioural statements are presented that are extracted from articles and authoritative reports describing incidents, observations from within the field of evacuation analysis and human behaviour in fire, or aspects of existing theories in adjacent fields that have been co-opted into evacuation analysis[3,4]. In essence, these statements have each appeared several times in the literature in some form – either as a finding from research or as an assumption in modelling analysis, or some combination of the two. Separately listed, these represent a disparate picture of human behaviour during fire evacuation. However, when organized according to the PADM framework, we move closer to a comprehensive theory of human behaviour in fire. Behavioural statements included here consist of mini-theories on behaviours that can occur during an evacuation, what influences these behaviours, and what the outcome of these behaviours might be. Since these mini-theories are connected and interdependent within the framework of the PADM, they are meant to be used together as a comprehensive theory (rather than in a piecemeal manner).

These behavioural statements have been obtained from a variety of sources concerning what people do in fires. Before now, there has been little attempt to compile these statements and develop an overarching conceptual model for human behaviour in fire. Previously, these statements have remained isolated key statements, which were occasionally used in current egress analysis and distributed between publications and other sources.

Twenty-seven statements are then presented below, organized by the steps/stages of the PADM. These behavioural statements are typically derived from incidents, (repeated) observations. This list is by no means exhaustive, but represents the key behavioural conventions that are identified, understood, and employed within model development and engineering practice to some degree of frequency.

Pre-decisional Processes

1) Previous experience of false alarms or frequent drills can reduce sensitivity to alarm signals, inhibiting perception processes[21].
2) Some individuals exhibit hypervigilance that makes them particularly sensitive to certain cues[3].
3) Habituation (where a process has become routine in nature), focus and stress can narrow the perceptual field, and thus, not all available cues will be internalised[22].
4) Sensory and cognitive impairments can inhibit the perception of cues[23].
5) Content and clarity of the cue matters. The more clearly presented, without jargon, the more likely it will be comprehended accurately[24].

[Stages 1 and 2] Assessing the situation and perceiving some level of risk

6) The precision, credibility, consistency, comprehensiveness, intensity and specificity of the external cues will affect the assessment of the situation and perception of risk[24].
7) Authority of the information source affects the perceived credibility of the information, and in turn, the assessment of the situation and risk[25].
8) Normalcy bias and optimism bias are commonplace. In other words, people often think that nothing serious is taking place, and that nothing bad will happen to them, respectively[26, 27].
9) Training on and/or experience with a particular incident type may allow a similar incident to be defined more quickly by the evacuee[28].
10) The actions of the surrounding population can influence the internal processes of the individual; e.g. if others are taking action, it must be a serious situation[29].

[Stages 3 and 4] Protective action search and selection

11) People tend to satisfice rather than optimise. In other words, they are more likely to choose an option that is perceived as "good enough" rather than the best option[30].
12) Pre-event commitment to a particular activity may cause individuals to decide against taking protective action[6].
13) Authority of the source performing the action or instructing others to perform the action affects the perceived credibility of the action[25].
14) The actions of the surrounding population can influence the options of actions developed by the individual[29].
15) Gender can influence the selection of actions to protect property[3].
16) Social and authoritative roles, such as management, and social connections can influence the selection of actions to help others[3].
17) Training and experience in previous fire/evacuation events can influence the search for and selection of a particular action or set of actions, e.g., rescue actions or preparation actions[28].

[Stage 5] Protective action implementation

18) Presence of smoke in a route does not always preclude the use of that route[31].
19) Training and experience may increase an individual's familiarity with the use of components/devices and subsequently improve their use[32].
20) People have different abilities that influence the actions selected and the way that they are performed.[23]
21) People seek information in situations where information is lacking or incomplete[3,31,32].
22) People engage in protective actions, including preparing to move to safety or helping to protect others from harm, before they initiate a movement towards safety[31]. These actions can also occur while moving to safety.
23) People move towards the familiar, such as other people, places and things[6,21].

24) People may re-enter a building, especially if there is an emotional attachment to the building, the contents and/or the inhabitants[31].

General statements

25) People will behave in a rational AND altruistic manner; panic is rare[31].
26) Evacuation is a social process, in that groups are likely to form during an evacuation[33].
27) Social norms (or rules) in place prior to a fire event form the basis of those employed during the event. In other words, norms before the incident will influence those developed in response to the event[34].

This list of behavioural statements provides our current understanding of human behaviour in fire, and organized using the PADM, begins the development of a conceptual model. In previous work, Kuligowski synthesized a number of fire and disasters theories to better understand the evacuee response during the WTC attacks[3]. This was translated by Gwynne into a structure more amenable to model implementation, and then further enhanced by Gwynne et al.[5]. Following on from this work, in the next section, an overview is provided of the ways in which a comprehensive model of human behaviour in fire could be incorporated into an agent-based evacuation simulation tool – both by model developers and by model users. The representation of these statements within a computational environment will allow their impact on performance to be represented, but may also act as a proving ground to further refine the conceptual model itself.

MODEL DEVELOPERS - IMPLEMENTING THE BEHAVIOURAL STATEMENTS WITHIN A COMPUTATIONAL EGRESS MODEL

A small number of the 60+ computational egress models currently available document the behavioural assumptions made in any great detail[35]. Even fewer models attempt to connect these assumptions into a coherent behavioural model. More commonly, model developers identify each development made (and the associated functionality associated with it) and document them in a piece-meal manner.

More often than not, egress models that clearly acknowledge the implemented behavioural model typically focus on the representation of evacuee movement rather than the evacuee decision-making process[35]. Some models represent a simplified form of the decision-making process by adopting a few of the behavioural statements. Less common are models that include (and document) more comprehensive representations of the decision-making process[35]. The majority of these can be found in research dissertations – where the developer has produced a single, coherent decision-making model. This is typically found in crowd dynamics, rather than egress modelling[36].

The current state of available computational tools does not readily allow the representation of the full-set of behavioural statements described previously. The lack of a comprehensive conceptual model (i.e. an implementation blueprint) certainly inhibits this representation. Therefore, a simplified behavioural model suitable for implementation within an agent-based computational egress model is presented. The primary purpose of this description is to outline the *types* of components that need to be represented in a computational egress model (in this case an agent-based model) to enable the implementation of a conceptual model. This model is based on the work originally performed by Gwynne[5] and Gwynne et al.[37] The original conceptual model was produced to reflect (and expand upon) the theoretical developments made by Kuligowski regarding the WTC incident[3] and the more limited set of behavioural statements presented at the time[5].

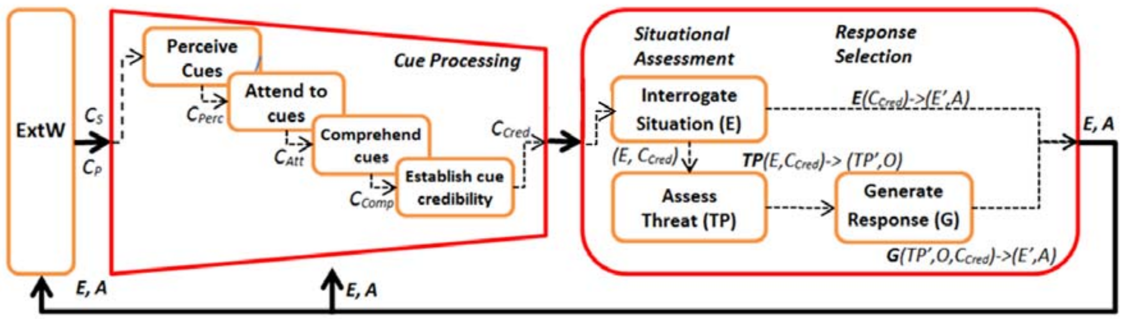

Figure 1: Simplified model for implementation[5]

A simple example of this model is shown in Figure 1. In this model, it is assumed that the agent is exposed to cues from the external world (***ExtW***) that are either physical (C_p) or social (C_s) in nature. Given that the cues exist, they are then filtered – a process wherein cues may be perceived, attended to, understood, and deemed credible by the agent. At each step, the original set of cues (C_s+C_p) is reduced (from C_{perc} to C_{att} to C_{comp} to C_{cred}) as individuals perform "cue processing". In the end, the information that might eventually be internalized by the agent is a sub-set of that which was originally available to them.

Next, a situational assessment is made based on the cumulative experiences amassed from similar prior events and from the external cues to which the agent is currently exposed (C_{cred}). This situational assessment represents the agent's understanding of the current situation.

This situational picture is then used to interrogate an internal Event Map (***E***). The Event Map is a repository of previously experienced events; i.e., previous associated roles, threat levels, objectives and behaviours. The current situational picture is then used to select a similar event from the Event Map to quickly establish the normative and social environment for the current situation. With the selection from the Event Map, the agent has an understanding of the situation and what they should do in response to it. The Event Map is updated as new information becomes available; i.e. the current situational picture is added producing an updated Event Map, (***E')***, over time.

For the Event Map to function, it requires some basic internal structures. The Event Map requires the following:

- A spatial map; i.e., an understanding of the space around the agent allowing experienced conditions to be located and routes to be understood and recalled;
- A normative map; i.e., an understanding of the roles, objectives and actions associated with different situations that might be recalled;
- A social map; i.e. an understanding of social relationships and their role in them;
- A role attribute; i.e., the current role(s) being adopted allowing their position in the social network of relationships to be established;
- A objective attribute; i.e., a set of short-term and long-term objectives allowing goal-based decisions to be taken and progress to be established;
- An action attribute, or the current action being performed;
- A set of other attributes; i.e., the agent's current status formed from static attributes (e.g., demographics, innate capabilities, etc.), and dynamic attributes set/updated as a result of the current situation (e.g. posture, psychological disposition, etc.);
- A threat perception function; i.e., the assessed risk to the well-being of agent and/or other agents/objects, should there be no change in the situation.

Where the current event has an equivalent 'mirrored' event stored in the Event Map, from previous experience, then the agent can quickly update their from prior experience.

If a match can be found in the Event Map, then the relevant parameter settings in the match are adopted. This provides a short cut in the decision-making process employed for routine situations or emergency situations recalled from the agent's past.

If no match is found in the Event Map, then the analysis becomes more convoluted, time-consuming and intensive. The agent is required to establish the threat posed and viable responses given the social/normative conditions indicated. At this point, the threat of the current situation is assessed (using the Threat Perception ***(TP)*** function). This involves examining the situational picture, determining the threat posed (to the agent or significant others/objects), and setting new objectives (***O***) given the threat established. Once new objectives have been established, a response has to be identified using the Response Generator ***(G)*** that is able to meet this objective. This entire process will be dependent upon normative, spatial and social structures, which both constrain and inform the viable objectives and actions open to the agent. Depending on the nature of the situation and the agent's history, these structures may be derived or formed anew. If these structures are new, this process will also require the agent to project the current situation into the future, assessing the potential effectiveness of their actions given stated objectives. This process is likely to be sub-optimal; i.e. satisficing rather than optimizing[30].

This process may also allow new relationships to emerge between actions, objectives, normative structures and social relationships that had previously not been present in their Event Map. The exact methods employed to generate the action options will be dependent on the threat perceived; i.e., the perceived time available constraining the depth/breadth of the option search.

Once this process is complete, the agent's internal attributes are then updated accordingly (***E'***), an action (***A***) is performed given the new objective and the whole process begins again in the next time frame. The agent's action may influence the external environment, and their action and current situational picture may influence the future perception of new information as it arrives (feeding back into the environment and cue processing as shown in Figure 1).

It is acknowledged that this is an abbreviation of an actual decision-making process. It is also acknowledged that these structures would need to be specified in much greater detail before implementation could take place. However, it should be remembered that the primary purpose of this description is to outline the *types* of components that would need to be represented in a computational egress model (in this case an agent-based model) to enable the implementation of a conceptual model, rather than specifying them in full. The suggested approach would at least be capable of reflecting the 27 behavioural statements identified earlier.

MODEL USERS - ACCOUNTING FOR BEHAVIOURAL STATEMENTS WITHIN EXISTING EVACUATION TOOLS

Now that a discussion has been provided for model *developers* on how to implement the set of behaviour statements into a computer model, guidance is offered to the model *user* on how to account for the behavioural statements when calculating RSET. As mentioned earlier, there are over 60 different computer evacuation models available to assess evacuation performance[35]. These range from hydraulic calculations that only produce aggregate results (e.g. overall evacuation time), to adaptive agent-based approaches where results can be collected at the agent level (e.g. distances travelled) as well as aggregate levels. However, the granularity of the results is entirely dependent on the internal structure of the model itself.

For all model scenarios, the model user is required to configure or manipulate a set of performance elements to calculate RSET[2]. Although evacuation tools differ in many ways, at the most fundamental level, most address a set of four basic performance elements to calculate RSET. These four basic performance elements are the following:

- [Pre-Ev] Pre-evacuation time – the time for evacuees to initiate response and commence movement to a place of safety once an incident has started.
- Physical movement characteristics [PMC] of people, including travel speed (the unimpeded speed at which individual evacuees move towards a place of safety) and flow conditions (the relationship between speed/flow, population density and population size within a local area).
- [RA] Route availability – the routes available to the evacuees.
- [RU] Route usage/choice – the routes selected by the evacuees from those available/aware of by the evacuee (which, in a few models, may be a result of social influence).

In more advanced simulation models, a fifth performance element can be added to the list: Behavioural Itineraries [BI]. The user can address evacuee delays during evacuee movement by assigning behavioural itineraries to evacuees or groups of evacuees. Behavioural itineraries are tasks performed during the pre-evacuation or movement phases of an evacuation, and are assigned usually to the individual or group. The behavioural itinerary requires the definition of the locations visited during the evacuation and the time spent at these locations. The itinerary then implicitly represents evacuee movement and the associated delays that are not directly associated with movement to a place of safety.

It is often left to the user to input data or select model parameters that affect each one of these five performance components. Given the lack of a comprehensive conceptual model in human behaviour in fire (and the subsequent representation within computational tools), it would be helpful for model users to understand the ways that they might reflect the set of 27 behavioural statements, previously described, in current computer evacuation models – especially when choosing input data or customizing model scenarios.

The behavioural statements described previously can be represented in egress modelling tools by manipulating one or more of the five performance elements. See Table 1 for suggestions on which of the components would need to be ***manipulated by a model user*** in order to represent each behavioural statement (in some form). Only those performance elements that are influenced by human behaviour are included in Table 1: pre-evacuation time [Pre-Ev], physical movement characteristics [PMC], route usage [RU], and behavioural itineraries [BI]. The route availability performance element [RA] is excluded from the table since it is often determined by the fire scenario, rather than by the occupants and their behaviour during evacuation. Additionally, although counterintuitive, perhaps, "physical movement characteristics" is included in Table 1. While a large portion of this element is influenced by physical characteristics of the person, some aspects of evacuee behaviour, for example, group formation, can influence travel speeds and flows.

In Table 1, cells marked by an "X" indicate the particular performance element or set of elements that would need to be manipulated in order to represent each behavioural statement. For example, behavioural statement [1] notes that "previous experience of false alarms or frequent drills can reduce sensitivity to alarm signals, inhibiting the perception processes". An "X" is placed in the pre-evacuation time column, since occupants engage in perception, one of the pre-decisional processes, before making a decision to take protective action – which can delay their evacuation. It makes sense for most of the behavioural statements to require the manipulation of [Pre-Ev], since the PADM focuses on the processes that lead up to deciding whether or not to evacuate, for example. However, Table 1 also shows (1) the ways in which [BI] can be used to represent the behavioural statements, or any protective actions taken during evacuation, and (2) [PMC] and [RU], two components that while may be seen as falling outside of the PADM process, are integral to the calculation of RSET and should be included in a conceptual model of human behaviour in fire.

Table 1: Aspects of an engineering model that can be manipulated by the user to represent behavioural statements.

Phase	Behavioural Statement	RSET Performance Elements			
		[Pre-Ev]	[PMC]	[RU]	[BI]
Pre-Decisional Processes	**[1]** Previous experience of false alarms or frequent drills can reduce sensitivity to alarm signals, inhibiting perception processes.	X			
	[2] Some individuals exhibit hypervigilance that makes them particularly sensitive to certain cues.	X			
	[3] Habituation, focus and stress can narrow the perceptual field, and thus, not all available cues will be internalised.	X			
	[4] Sensory and cognitive impairments can inhibit the perception of cues.	X			
	[5] Content and clarity of the cue matters. The more clearly presented, without jargon, the more likely it will be comprehended accurately.	X			
[Stages 1 and 2] Assess Situation/Risk	**[6]** The precision, credibility, consistency, comprehensiveness, intensity and specificity of the external cues will affect the assessment of the situation and perception of risk.	X			
	[7] Authority of the information source affects the perceived credibility of the information, and in turn the assessment of the situation and risk.	X			
	[8] Normalcy bias and optimism bias are commonplace. In other words, people often think that nothing serious is taking place, and that nothing bad will happen to them, respectively.	X			
	[9] Training on and/or experience with a particular incident type may allow a similar incident to be defined more quickly by the evacuee.	X			
	[10] The actions of the surrounding population can influence the internal processes of the individual.	X			
[Stage 3 and 4] Protective Action Search and Selection	**[11]** People tend to satisfice rather than optimise.	X		X	X
	[12] Pre-event commitment to a particular activity may cause individuals to decide against taking protective action.	X			X
	[13] Authority of the source … affects the perceived credibility of the action.	X			X
	[14] The actions of the surrounding population can influence the options of actions developed by the individual.	X		X	X
	[15] Gender can influence the selection of actions to protect property.	X			X
	[16] Social and authoritative roles, and social connections, can influence the selection of actions to help others.	X			X
	[17] Training and experience in previous fire/evacuation events can influence the search for and selection of a particular action or set of actions, e.g., rescue actions or preparation actions.			X	X
[Stage 5] Protective Action Implementation	**[18]** Presence of smoke does not always preclude the use of a route.			X	X
	[19] Training and experience may increase an individual's familiarity with the use of components/devices and subsequently improve their use.	X			X
	[20] People have different abilities that influence the actions selected and the way that they are performed.	X	X	X	X
	[21] People seek information in situations where information is lacking or incomplete.	X			X
	[22] People engage in protective actions, including preparing to move to safety or helping to protect others from harm, before they initiate a movement towards safety. These actions can also occur while moving to safety.	X			X
	[23] People move towards the familiar, such as other people, places and things	X	X	X	X
	[24] People may re-enter a building, especially if there is an emotional attachment to the building, the contents and/or the inhabitants.				X
General	**[25]** People will behave in a rational AND altruistic manner; panic is rare.	X	X	X	X
	[26] Evacuation is a social process, in that groups are likely to form during an evacuation.	X	X	X	X
	[27] Social norms (or rules) in place prior to a fire event form the basis of those employed during the event.	X	X		X

These behavioural statements are not meant to be seen as separate theories that can be used on an individual basis within evacuation modelling techniques. Instead, these theories should ideally be incorporated together as one comprehensive model (and/or be produced as an outcome of the model). When doing so, it is important to acknowledge the dependencies or interactions among these behavioural statements. For example, managers and others with responsibilities (roles) might be located in a building that is subject to frequent false alarms. This raises the question of the interaction between roles and responsibilities and frequency of false alarms and their influence on situation and risk assessment. Where the statements cannot be addressed as one set, they should at the very least be recognised and their inclusion (or exclusion) justified.

The manner in which a user might represent these behavioural statements depends largely on the data available. Broadly speaking, these statements can be considered within an RSET calculation or broader fire engineering process in the following ways:

1. *The set of behavioural statements used has sufficient supporting data such that it can be represented directly within the egress scenario.* Depending on the data and the model, this might be employed to represent the higher-level conditions that emerge (e.g. flow) or agent-level actions (e.g. travel speeds).
2. *The set of behavioural statements has only been identified as influential to a particular component or set of components, and there is currently insufficient supporting data to quantify it.* The statements might then be used to define a scenario or in a sensitivity analysis by varying parameters in the calculation/egress model. This would enable the impact of different parameter levels upon the results without necessarily having definitive indications of what the levels might be. An example of this is varying the proportion of a population that uses a particular route to establish the sensitivity of the results to exit familiarity.

The general statements describe the decision-making process, rather than the specific factors that influence this process. As such, they influence how many of the earlier statements are employed. For instance, the behavioural statement that highlights "rational behaviour as more likely than panic" might have an impact on the representation of some of the other factors identified and also be useful when examining the real-world implications during the analysis of the results produced.

As more relevant data is collected, so the quantification of the behavioural statements within fire engineering will become more commonplace, providing less of a need for the user to rely entirely on sensitivity analysis across a wide range of values.

CONCLUSION

Understanding and representing evacuee behaviour, as a model user and a model developer, is a difficult and complicated task. This task is made all the more difficult by our partial understanding of the problem at hand, further compromised by our tendency to oversimplify and focus on the physical aspects of an evacuation, rather than the psychological and the sociological aspects. Currently, there is no applicable comprehensive conceptual model describing evacuee behaviour. This has the following important consequences:

- For model developers: it limits the scope and complexity of the blueprint available to current egress models.
- For model users: it places the onus on them to identify and represent behavioural factors via model configuration, and also to differentiate between genuine results and user specified outcomes.

In lieu of a comprehensive conceptual model of human behaviour in fire, this article has presented a list of behavioural statements, framed to initiate the development of such a model. These are used to identify, for model developers, the egress model components that are required to represent the statements presented and identify how model users might represent the statements using a small set of core modelling elements. It is hoped that by doing so, a wider array of evacuee behaviours will be considered in the modelling process.

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