The Need for Behavioral Theory in Evacuation Modeling

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Summary. This paper posits the need for a complete, comprehensive conceptual model about human behavior in fire evacuations. This would be of intrinsic value to improve training, education, and future data collection efforts, but would also allow for a complete behavioral representation to be embedded within simulation tools. This paper begins by discussing the current, separate theories or “behavioral facts” extracted from research on evacuations from building fires. Then, the paper discusses the methods used by current computer evacuation models to simulate these “behavioral facts” and the limitations of these methods. Last, the paper argues for the inclusion of a comprehensive behavioral conceptual model in computer evacuation models, specifically by highlighting the benefits of behavioral theory for evacuation models and providing examples of social theories used to predict whether people will evacuate from disasters in communities.

1 Introduction

The rapid increase in computer capability and decrease in monetary cost has expanded the use of computer models in all fields of engineering. This is particularly true for evacuation models. Developers are consistently creating and updating evacuation models to simulate and visualize larger and more complex structures. These models are based on movement and behavioral data in order to simulate how occupants evacuate from buildings on fire. However, there is one particular aspect that is continually missing from computer evacuation models: the ability to *accurately* and *comprehensively* simulate human behavior in fire [1]. To do this would require a complete behavioral conceptual model to be embedded within the simulation tool.

It is suggested here that instead of simulation tools being based on the piece-meal inclusion of “behavioral facts” or theories, as they are currently, they should instead be based on a comprehensive conceptual model of how people move and behave during building fires. Evacuation models currently include comprehensive theory on how people *move* during evacuations [2,3,4,5,6], including equations from this type of data [7], graphical representations of speed and flow with density [4,7], and even data that accounts for occupants with disabilities [8] or other impairments. However, there is an absence of a comprehensive theory on how people behave during fires.

This paper posits the need for a complete conceptual model of human behavior in fire evacuations. These would be of intrinsic value to improve training, education, and future data collection efforts, but would also allow for a complete behavioral representation to be embedded within simulation tools for use in performance-based design. Without this conceptual model, evacuation models rely on user assumptions and model simplifications about occupant behavior that are unrealistic and can produce inaccurate results, as will be explained in this paper. In cases where assumptions lead to the unrealistic *reduction* in evacuation results, buildings or procedures are designed according to an unrealistic calculation of the required egress time which can lead to insufficient egress routes and fire protection systems in the building, inadequate notification systems, and/or unsafe procedures; putting lives at risk. In other cases, where assumptions in evacuation models lead to the use of an unnecessarily large safety factor, buildings may be designed with a higher-than-needed level of safety and an overly expensive cost to the building owner.

This paper begins by discussing the “behavioral facts” extracted from research on evacuations from building fires. Then, the paper discusses the methods used by current computer evacuation models to simulate these “behavioral facts” and the limitations of these methods. Last, the paper argues for the inclusion of a comprehensive behavioral conceptual model in computer evacuation models, specifically by highlighting the benefits of behavioral theory for evacuation models and providing examples of social theories used to predict whether people will evacuate from disasters in communities.

2 “Behavioral Facts”

Currently, in the field of human behavior in fire, “behavioral facts” have been obtained from a variety of incidents about what people do in fires [9]. These “facts” represent key points that explain separate behaviors in fire evacuation. However, there has been little attempt to connect all of these “behavioral facts” and develop an overarching, complete conceptual model for human behavior in fire. These “facts” therefore remain as isolated key statements used in current egress analysis, rather than a coherent behavioral framework. When/if these statements are embedded within egress models and simulated in isolation, the results generated contain significant gaps in the simulated evacuee response.

There are specific “behavioral facts” that have been gleaned from research into evacuation from building fires and community disasters. First, when a fire event occurs in a building, people’s initial response is to believe that they are safe [10,11]. The phenomenon, known as normalcy bias, states that people in any type of crisis tend to initially interpret their situation as safe and secure [12]. When occupants are faced with ambiguous and/or inconsistent cues (i.e. cues that are difficult to understand or interpret), normalcy bias is likely to extend for longer periods of time while the occupants remain inside the building. *Behavioral fact #1: People’s first instinct is to feel safe in their environment.*

When presented with ambiguous cues, people in building fires and other emergencies consistently attempt to gain additional information about what is going on [2,9,13,14,15]. People are likely to engage in information seeking activities, such as asking others, forming groups to discuss the situation (i.e. milling), investigating the building for the source of the event, and searching for information from media or internet sources. In emergencies, people are "information hungry" and will make efforts to gain additional information, especially in situations that are unclear and/or confusing. *Behavioral fact #2: People will engage in information seeking actions, especially when cues are ambiguous and/or inconsistent.*

Generally, people in building fires act rationally and altruistically rather than being panic-stricken [9,16]. Previous building fire and community disaster events have shown that people help others during evacuations, including looking for others inside the building, rescuing people from situations where they are trapped or injured, and assisting occupants out of the building and out of danger (e.g., carrying them down several flights of stairs). Also, people have shown that they will remain on their floor and fight the fire before the fire department arrives to save property and/or others from harm [15,17,18]. *Behavioral fact #3: People act rationally and altruistically during building fires.*

In addition to information seeking and helping others, occupants will also perform preparation activities before moving to the stair [2,19]. These activities can include dressing or putting on their coat, gathering personal items, securing their office or residence, and obtaining items for longer stair travel (e.g., a change of shoes, a flashlight, and other supplies). *Behavioral fact #4: People are likely to engage in preparation activities before beginning their evacuation response (e.g., stair travel, elevator travel, etc).*

Once people have decided to evacuate, they are likely to move to the familiar [20,21]. Occupants are likely to traverse familiar routes in the building and move toward familiar exits (e.g., the elevator lobby) in a building fire or other emergency. *Behavioral fact #5: Once they begin evacuation movement, people move to the familiar.*

All of these actions and tendencies are likely to delay people from reaching safety and take certain periods of time to complete [2,15,22,23]. All of these "behavioral facts" show that people are more likely to delay in a building fire rather than immediately and efficiently move to a position of safety outside (or even inside) of the building. Therefore, the "behavioral facts" provide fire researchers with important information about what behaviors can occur during a building evacuation and that these behaviors result in significant delay times for occupants.

However, there is little or no understanding of why these behaviors occur. The evacuation modeling field is then left with only piece-meal "facts" or theories to use when incorporating the simulation of behaviors in a computer evacuation model. Without a complete behavioral conceptual model, evacuation model developers rely on the user to (or not to) include these separate, piecemeal "behavioral facts," leading to the piecemeal simulation of disconnected behaviors, as discussed in the following section.

3 Building Evacuation Models[a]

Currently, there are over 40 different evacuation models [24,25] available to users interested in simulating evacuations under a variety of circumstances (e.g., building configurations, evacuation procedures, and environmental conditions). Generally, these models simplify behavior during evacuations, if behavior is included at all. This section provides an overview of the three primary methods in which evacuation models simulate human behavior, includes examples from evacuation models and demonstrates potential problems with each method. The three methods are the following: 1) behavior is defined entirely by the user, 2) behavior is simulated based on a specific condition (if-then statements), and 3) behavior is simulated based on multiple conditions.

3.1 Behavioral Technique 1: The behavior is defined entirely by the user

The first way that behavior can be included in evacuation models is based entirely on user input. In this technique, the user defines the behavior before the simulation begins for an individual or a group in the building. The user assumes that the behavior is likely to occur (or even that it will definitely occur) at some point during the simulation. Through this technique the evacuation model is being used to specifically assess the consequence of a particular action rather than predicting whether the action will occur at all.

There are many examples of how a user defines behavior (both spatial and/or implicit[b] behavior) from the models that currently exist. Examples of defined spatial behavior are: 1) the user can assign[c] certain individuals or groups a lower unimpeded movement speed (e.g., EXIT89[d], STEPS, ASERI) to simulate slower people, 2) the user can assign certain individuals or groups a route from point “A” to point “B” in the building to simulate route choice on their floor and/or through the building (e.g., Simulex, GridFlow, EXIT89), and 3) the user can assign a specific itinerary (a sequence of actions) or a

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[a] All references for this section can be found in the following: (Kuligowski and Peacock 2005) [24]

[b] Spatial behavior is a behavior performed by the occupant that utilizes movement over some distance/area of the floor plan in the building (e.g., physically moving from one space on the floor plan to another) and implicit behavior [25] is behavior that is not overtly performed by the occupant, but accounted for by other means (e.g., simulating that all occupants wait at a location for a set period of time to account for actions that could be performed).

[c] The user can assign by manual (providing an actual value) or through probabilistic (providing a distribution or a probability) means.

[d] Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

specific action to an individual or group (e.g., CRISP, buildingEXODUS). The user can also define implicit behavior [25], i.e., accounting for actions that are not "physically" performed by the simulated occupants. Examples of defined implicit behavior are: 1) the user assigns time periods of delay/waiting (e.g., an actual time period of delay, a distribution of delay times, etc.) to individuals or groups to account for any actions that they might perform during the pre-evacuation or evacuation periods of a building fire (e.g., Simulex, EXIT89, GridFlow), and 2) the user defines a specific area of the stair that is blocked for a time period to simulate counterflow of individuals and fire fighters (e.g., EXIT89).

There are problems associated with this behavioral technique. No behavior is simulated without input from the user. The behavior simulated in the scenario is actually prescribed by the user rather than predicted by the model. Therefore, the user is required to have sufficient expertise to define the different actions that would take place in the scenario, as well as being required to assume that these actions take place even before understanding the other dynamics of the scenario that occur while the simulation is running (e.g., the fire spread, what other occupants are doing in the building, what the staff is doing, etc.). The user is required to be both an expert and a psychic; both of which cannot and should not be expected.

3.2 Behavioral Technique 2: The behavior is simulated based on a specific condition (if-then)

The second way that behavior can be included by evacuation models is to simulate a known behavior when the occupant encounters a specific condition. This technique is based on "if, then" statements; meaning that if an occupant encounters X, then s/he or the group will do Y. Even when using this technique, the user is still involved in enabling the capability of the "if, then" statements or even identifying the condition that may (probabilistically) or will (deterministically) prompt the action to occur. In this technique, both the evacuation model and the user play a role in simulating behavior.

There are many examples of conditional behavior in current evacuation models. In this technique, there are simulated actions influenced by the building, environmental cues (i.e. smoke density and layer height), and/or the actions of other simulated individuals/groups. First, an example of an action influenced by the building includes: if an exit route is simple to traverse and/or if the route is memorable, then the occupant is likely to traverse this route to safety (e.g., BGRAF), in comparison with the other routes in the building. Examples of actions influenced by environmental cues include: 1) if the occupant is exposed to smoke that reaches an optical density of a certain level, s/he will redirect to another route (e.g., BGRAF, EXITT, CRISP), 2) if the occupant is exposed to smoke that reaches an optical density of a certain level, then s/he will stop "investigating" (e.g., EXITT), 3) if an occupant is exposed to specific levels of gases within the smoke layer, then s/he will slow his/her walking speed and may even become incapacitated (e.g., GridFlow, buildingEXODUS), and 4) if the occupant is exposed to smoke that reaches a certain extinction coefficient and/or smoke layer height, then s/he will crawl (e.g., buildingEXODUS).

Last, there are examples of actions that are influenced by other occupants in the building. These examples include the following: 1) if there is a specific threshold of people waiting at a current exit, then an occupant will redirect to another exit route (e.g., BGRAF, EXITT), 2) if an occupant is identified as sleeping or disabled (by the user), s/he will follow the movements made by able-bodied individuals (e.g., EXITT), and 3) if the "target" occupant in the current room has already been warned (or rescued), then the occupant will warn the rest of the household (destination equals room with most senior occupant) (e.g., CRISP offers several other conditions and actions to select for each scenario).

As with Technique 1, there are problems associated with the conditional simulation of behavior. As mentioned earlier, model users are required to either enable the capability of the "if, then" statement(s) or identify the conditions that will prompt these actions to occur, meaning that behavior is not predicted by the model, but again prescribed by the user. This requires a high level of expertise from the user. Also, this technique does not account for all possible actions that could occur in a building evacuation but rather only those are specified as conditional.

3.3 Behavioral Technique 3: The behavior is simulated based on multiple factors of influence

Behavior can also be simulated based on multiple influential factors. Although the simulated actions are similar to those in Behavioral Technique 2 (e.g., choosing a route, turning back, helping others, and closing doors), these actions are individually chosen for occupants based on a series of factors throughout the evacuation. Factors can include information that the occupant knows prior to the fire, what information is gathered during the event, and what others know in the building. The user's role in this technique involves providing occupant threshold values for many of the factors, such as crowding factors, initial knowledge of the best exits (e.g., BFIRES), smoke tolerance, and preference levels, such as preference to wait, crowding, etc. (e.g., BGRAF).

There are examples of behavior that is influenced by multiple factors. Exit route choice, for example, can be established by consensus of the occupants within a certain space in the building (e.g., BFIRES). Exit choice of the featured occupant is influenced by whether any occupants co-occupy the space with him/her, whether any other occupants have information that this occupant is not aware of (e.g., the best way out of the building), whether others in the space are injured or in need of help, and whether all occupants in the space agree on an exit route. Also, an occupant can choose an exit route choice (e.g., buildingEXODUS) based on a variety of different influences, including whether other occupants are nearby, the nature of the information about an exit provided by other occupants, the identity or the role of the occupant sharing information, and whether the exit provides an advantage (e.g., distance, environmental conditions); and will redirect to another exit based on the extinction coefficient of the smoke at the current exit, the occupant's knowledge of other exits, the known distance to other exits, and the likelihood of redirecting (from empirical fire data [17,18]).

In Technique 3, behavior is included in the model based on multiple factors. Whereas some actions are simulated as a result of a multi-stage process model, others are simulated as a result of a variety of prioritized influences that prompt actions taken. Fire studies have shown that realistic behavior is the result of multiple factors rather than binary relationships [19,26]. As with the other techniques, however, the user is required to provide threshold values for influential factors and/or enable the behavioral algorithm to run during the simulation, which limits prediction capabilities.

3.4 Summary

As shown by the three techniques, the current computer models attempt to simulate behavior during building fire scenarios. Evacuation models can simulate actions such as route choice, crawling, rerouting, moving at a slower speed, delay of response or stopping action, any kind of itinerary (spatial sequence of movement from one point to another), and even group sharing of information to make decisions on movement. These types of actions are likely to occur in building fire evacuations; however, the current models are essentially simulating separate "behavioral facts" rather than attempting to represent behavior based on a complete behavioral conceptual model.

There are significant consequences that result from a lack of a conceptual model of human behavior in fire for users, evacuation models, and those who judge evacuation results (i.e. the authority having jurisdiction). Currently, without a conceptual model embedded within egress models, computer models are limited in how evacuation is simulated; often requiring users to provide a large amount of input data on occupant behaviors. In addition, users' understanding of human behavior in fire is also limited by the lack of theory, prompting greater emphasis on the simulation of isolated key statements and/or the use of default values provided by the evacuation model. Default values available to users, such as behavior on stairs (e.g., staggered stair movement in buildingEXODUS), behavioral patterns for specific occupant types (e.g., fire fighters in Simulex), and familiarity with the building (e.g., movement to the closest exit in Evacnet4), may encourage a more passive role on the part of the user and reduce the current, necessary preparation and analysis required by the user to run the simulation responsibly.

4 Benefits of Behavioral Theory

There are many benefits to the development of a comprehensive conceptual model for the field of human behavior in building fires. The inclusion of a conceptual model into computer evacuation tools will enable a comprehensive model that can actually *predict* occupant behavior in a building fire based only on initial input. A computer model that incorporates a complete behavioral conceptual model would be able to predict situations rather than engineer an outcome based heavily on user input. A conceptual model will reduce the burden placed on users of evacuation models and rely on the model to simulate behavior during an event. Additionally, a comprehensive behavioral model of building evacuations illustrates where more data needs to be collected in order to truly understand human behavior in future fire evacuations.

Researchers in the field of disasters have been developing conceptual models for human behavior in response to community-wide disaster events for decades [14,27,28]. These can provide a roadmap to the development of conceptual models for occupant evacuation from building fires. Disaster researchers have developed theories to predict whether a member of a community will evacuate in response to a (or several) community-wide warnings. Data, collected (e.g., survey techniques) and analyzed (e.g., regression models) via quantitative methods, are used to identify those factors that influence certain stages of warning response, including whether a person believes the warning message, whether he/she feels at risk in the face of the incoming disaster, whether he/she confirms the warning by asking or seeking additional information about what is going on, and eventually whether the person evacuates his/her home or business based on the warning message. From a comprehensive understanding of human behavior, as shown in Figure 1, quantitative computer models can then be developed to predict whether a person evacuates the community when warned to do so.

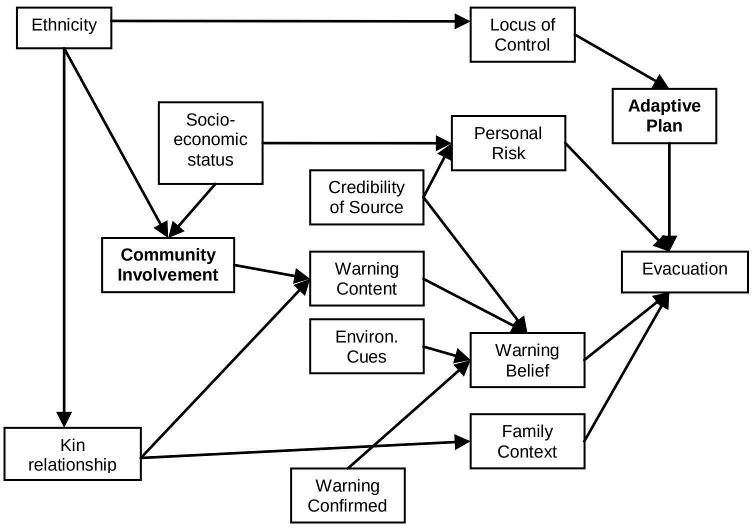

Figure 1: Conceptual model for predicting whether a member of a community will evacuate or not [29].

In addition to creating more improved evacuation models, conceptual models similar to Figure 1, can help to improve evacuation response in the event of future disasters. By understanding which factors influence evacuation response, steps can be taken to improve community (or building-wide) disaster readiness before any type of event occurs. For example, emergency officials can stress the importance of having an evacuation (adaptive) plan for disasters at home or for the office. Also, emergency officials, by understanding that community involvement influences effective warning response, can plan community-wide (or building-wide) social events so that members of a community (or building) can meet one another. These factors, bolded in Figure 1, can be implemented beforehand and may help to elicit an effective evacuation response when a disaster actually does hit a community.

Once a disaster occurs, steps can also be taken at the community-level to positively influence evacuation behavior. For instance, emergency managers in charge of developing the warning message can positively influence evacuation by crafting the message content in a certain way and providing a credible person or group (e.g., the fire department) to deliver the message to the community. These factors, in addition to allowing for the creation of an improved evacuation model, can inform local and community officials on how to better their community evacuation in response to future events.

5 Conclusion

There is a need in the field of computer evacuation modeling for a comprehensive conceptual model of human behavior in fire to more completely simulate behavior during building evacuation scenarios. Currently, separate, "behavioral facts" on human behavior in fire exist and are used to simulate behavior in computer evacuation models. Without a conceptual model, simulated behaviors will be partial and susceptible to inexpert judgments made on the part of the user. Evacuation models rely on user assumptions and model simplifications about occupant behavior that are unrealistic and can produce inaccurate results. These inaccurate results can lead to unsafe building designs and procedures (in the event that evacuation times are underestimated) and/or to the assignment of inappropriate and unfounded safety factors which can unnecessarily increase the cost of buildings.

Finally, the paper investigates the theories from social science (e.g. the sociology of disasters) to demonstrate the construction of a conceptual model of human behavior in fire during building evacuations. This paper lays the foundation for a more comprehensive behavioral model that could then be directly implemented within a simulation model. A comprehensive (and predictive) model would then be less susceptible to significant behaviors being omitted and more sensitive to a range of influential factors, which in turn provides more accurate results for understanding occupant and building performance during a fire evacuation. Not only can a conceptual behavioral model serve as a blueprint for the development of a more comprehensive and accurate computer evacuation model, but can also provide guidance for future data collection efforts in the field of evacuation from building fires.

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