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Translating Behavioral Theory of Human Response into Modeling Practice

S.M.V. Gwynne
Hughes Associates, Inc.

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By
S.M.V. Gwynne
Hughes Associates, Inc.

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Prepared for:

National Institute of Standards and Technology
100 Bureau Drive, Stop 1070
Gaithersburg, MD 20899-1070
Ph. 301-975-2309

Prepared by:

S.M.V. Gwynne
Hughes Associates, Inc.
3610 Commerce Drive, Suite 817
Baltimore, MD 21227-1652
Ph. (410) 737-8677 FAX (410) 737-8688
www.haifire.com

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CONTENTS

TRANSLATING BEHAVIORAL THEORY OF HUMAN RESPONSE INTO MODELING PRACTICE

S.M.V. Gwynne
Hughes Associates, Inc.
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1.0 INTRODUCTION

Life safety consultants, including fire protection engineers, fire marshals, and code consultants, use calculation techniques to assess the safety levels provided by a building in the event of an incident. This is conducted (as part of a performance-based approach) by using hand-calculations or computer simulation tools to calculate how long a population would take to evacuate a building design. If the population reaches safety before conditions in the building become untenable (calculated by fire and toxicity models), by a sufficient margin (determined by some added safety factor), then the structure is deemed to be acceptable [1]. Given this, the assessment process is critical to the safety level of the building design.

Egress models are a key method in assessing this performance. Here, egress models relate to the engineering or computational tools employed to quantify egress performance. However, egress models are now employed more frequently and in a greater variety of ways. This is due to the increasing novelty and complexity of building designs (e.g., vast multi-use resort complexes), the expanding use of egress models in different domains (e.g., safety, security, circulation, rail, aviation, etc.), and the greater appreciation of approaches that allow performance to be quantified. The limitations of the current models are therefore being tested given their more frequent use and the manner in which they are being employed.

A key limitation of current egress models is the scope and sophistication of the behavioral models that are embedded within them to help represent evacuee performance; i.e., the method used to determine what evacuees do and how long it takes them to do it. Kuligowski has recently produced a predictive behavioral model, as part of her analysis of the WTC incident using the HEED database (High-Rise Evacuation Evaluation Database) as source material [2,3]. She specifically addressed the pre-evacuation period; i.e., the process that leads to an individual initiating her movement towards safety. This represents an important step in the understanding of human behavior in fire and in the simulation of such behavior. However, this theoretical model is *qualitative* in nature and focuses specifically on the WTC incident. For this to be embedded within an existing egress simulation tool, effort is required to identify the modeling structures needed to house such a model and the attributes and processes needed to facilitate its representation in such a way that the model can be expanded beyond the pre-evacuation period and beyond the WTC incident. This identification will allow the behavioral theory developed by Kuligowski to be modified in such a way that it can be embedded within a modeling framework that provides the necessary inputs to which the theory is sensitive, represents key behavioral processes and represents the expected evacuee behaviors as outputs.

The purpose of this report is to describe the ways in which a computer egress model can incorporate the Kuligowski pre-evacuation behavioral model (henceforth referred to as the EDK model after the initials of Erica Dawn Kuligowski). This report will discuss what type of structures will need to be present within an egress model in order for the pre-evacuation behavioral model to be implemented.

Implicit to this evaluation is its independence from specific existing egress tools; i.e., the descriptions do not rely on or require components provided by specific existing egress models. A general approach is important to address how such a theoretical model could be translated into practice, rather than actually putting the model into practice, which would be premature (given the lack of supporting data, model generalization, etc.) and which is beyond the scope of this work. However, this initial work should form an essential step in identifying the types of actions that current and future egress model developers will need to perform in order to include credible and functional behavioral models.

2.0 BACKGROUND

Evacuee behavior is a primary determinant of the egress performance of a building design. It therefore has to be addressed within an egress model in some form. As credible as calculation techniques may seem, they represent the human emergency response in a grossly simplified form, often not representing it all.

Egress models quantify evacuation performance by establishing how long it takes for occupants to reach a point of safety given the scenario being examined. In order to make this calculation, the models attempt to represent two things: 1) the actions that people take and 2) how long it takes to perform each action.

Typically, evacuee behavior is either ignored within an egress model (e.g., people move to the nearest point of safety), grossly simplified (e.g., represented as stimulus-response), empirically represented (e.g., a single value might represent a process) or is hard-wired by the user to examine specific scenarios (e.g., a limited set of rules connecting conditions to responses) [4,5]. Some calculation techniques assume people respond immediately and appropriately to even the most ambiguous scenario conditions. Other, more sophisticated techniques use safety factors or engineering judgments to account for any behavioral deviations from an optimal response. For example, time delays can be assigned to an evacuating building population to account for the performance of actions that are not directly related to safety. However, these arbitrary measures only compensate for the assumed final outcome of such actions, rather than representing the process by which these outcomes are produced. This makes these compensatory measures insensitive to changes in the underlying scenario and to the individual decision-making process. These measures fail to compensate for the lack of behavioral prediction included in calculation techniques, in that the engineer essentially determines human behavior ahead of time based on her judgment and assumptions.

All of these approaches may have their place when addressing certain scenarios. In addition, it should be recognized that data required to support models of evacuee behavior are relatively scarce, inconsistent and often inconclusive. Data are therefore often insufficient for the development and embedding of behavioral theory into modeling practice. As a consequence, behavioral models (i.e., representing a decision-making process that, given certain conditions, lead to evacuees selecting from a range of actions), have occasionally been simplified through choice, through oversight and/or through necessity. However, without a genuinely process-based predictive element to the behavioral model the results that emerge from current models are going to be a crude estimate of reality that omit key phenomena and that are insensitive to a number of potentially important factors. These models will then reflect the configuring actions of the engineer more than the expected actions of the evacuee. The explicit representation of the evacuee decision-making process may lead to simulated consequences emerging that may simply not be possible if behaviors are only implicitly represented, simplified or ignored [6].

There has been a longstanding belief in the field of fire protection engineering that human behavior during fires is just too complicated to predict or is unpredictable by nature [7]. This has likely influenced the assumptions of emergency behavior currently used in egress models – assumptions that can potentially produce inaccurate results. In cases where assumptions lead to evacuation estimates that are either too optimistic or too conservative, buildings and safety procedures may be designed that are insufficient on the one hand or unnecessary and costly on the other. Perhaps more fundamentally, these techniques are not currently attempting to accurately represent the decision-making process, while attempting to 'accurately' simulate the more physical aspects of agent actions; however, in reality the two elements are highly coupled. This discrepancy is exaggerated through the more detailed (process-based) representation of other elements; e.g., the evolution of the fire, the physical/physiological impact of the environmental conditions on the population, the refined representation of the space itself. *There is little point in going to the trouble of representing the physical environment in a sophisticated manner if the populations' behavior is insensitive to these conditions.*

The EDK model (see Figure 1) was developed by examining occupant experiences in the destruction of the WTC towers following the terrorist attacks of September 11, 2001, derived from the HEED database [2,3]. The main focus of the EDK model was to understand the actions performed during the pre-evacuation period of the WTC disaster and the process by which evacuees decided upon these actions. In Section 3.0, the author describes some of the current key assumptions regarding human behavior in fires. In Section 4.0, the author provides a brief description of the current state of egress modeling, specifically the ways in which egress models typically incorporate human behavior during evacuation. In Sections 5.0 and 5.1 the process of embedding a behavioral model is discussed along with a justification for selecting an agent-based approach for the discussion here. In Section 5.2, the report will present the EDK conceptual model that predicts specific actions taken in the pre-evacuation period (see [1] in Figure 1). In doing so, the original description of the model will be simplified, making it more accessible beyond theoretical social scientists. Section 5.4–5.7 will focus on the key structures required to translate the Kuligowski pre-evacuation behavioral model [2] into a more generic model for use by computer egress models (see [2] in Figure 1). Finally, in Section 5.8 the report will end with a discussion of the needs of current computer egress models in order to implement this type of behavioral model in the future and the implications of including such a behavioral model upon the results that might be produced (see [3] in Figure 1).

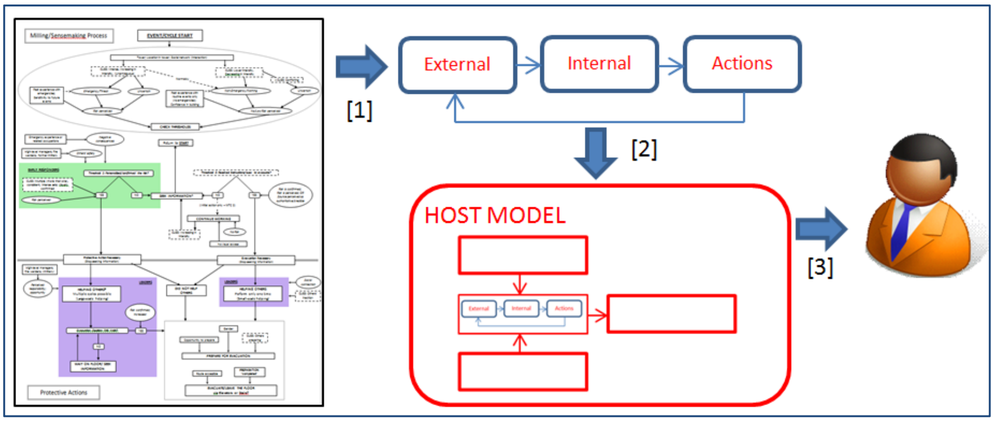


Figure 1: Embedding the EDK model.

3.0 CURRENT UNDERSTANDING OF HUMAN BEHAVIOR IN FIRES

Currently, there is an absence of a comprehensive understanding, or theory, of how people behave during fires [8,9]. Instead, researchers in the field of human behavior in fire have developed mini-theories that focus on specific aspects of crisis behavior – referred to previously by Kuligowski and Gwynne [9] as 'behavioral facts'. These 'facts' have been obtained from a variety of sources (academic, regulatory, anecdotal, etc.) over several decades and are now used as rules of thumb to inform expert assessment of evacuee behavior [10]. It should be noted that many of these facts are still unfamiliar to many in the field (engineers, researchers, regulators and practitioners) who frequently assess egress performance. These represent some of the core elements derived within the field of human behavior in fire and are employed to estimate response given evacuation scenarios.

These 'behavioral facts' explain expected influences and responses during a fire evacuation. It should be noted that the list below specifically relates to understanding derived from within the field of human behavior in fire (or which have been co-opted into the field, e.g., Latane and Darley [11]). This list could be extended significantly if other adjacent fields of analysis were examined, such as disasters, etc. As with subsequent description of the EDK model, these facts will be presented with as little technical jargon as possible to increase accessibility.

There has been little attempt to connect these 'behavioral facts' and develop an overarching and complete conceptual model for human behavior in fire. That is not to say that some models do not represent several of these facts; only that they have typically been implemented independently with no overarching logical framework connecting them [2]. This is primarily because the field is immature and is derived from an engineering perspective where models are enhanced through and incremental process. These facts therefore remain as isolated statements used in current egress analysis, rather than a coherent behavioral framework that is used to develop scenarios, develop and configure models, and understand evacuee performance. When/if these statements are embedded within egress models and simulated in isolation, the results generated contain significant gaps in the simulated evacuee response – both in terms of the interaction between these facts, the process by which the behaviors arise and intermediary positions between/within the behaviors themselves.

A brief selection of these ‘behavioral facts’ is described below. It should be noted that the facts are generalizations for the purpose of this report. Additionally, their affect would be influenced by local conditions, individual attributes and experiences and various other factors. This is expanded upon in the description of the EDK model itself.

1. When a fire event occurs in a building, rather than a panic-based response, people are more likely to believe that they are safe [12,13]. The phenomenon, known as *normalcy bias*, states that people in any type of crisis tend to initially interpret their situation as safe and secure [14]. 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: Rather than panicking, people's first instinct is to feel (sometimes inappropriately) safe in their environment.*
2. People may not have access to all of the information available relative to their environment (given their capabilities, their activities and their association with the space) and may not perceive the information in a uniform way should they become aware of it [10]. People prioritize certain pieces of information over others, may ignore information deemed peripheral and/or may disregard information deemed to be irrelevant. All of these tendencies may or may not be appropriate given the scenario faced. They then use this information to form a picture of the situation, which is used to assess the nature of the scenario. *Behavioral fact #2: Perception of information is critical as it influences the information available and the manner in which it is prioritized. The information used is not simply contingent on the information available.*
3. When presented with ambiguous cues, people in building fires may attempt to gain additional information about what is going on [10,15,16,17]. 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 [2,3,5,8,9]. *Behavioral fact #3: People will engage in information seeking actions, especially when cues are ambiguous and/or inconsistent.*
4. People cannot always be expected to automatically increase their safety levels [10,15,17,19,20,21,23]. People may perform activities that moves them closer to the incident (for instance, *Behavioral fact #3*), exposes them to declining environmental conditions, and/or delays their movement to a place of safety. They may also perceive different levels of threat posed by the incident, influencing their assessment of its severity and their need to avoid it. Their threat perception will be influenced by their access to information, their personality traits, experiences, surrounding conditions and perceived options. *Behavioral fact #4: People will not necessarily reduce their exposure to hazardous conditions.*
5. Generally, people in building fires act in a broadly rational manner (given the information available) and altruistically rather than selfishly at the expense of those around them [10,18]. Previous building fire events (and community disaster events) have shown that people often 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) [17,19,20]. *Behavioral fact #5: Broadly speaking, people act rationally and altruistically during building fires*.

6. A person's role in a situation prior to an incident will influence her response during the incident. The individual does not instantaneously adopt a new persona, ignore existing relationships or develop a set of new norms defining potential responses except in situations deemed to be unusual or extreme; e.g., when they are being directly affected by the incident. The responsibilities and affiliations of an individual during an incident are therefore at least informed by those that existed before the incident occurred. This influences both her response and the manner in which to assess the actions of others (e.g., authority figures). *Behavioral fact #6: People do not instantaneously switch to a different set or behavioral rules and roles unless provoked by the most extreme environmental conditions. The rules and roles prior to the event forms the basis of those employed during the event.*

7. In addition to information seeking and helping others, occupants will also perform preparation activities before leaving potentially delaying their response significantly [21,22]. *Behavioral fact #7: People are likely to engage in preparation activities before beginning their evacuation response that then go to delaying their response.*

8. Once people have decided to evacuate, they are likely to move to the familiar [23,24]. A person's understanding of the space will be contingent upon her normal use of the space. 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. Where people are unfamiliar, they may engage in wayfinding behavior, leading to inefficient route selection and route use [25].This affiliative behavior may relate to the routes available and to the people around them – relationships that existed previously will impact behavior during an event. Group affiliation and membership does not evaporate during an incident but will continue to be an influence [26]. *Behavioral fact #8: People move to the familiar. The relationships with the structure and people that existed prior to the incident influence response during the incident.*

9. The actions of others in the environment influence the decision-making process [11]. The extent of this influence will relate to the identity of those performing the actions and the number of people performing the actions, amongst other things. *Behavioral fact #9: The surrounding population will influence the individual's decision-making process.*

10. People have different physical, social, sensory and cognitive abilities. These influence the decision-making process, the information on which it is based, action selection and the enactment of the action selected. *Behavioral fact#10: People are heterogeneous.*

These 'behavioral facts' are likely to influence the decision-making process and subsequently the time that it takes a person to reach safety and the manner in which they do so [12,17, 27,28]. These 'behavioral facts' indicate that evacuee response can be relatively complex, be iterative and highly sensitive to the physical and social environments that are faced. 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, they do not provide a coherent framework by which an individual translates their situation into a behavioral response. This type of process would be required for an egress model to represent the decision-making process.

There may be some understanding of how these behaviors evolve and subsequently influence individual actions. However, there is only a limited understanding (and representation) of how these behaviors interact and function as a single behavioral framework. The egress modeling field is then left with only individual 'facts' to use when simulating evacuee behaviors. Without a comprehensive behavioral model, egress model developers rely on the user to (or not to) either include these separate, piecemeal 'behavioral facts' within egress models, or compensate for potential omissions leading to the piecemeal simulation of disconnected behaviors. In essence, these facts are occasionally assumed or imposed within (the most sophisticated) models, without their occurrence being predicted.

4.0 CURRENT STATE OF EGRESS MODELS

To quantify evacuee performance egress models need to represent evacuee actions. The number and variety of the actions included within the models may vary widely. In addition to total building evacuation times, egress models can provide a range of other indicators at the individual, component, area or structural levels, depending on the model, that might relate to a range of different factors; e.g., congestion, distances travelled, numbers of specific acts, route use, clearance times, etc. However, due to the lack of supporting data and theory on occupant behavior or actions, egress models typically simplify the evacuation process and focus primarily on how long it takes to perform one kind of action: the movement of occupants from their initial positions to the outside of the building (or a place of safety). This result might be a useful indicator as a baseline for performance. However, it will not be sufficient as a realistic estimate of (1) the expected quantitative performance – how long it might actually take for the population to reach safety, and (2) the expected qualitative performance – what decisions will be taken and actions performed during the evacuation. Point (2) is critical in establishing where issues might arise during an evacuation, how severe they might be and in devising mitigating procedural efforts. (Indeed, point (2) might inform point (1).) Both (1) and (2) are also critical in validating the performance of a model – it is not sufficient for a model to blindly produce 'reasonable' quantitative results should the underlying qualitative conditions not be credible [6,29]. This might leave the model vulnerable to producing inaccurate results should the underlying scenario be modified.

Broadly speaking the behavioral approach adopted by egress models can be grouped into three main categories (derived from [30]):

- **Empirical models** – ***the model imposes the relationship between parameters***: where mathematical functions are derived from empirical data to prescribe relationships between observed physical variables. In this instance, the population is not responsive, but instead has their response entirely determined by the functions provided.
- **Engineering models** – ***the model/user imposes the values upon behavioral parameters:*** where an attempt is made to represent key evacuation components and relationships; however, behaviors are imposed by the engineer (via data or switches) in order to test

specific scenario conditions. It is then up to the user to examine the available literature for appropriate input values. The population is primarily reactive to the surrounding conditions, given these user-defined constraints.

- **Predictive models** – ***the model generates parameter values:*** where an attempt is made to represent key evacuation components and relationships. Behavioral responses are generated given agent attributes, and the social and physical setting. The population is sensitive to the surrounding conditions and process-driven. The manner of the agents' response may vary from reactive (where external stimuli prompt specific behavioral actions), cognitive (where external stimuli initiates a process where information is processed according to the attributes and experiences of the agent), to social (where cognitive agents are also aware of the existence, identity and actions of other agents).

Currently, most models adopt either the empirical or engineering approaches, or some hybrid of the two. Several models have predictive elements (including [31,32,33,36]); however, these tend to represent agents as reactive, with little reference to the internal processing of information [4,30].

An implication of these different model categories is the type of output that might emerge; i.e., the nature of the emergent output rather than simply the format of this output. This implication will be discussed in more detail in the final sections of the report, in conjunction with the embedded version of the EDK model. The three categories highlighted offer different constraints on the qualitative (the type/descriptive) and quantitative (the extent/numerical) output that can be produced (see Table 1, which highlights the type of output provided by each category of model at the individual and population level). For instance, the empirical model provides no feedback on the agent level; i.e., it provides no feedback on individual quantitative performance (e.g., the time for an individual to arrive) or qualitative performance (e.g., the route that an individual adopted). However, feedback may be provided at the population level on quantitative (e.g., the time spent queuing) and qualitative conditions (e.g., the location of congestion), assuming sufficient user expertise. In contrast, the predictive model can *estimate* the actions that an individual might perform (i.e., that these might not be a given) and their consequences, along with conditions that might be produced at the population level.

Table 1: Level of output given model category [30].

Output	Empirical	Engineering	Predictive
Individual Level	N/A	Quantitative	Quantitative Qualitative
Population Level	Quantitative Qualitative	Quantitative Qualitative	Quantitative Qualitative

These differences influence the type of insight that can be gained by the user [34]. It can also lead to significant misunderstanding and misinterpretation should the model's underlying assumptions not be fully understood by the user who might then mistake pre-determined parameter settings with results generated by the model and vice versa.

The three model categories included in Table 1 determine how the actions are initiated – by the user or from within the model itself. It should also be noted that the exact manner in which the engineering and predictive models actually *represent* actions can also differ significantly [35,36]: actions may be represented as an overall delay time (i.e., implicitly representing the cumulative impact of several actions); each action may be independently represented as a delay; each action might be explicitly represented, with a quantitative impact (e.g., associated delay) and qualitative impact (e.g., effect upon another object or agent). These approaches again have implications in the results that can be produced and the insight that can subsequently be gained. However, again the adoption of the explicit representation of actions is somewhat undermined by limitations in the data available.

This report represents an attempt to describe the structures required within an agent-based simulation tool to embed the EDK model to move towards a fully predictive model. This focuses on the pre-evacuation period, in line with the EDK model. However, the structures used are not specific to the WTC data set itself, and should therefore be of use when generalizing the model. The structures suggested have been designed with the knowledge that the evacuation movement period will also need to be represented.

Section 5.0 describes the development of the EDK model informed by several areas of the social sciences and based on specific theories related to decision-making in response to emergency situations; e.g., symbolic interactionism (SI), social constructionism, Protective Action Decision Model (PADM), and the modified Emergent Norm theory (ENT)[2]. This description is necessary to provide some basis for the translated model and outline the underlying model assumptions, allowing the model's strengths and limitations to be better understood.

5.0 EMBEDDING THE PREDICTIVE MODEL WITHIN AN EGRESS SIMULATION TOOL

The EDK predictive behavioral model generates an individual's response to the surrounding conditions during the pre-evacuation phase. The EDK model describes the processes by which (1) an individual is exposed to external information; (2) she processes this information given her attributes and experiences to establish relevance, importance and implications of the information as perceived; and (3) the modification of the individual's objectives and actions reflecting her updated understanding of the situation. This model is useful in understanding the types of responses that were performed during the World Trade Center incident of 2001, but also in predicting evacuee responses subject to similar situations. However, the model in its current form is not amenable to embedding within a broader evacuation simulation model. It is also specific to the WTC incident and is not necessarily suitable to application beyond this event. It also focuses specifically upon the pre-evacuation phase and therefore does not account for subsequent actions during evacuation movement. Some generalization (and then, once implemented, validation) is therefore required – both in terms of allowing it to be applied beyond the original source material and to interface with a representation of the evacuation movement phase.

The work outlined in the following sections has the following objectives:

- Identify the core elements of the original EDK model as they pertain to the original incident.

- Develop a simple block model of the factors identified in the original EDK model in a more generalized form.
- Develop the component structures that reflect key conceptual elements in the Kuligowski thesis.
- Produce an overview of the translated version of the EDK model.
- Ensure that the translated version of the EDK model is amenable to representing both the pre-evacuation and the evacuation movement phases.
- Identify and develop factors that require composite structures (i.e., not based directly on agent attributes) and/or which represent key conceptual assumptions within the EDK model.
- Compare the 'performance' of the translated EDK model with the behavioral facts and with the original EDK conceptual model.

Producing a functioning embedded model is beyond this report, given the specificity of the original EDK model. However, the work outlined should make the translation of the EDK model to an agent-based egress model more straightforward and accommodate the further development required once the evacuation movement component of the behavioral model has been developed.

The EDK model has been examined in detail in order to extract the fundamental components that need to be reflected within a broader egress model. This examination focused on the Kuligowski thesis [2] and several other sources referenced in the thesis, where deemed appropriate. In addition, a broader analysis was conducted of material related to agent-based modeling, social simulation and complex adaptive systems [37,38,39,40,41,42,43,44,45,46,47,48,49, 50,51,52, 53, 54, 55,56,57,58,59,60,61,62,63,64,65,66]. This additional work was both to structure the overall approach and to inform the discussion of potential model output presented in Section 5.8.

An overview of the analytical process adopted is shown in Table 2. This identifies the primary stages involved in the work process. These stages are grouped and discussed in the following sections.

Table 2: Process overview.

Stage	Purpose
(1) Select a simulation approach	After a provisional examination of the Kuligowski thesis, examine options to determine viable modeling approaches
(2) Description of EDK Conceptual Model	Understand general approach and identify the basic elements that form the EDK conceptual model. Identify the factors that are explicitly and implicitly identified in the conceptual model. Review additional material necessary to support understanding.
(3) Interpreting the EDK Model	Translate original Kuligowski description into engineering language
(4) Simplifying the EDK Model	Produce skeleton of EDK model, employing original concepts in a more structured format

	suitable for translation into objects
(5) Translating the EDK Structures	Translate original EDK concepts into attributes and functions that might be represented within a broader egress model.
(6) Developing composite attributes and functions	Describe key developments – composite entities or entities - that represent key elements of original EDK model
(7) Testing performance of developed model with original EDK overview concept	Ensure that the iterative loops and processes highlighted in the EDK conceptual model (see Appendix A) can be represented within the translated version. Ensure that the behavioral facts identified in Section 3.0 can be represented.
(8) Establishing implications of model development	Conduct research in order to establish the benefits of the development and inclusion of such a predictive model, how the model might be included within the existing model approaches available and what effect this inclusion might have on the results produced.

5.1 Stage 1: Selecting a Simulation Approach

A provisional review of the Kuligowski thesis was conducted to support the selection of a modeling approach. A number of modeling approaches are available for use in representing evacuee performance [37,41,42]. Several of these were examined in order to identify the most intuitive, efficient and applicable approach. An agent-based modeling (ABM) approach is adopted here. In this context, an agent is a simulated actor whose actions and interactions (with other simulated agents and objects) form the focus of the simulation process. This approach is based on the following assumptions (derived from [37,39]):

1. Agents are autonomous – there is no centralized overarching intelligence governing agent response. Decisions are therefore made locally.
2. Agents are located and operate within a pre-defined space – agents are located and interact with a proximate portion of this space in accordance with a set of criteria relating them to their external conditions.
3. Agents are social – agents are able to interact with each other and environmental objects within the proximate space as defined in (2).
4. Agent actions and interactions are located temporally – agent actions can be fixed in both space and time. This allows (although does not necessitate) decision-making to have an historical context.
5. Agents can perceive information – agents can react to external information based on environmental conditions within the proximate space, possibly including other agents.
6. Agents can exchange information – information can be internalized or emitted by the agents
7. Agents can store information – information can be stored locally by the agent that can then be accessed by them at a later point in time.
8. Agents have objectives – agent behavior is goal-oriented.

9. Agents can act – agents can manipulate their reaction based on a process that includes internal objectives, information available and external conditions to produce strategic responses.

The ABM approach is then able to represent sets of mobile, information processing entities that are sensitive to the information in their vicinity, able to interact with other entities and able to adapt/react their responses based on their objectives. The ABM approach has numerous benefits when representing evacuee performance using a predictive model:

- A correspondence between simulated agents and real-world evacuees and the actions that might be performed.
- The representation of heterogeneous evacuee populations.
- The representation of heterogeneous spatial/environmental conditions that might appear during an incident.
- The representation of evacuees recognizing each other and engaging in social interactions.
- The representation of evacuees making choices based on their objectives, while having the effectiveness of these choices limited by the information available.
- The representation of an evacuee making localized adaptive responses based on communication with the environment and their sensitivity to surrounding conditions

Given these advantages, the ABM approach is adopted. Therefore, structures are developed given that the attributes and functions would need to be compatible with an ABM approach.

5.2 Stage 2: Description of EDK Conceptual Model

5.2.1 Approach

The main objective of the Kuligowski research was to inductively develop an individually-based theoretical model that explained why certain activities were performed by individuals during the pre-evacuation period of their evacuation from the WTC towers during the 2001 incident [2]:

> *‘The purpose of the model is to provide a qualitative understanding of why people behaved as they did prior to beginning evacuation from the towers.’[2]*

The key to developing this type of model is the understanding that any action performed in a situation, including a disaster situation, is the result of a behavioral or decision-making *process* [67], rather than based on random chance or based on a reactive process with actions resulting directly from a change in the environment (i.e., a stimulus-response relationship). Social science research from community evacuations during disasters and building fire evacuations [2,5,12,13,14,16] has shown that before individuals perform an action, they go through a behavioral process including the following steps: perceive (or receive) certain cues, interpret the situation and the risk based on the perceived cues, decide on what to do (i.e., the action) based on their interpretations, and then perform the selected action. Each action taken is influenced by this process. With this behavioral process in mind, the following questions served as the basis for the study:

- What actions did building occupants undertake during pre-evacuation of the 2001 WTC evacuation
- Why did they undertake such actions?

In order to answer these questions, Kuligowski examined data collected as part of Project HEED [3], where survivors from the 2001 WTC incident were interviewed regarding their experiences during evacuation from WTC 1 and 2. Two types of data were made available [3]. For 252 WTC survivors, data were received from a pre-interview questionnaire and face-to-face interview transcripts, of which 245 interviews were deemed relevant. Information on occupant characteristics included the following: WTC tower number, floor number, gender, date of birth, height, weight, education, medical condition, family information, physical exercise regimen, experience in the 1993 bombing, knowledge of the WTC and its exit routes, social roles (both fire and company-based), fire safety training and experience. In addition, each interview transcript contained detailed information about occupant experiences during the evacuation, beginning from the point they entered the towers on September 11, 2011 until they evacuated them that same day. More information on Project HEED and the methods used to collect data can be found here [3,68].

Kuligowski employed qualitative analysis techniques to develop the WTC predictive behavioral model of pre-evacuation actions. First, the HEED data were indexed according to major themes identified (i.e., individual characteristics, environmental cues, internal cognitions, and actions). Then, within each major theme, the raw, detailed data were transformed into more abstract codes by identifying the ways in which the themed data differed. For example, environmental cues differed both by type (i.e., physical and social cues) and by the intensity of the cue (i.e., high intensity such as seeing flames or smoke on the floor and low intensity such as seeing the lights flicker). Once more, abstract codes were assigned to each WTC occupant's pre-evacuation experience. Extensive work was performed to identify links and connections between categories of one theme and categories of another theme (or multiple themes) (see [2]).

Through this approach, Kuligowski developed a predictive pre-evacuation action model for the 2001 WTC disaster (see Appendix A). The model identifies the specific factors that influenced WTC occupants to develop interpretations of the event, formulate perceptions of risk, and perform pre-evacuation actions.

A summarized version of the EDK model is outlined in Appendix A and presents a complex model of occupant factors, cognitions, decisions, and actions. (A simplified version of the overall process described by the EDK model is shown in Figure 2.) The entire model is described in full elsewhere [2]. This diagram is included to highlight the real-world factors that are explicitly mentioned in the EDK model and would then need to be included in an egress model in order to represent the EDK model and predict pre-evacuation actions in a building fire event. However, a number of other factors and processes are implied by the EDK model. Although not explicitly mentioned, these would also need to be represented within a model in order to adequately represent the factors highlighted in the EDK model.

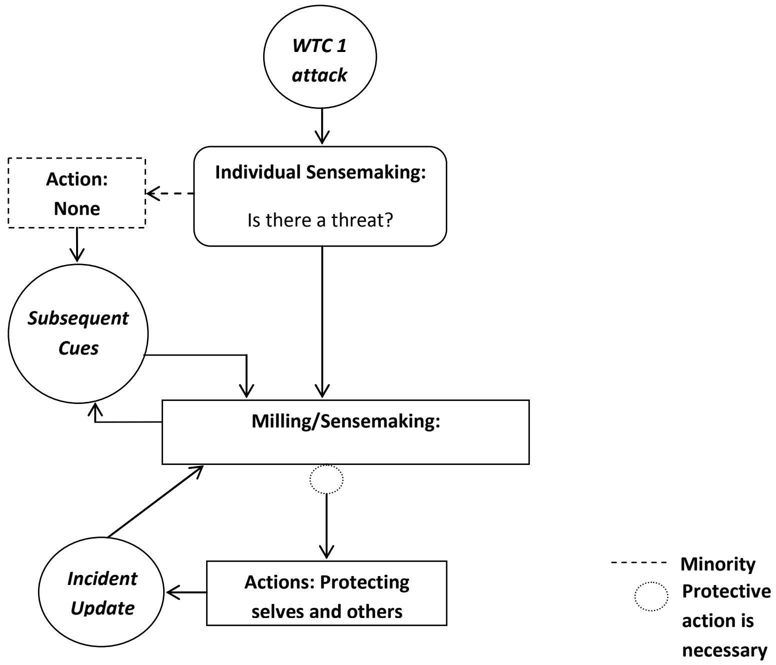


Figure 2: Simplified overview of the high-level process described in the EDK model. Reproduced from Kuligowski [2].

5.2.2 EDK Model

The research was conducted and the model eventually developed according to the following premises:

> *'1) When the event first occurred, WTC occupants engaged in symbolic interaction processes to create meaning. This meaning in the WTC was a new normative structure to guide their future behavior. To create this new normative structure, they engaged in information seeking actions to define the situation and what it meant to them.*
> *2) Based on the definition of the situation (above), a new line of action was created. If occupants interpreted the situation as one that was risky to them, they began performance of protective actions. If not, they continued their previous actions or continued information seeking.*
> *3) Each protective action was also constructed based upon the meanings assigned to objects in the occupants' environment, the definition of the situation, and the assessment of risk.*
> *4) The search for the new normative structure and the performance of protective actions occurred within both pre-existing social relationships and norms (an individual's social stock of knowledge).' [2]*

As part of her research, these premises were examined in detail and the thesis concluded that they were supported by the evidence examined and the model developed. These premises then act as core principles of the EDK model.

5.2.3 EDK Model: Establishing the Situation

In the model, the WTC pre-evacuation period is divided into two main phases: Phase 1- the milling/sensemaking phase and Phase 2 - the protective action phase. In this context, sensemaking relates to an individual understanding the external information available by internally interrogating experiences (from her own social stock of knowledge or conventional knowledge [2]) in order to establish a picture of the situation; i.e., establishing whether the current situation can be mapped onto existing experiences to derive the threat level and viable actions without the need for detailed decision-making to assess the situation anew. *Milling* represents an individual that is actively seeking new information through communication with the surrounding environment, including the surrounding population, to formulate an assessment of an unfamiliar situation [2]. During the process, potential ideas are suggested by individuals (labeled keynoters) who act to advance the assessment of the situation; i.e., suggest possible explanations of the situation and what might be done to address it.

In the milling/sensemaking phase (Phase 1), WTC occupants initially engaged in one of two different actions: occupants either continued their original actions (i.e., continuing to work) or took steps to see if they should modify her original actions (i.e., seeking additional information). No one was observed immediately reacting without first confirming the situation by seeking for new information.

Occupants decided that protective action was necessary once they reached one of two thresholds (see Appendix A). Some occupants decided to take protective action when they personalized or confirmed the risk to themselves without direct instruction from someone else (reaching Threshold 1). These were deemed to be *Early Responders*. Other WTC occupants decided that protective action was only necessary once they were told to evacuate by someone else (reaching Threshold 2). Since the early responders often became the catalyst for others to evacuate (i.e., the source of Threshold 2), it was especially important to identify the factors that influenced early responders to decide to evacuate.

According to the EDK model, WTC occupants with (a) previous experience in emergencies associated with a negative outcome and/or (b) a specific sensitivity to future emergency events were more likely to identify the situation as posing a threat when they received several high intensity and non-ambiguous physical and social cues from the environment. Early responders, who were primarily higher-level manager, fire wardens, military personnel, or individuals with experiences or occupations in emergency situations, went on to confirm the nature of the threat. As soon as they (visually) confirmed the risk, they decided that protective action was necessary. In effect, historical information was compiled with new information to establish a picture of the situation and this picture suggested protective action was required. Before they reached this threshold, however, early responders continued to engage in multiple cycles of sensemaking actions.

The main factor that predicted when early responders decided to evacuate was their internal cognitions. Specifically the confirmation of risk; i.e., whether they perceived the cues available as indicating a sufficient risk to require response. Typically, egress models predict action on the basis that external factors lead directly to action (see Section 4.0). Internal cognitions, in this case risk perception, directly drive decisions that lead to action; other factors, such as individual characteristics and environmental cues, directly influenced the internal cognitions, which then influenced decisions made to take action.

Internal cognitions were influential to all other decisions and actions in the EDK model. Individuals who received instructions to evacuate and decided to evacuate based on Threshold 2 formulated one of two internal cognitions that influenced their decision: 1) a perception/ confirmation of risk – the new information confirmed prior assessment or 2) an assignment of credibility to the source of the evacuation instructions – although no prior threat was suspected, the source alone was believed.

5.2.4 EDK Model: Responding to the Situation

What separated the two phases (milling/sensemaking and protective action) was the decision that protective action was necessary. In Phase 1 individuals engaged in actions to better understand the situation and then establish whether they needed to take protective action in the face of changing conditions. Once they made that decision, occupants engaged in actions to achieve protection for themselves or for others in the building. As shown in Appendix A, WTC occupants continued to engage in multiple cycles of milling/sensemaking actions, based on a feedback loop, until they decided to evacuate. The process was not instantaneous, but instead involved cycles of assessment, actively gaining new information and processing this information.

In the protective actions phase (Phase 2), occupants engaged in actions that were focused specifically on protecting themselves and possibly those around them, depending on their perceived responsibilities and the social connection with those around them. These actions included helping others, preparing for evacuation, taking refuge (if evacuation is not possible), and then moving to the exits.

Internal cognitions also influenced WTC protective actions. Protective actions were taken by individuals based upon their perceived responsibility for others in the building, their perceived opportunity to take these actions (i.e., whether the environment allowed them to perform the desired protective actions), their perceived social connections with others in the building, and the credibility that they assigned to others' actions around them (based on the credibility of the individual taking the action).

5.3 Stage 3: Interpreting the EDK Model

The EDK model is based on a number of key sociological approaches and theories. These are described in some detail in the Kuligowski thesis [2], employing detailed sociological descriptions and terminology. The approaches and theories underlying the EDK model are outlined below in simplified form:

1. Symbolic interactionism – people act towards things based on the meanings assigned to them, where these meanings are derived from social interaction and subsequently modified through interpretation and assessment. Therefore, when new information arrives it is interpreted by the individual and does not necessarily have a universal or unambiguous meaning that determines action.

2. Social constructionism – people habitualize frequently occurring situations and associated behaviors. These are eventually institutionalized; i.e., actions, roles and situations are associated through the existence of institutions that are produced through a history of social interaction. This process (patterns existing either suggesting or prescribing relationships between actions, roles and situations), allows the efficient identification of viable actions in response to the situation faced. Given this, situations do not necessarily need to be defined anew each time they are encountered, but a 'cognitive shortcut' is instead employed allowing actions to be quickly associated with the situations faced. As reported by Kuligowki, Berger and Luckman state that 'the institution posits that actions of type X will be performed by actors of type X' [69]. A 'social stock of knowledge' is then formed and accessed to allow the situation to be understood by the individual when faced with situations that can be recalled from experience or understanding (i.e., habitualized actions and institutions). When combined with (1) and with conventional wisdom, it allows a definition of the current situation to be constructed through interaction and interpretation, which is dependent on historical events and recalled experiences, as well as on social interactions.
3. Events can be encountered where the 'social stock of knowledge' no longer applies; i.e., which are unfamiliar in nature or extent leading to a normative crisis. In such circumstances, Emergent Norm Theory suggests that individuals interact to produce new norms to guide their behavior. In effect, a new set of viable actions is defined in response to the changing situation. Therefore, when an individual can no longer make sense of her surrounding conditions in accordance with previous experiences or understanding she actively seeks out new information (milling) in order to generate a new understanding and an associated set of possible actions to deal with the situation. This process does not occur independently of previous understanding (nor role [40]), which informs the basis of the new norms and relationships that arise. This may involve modifying the set of viable actions given the situation and/or the social relationships with those around the individual.
4. Given (3), the individual has to formulate actions. The Protective Action Decision Model describes how information from the social and physical environment is perceived, internalized and processed to determine which actions are then necessary. The action options are assessed given the threat perceived from the external and internal cues available.

The translated EDK model would need to be developed on the basis of these approaches and theories in order to be consistent with the original thesis.

This translated model describes a process by which individuals are exposed to information and then act in response to this information given internal processes; i.e., external cues do not directly influence actions, but instead typically[1] inform a process by which external information is combined with internal information to produce an assessment of the situation. All individuals within the model receive cues. These cues are then processed according to the previous

[1] There may be situations (e.g., where the individual is directly exposed to extreme temperatures or is incapable of processing the information provided) when the decision process is not implemented. This variation of the decision-making process (and its sensitivity to the perceived time available) is addressed in Section 5.6.2.

experiences, role and knowledge of the individual involved. This process enables the individual to assess the threat posed by the situation as indicated by the cues and then establish viable responses. This process also describes how the exact same set of external information does not necessarily produce the same outcome in different individuals – the assessment of these cues is also sensitive to internal cues derived from experience. The nature and intensity of the cues influence the perceived threat of the incident. Similarly, the role of the individual (i.e., perceived responsibilities) also affects this perception. If the individual perceives that she has a responsibility for others, then the perceived threat also includes the threat posed both to her individually and the threat posed to others. Responsibility influences the perceived threat. Those without responsibility primarily perceived individual threat.

For some individuals, with the prerequisite experience, sensitivity to the cues and/or assumed responsibility, the cues are sufficient for them to recognize a threat and then engage in protective actions (deemed early responders). Some responded without instruction – either due to their independent assessment of the cues and the projected negative consequences to them personally or to others, if their role dictated. This may not have been an immediate response, but may well have required information seeking to confirm that nature of the threat; however, it would have been without instruction from others.

For those with responsibilities for others, once they had responded they engaged in large-scale assistance; i.e., they deliberately sought out other individuals to aid rather than only aiding those in their immediate proximity. They continued to do this until conditions worsened (i.e., the threat was assessed to be personally too severe to continue on) or the target population had commenced protective actions. Others who responded early but who did not have responsibilities for others took protective action for themselves.

Others went through the same initial process of interpreting the cues provided or seeking information for clarification. However, their assessment did not lead them to independently determine that protective action was required. Instead they continued with their current action or sought more information, and required direct instruction from early responders, in order to initiate their protective action (whether or not any threat was perceived).

These 'later' responders either took protective action for themselves or provided assistance to those around them (i.e., on a smaller scale than the early responders), where a social connection existed between them and those around them or where those around them were seen not to be responding.

The following description summarizes the key processes explicitly outlined by the EDK model and suggested by the simplified description presented above:

- P1 Individuals received information/cues.
- P2 All responders perceived cues that led to internal processes according to their social stock of knowledge.
- P3 More information was often sought – either by interacting with the environment or with other people. This was to aid in the understanding and definition of the situation.
- P4 The individual's role, experiences and attributes influenced how the information was assessed and internalized; i.e., there were both internal and external information that influenced the assessment of the situation.

P5 Those who associated the information available (given their previous experience or training) with negative outcomes to themselves or to those for whom they were responsible, sought more information and then engaged in protective actions; i.e., decided to do something about the situation without prompting.

P6 Those who had neither sufficiently unambiguous information nor sufficient experience to understand the outcome suggested by the situation, continued working or sought more information. This population required instruction by the early responders prior to initiating protective actions.

P7 Those with responsibilities provided assistance beyond their immediate surroundings as part of their protective actions; i.e., their responsibilities influenced both their assessment of the threat and the subsequent response. They continued to do this until the threat became too severe or no further assistance was required. Other early responders performed protective actions for themselves.

P8 For the rest of the population, those with social connections with those around them provided local assistance once they had been instructed of the incident. Others, performed protective actions for themselves once they had received instruction.

This process enabled the population to assess the threat posed by the situation as indicated by the cues. That is not to say that the representation of these processes alone within a model would be sufficient to represent the EDK model; they would not. Other processes are implied by the EDK model (either implied in the factors identified or in the assumptions on which the model is based), a selection of which are described in some detail in the following sections.

5.4 Stage 4: Simplifying the EDK Model

The material available was examined to identify the attributes identified that might influence performance; i.e., that might affect a simulated agent. In the original model, these attributes were not necessarily associated with the individual, given the qualitative nature of the model, but were instead associated with the concepts and processes highlighted. The attributes have now been collected in accordance with the host objects and maintain the labels originally provided, ensuring the specificity of their subject. The simplified overview of the EDK model is shown in Figure 3. In this format, the relationship between the individual, the cues provided to them and the viable responses is shown more clearly than before, without specific reference to the manner in which these responses are selected or the implied underlying structures for these responses to be performed. As mentioned, the attributes shown are still specific to the WTC at this stage.

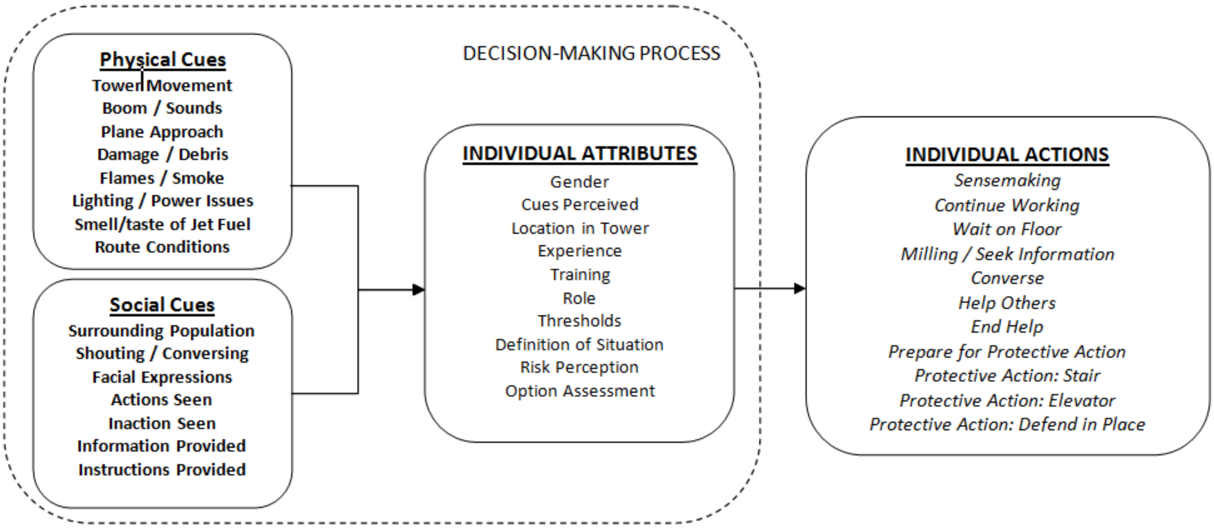


Figure 3: Attributes derived from the EDK model description.

Arranging the attributes in this manner indicates the types of objects and attributes that might need to be included within an ABM representation of the EDK model.

5.5 Stage 5: Translating the EDK Structures

An embedded version of this behavioral model could be used to drive the response of the simulated agents and aid in the process of generalizing the predictive model. In its present form (see Figure 3), this development might then be used to simulate the WTC evacuations in order to gain further insight into what happened, why it happened, and what might have happened had there been changes to the scenario - in relation to the pre-evacuation phase. This might produce valuable insight in and of itself. However, for a broader application base, the theoretical model would need to be generalized. The discussion below addresses the following developmental steps:

1. The elements that would need to be represented within an egress model for a generalized version of this decision-making model to be embedded within a broader egress application.
2. The processes and composite elements required (implicitly suggested) for the EDK model to function within a broader egress application.
3. An indication of the types of actions that would be needed to allow both the pre-evacuation and evacuation phases to be represented.

The description presented has a number of limitations. It should be noted that model implementation details are not presented here. These will change from model to model, and would certainly need to be developed for a more generic model to actually be embedded. The following sections describe the types of structures needed to embed the predictive response model described in the previous sections. As such, this section will provide an overview of these structures, as opposed to the detailed functional relationships between these structures. The suggestions made have not been optimized for efficiency or tested to ensure that there is no duplication within the structures. The structures presented are suggestive of those that would be required to address the EDK model, rather than as a definitive blueprint.

This discussion focuses on the external objects with which an agent might interact, attributes and functions internal to the agent, and potential agent responses. These would then provide the key attributes and functions required for an ABM representation to be produced. Several composite structures and processes are described in more detail in the next section. These relate to structures that specifically address the theoretical assumptions of the EDK model (as described in Section 5.3) and assumptions that might then be carried through into implementation.

An overview of the key attributes required is shown in Figure 4. This has been derived from the attributes shown in Figure 3 and in Appendix B, along with the processes outlined as P1-P8 in Section 5.3. The attributes shown have been restructured to be more general in nature and be more amenable to representation within a computational tool.

Each of the three components (external conditions, internal conditions and agent actions) is now described. External conditions would be those associated with objects external to the agent; i.e., that appear in their environment. These would then influence the agent through the use of a function that would affect the internal attributes of the agent representing the passage of information or physical influence. Internal conditions are those attributes that are directly associated with the agent object within the model. It may be that generic structures are created and that specific instances of these structures are represented within each agent; however, each agent would have a unique combination of these attributes according to its experience and innate capabilities. Agent actions are again associated with the agent; however, these functions provide the link between the internal cognitions of the agent and the internal attributes of other external objects (including other agents), or the manipulation of its own internal attributes.

Several modifications from Figure 3 are immediately apparent. The naming convention is more categorical, rather than specific allowing the agent's progress to be associated with a broader range of scenario conditions. A number of the attributes in Figure 4can be directly traced back to the factors outlined in Figure 3, while others are sets of these factors that are then sensitive to the representation of the external objects within the model. This has been conducted to identify the types of conditions that need to be represented within an egress model, rather than the specifics associated with the WTC incident. This is based on a recognition that some of these cues are not currently amenable to representation and may not become so in the near future; e.g., the impact of facial expressions. However, the impact of the broader category of cues highlighted is both amenable and critical to the representation of the model; e.g., Agent Actions, Human Notification, etc.

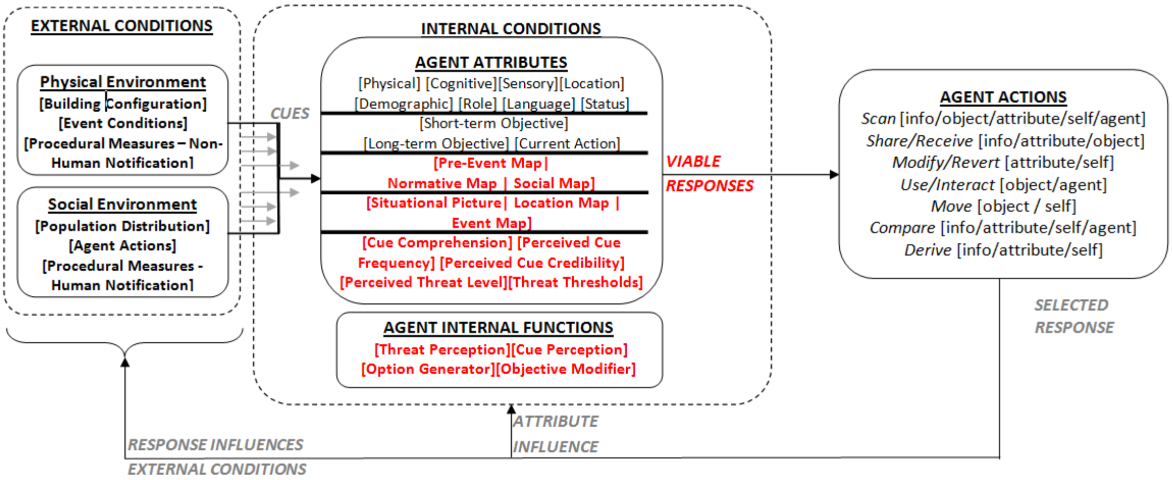


Figure 4: Overview of the components required to embed the predictive model.

The requirements of this simple design are now described in more detail with each of the key elements addressed. The EDK model requires a number of model components to be represented and represented to a given degree of detail: model scope and model refinement. A number of the existing egress models would not have the capacity to embed the EDK model without requiring significant structural modifications [2]. A number of existing model reviews have been examined to established the range of model scope and refinement; i.e., what is included in each model and how it is currently included [4,5,35,36]. For each model the methods employed to represent key elements have been examined. These elements include how the model represents the space, the population, the environmental conditions, the procedural measures in place, the agent structure, the information available and the output that is produced as a result of the simulation process. The EDK model was then examined to establish what was needed of each of these components in order to ensure that the model in question could house the EDK model in some form. This would not necessarily be an 'ideal' inclusion, with all of the details and relationships intact, but a *sufficient* inclusion – enough to represent the behaviors indicated in some form or another. It is then possible to identify the shortfall between the state-of-the-art egress models, and the techniques required in order to permit the predictive response model to be embedded in some form. Table 3 highlights the key components represented within current egress models and the degree of refinement to which they are represented. Table 3 is designed to highlight the current approaches employed to represent these components given that they would need to be represented to a certain degree of refinement in order to represent the cues and processes highlighted in the EDK model. Areas shown in grey are currently represented within egress models. The area within the bold border is deemed to be required in order for the EDK model to be implemented; i.e., functionality within this area should be sufficient (even if not ideal) to represent the EDK model. Table 3 is certainly not exhaustive (especially given the continual arrival of new models and techniques); however, it is indicative of the need to understand model assumptions and capabilities before embedding a behavioral model and how these assumptions may constrain the effectiveness of the embedded behaviors once included.

Table 3: State-of-the-art egress model representation (grey); required representation (within black border) [4,29,34,35,36]. [EC] = External Cue; [IC] = Internal Cue. Grey = currently represented; White = Not currently represented.

	METHOD OF REPRESENTATION				
	LESS REFINED→		→		→MORE-REFINED
[EC] SPACE Sp	[Coarse]		[Fine]		[Continuous]
[EC] ENVIRONMENT En	[None]	[Static - User-Defined]	[Dynamic - User-defined]	[Dynamic - Simulated]	[Dynamic - Predicted]
[EC] POPULATION Po	[Uniform - Homogeneous]		[Distributed - Homogeneous]		[Distributed - Heterogeneous]
[EC] PROCEDURAL MEASURES Pr	[None]		[Implicit / Movement]		[Explicit / Behavioral]
[IC] AGENT Ag	[Number - Empirical]	[Ball-Bearing]	[Individual-Imposed]	[Individual-Reactive]	[Individual-Predictive]
[EC/IC] INFORMATION In	[None]	[Existence]	[Existence] [# Examples] [Location]	[Existence] [# Examples] [Location] [Content] [Extent]	[#Examples] [Source] [Credibility] [Content] [Intensity] [Location] [Target] [Channel]
MODEL OUTPUT Ou	[High-Level Indicators]		[High-level indicators] [Low-level indicators]		[High-level Indicators] [Low-level indicators] [Interaction]

These components can be broadly grouped into those that represent external objects/cues (e.g., the space, the environment, the population, the procedural measures employed), internal objects/cues (e.g., representation of the agent, information) and the output that can be produced by the model. For instance, models typically represent environmental conditions in one of several ways: it is ignored, environmental conditions are static, but user-defined; environmental conditions are dynamic, but user-defined; environmental conditions are dynamic, but simulated based on empirical relationships; or, environmental conditions are dynamic, but predicted [4,5,35,36]. The EDK model is sensitive to environmental cues, especially in changing environmental conditions. Therefore, the first two approaches would not be suitable for embedding the EDK model. This categorization is then adopted for all of the components highlighted.

It is apparent that there are significant limitations in the current egress models in their capacity to represent several of the key components – at least to the degree required to embed the EDK model – specifically in the representation of the procedural measures, the agent and the information exchanged. Of course, these are not the only limitations, but these were the most apparent. The nature of these missing components is addressed in some detail in the following sections.

In the following sections, a number of suggestions are made for the representation of basic objects and attributes (see Section 5.5) and then complex attributes and processes (see Section 5.6) that might be employed to reflect the EDK behavioral model. These provide explanations of the attributes and processes included in Figure 4. These are presented at a high-level and in a generic format (i.e., not specific to a particular model design, software engineering approach, mathematical logic or social science format). The reason for this informal approach is exactly because people from different areas may initially need to examine and understand these discussions and may not be familiar with the syntax of a particular description.

The descriptions shown here provide the basis for model development. Given the range of possible behaviors described (and the approaches that might be adopted to represent them) broad categories are first established to provide a foundation for understanding what needs to be represented and an example approach. Guidance is provided on the types of objects that would need to be represented in order to implement such a model and examples of object structures, attributes, and connecting functions are provided. Undoubtedly, there are numerous other objects and functions that would be needed and which would need to be characterized in much greater detail ready for implementation.

A number of different organizational approaches are possible to include these concepts within a broader egress model. The following sections then represent a suggestion as to how this might be achieved and provides high-level examples of the structures that would need to be in place to do so. The following sections highlight the types of structures that would need to be derived for the development of a comprehensive model.

The following sections are organized to broadly reflect the key components identified in Figure 4. The representation of external conditions is described in Section 5.5.1. This is followed, in Section 5.5.2, by the representation of the cues indicated by these external conditions. In Section 5.5.3 the basic agent attributes are presented. In Sections 5.6.1and 5.6.2, the composite attributes and internal functions (identified in red in Figure 4) are described. These concepts are described in some detail given their importance in reflecting many of the assumptions underlying the EDK model and the novelty of several of the concepts presented. Finally, in Section 5.6.3 the agent actions that can require interaction with external objects are described.

5.5.1 Representing Physical and Social External Conditions

For an egress model to function at all, it needs to address two key external components: the physical environment (see Figure 4 and Table 4) and the social environment (see Figure 4 and Table 5). In effect, these components describe the social and physical landscape that faces an agent. This landscape would be formed from a number of objects with which the agent can exchange information, which constrain the performance of actions and which can potentially affect its internal attributes through mediating functions.

The elements described may influence the decision-making process of the agents along with influencing and constraining the manner in which subsequent acts are performed. The following sections focus primarily on the decision-making process.

Table 4: External model elements: physical environment.

MODEL COMPONENT	Attribute	Description
PHYSICAL ENVIRONMENT	*Building Configuration [DYNAMIC]*	Space within which the event occurs. This is typically provided at the outset of the simulation and remains constant throughout, without the intervention of the event. The agent would have an expectation as to the nature and condition of the physical environment based on its previous experience. Deviations in the building configuration would then notify the agent of a changing scenario (e.g., tower movement, debris).
	Event Conditions [DYNAMIC]	Nature of the event/incident and the conditions produced (e.g., event trigger, smoke/visibility levels, temperature, toxins, building damage, lighting levels, power status, debris, building shaking, etc.). These might influence the physical and cognitive attributes of the agent.
	Procedural Measures – Non-Human Notification [DYNAMIC]	Procedural measures employed to mitigate the emergency conditions during the event or warn of the event within reference to or use of human resources (e.g., sprinklers, alarm bell, emergency lighting, etc.). There is no direct or indirect data exchange with another agent here.

Table 5: External model elements: social environment.

MODEL COMPONENT	Attribute	Description
SOCIAL ENVIRONMENT	*Population Distribution [DYNAMIC]*	The size, heterogeneity and distribution of the agent population (e.g., existence of the surrounding population and their actions and discernible attributes).
	Agent Actions [DYNAMIC]	The discernible actions being performed by the other agents in the population (e.g., conversing, indirect/direct communication, actions. inaction, etc.).
	Procedural Measures – Human Notification [DYNAMIC]	The information deliberately provided by staff agents or through notification systems (e.g., PA, voice alarm, etc.), staff intervention, etc.

The components described in Table 4 and Table 5 represent the external entities that might influence an agent's internal cognitions and which are either explicitly or implicitly mentioned in Figure 3, Figure 4 and Figure 9. Although these components could be represented in a number of ways, depending upon the nature of the egress model (see Table 3) [4,5,35,36], these components would certainly need to be addressed in some form to adequately cater for the cues that an agent might face.

The spatial component describes the structure within which the agent navigates and moves. As such, it both facilitates and constrains agent movement. The environmental component describes the nature of the event and the impact that it has upon physical conditions faced, including the deterioration of the structure itself. As such, the environmental component can be extremely dynamic and may lead to the spatial component also potentially being dynamic during the event. It is recognized that a number of different approaches can be adopted in the representation of the relationship between the space, the environment and the agent. The final components of the physical environment are those procedural measures that do not involve human communication. These include sirens, alarms, strobes, the activity of suppression systems, etc.

The social environment includes the presence of the agent population, the discernible actions in which these agents may be engaged (described below) and the procedural measures that involve human communication (see Table 5).

5.5.2 Representing Cues

For such a model to address the agent interaction with these components, some representation of the passage of information is also required; i.e., the manner in which the conditions of the external environment influence the agent internal cognitions. This may involve a distinct cue/information object represented within the model (see Table 6), or have the cue implicitly represented by the agent accessing external object attributes to represent the passage of information from the external environment to the agent via a functional relationship. It would then be highly dependent upon the representation of the agent themselves and their interaction with the cue representation. An example set of cue attributes is shown in Table 6. These attributes may not be appropriate for all types of cues, which may range widely; for instance, notification messages, the presence of smoke, etc. As mentioned, these attributes may be part of a distinct cue object, or be derived from the attributes of the original source object; however, the attributes described in Table 6 describe facets of information exchange (some explicitly addressed in Figure 3 and Figure 4) whose influence would need to be represented. For instance, the last three attributes (*Comprehension*, *Credibility*, and *Frequency*) would be dependent on the agent's perception of the cues available and their experience, and would therefore likely be associated with the agent object rather than the cue itself. They would then be sensitive to the agent attributes and therefore although influenced by cues would not necessarily be an attribute of the cues. A more comprehensive description of these attributes is then provided in the description of composite agent attributes/functions in Table 8.

Table 6: Cue Object.

Attribute	
Source	The source of the information/cue will influence the perceived credibility of the information as part of the threat perception process.
Immediacy	The time constraints implied by the cue.
Intensity	The intensity of the cue in comparison with the expected range of potential values that the cue might take. For instance, whether the visibility afforded by smoke in the environment is 1m or 10m.
Channel	The mode/manner by which the cue arrived. This may influence the credibility of a series of cues, assuming that they arrived through several different channels. It may also influence whether the information is perceived given any sensory limitations (e.g., impairments) that the agent might have.
Content	The information contained in the cue that might affect the agent's perception and subsequent decision-making process.
Format	The configuration of the information. It may arrive in many ways influenced by whether it is a purely environmental phenomena (e.g., smoke or darkness), whether it is procedural (e.g., a bell, a recorded message, a flashing light), or social (e.g., conversation, gestures, etc.), and so on.
Target	The intended target of the cue (if appropriate). This might influence the perceived threat, especially the personalization of the information – whether the agent determines that the information indicates a situation that affects them.
Consistency	The derived validity of the cue given previous cues; i.e., whether numerous cues indicate the same information. This will add to the overall credibility of the information provided.
Clarity	The level to which the information in the cue is unambiguous; i.e., the potential for confusion over the content of the information. For instance, the difference between the faint smell of smoke and interacting directly with a burning room.

Attribute	
Relevance	Whether the information is deemed to be relevant to the current assessment. Derived through comparison with situation map.
Speed	The time taken for the cue to arrive. For instance, some procedural messages take some time to be completed.
Intrusiveness	Ability of the cue to attain and retain the agent's attention.
Accuracy	The degree to which the information actually reflects reality. This is particularly important if any discrepancy can be clearly ascertained by the agent and will then affect credibility.
Completeness	The extent to which all of the intended message / cue was received.
Comprehension	Whether the information can be understood.
Credibility	The extent to which the information in the cue is deemed acceptable (not actionable at this stage).
Frequency	The number of related cues provided in the current situation.

5.5.3 Representing Basic Internal Agent Attributes

Several of the current egress models [2,4,7,35,36] include agents that (1) have internal memory states represented as distinct attributes, (2) are susceptible to external conditions through functional relationships, (3) are able to perform a number of different actions based on internal calculations, and (4) can select a response in accordance with changing external conditions. As such, they would be able to represent the processes indicated in the previous sections in some form. However, the inclusion of these capabilities (1-4) are typically incomplete, focus on direct agent movement to a place of safety, and (5) include a simplified decision-making process that is not sufficiently sensitive to internal cognitions (including situational picture, threat perception, sensitivity to social connectivity and normative structures). It is this last point that is perhaps the most fundamental limitation, as it drives the need for many of the other components. Typically the decision-making process is broadly stimulus-response based, independent of the situational awareness of the agent involved and/or the social structures present. The model presented in the first sections of the report outlines the complexity required to embed the EDK conceptual model and suggests the key components required. These are now outlined.

For an agent object to represent the conceptual model described, a number of agent attributes will be needed - to describe the agent's initial set of attributes at the outset, how these attributes change during the event and the impact of these changes upon the decision-making process and action selection. These attributes will include simple numerical, logical or categorical values, or require more complex structures to be developed (see Table 7).

The *Physical*, *Cognitive*, *Sensory*, *Location*, *Demographic*, *Role*, *Language* and *Status* attributes are fairly intuitive and closely reflect real-world entities. An agent's *Short-term Objective* represents the agent's goal in addressing its immediate surroundings given the current definition of the situation. This might include leaving a room, searching for a person, finding more information, and so on. The *Long-term Objective* refers to the overall objective given the definition of the event; e.g., to reach safety. The *Long-term Objective* will then be met by the fulfillment of the set of *Short-term Objectives* employed. The *Current Action* represents the action selected by the agent in the previous time frame as a result of the previous decision-making process in response to the *Short-term Objective*; i.e., given that the agent set themselves a *Short-Term Objective* in time *t*, the *Current Action* employed in time *t+1* will be an attempt to fulfill this objective. The objectives can be compared with the outcomes of current actions to establish the success of the actions and whether they are sufficient to meet current objectives.

Table 7: Required Agent Attributes [2,70].

Attribute	
Physical *[STATIC / DYNAMIC]*	Innate physical characteristics; e.g., achievable travel speeds in clear conditions, initial fitness, existing impairments, injuries, etc. These will certainly influence the performance of any action, but will also influence the agent's assessment of its current status and potential performance when generating and assessing action options.
Cognitive *[DYNAMIC]*	Innate cognitive characteristics that influence, to different degrees, the ability to process information, generate/process options, performance speed, susceptibility to error and biases (e.g., normalcy, anchoring[2]), and the manner in which the information is processed. These may also include limits on the ability to store information, generate new options, assess options, perform given time constraints, etc.
Sensory *[DYNAMIC]*	Innate abilities to internalize information from external sources (e.g., visual, aural, tactile, etc.).
Location *[DYNAMIC]*	Spatial position within structure. Directly influences the external information available to the agent at any time.
Demographic *[STATIC]*	Innate characteristics that may influence the performance of an agent or the manner in which the agent is perceived by others (e.g., age, gender)
Role *[DYNAMIC]*	Original role within the social and organizational structure in which the event occurs. This may be modified during the event based on the norms that may emerge and on the agent's definition of the situation. The original role may be kept in memory as a reference point for comparison. It is possible that an agent has several roles depending of the situation and surrounding population during the event.
Language *[STATIC]*	Ability to comprehend verbal/textual information or instructions provided during the event.
Status *[DYNAMIC]*	The alertness, focus and/or attentiveness of the agent in the current situation.
Short-term Objective *[DYNAMIC]*	The objective of the agent that influences its immediate internal cognition; e.g., is the agent able to meet its current short-term

[2] Anchoring is the tendency for people to rely too much on a piece of evidence when making a decision.

Attribute	
	objective given the current situation, normative structure, viable actions and projected action performance.
Long-term Objective [DYNAMIC]	The event-based goal of the agent; e.g., whether it still sees the situation as routine or as interrupting its routine actions and require a modified response - feel it needs to continue with its routine action, evacuate or defend in place. The agent's response given its definition of the overall situation that is then formed from meeting the set of short-term objectives.
Current Action [DYNAMIC]	Action being performed by the agent at the current time.

5.6 Stage 6: Representing Agent Composite Attributes and Functions

The rest of the attributes are more complex in structure or derivation. These either relate to composite attributes, functions that update internal attributes (these differ from actions, as they are facilitating functions that enable internal processes to function, rather than deliberate outcomes of the decision-making process) and/or reflect key assumptions in the original EDK model.

5.6.1 Composite Attributes

The composite attributes are described in Table 8 and example formats are provided where relevant; i.e., examples of the data components that these structures might include when implemented. These include *Cue Comprehension, Perceived Cue Credibility, Perceived Cue Frequency, Normative Map*, *Social Map*, *Situational Picture*, *Location Map*, *Event Map*, *Pre-Event Map*, *Perceived Threat Level*, and *Threat Thresholds*.

Table 8: Composite Agent Attributes

Attribute/Function	
Cue Comprehension [DYNAMIC] (Derived - ***CompCue****) (from* Table 6*)*	Whether the information be understood and derived meaning. Derived through comparison with language.
Perceived Cue Credibility [DYNAMIC] (Derived - ***CredCue****) (from* Table 6*)*	Given a combination of the cue attributes and the historical understanding of the agent, the extent to which the information in the cue is deemed acceptable (not actionable at this stage). Stored within the agent.
Perceived Cue Frequency [DYNAMIC] (Derived - ***CueFreq****) (from* Table 6*)*	The number of related cues provided in the current situation. Stored within the agent. This may also relate the time that the agent is exposed to the cue.

Attribute/Function	
Normative Map *[DYNAMIC]*	This describes the permissible actions for a given role in a particular situation. A set of roles and associated actions are listed, outlining the actions that can be performed by that role. A *Normative Map* is then selected and applied to a particular situation. This may be updated should new norms emerge allowing new actions to be deemed viable in a given situation or new situations to be defined. This could then be associated with specific situations and social settings to designate how the roles/actions interact with external conditions (see *Event Map*, below).
Example Format of Normative Map: **NormMap1: [Role1 | Action11 | Action12 | Action13] [Role2 | Action21 | Action22 | Action23]**	
Social Map *[DYNAMIC]*	The social structures/hierarchy present that influence agent interaction. In the example schema, this represents a graph connecting agents (*Role* and *Role_of_Other*) and indicating the relative strength (*Connectivity_Other*) and hierarchy (*Relative_Position*, *Responsibility(Role_of_Other)*) of their social connectivity. This may influence the actions deemed relevant in relation to the other agents, the responsibilities towards those agents and the credibility of information arriving from those agents (*Credibility(Role_of_Other)*), amongst other influences.
Example Format of Social Map: **SocMap1:[Role | Role_of_Other | Connectivity_Other | Relative_Position | Responsibility(Role_of_Other) | Credibility (Role_of_Other)]**	
Situational Picture *[DYNAMIC]*	A snapshot of the current situation in which the agent finds itself. This includes a description of the agent's *Location*, *Time*, *Current_External_Cues* available to them, its *Role* in this situation, *Current_Action* in which it is engaged, their objectives and *Current_Status* of the agent (in conjunction with its surroundings). This will be updated constantly to reflect new information. This will
Example Format of Situational Picture: **SitPic1:[Location | Time | Current_External_Cues | Role | Current_Action | Current_Short_Objective| Current_Long_Objective | Current_Status]**	
Location Map *[DYNAMIC]*	Mental representation of the structural space (described as a list of *Locations*), the connectivity between the spaces (*Connectivity*), and the agent's preferences for use of the space (*Priority*, especially given *Previous_Use*) given the conditions at particular locations (*Status*). This will influence the routes that might be deemed available and their relative attractiveness to the agent.
Example Format of Location Map: **LocMap1: [Location1 | Location2 | Connectivity | Priority | Status | Previous_Use]**	
Event Map *[DYNAMIC]*	The agent's understanding of the event as gathered from the historical experiences during the current event (*EventMap_Previous*) and the physical/social/internal cues to

Attribute/Function	
	which the agent has been exposed (*SitPic1*). In the example schema, this represents a collection of situational pictures (*SitPic*), the current locational map (*LocMap1*), normative/social map (*SocMap1*, *NormMap1*), derived threat perception (*PercThreat*), the current outcome given the actions being performed (*Current_Outcome*), and the assessed likelihood of the agent reaching its objective (*Prob_Confidence*) given the current situation.[3]
Example Format of Event Map: EventMap_Current [SitPic1 | LocMap1 | NormMap1 | SocMap1| PercThreat | Current_Outcome | Prob_Confidence | EventMap_Previous]	
Pre-Event Map [DYNAMIC]	Information collected prior to the current event by the agent through experience, training, expertise, conventional norms, social connectivity, previous cues/situations and the prior actions and outcomes associated with this information, etc. In the example schema below, this represents the stored *Event Map* for a particular event and the associated final *Location Map*. This may also represent *Event Maps* provided from others to represent general knowledge and conventional norms / understanding; i.e., secondhand knowledge.
Example Format Pre-Event Map: PreEvMap1:[EventMap1 | FinalLocMap1] PreEvMap2:[EventMap2 | FinalLocMap2]	
*Perceived Threat Level [DYNAMIC] (Derived - **PercThreat**)*	Perceived threat to the agent (or to those socially significant or for whom an agent has responsibility) primarily given the information provided by the external cues (see Table 6), as represented in *Cue Comprehension, Perceived Cue Credibility, Perceived Cue Frequency* examined using the *Threat Perception* function and internal cues such as the agent's *Event Map*, *Pre-Event Map*, and *Situational Picture*.
*Threat Thresholds [DYNAMIC] (Derived - **ThreatL**)*	Internal attributes that determine whether the threat perceived (instantaneously or cumulatively) is sufficient for the situation to be seen as a threat to the agent or to others; i.e., in comparison with the *Perceived Threat Level*.

The *Normative Map* describes the actions that are deemed acceptable for the role of the agent. These are then associated with the situation in which the agent finds themselves. In effect, this outlines the expected actions available to the agent given its role that is then further refined through cross-referencing these actions with the agent's situation. These norms may evolve (and be updated) given the threat that is perceived and the agent's ability to meet its objectives.

The *Social Map* describes the social connectivity between the agent and the surrounding agent population - the social structure within which the agent exists; i.e., those around the agent with

[3] It is recognized that the *Social Map* and *Normative Map* could also be referenced elsewhere; for instance, as part of the *Situational Picture*.

which there is a stored social relationship. A sub-set of the simulated agents may therefore be familiar to the agent, given its role, shared experiences, and historical interactions. This might influence the actions selected and the perception of the actions of other agents. It will also influence the threat perception of the agent – given that this perception may be specific to them - based on social connectivity or responsibility. A simplified visualization of a social map is shown in Figure 5(a), where, for instance, the arcs shown may have values associated with them indicating the strength of association.

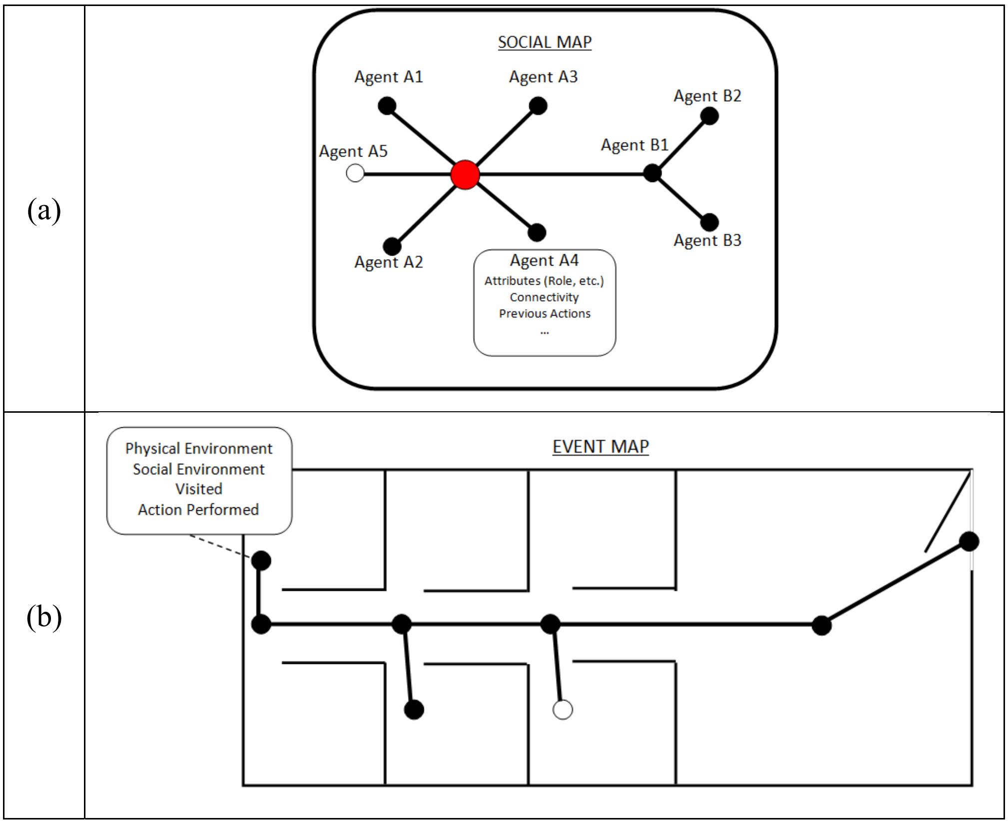


Figure 5: Simplified visualizations of the (a) social map and (b) the event map.

The *Situational Picture* represents the agent's understanding of the current situation/episode. It is a snapshot of the agent's current situation given its location and the external cues available, in conjunction with its immediate goals and ability to achieve them.

The *Location Map* is a basic representation of the agent's understanding of the structure within which she is located. This focuses on its ability to traverse the routes within the structure and reflects its longstanding familiarity with the space and tendency to use some routes over others.

The *Event Map* is produced from the updated *Location Map* combined with the *Situation Pictures* collected previously during the event, to form an overarching understanding of the event. A simplified visualization of this is shown in Figure 5(b), where a graph of known space is shown, with conditions at nodal locations within the graph being stored.

The *Pre-Event Map* represents the information brought to the event by the agent. This provides a filter through which external cues are interpreted, many of the existing internal cues that can be provided and may provide a cognitive short-cut for when the agent is familiar/ habituated with a situation; i.e., where the agent's response does not necessarily go through the analytical processes that might otherwise be the case to perceive a threat and derive an appropriate response, but where a preferred action is selected given the cues faced during previous experiences of the same (or similar) situation. The *Pre-Event Map* connects the expected external cues, agents, norms, locations, objectives, permissible actions and expected outcomes. The *Pre-Event Map* therefore acts as both a means of assessing the cues and a means of determining a response when the cues faced are deemed to be routine. This assessment may indicate a situation where risk is not perceived (e.g., a routine situation or a situation where cues recall a situation that does not suggest risk) or where it is perceived (e.g. where the agent is assumed to have had a previous experience with an incident that posed a threat and required a response). In both instances, the existing recollection may shortcut the threat perception process by providing an existing threat level and set of viable responses.

Finally, there are the *Perceived Threat Level* and *Threat Thresholds*. These are employed during the *Threat Perception* activities (see Section 5.6.2). The *Perceive Threat Level* relates specifically to the agent (or to those socially significant or for whom an agent has responsibility) and is the result of the *Threat Perception* given the information available from the external cues (see Table 6), and internal cues such as the agent's *Event Map*, *Social Map*, and *Situational Picture*. The *Perceived Threat Level* can then be compared against the *Threat Threshold* to establish whether the scenario poses a threat that requires the situation to be redefined affording a new normative structure.

5.6.2 Agent Functions (Internal)

A number of functions are explicitly identified or suggested in Figure 4 as being necessary to implement the EDK model. These are identified and described in Table 9. These functions influence internal attributes primarily in the form of attribute updating or calculation. Functions that the agent can employ to affect external attributes are described in Section 5.6.3.

Table 9: Internal Functions.

Function	
Cue Perception *[DYNAMIC]* ***(CuePerc)***	The function that filters the external cues in the current situation, based on the internal attributes of the agent and the composite functions outlined in Table 8, to determine whether the information available is internalized.
Threat Perception *[DYNAMIC]* ***(ThreatPerc)***	This function is primarily called when the situation faced by the agent does not match an existing situation in the *Pre-Event Map* (or when there is some doubt in the nature/severity of the event indicated – where confirmation is required). In effect, the agent is not able to derive from memory the requirements posed by the situation and then provide relevant action options. It will make use of the expected conditions, external conditions (represented through the internalized *Cue Comprehension, Perceived Cue*

Function	
	Credibility, Perceived Cue Frequency) and generate a *Perceived Threat Level* that can then be compared against the *Threat Threshold* to determine the nature of the situation faced.
Objective Modifier [DYNAMIC] ***(ObjMod)***	Given the new *Perceived Threat* level and the *Event Map*, the agent may need to modify its long-term and short-term objectives based on its new understanding of the situation. The function may also be called as a result of a recalled situation from the *Pre-Event Map* that requires a redefinition of the situation, but where the modified objectives are known from experience.
Option Generator [DYNAMIC] ***(OptGen)***	Given that the agent does not recall the current situation (from its *Pre-Event Map*) and therefore have access to a supply of existing option suggestions, it then has to develop viable action responses. This will be based on the *Threat Perception,* the new *Objectives* developed, and on the external and internal information available.

The *Cue Perception* function provides a simple interface between the agent and the surroundings, determining whether the information available affects the internal attributes of the agent. In the PADM approach, this might reflect whether the information was perceived at all (given sensory attributes and agent status), whether the information is understood (given language and cognitive attributes), and whether it is deemed credible and appropriate (given internal attributes such as the *Social Map*, the *Pre-Event Map*, etc.). During an actual implementation, the *Cue Perception* and *Threat Perception* functions may well be represented as the same entity. They are described separately here purely to outline the two processes. Indeed, the functions might be represented in many ways; for instance, as self-contained functions, sets of functions, chained functions, etc.

The *Threat Perception* function is used to assess the combined external and internal cues in the current situation to establish whether the current objective is still appropriate and whether it can be met given the current set of available (viable) actions. It might be employed should the current situation not match with anything stored in the *Pre-Event Map*; i.e., that there is no suggested set of norms, actions and objectives for the situation faced. As such, more detailed analysis is required by the agent to establish the threat posed.

Given the situational context, this function would need to examine the cues available (and internalized by the agent in the form of the *Cue Comprehension*, *Perceived Cue Credibility* and *Perceived Cue Frequency* attributes) and then assess the level of threat indicated by them. An example approach is presented. This is a deliberately simple approach, analogous to the FED model described by Purser for the impact of environmental conditions upon an evacuee [71], in order to describe the impact of cues of different indicative strength.

The *Cue* attributes highlighted in Table 6 would be interrogated in order to establish: the credibility of the information provided (the *Perceived Cue Credibility* derived from the *Accuracy*, *Source*, *Consistency*, *Format* and *Channel* attributes); the time constraints suggested (*Immediacy* attribute); the severity of the incident suggested (including the *Cue Comprehension* attribute derived from the *Intensity*, *Completeness*, *Clarity* and *Content* attributes); and whether it affects the agent or socially significant others (*Target*, *Relevance*, etc.), and so on. The incident suggested by the incoming *Cues* could then be quantified using a simple scale (or scales), where the relative impact of a cue is stored (perhaps in conjunction with the exposure time and number of cues received, *Perceived Cue Frequency*): this would then allow the threat posed by different cues to be combined according to a single simplified scale. When the value produced by the assessed cues is sufficiently high (i.e., over the *Threat Threshold* attribute) the agent would recognize a change in the situation and decide to act accordingly. As indicated in the EDK model, this may occur after the agent is exposed to the cumulative arrival of numerous cues, with some cues having much more indicative power than others. In essence, each cue carries an indicative dose (where the impact of the cue is determined by its indicative strength given the time of exposure), that contributes to the threat perception. It may be that this dose is so significant that it alone may be perceived as a threat.

Given the application of the *Threat Perception* function, the *Objective Modifier* and *Option Generator* will be employed to establish the agent's required objectives to meet the changing environment and the actions needed to meet these objectives. The *Objective Modifier* changes the short-term and/or long-term goals of the agent based on its assessment of the situation. The *Option Generator* then allows action options to be identified (if need be) and assessed such that an action can eventually be adopted. The manner in which option generation is performed may be linked to the extent of the threat perceived and the associated time constraints. For instance, the nature of the search of objectives and action options may range from optimizing (i.e., choosing the best action to meet the objective), satisficing (e.g., choosing the first action to meet the objective), or an arbitrary selection process (e.g., randomly choosing an action, or choosing an action with no assessment at all) depending on the perceived time constraints [2,72].

In all cases, these functions would require significant development given the pivotal nature of their contribution to the overall model.

5.6.3 Agent Functions (External)

Given the arrival of external cues, the compilation of this arrival with internal cues and subsequent analysis, the agent may wish to engage in one of a number of actions, typically represented as functions within an ABM. The sub-set of actions available will be constrained by the agent's perception of the situation along with the actual environmental conditions.

In the original EDK model, the actions outlined were specific to the WTC incident. They were also limited to the pre-evacuation phase. The actions listed in Table 10 represent the possible responses of the agent that can represent all of the original EDK actions, translate these actions beyond the specifics of the WTC incident, and also be applied to other phases of the evacuation process. This has been achieved by

- decontextualizing the actions, presenting them in a modular format (whereby it is assumed that they can be recombined to form more complex chained tasks),
- identifying the targets/objectives to which the actions can be applied,
- and presenting these actions in a more uniform manner.

As mentioned previously, it may be possible to represent the internal functions outlined in Table 9 as being special examples of those shown in Table 10; i.e., that a single set of actions could be developed which might then be targeted at internal or external attributes or objects. It should also be noted that the number of combinations of these actions will be limited; i.e., not all combinations will make sense given the behaviors that can be expected. This will be necessarily in order to simulate human responses in a more naturalistic manner.

These actions represent deliberate attempts to respond to the incident. These attempts are not all physical and are not all exclusive to one particular evacuation phase. As noted by Kuligowski, the evacuation process is iterative by nature [2]. These actions therefore represent the set of actions that, when chained, may be used to reflect the array of complex responses that can be developed as part of the evacuation process.

Table 10: Agent Actions.

Action	Description	Impact
Scan [info/object/ attribute/self/agent]	Deliberate attempt to find a specified object. The object can be information, a physical object or an agent.	May lead to new information being received by an agent that then influences its internal attributes. Can also be used by agents to review its current attribute status.
Share/Receive [info/agent/ attribute/object]	Arrival of new social information that needs to be stored within the agent or the provision of new social information to another agent (e.g., through communication).	May update the agent's internal attributes or the attributes of another agent.
Modify/Revert [attribute/self]	Agent modifies its own attributes either to a new of previous setting (changing objective from evacuate to remain).	Any of the dynamic attributes may be modified (e.g., change appearance) or altered including the short/long-term objective.
Use/Interact [object/agent]	Deliberate attempt by agent to interact with an object (e.g., use a fire extinguisher) or another agent that does not require the movement of information.	May influence performance/internal attributes of other agent/object.
*Move** [object/self/agent]	Agent changes its location (e.g., initiates their evacuation), or the location of an object.	Changes the location of the agent and possibly the conditions that it faces.
Compare [info/attribute/self/ agent]	Function used to compare the values of several attributes either within the agent themselves, other agents, or objects (e.g., compare two exits to establish their current statuses).	Allows conditions to be compared across different locations and across different time periods. Can allow the agent to project into the future to assess future conditions and the outcome of potential future actions.
Derive [info/attribute/self]	Function to compile information from several internal attributes in	Allows attributes to be combined, refined, summary assessments to

	order to make a broader assessment of the information faced.	be made, and or new attributes to be produced.

* it is noted that these actions can be simplified still further. However, this is not attempted to make the actions more intuitive.

It should be noted that the actions identified in the original EDK model can be formed from a chained sub-set of these action tasks. For instance, "seek information" may be formed from the following set of functions when coded in the following way:

[Move(Self), Scan(Object/Agent),Receive(Info),Compare(SitMap),Move(self)]

or something similar. This chain of actions might be modified to represent milling, for instance, where the agent may *Interact* with other agents, and so on. As has been noted elsewhere [73,74], the set of possible actions is finite with many combinations of the actions described in Table 10 not reflecting credible or recognizable behaviors seen in an emergency situation.[4]

5.7 Stage 7: Verification of Translation

This stage of development is designed to ensure that the iterative loops and processes highlighted in the EDK conceptual model (see Appendix A) can be represented within the translated version. This is presented in two steps: ensuring that the objects described can be combined to represent the process described in the EDK conceptual model and then whether this representation captures some of the underlying behavioral assumptions indicated in the EDK model.

5.7.1 Implementation

The exact method used to implement the structures described previously will be sensitive to the host model. The EDK conceptual model outlines the stages through which an individual passes and the iterative cycles through which the individual passes. However, a suggestion is made below as to the manner in which these structures may interact during a broadly linear process – to simplify the visual representation. This is to allow the performance of structures and processes to be verified in comparison with the core elements of the EDK model and with our current understanding of expected evacuee behavior. An example approach is shown in Figure 6. This, deliberately simple example, will then be referred to in the following discussion.

[4] As Chomsky note, 'We have all sorts of tacit and complex knowledge concerning our relations to other people. Perhaps we have a sort of 'universal grammar' of possible forms of social interaction, and it is this system which helps us to organize intuitively our imperfect perceptions of social reality...If we succeed in finding our place in society, that is perhaps because these societies have a structure that we are prepared to seek out.'

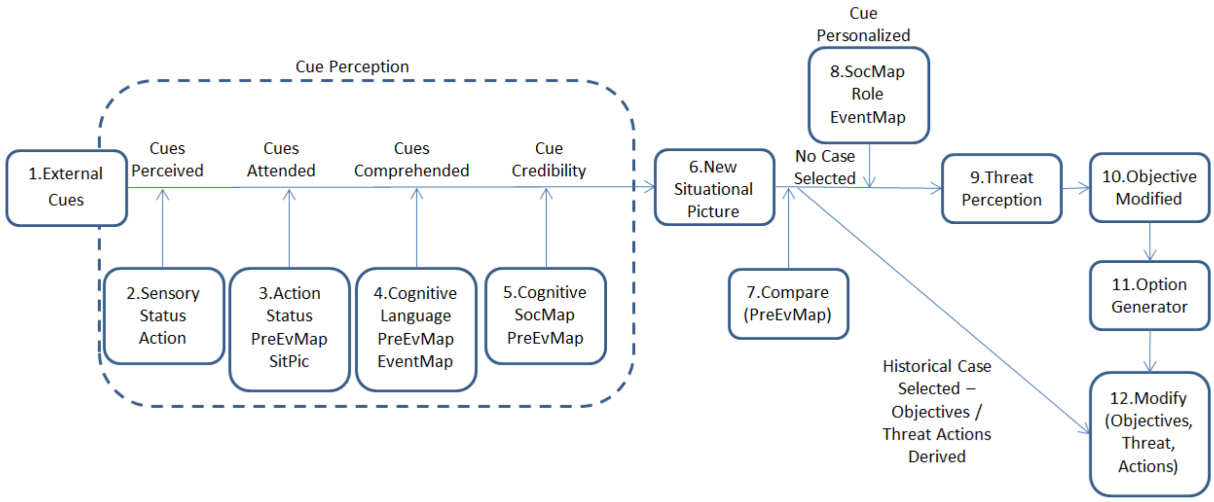


Figure 6: Example of implemented structures and processes interacting.

A simple example is shown in Figure 6. Here, the agent is exposed to external cues that are then filtered (using the *Cue Perception* function) given that they are perceived by the agent. The agent attends to the information, understands it, and deems it credible. This would be performed through comparison with the various internal structures highlighted in Boxes[2,3,4 and 5] shown in Figure 6. A new *Situational Picture* is formed based on previous experiences (previous *Situational Picture*) and the new information derived from the *External Cues*. This is then compared with the *Pre-Event Map* to identify the expectations of the current situation; i.e., what the appropriate roles, norms, and outcomes might be. If a match can be found, then the relevant information in the match is then adopted, providing 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 (even taking into account inaccurate matching to account for normalcy bias, etc.), then the analysis becomes more detailed, time-consuming and intensive – potentially increasing the threat perception (and anxiety levels). At this point, the threat of the current situation is assessed using the *Threat Perception* function (including an initial assessment as to whether the information relates directly to the individual agent or to others to whom the agent is socially connected or responsible), new objectives identified and action options generated given these objectives. 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. The agent's internal attributes are then updated accordingly, an action is performed and the whole process begins again in the next time frame.

It may well be (as was identified in the original EDK conceptual model) that there is insufficient information to establish the situation clearly (e.g., no historical case is selected and insufficient information to assess the threat). At this stage, the agent may engage in information seeking activities (e.g., Milling), reflecting its new objective of completing the assessment. As mentioned, this is one simple example (outlined in Table 11). In other examples, steps may be omitted, steps may be repeated, or steps may be performed in a different order. In addition, the functions and attributes highlighted can be interrogated and utilized in many different ways to produce similar results. This would depend on the exact manner in which they were implemented. This hypothetical example is simply shown to demonstrate the manner in which the functions and attributes can interact and to allow for a clearer comparison between the suggested structures and the conceptual EDK model described in the next section.

Table 11: Example use of functions and attributes for the process outlined in Figure 6 and described in Section 5.6.2.

Event #	Function Activity	Description
2	*PercCue = CuePerc (ExternalCues,SensoryAttributes, Status)*	Determine *PercCue* – cues that are perceived by the agent given its sensory abilities, etc.
3	*AttCue = CuePerc (PercCue,SitPic, PreEvMap,Status)*	Determine *AttCue* – interrogate current situation to establish whether current actions and status allows agent to attend to perceived cues.
4	*CompCue = CuePerc (AttCue,CogAtt,Lang, EventMap,PreEvMap)*	Determine which of the *AttCue* can be processed by the agent given its cognitive skills (derived as *CogAtt*) and whether they can be understood (where language skills are derived as *Lang*). *AttCue* is then filtered down into *CompCue* – cues that are comprehended. Stored in *Cue Comprehension* attribute.
5	*CredCue = CuePerc (CompCue,SocMap,PreEvMap)*	Establish credibility of comprehended cues (*CompCue*) through comparison with the social map (*SocMap derived from EventMap*) and with experience (*PreEvMap*) given the source of the cues, to determine credibility (*CredCue*). Stored in *Perceived Cue Credibility* attribute.
6	*Modify (SitPic,CredCue)*	Update situational picture (*SitPic*) with new information from cues derived as credible.
7–12	*Modify (EventMap,SitPic)* *HistCase=Derive(EventMap,PreEvMap)* *If (HistCase) then* *{* *Modify((Threat, Objective, ActionSet) | Scan (NormMap | HistCase))* *}* *else* *{* *PercThreat=ThreatPerc(ThreatL, CredCue, CueFreq, EventMap, PreEvMap)*	Update the *EventMap* to include new situational picture (*SitPic*). If the situation is recognized from experience (where the current *EventMap* is compared with the *PreEvMap*), then agent recalls the appropriate historical situation and derives related action, objective and threat (or sets of these entities) given those stored in the *PreEvMap* and the associated *NormMap*. Otherwise, the

Event #	Function Activity	Description
	Modify (NormMap | Scan(EventMap, PreEvMap | PercThreat)) *Objective = ObjMod (NormMap,PercThreat)* *Action = OptGen (Objective, PercThreat, SocMap)* *}*	agent will need to pass through a more intensive threat perception process. Here, the cues are assessed to determine whether the cumulative, combined or individual threat indicated by the cues is sufficient (given its role and social connectivity) for the agent to potentially modify its normative map (i.e., to generate new sets of viable objectives and actions for the situation), and then produce an objective and set of viable response actions, given the derived threat to the agent and socially connected others. The efficiency and scope of the selection process is dependent upon the nature and severity of the threat.

5.7.2 Representation

This section assesses whether the suggested approach is able to represent the behavioral 'facts' present in the field of understanding and the elements specifically suggested by the EDK conceptual model.

The first comparison is with the set of 'behavioral facts' highlighted in Section 3.0. These are then compared with the model capabilities described in the previous sections and with the example implementation highlighted in Figure 6. It is suggested that any implementation would need to represent the behavioral facts highlighted in order to represent the specifics of the EDK conceptual model and the key behavioral factors, many of which are implicit in the EDK model. As can be seen in Table 12, the implemented model addresses these requirements.

Table 12: Comparison between model capabilities and behavioral facts.

Behavioral Fact	Representation
1: Rather than panicking, people's first instinct is to feel (sometimes inappropriately) safe in their environment.	*The translated model represents a process that is driven by a sensitivity to information and the internal cognitive processes. It is therefore not panic-driven. There is the opportunity for representing inappropriately delayed response in the decision-making process indicating normalcy bias. For instance, when comparing the current situation with historical experience there may be a tendency to match the situation where differences exist (see Boxes[7/8] in*

Behavioral Fact	Representation
	Figure 6).
2: Perception of information is critical and is not simply contingent on the information available.	*The Protective Active Decision Model process is represented. Therefore, external information is not automatically internalized, but is filtered through sensory, experiential and cognitive processes, as indicated in the various cue perception stages indicated.*
3: People will engage in information seeking actions, especially when cues are ambiguous and/or inconsistent.	*Agents are able to formulate a range of actions depending on their objectives (see Boxes [10/11/12] in Figure 6). These actions include Scan and Receive (see Figure 4).*
4: People will not necessarily reduce their exposure to hazardous conditions.	*In responding to (3) agents may move towards the incident. Also, given the Social Map, threat perception may be pooled and. as such, an agent may respond to the threat posed to a number of people rather than just themselves.*
5: Broadly speaking, people act rationally and altruistically during building fires.	*As in (1) the process outlined is sensitive to information and experience. Therefore, the decision-making process will attempt to address objectives through assessing viable actions given perceived understanding. This will not be optimal, but it will be rational, albeit bounded by the information available and assessment capabilities.*
6: People do not instantaneously flip to a different set or behavioral rules and roles unless provoked by the most extreme environmental conditions. The rules and roles prior to the event forms the basis of those employed during the event.	*As in (1), there will be a tendency for people to underestimate the threat posed through normalcy bias; e.g., matching situations where there is not match to be found. However, where this match is not made, a new assessment is made, establishing the threat level, the new normative structure (reflected in the objectives and actions identified) and allowing the agent to meet the new situation in the desired manner, outside of the previous normative structure if need be (see Boxes[7-12]in Figure 6).*
7: People are likely to engage in preparation activities before beginning their evacuation response that then go to delaying their response.	*The agent's situation and status is recorded, along with its short-term objectives. Actions need to be performed in order to meet these objectives, which may relate to the time before the agent initiates movement to a place of safety. The capacity for agents to seek out additional information and then interact with the objects around them allows them to both confirm the nature of the response required and then initiate preparatory actions.* *This preparatory delay can also be further*

Behavioral Fact	Representation
	extended given an initial delay in characterizing the situation as requiring a response at all. Given that it is possible for agents not to define the situation as being a threat, and do so reducing the actual threat posed, they may continue on with their routine activities and may then assume that the risk is less than expected when they eventually move off, allowing them to perform preparatory actions (formed from the chaining of the modular actions identified).
8: People move to the familiar. The relationships with the structure and surrounding population that existed prior to the incident influence response during the incident.	*This is reflected in the Location Map and the fact that some routes are unknown while others are preferred. The relationship with the surrounding population is explicitly represented in the Social Map, which will then influence the perception of information and the actions taken.*
9: The surrounding population will influence the individual's decision-making process.	*The social environment provides a key set of cues into the model. In addition, the identity of the population is recognized as being a factor in the Social Map.*
10: People are heterogeneous.	*The agents have a set of internal attributes that reflects their innate, experiential and decision-making capabilities.*

The second comparison to be made is between the attributes derived from the original EDK model (see Figure 3) and those suggested as being required to embed the model (see Figure 4). From this comparison several statements can be made:

1. The physical and social cues are represented in generalized form within the suggested version. The exact manner in which these cues are represented is to a large degree dependent upon the host model. However, all of the key attributes are present.
2. Again, the agent attributes are reflected, along with the structures and processes implied by the identification of these attributes and the underlying EDK model assumptions (see below).
3. The agent actions have been distilled into a modular format. Therefore, the broad set of actions highlighted in the original EDK conceptual model can be accommodated through the reformulation of the modular actions into chained sets. In addition, a function is highlighted to outline how these tasks may be selected.

The suggested implementation can address the attributes highlighted in Figure 3; therefore, based on the assumption that Figure 3 is a reasonable representation of the core EDK attributes, then the suggested implantation of the EDK model seems adequate.

The third comparison can be made with the key underlying/implicit processes and assumptions within the EDK model. This list is certainly not exhaustive (indeed it is further reduced given that some of the key elements are discussed in the previous two comparisons), but is certainly indicative of the extent and nature of the coverage provided by the suggested implementation. Again, the comparison indicates reasonable representational agreement (see Table 13).

Table 13: Comparison between EDK assumptions and suggested representation.

EDK Model Assumption/Process	Representation
Individuals received information/cues that were perceived leading to internal processes according to their social stock of knowledge, including their role, following the sociological traditions of symbolic interactionism and social constructionism. *The individual's role, experiences and attributes influence how the information is assessed and internalized; i.e., there are both internal and external information that influenced the assessment of the situation.* '*Environmental cues were perceived, interpreted through a filter based upon an individual's stock of knowledge, and then based on this newly developed situational reality, subsequent actions were performed.' (p158, Kuligowski [2]).* *'Instead of being linked directly to actions taken, pre-disaster social roles, training, and experience (or an individual's social stock of knowledge), were linked to the meanings established for actions. Perceptions of responsibility, social affiliation, habituation, and familiarity, all of which directly influenced the performance of protective actions, were developed primarily based upon pre-existing social roles and relationships in the building and previous experience in emergencies. This is consistent with…the notion that an emergent norm should be viewed more as a revised definition of the situation, developed within the context of pre-existing norms and social relationships, as opposed to a completely novel one.' (p160, Kuligowski [2]).*	*The suggested implementation explicitly represents the passage of information from the external to the internal. The process is not assumed or automated but highly dependent on the perception of the external cues. Once perceived, internal processes assess and filter this information according to the normative, social, situational and historical stores of information (i.e., the social stock of knowledge).*
More information was often sought – either by interacting with the environment or with other people. This was to aid in the understanding and definition of the situation.	*The agents are able to set their own objectives given the situational picture. Given this they are explicitly able to seek new information in order to better access the*

EDK Model Assumption/Process	Representation
	threat faced or to better define the situation should it not match with an existing example in the Pre-Event Map.
Those who associated the information available (given their previous experience or training) with negative outcomes to themselves or to those for whom they were responsible, sought more information and then engaged in protective actions. Those who had neither unambiguous information nor sufficient experience to understand the outcome suggested by the situation continued working or sought more information. This population required instruction by the early responders prior to initiating protective actions.	*Threat perception is made on an individual basis. This is made in accordance with the agent's Pre-Event Map, agent internal attributes and the information available. In addition, the Cue/Threat Perception function can be defined at the individual level. Therefore, the association of a situation with negative consequences (from the History Map or from Threat Perception) is conducted at the individual level allowing responses to be determined accordingly.*
Those with responsibilities provided assistance beyond their immediate surroundings as part of their protective actions; i.e., their responsibilities influenced both their assessment of the threat and the subsequent response. They continued to do this until the threat became too severe or no further assistance was required. Other early responders performed protective actions for themselves. *For the rest of the population, those with social connections with those around them provided local assistance once they had been instructed of the incident. Others, performed protective actions for themselves once they had received instruction.*	*Agents have roles that can influence their assessment of their situation and their normative responsibilities. In addition, the Social Map provides additional social connectivity allowing the surrounding population to be differentiated and factored into the action selection process.*
Emergent Norm Theory and the potential for normative crises	*The agent is able to compare represented attributes of the situation with attributes of stored historical events. Should the attributes be comparable, then viable actions and objectives can be established and will be available to the agent. Should there be no match, then the agent will potentially be subject to a normative crisis requiring either individual or social assessment of the situation to develop new norms, objectives and associated viable actions. How this is achieved will be dependent on the time available, with actions selected with little assessment when time constraints are severe, using satisficing*

EDK Model Assumption/Process	Representation
	principles when a threat is present, or attempting to optimize the response where a great deal of time (or instruction) is available.
The Potential for Mental Modeling	*In order to generate new action options, especially when experiential guidance is not available, options will have to be tested – albeit in a potentially sub-optimal manner. In doing this, the agents will need to project their potential performance into the future in order to make direct comparison between potential outcomes [32].*
Social Stock / Habitualization / Institutions	*The model specifically addresses the importance of the experiences of the agents from prior events and that these influence the decision-making process in the current timeframe. This is taken further by the need for the experiential structures (Pre-Event Map, Normative Map, Social Map, etc.) to reflect the importance of agent interactions and new experiences.*
Hypervigilance / Keynoting / Anchoring	*The set of Agent attributes is specific to the individual. Given that the passage of information is clearly represented the individual tendencies to focus in on some information provided to the detriment of other information or the tendency to fixate on well-known processes can be represented at the individual basis. In addition, the ability for the agent's Role to influence its credibility and ability to suggest normative developments is represented in a similar manner.*
Milling / Sensemaking	*Agents are able to seek information and interact with other agents in order to update their internal attributes (i.e., their understanding of the situation). Information from the social and physical environment influences their understanding. This information can be deliberately sought to complete their Situational Picture, or existing information from their Situational Picture might be used to comprehend the existing situation.*

The comparisons made are indicative of the sufficiency of the structures and processes suggested in Section 5.5. The satisfactory nature of these comparisons is not definitive in that other structures may certainly achieve the same outcome and that other structures may do so more efficiently and in a manner more representative of the original EDK conceptual model. However, from the comparisons made it appears that the suggested structures would represent key aspects of the EDK conceptual model. Further analysis and comparison would help refine and validate the approach adopted.

The structures identified may be sufficient, but they have not been shown to be necessary. The benefits and implications of incorporating the structures suggested (and therefore representing many of the core attributes and assumptions of the EDK conceptual model) have been briefly alluded to in earlier sections. These are discussed in the next section.

5.8 Stage 8: The Benefits and Implications of the Suggested Approach

Egress models operate at different levels of refinement [4,7,34,35]. That is, they represent the key components – structural, environmental, population, procedural, information, behavioral, etc. – at different levels of detail, making different assumptions, using different structures and, critically, allowing them to interact in different ways. This was discussed in Section 4.0 and represented in some detail in Table 3. However, this representation has important implications upon the results that the model is able to produce and the insight that can be provided to the model users.

The translation of the EDK conceptual model into a form that can be embedded within a broader egress model places a number of structural requirements upon the model (see Table 3). These requirements relate to attributes and functions within (and between) the agents and objects. These provide the fundamental components within the model. However, the EDK conceptual model refers explicitly to influences that lie outside of the individual, but which are internalized either historically or during the event in order to influence individual performance. These include societal factors, organizational factors, group factors, information derived from self-analysis, and external cues. Therefore, although some of these factors are explicitly represented within the EDK model as separate entities, others reside as an effect within the individual themselves – that are instilled previously and that they effectively bring to the incident. This is also reflected in the translated design, where, for instance, although societal level structures are not represented, their impact can be ‘felt’ through the experiences of the agents themselves; e.g., through their awareness of the organizational structure, the acceptable norms in the situation faced, the legal structures constraining the norms present in the situation, etc. This is critical, given the importance placed upon the internalization of external cues and the influence of historical information upon this internalization by the EDK model. This section discusses the impact of representing the various levels of interaction and emergence that might occur and the causal relationships between them. This is important both in terms of capturing real-world phenomena and also in the predictive capabilities of the model itself.

A key benefit in the development and use of a predictive egress model is that it may produce results and insight that cannot (certainly in a practical sense) be derived analytically from initial conditions. That is, the combined set of interactions between the simulated agents produce consequences that cannot be otherwise derived[5]. The representation of these interactions influences the conditions that can emerge and the relationships that can be represented within the model. In a practical sense, the representation of these interactions influences the types of results that are available to a user and to what degree they have been predicted by the model. These emergent possibilities are more clearly established in Table 14, which describes the levels at which events and actions may take place within the social situation represented.

Table 14: The potential for emergence, derived from Sawyer [30].

<table>
<tr><th>Level ID</th><th>Level</th><th colspan="2">Description / Examples</th></tr>
<tr><td rowspan="2">E</td><td rowspan="2">Emergent: System Level

[Beyond Incident – compilation/impact of conditions across incidents]</td><td colspan="2">Emergent outcomes that exist beyond the incident, that influence structures up to the societal level and primarily relate to future incident conditions.</td></tr>
<tr><td>Organizational Structures
Structural Changes
Formal Modifications to Procedure Guidance</td><td>Legal Structures
Societal Norms
Legal Changes
Safety Culture
Regulatory Structures
Historical Definition of Incident</td></tr>
<tr><td rowspan="2">D</td><td rowspan="2">Emergent: Scenario Level

[General – compilation/impact of conditions across episodes]</td><td colspan="2">Emergent conditions/outcomes that arise in relation to the totality of the incident (i.e., the sequence of the episodic situations in C) up to the point in question. The cumulative impact of the incident (as defined by the chain of episodic events) upon the emergent conditions.</td></tr>
<tr><td>Learned Social Roles
Emergent Norms
Definition of incident
Adapted Procedural Response</td><td>Availability/Use of Space
Physical condition of the agent population</td></tr>
<tr><td rowspan="2">C</td><td rowspan="2">Emergent: Episodic Level[75,76]

[Local/Sensitive to situation as defined by agent]</td><td colspan="2">Emergent conditions/outcomes that arise specifically in the situation in which the agent finds themselves.</td></tr>
<tr><td>Local Group Dynamics
Local Situation Awareness)
Local Agreed Response to Situation</td><td>Flow/crowd Patterns
Flow Rate
Movement Rates
Congestion Levels</td></tr>
<tr><td>B</td><td>Interaction Level

[Local/Time Specific – events between agents]</td><td colspan="2">Interaction between agents/objects through exposure to information/cues or physical changes in the surrounding conditions that influence performance and affect internal attributes. These may be non-physical (less tangible), or physical. Agent may also interact with its own internal states; e.g., exchange data from memory to inform decision-making process – recollection as an additional cue.</td></tr>
</table>

[5] A detailed discussion of the philosophical and practical implications of emergence within simulation tools is beyond this report. However, a number of texts have been written on this very topic [30,41,42,37,70].

		Social Communication Social Cues	Environmental Cues Spatial constraints
A	**Agent /Object Level** **[Components and processes that define agent/object]**	Attributes and processes internal to the fundamental objects within the incident. For instance, the sensitivity of an agent to social and physical cues, internal attributes that influence the decision-making process (physical, cognitive and social attributes, memory, understanding of the incident, current role, perception of risk/threat, etc.), and the action options available to the agent: Input (Cues) → Decision-Making → Output (Actions) The agent represents the sum of these attributes and processes.	

In Table 14 the levels at which a model can potentially operate (and the levels at which the model can subsequently provide insight) are identified. This is obviously a simplification, but should help identify the benefits of including the EDK conceptual model (given that these levels are either indirectly or directly referred to within the model), but also of representing the structures necessitated by this inclusion. It also closely fits the discussion presented by Kuligowski in her thesis regarding the importance of collective/social interaction in understanding and responding to the event [2].

Level A represents the basic objects and agents represented within the model. Each of these would then be the result of a set of attributes and functions that form each agent or object into a unique entity within the model. Many of the current models (e.g., empirical models) do not represent agents and/or objects at an individual level.

Level B represents the (possible) interaction between these objects and actions. Obviously, the Level A objects and agents would need to be represented in order for this interaction to take place, along with the appropriate functional description of the nature and result of this interaction. In the translated model, this interaction can be physical (tangible objects and agents) or non-physical (including social and cognitive elements).

Levels C-E represents the conditions that can emerge given the Level B interactions. Level C relates to those conditions that are specific to the situation faced by the agent at that moment in time, labeled episodic (potentially reflected in the Situational Picture of the agent in the translated model). These might include non-physical elements (social dynamics) and more tangible, physical elements (crowd patterns, congestion levels, structural conditions, etc.). These emergent conditions may be perceived in some form and then influence the agent's awareness and assessment of the situation. Level D relates to the conditions that emerge across the entire event (potentially reflected in the Event Map of the agent in the translated model). These might relate to the modified role and normative structure produced as a result of the agent/object interactions during the event. Finally, Level E relates to those emergent conditions that last beyond the life of the event itself; e.g., changes to the organization, physical changes to the structure, modifications to the procedures, legal structures, societal norms, safety culture, regulatory guidance, etc.

Although there may be some academic benefit in the previous discussion, the real benefit is in the implications for understanding causation (upward and downward) and in the egress models capacity to reflect this causation in a predictive manner; i.e., to represent how the real-world 'levels' may act upon each other and influence the simulated results. Where a model employs causal relationships and is then able to predict emergence, then the results will provide insight to the user; where this is not possible then the user may be required to set conditions to compensate for the lack of emergence or will simply not have access to this phenomena (real or simulated). Examples of how this causation may influence emergence (and therefore agent performance) are shown in Figure 7 and Figure 8.

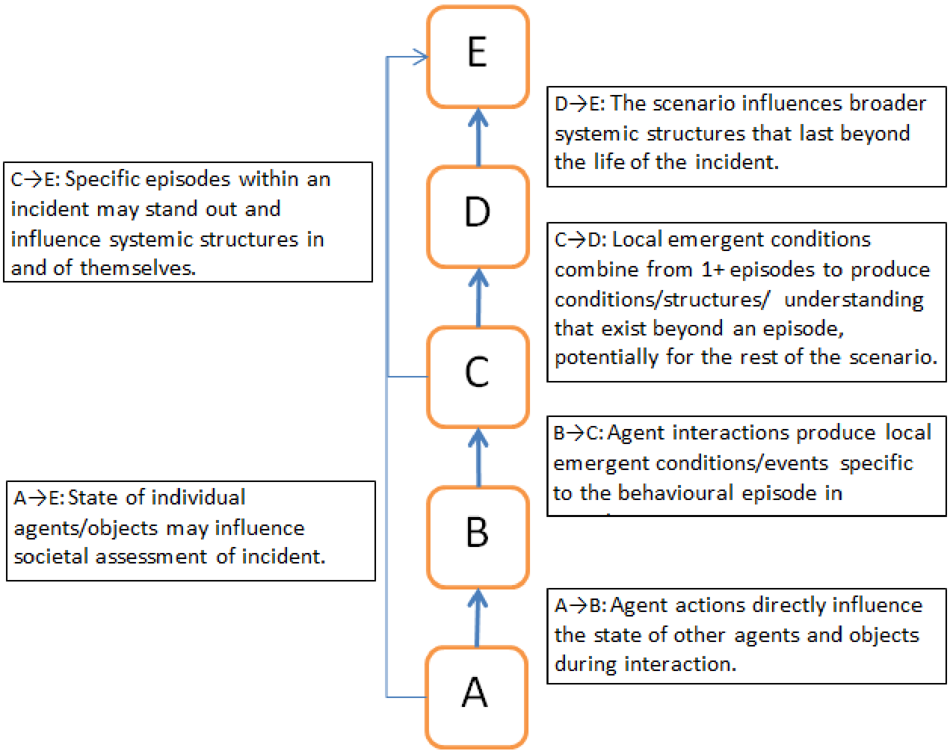


Figure 7: Bottom-up causation implied by Levels A-E, shown in Table 14.

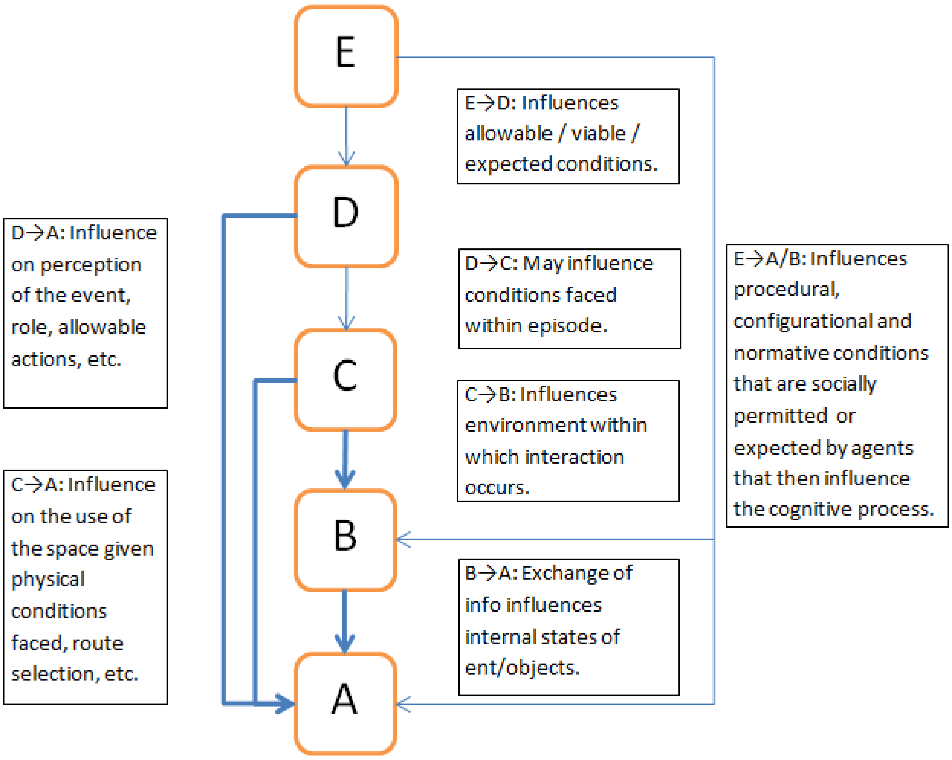
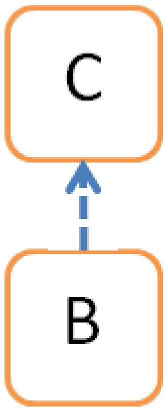
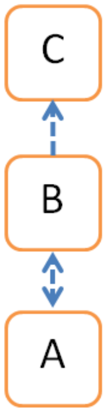
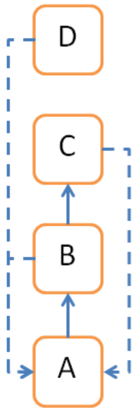


Figure 8: Top-down causation implied by Levels A-E, shown in Table 14.

These causal relationships are key to our understanding and representation of evacuation performance. In the EDK conceptual model clear reference is made to historical influences upon an individual's assessment of a situation, the impact of long-term and short-term normative structures, the agent's perception of the immediate surroundings, and the ability to internalize, assess and generate viable action options in response to this situation. Following on from this, one agent's cue is another agent's output and structures can be formed from multiple agents – leading to the types of complex causation highlighted during this discussion. Importantly, although much of this causation is captured in the EDK conceptual model, it is often missed within existing egress models. The implications of the representation of these causal relationships are shown in Table 15. Here the three broad types of egress models are examined according to their ability to represent the causal relationships highlighted previous and the implications that this might have upon the user's interaction with the model. In reality, models are composites potentially employing empirical, engineering and/or predictive elements for different aspects of the model. This may make assessing the causation represented and the benefits to the user more complex, confusing results that are genuinely emergent, those that are imposed, and those that are hybrid results.

Table 15: Representation of causation within egress models [30,40].

Factor	Empirical Models	Engineering Models	Predictive Models
Primary Focus	To examine the consequences of imposed flow conditions.	To examine the consequences of imposed scenario conditions upon the conditions generated. Specific to time frame within scenario.	To examine the relationship between individual agent actions, the scenario conditions faced and the emergent conditions that are produced.
Description	Mathematical functions derived from empirical data to describe relationships between observed physical variables. Emergence is implicit.	Basic physical attributes at agent level. Detailed sociological/psychological attributes assumed. Emergence focuses upon physical attributes derived from set attributes. The physical emergence present is primarily limited to bottom-up causation.	Fundamental processes and components represented. Assumptions/judgments made to compensate for missing data / theory. However, relationships between modeled elements are represented. Emergence is primarily focused on bottom-up causation.
Required User Intervention	Level [A] is ignored. Level [B] is implicitly represented through the imposition of specific values in Level [C] in order to produce other episodic emergents as outputs.	Level [A] The user imposes the agent decision-making process to represent scenarios/procedures of interest; specifically, these models may impose the action outcomes divorced from specific inputs and internal processes. Agents typically represented as inputs/outputs with simplified/absent internal process and little or no downward causation from emergent conditions. Imposed agent responses represent social and psychological processes. Level [B] Model calculations focus primarily on physical	Level [A] User configures initial agent and scenario attributes. Level [B] Interaction between these elements is then explicitly modeled, given internal processes and agent outcomes. Able to represent the exchange of information along with the physical interactions. Level [C] Interactions produce physical emergent conditions and some limited social emergent conditions. Some downward causation from Levels [C→A] (where agent decision-making considers

Factor	Empirical Models	Engineering Models	Predictive Models
		interactions. Level [C] Emergent conditions derived from physical interactions.	surrounding conditions), Levels [C→B] (where the identity of an individual may influence the communication process] and from Levels [D→A] where spatial/procedural modifications may influence agent decision-making process.
Emergent levels typically represented			

The final row in Table 15 outlines the causation that is typically represented in current egress models given the approach adopted (although it is acknowledged that research is being conducted at all times to modify these causal influences). The representation of these causal relationships directly influences the emergent conditions that can be produced by the model, the causal relationships that can be represented and the expectations of and insights provided to the user. It is apparent that these fall someway short of the causal relationships highlighted in Figure 7 and Figure 8. This would not be important (specifically regarding the engineering process [1]) and would be utterly academic if social causation had no impact upon quantitative performance; i.e., that the results of primary interest to engineers (e.g., movement speeds, pre-evacuation times) were uninfluenced by non-physical elements. Unfortunately, they are influenced by such elements and, as the EDK model demonstrates, these influences may lay outside of the immediate temporal-spatial location. Attempts to compensate for the absence of these causal relationships will require an enormous amount of expertise on the part of the user and a great deal of insight into the impact of complex causal relationships in addition to the complexity of the scenario being examined. This may well be beyond most users, irrespective of their expertise.

It is contended that including a behavioral model, based on the EDK concept, within an egress model will improve the representation of the causal relationships outlined and therefore minimize the expectations of the user while providing greater insight into the physical and social dynamics being simulation. Of course, the EDK model does not represent all of the relationships shown in Figure 7 and Figure 8 (for instance, the upward causation from A→E and C→E would like be missing). However, the inclusion of the following:

- Agent-based long-term (*Pre-Event Map*) and short-term (*Event Map* and *Situational Map*) memory states
- Agent-based social structures (*Social Map* and *Role*) that
  - can be updated (e.g., using the agent *Modify* function);
  - can in turn influence agent performance; which in turn,
  - can influence the performance of other agents and their perception of the situation (physical and social)

indicates that the EDK model has the potential for capturing many of the causal relationships that might be present.

5.9 Further Developments

A number of other efforts would be required before the EDK conceptual model could be embedded within an egress model. These reflect limitations in the work presented.

1. Comparison with comparable models. The work here has been presented on the basis that the EDK conceptual model is sufficient for representing evacuee behavior. There are several other models that attempt to represent evacuee behavior, albeit in a simplified manner. However, these should be examined in detail (a process started in the Kuligowski thesis and elsewhere [2,7,10]) to confirm suitability.
2. The EDK model should be formally extended to address other phases in the evacuation process. This has been initiated here by identifying structures that might be needed in such work, however, there is much still to do in this effort.
3. The EDK model should be verified through comparison with other incidents. This should be possible given that the translated version of the model assumes that the EDK model is only a basis and generalizes many of the elements represented beyond the original target area.
4. The EDK model was qualitative in nature. The current description describes when certain actions occur and the process that leads to these actions being selected. It does not quantify the time taken for the actions to be performed or the delays that might be incurred. For this to be achieved, numerical estimates would need to be associated with the actions performed. This process is initiated within the Kuligowski thesis [2], where is provided describing the time taken to perform certain actions. Similarly, Galea et al have produced an engineering model to describe the relationship between delays incurred and pre-evacuation actions [77]. This type of model could be coupled with the EDK conceptual model to quantify the process being represented.

Table 16: Expect delays for specific actions. Reproduced from [2].

Action	Delay (minutes)
Preparation	½–5

Information Seeking (discussion)	3
Information Seeking (looking from window)	1–5
Helping (by authorities)	4–10

5. The translated model would need to be more formally specified, include a more detailed representation of objects and functions required, and be in a format more appropriate for software development.

5.10 Conclusion

The EDK model developed by Kuligowski represents a significant advancement in the understanding of human behavior in fire. It also provides a basis for an advance in the field of egress modeling: moving from the engineering to a more predictive approach, if implemented. This will have implications for the requirements of the model user and on the insights that a user might gain when using such an egress model.

In this report, a process has been developed whereby the original conceptual EDK model is broken down into its constituent parts in order to identify the core assumptions and structures. These are then translated into comparable structures that might then be embedded within a general evacuation tool assuming that it represents the necessary core components to the required degree of refinement. This process provides the basis for the challenging but necessary development of a comprehensive and refined behavioral representation. The generalized format adopted here should enable future research to focus in on specific components while understanding where a component fits into the overall decision-making structure; i.e., making progress on certain areas without necessary addressing the whole problem at once.

It is acknowledged that the work presented does not provide a detailed blueprint for the development of a fully comprehensive egress model. Instead, this report highlights the key structures and functions that would need to be developed in order for such a model to be produced. The devil is certainly in the detail of these structures and much further research is required (along with suitable data) to fully develop the structures (e.g., functions and attributes) needed. However, up until this point these structures, their underlying purpose and the manner in which they might interact has not been well understood. It is suggested that this report has furthered this understanding, building on the initial work conducted by Kuligowski.

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6.0 APPENDIX A: DETAILED EDK MODEL

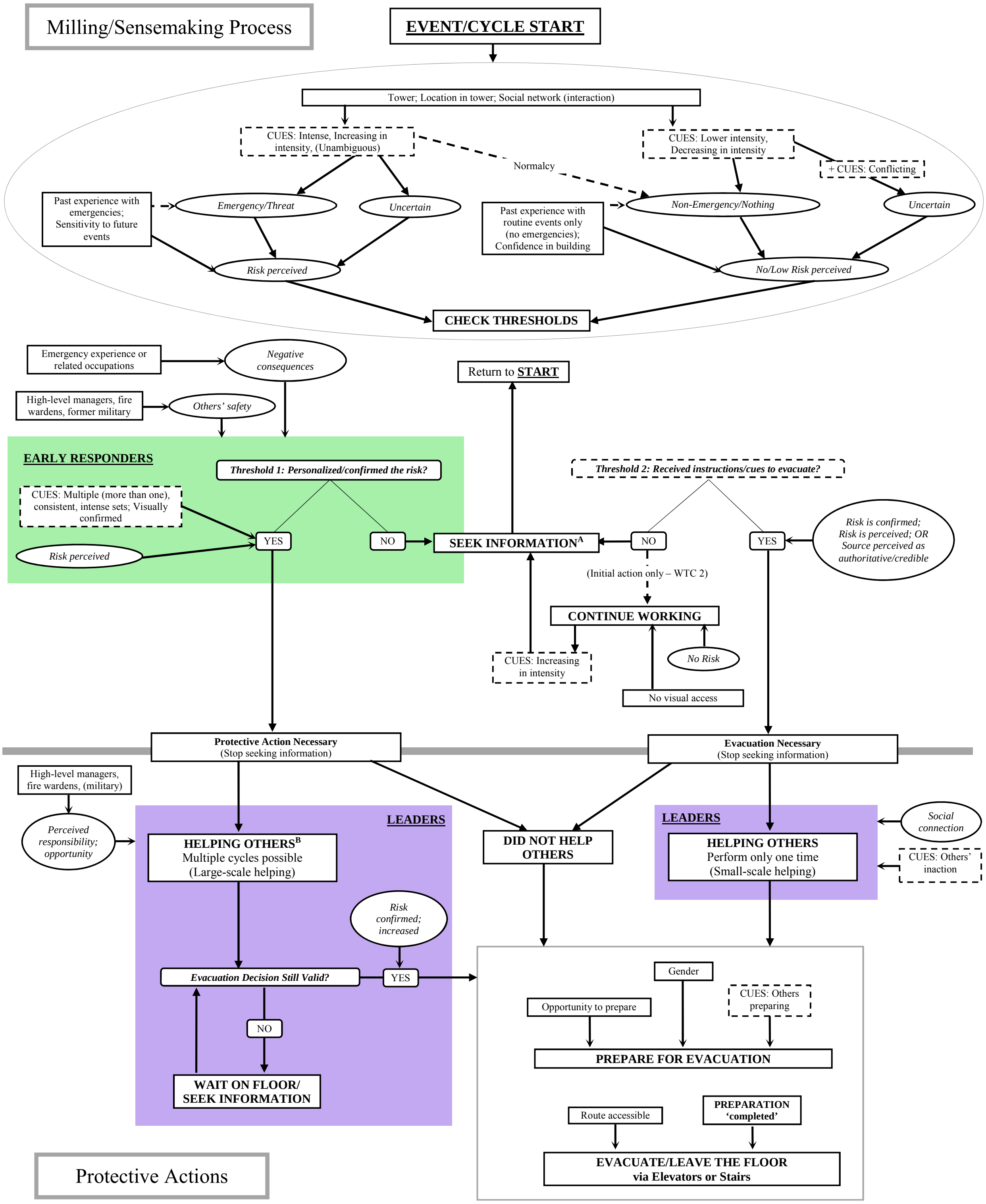

Figure 9: The predictive model of pre-evacuation actions in the 2001 WTC disaster. Reproduced from [2].

7.0 APPENDIX B: EDK MODEL FACTORS

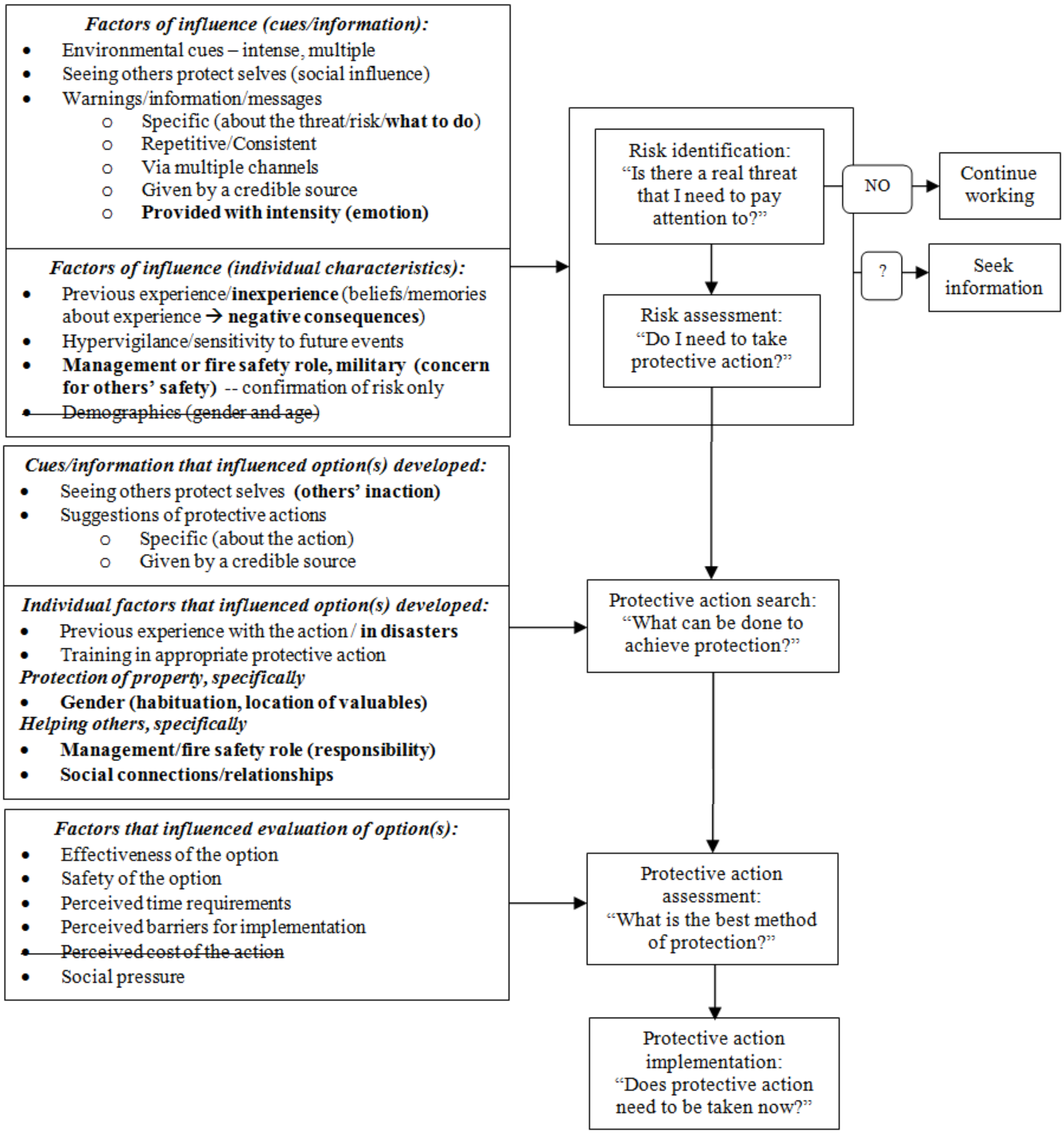

Figure 10: EDK model factors compared with PADM factors. Bold indicates new findings, strikethrough indicates that factor was not deemed to have an impact. Reproduced from [2].

8.0 REFERENCES

1 Purser, D.A. and Gwynne, S.M.V. (2007), Identifying Critical Evacuation Factors and the Application of Egress Models, *Proceedings of Interflam 2007*, University of London, Royal Holloway College, UK, September 3–5, pp. 203-215.

2 Kuligowski, E.D. (2011),*Terror Defeated: Occupant Sensemaking, Decision-Making And Protective Action In The 2001 World Trade Center Disaster*, University of Colorado, PhD Dissertation, http://gradworks.umi.com/3453742.pdf.

3 Galea, E.R. , Shields, J., Canter, D., Boyce, K.E., Day, R., Hulse, L., Siddiqui, A. Summerfield, L. , Marselle, M., and Greenall, P. (2008) , Methodologies Employed in the Collection, Retrieval and Storage of Human Factors Information Derived from First Hand Accounts of Survivors of the WTC Disaster of 11 September 2001, *Journal of Applied Fire Science*, Vol 15, Number 4, 253-276.

4 Kuligowski, E. D., Peacock, R. D., Hoskins, B. (2010), *A Review of Building Evacuation Models*, 2nd Edition, NIST, Tech Note 1680.

5 Santos, G. and Aguirre, B. E. (2004), Critical Review of Emergency Evacuation Simulation Models, pp. 27-52 in *Workshop on Building Occupant Movement During Fire Emergencies*, edited by R. D. Peacock and E. D. Kuligowski. Gaithersburg, MD: National Institute of Standards and Technology.

6 Siddiqui, A.A., and Gwynne, S.M.V. (2012), Employing pedestrian observations in engineering analysis, *Safety Science* 50, 478–493, 2012.

7 Gwynne, S. (2000). *The Introduction of Adaptive Social Decision-Making in the Mathematical Modelling of Egress Behaviour*. PhD Thesis, School of Computing & Mathematical Sciences, the University of Greenwich: Greenwich, England.

8 Averill, J. D. 2011, Five Grand Challenges in Pedestrian and Evacuation Dynamics, *Pedestrian Evacuation Dynamics 2010*, pp1-11,Springer Publishing.

9 Kuligowski, E.D. and Gwynne, S.M.V. (2008), The Need for Behavioral Theory in Evacuation Modeling, *Proceedings of the 4th International Conference on Pedestrian and Evacuation Dynamics (PED2008)*, University of Wuppertal, Germany, February 27–29.

10 Bryan, J. L. 2002, Behavioral Response to Fire and Smoke, In P.J. DiNenno & W. D. Walton (Eds.), *The SFPE Handbook of Fire Protection Engineering* (Third ed., pp. 3-315-3-340). Bethesda, MD: Society of Fire Protection Engineers.

11 Latane, B. and Darley, J.M. (1970), *The Unresponsive Bystander: Why doesn't he help?,* New York, NY: Appleton-Century Crofts.

12 Aguirre, B.E. (2005), Emergency Evacuations, Panic, and Social Psychology: Commentary on 'Understanding Mass Panic and Other Collective Responses to Threat and Disaster', *Article #402*. Newark, DE: University of Delaware, Disaster Research Center.

13 Quarantelli, E. L. (1991), *Radiation Disasters: Similarities to and Differences from Other Disasters*, *Preliminary Paper No. 153*, Newark, DE: University of Delaware Disaster Research Center.

14 Okabe, K., and Mikami, S., (1982), A Study on the Socio-Psychological Effect of a False Warning of the Tokai Earthquake in Japan, *A Paper presented at the Tenth World Congress of Sociology*, Mexico City, Mexico, August.

15 Fahy, R.F. and Proulx, G., (1997), Human Behavior in the World Trade Center Evacuation, pp. 713-724 in *Fire Safety Science -- Proceedings of the Fifth International Symposium*, edited by Y. Hasemi. London, England: Interscience Communications Ltd.

16 Mileti, D.S. and Sorensen, J.H. (1990), *Communication of Emergency Public Warnings: A Social Science Perspective and State-of-the-Art Assessment*, Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy.

17 Canter, D., Breaux,J., and Sime.J., (1980), "Domestic, Multiple Occupancy and Hospital Fires." pp. 117-136 in *Fires and Human Behaviour*, edited by David Canter. New York, NY: John Wiley & Sons.

18 Sime, J. D. (1980), The Concept of Panic, In D.Canter (Ed.), *Fires and Human Behaviour* (First ed., pp. 63-81). London: John Wiley and Sons.

19 Bryan, J. L. (1977), *Smoke as a Determinant of Human Behavior in Fire Situations (Project People)* (Rep. No. NBS-GCR-77-94). Washington, DC: National Bureau of Standards.

20 Wood, P. G. (1972), *Fire Research Note 953* Borehamwood, UK: Building Research Establishment.

21 Proulx, G. (2002), Movement of People: The Evacuation Timing, In P.J.DiNenno & W. D. Walton (Eds.), *The SFPE Handbook of Fire Protection Engineering* (Third ed., pp. 3-341-3-366). Bethesda, MD: Society of Fire Protection Engineers.

22 Averill, J.D., Mileti, D.S., Peacock,R.D., Kuligowski,E.D., Groner,N., Proulx,G., Reneke.P.A.,and Nelson, H.E., (2005), *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Occupant Behavior, Egress, and Emergency Communications, Report NCSTAR 1-7*. Gaithersburg, MD: National Institute of Standards and Technology. http://wtc.nist.gov/NISTNCSTAR1-7.pdf

23 Sime, J.D. (1983), Affiliative Behaviour During Escaping To Building Exits, *Journal of Environmental Psychology*, 3, 21-42.

24 Gwynne, S., Galea, E. R., Owen, M., & Lawrence, P. (1999), *Escape as a Social Response*. Report Published by the Society of Fire Protection Engineers.

25 Passini, R.,Proulx, G. (1995), Building Access And Safety For The Visually Impaired Person, Faculte De L'amenagement, University Of Montreal., *Proceeding For The International Conference On Fire Science And Engineering, ASIAFLAM'95,* Eds: Chow, W.K.Et Al, pp139-150, March, ISBN 0951632078.

26 Johnson, N.R., Feinberg, W.E. Johnston, D.M., (1994), Microstructure and Panic: The impact of social bonds on individual action in collective flight from The Beverly Hills Supper Club Fire, pp. 168-189 in *Disaster, Collective Behavior and Social Organization*, edited by R. Dynes and K. Tierney. Newark, NJ: University of Delaware Press.

27 Proulx, G. and Fahy.R.F (1997), Time Delay to Start Evacuation: Review of Five Case Studies, pp. 783-806 in *Fire Safety Science – Proceedings of the Fifth International Symposium*. London, England: Interscience Communications Ltd.

28 Proulx, G. (1995), Evacuation Time and Movement in Apartment Buildings, *Fire Safety Journal* 24:229-246.

29 Galea, E. R. (1997), *Validation of Evacuation Models*, CMS Press Paper No.97/IM/22 ISBN 1899991 22 0.

30 Sawyer, R.K. (2005), *Social Emergence: Societies as Complex Systems*, Cambridge University Press.

31 Korhonen,T., and Hostikka,S. (2009), *Fire Dynamics Simulator with Evacuation: FDS+Evac*, Technical Reference and User's Guide, VTT Technical Research Centre of Finland.

32 Gwynne,S., Galea, E.R., Lawrence, P.J., Owen, M., and Fillippidis, L. (2001), Adaptive Decision-Making in Response to Crowd Formations in buildingEXODUS, *Evacuation from Fires*, Chapter 4, Paul R. Decicco (ed.), Baywood Publishing, New York, NY.

33 Schneider,V. (2001), Application of the individual-based evacuation model ASERI in designing safety concepts, in: *2nd International Symposium on Human Behavior in Fire*, Boston, MA, pp. 41-51.

34 Gwynne, S.M.V. and Kuligowski, E.D. (2009), Simulating a Building as a People Movement System, Journal of Fire Sciences, v27, July, pp343 – 368.

35 Kuligowski, E.D. and Peacock. R.D. (2005), *Review of Building Evacuation Models*. *Report NIST TN 1471*. Gaithersburg, MD: National Institute of Standards and Technology.

36 Gwynne,S., Galea, E.R., Lawrence, P.J., Owen,M., Filippidis,L.(1999), A review of the methodologies used in the computer simulation of evacuation from the built environment, *Building and Environment,* 34, 741-749.

37 Miller, J.H.(2007), *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*, Princeton University Press.

38 Mitchell, M. (2011), *Complexity: A Guided Tour*, OUP Press.

39 Gilbert, N. (2008), *Agent-Based Models*, SAGE Publications.

40 McPhail, C. (1991), *The Myth of the Madding Crowd*, Aldine Transaction, 1991.

41 Railsback, S.F. and Grimm, V.(2011), *Agent-Based and Individual-based Models,* Princeton University Press.

42 Gilbert, N. and Troitzsch, K.G. (2005), *Simulation for the Social Scientist*, Open University.

43 Schelling, T.C. (2006), *Micromotives and Macrobehavior*, Norton and Co.

44 Epstein, J.M. (2007), *Generative Social Science: Studies in Agent-Based Computational Modeling,* Princeton University Press.

45 Gilbert, N. (1998), The Simulation of Social Processes, Edited transcript of a talk given at the SMAGET Conference, Clermont-Ferrand, France.

46 Gilbert, N. and Terna, P. (2000), How to Build and Use Agent-Based Models in Social Science, *Mind and Society*, 1,1, pp57-72.

47 Berry,B.J.L., Kiel, L. D. and Elliott, E. (2002), Adaptive agents, intelligence, and emergent human organization: Capturing complexity through agent-based modeling, *PNAS*, May.

48 Gilbert, N. (2007), Generic Model of Collectivities, *Cybernetics and Systems*, 38:7, 695-706.

49 Johnson, S. (2002), *Emergence*, Penguin

50 Axelrod, R. (1990), *Evolution of Co-operation*, Penguin.

51 Epstein, J.M. and Axtell, R. (1996), *Growing Artificial Societies From the Bottom Up*, MIT Press.

52 Hedstrom, P. (2011), *The Oxford Handbook of Analytical Sociology*, Oxford University Press.

53 Deffuant, G. (Eds.) (2011), *Understanding Complex Systems*, Springer.

54 Wooldridge, M. (2009), *An Introduction To Multi-agent Systems*, Wiley and Sons.

55 Gilbert, G.N. (1996), Holism, Individualism and Emergent Properties, *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, ed: Hesselman, E. et al, 1-12.

56 Ramanath, A.M. and Gilbert, N. (2004), The Design of Participatory Agent-Based Social Simulations, *Journal of Artifical Societies and Social Simulation*, 7,4.

57 Aguirre, B. E., El-Tawil,S., Best,E.,. Gill, K.B., & Fedorov, V.(2011), Contributions of social science to agent-based models of building evacuation, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3, 415-432

58 Drury,J., & Stott, C., (2011), Contextualising the crowd in contemporary social science, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3,275-288.

59 an Zomeren,M., & Spears,R., (2011), The crowd as a psychological cue to in-group support for collective action against collective disadvantage, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3, 325-341.

60 Cole,J., Walters,M., & Lynch,M., (2011), Part of the solution, not the problem: the crowd's role in emergency response, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3, 361-375.

61 Neville,F., & Reicher,S., (2011), The experience of collective participation: shared identity, relatedness and emotionality, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3, 377-396.

62 Köster,G., Seitz,M., Treml,F., Hartmann,D., & Klein,W., (2011), On modelling the influence of group formations in a crowd, *Contemporary Social Science: Journal of the Academy of Social Sciences*, 6:3, 397-414.

63 Gilbert,N. (2002), Varieties of Emergence, *Workshop on Social Agents: Ecology, Exchange and Evolution*.

64 Epstein, J. M. (1999), Agent-Based Computational Models and Generative Social Science, *Complexity,4,5.*

65 Axtell,R., Epstein, J.M. , and Young, P. M. (2000), *Emergence of Classes in a Multi-Agent Bargaining Model*, Center on Social and Economic Dynamics, Working Paper 9.

66 Elsenbroch,C.(2012), Explanation in Agent-Based Modelling: Functions, Causality or Mechanisms?, *Journal of Artificial Societies and Social Simulation*, 15, 3, 1.

67 Blumer, H., (1969), *Symbolic Interactionism: Perspective and Method*. Berkley, CA: University of California Press.

68 http://fseg2.gre.ac.uk/HEED/index.html (18/08/2012)

69 Berger, P. L. and Luckmann,T., (1966), *The Social Construction of Reality: A treatise in the sociology of knowledge*, New York: Anchor Books.

70 DeLanda, M., *Philosophy and Simulation: The Emergence of Synthetic Reason*, ISBN 978-1441170286, Continuum Publishing, 2011.

71 Purser, D.A. (2008), Assessment of Hazards to Occupants from Smoke, Toxic Gases and Heat, In P.J.DiNenno et al (Eds.), *The SFPE Handbook of Fire Protection Engineering*, (Fourth ed., pp. 2-96-2-193). Bethesda, MD: Society of Fire Protection Engineers.

72 Klein, G.(1999), *Sources of Power: How People Make Decisions*, MIT Press.

73 Chomsky, N. and Foucault, M. (2006), *The Chomsky-Foucalt Debate: On Human Nature*, The New Press.

74 Chomsky, N. (2002), *Syntactic Structures*, Mouton de Gruyter, 2nd edition.

75 Lerup, L. (1977), *People in Fires: A Manual for Mapping*, Berkeley, University of California.

76 Keating, J. and Loftus, E.(1984), *Post Fire Interviews: Development and Field Validation of the Behavioral Sequence Interview Technique*, NBSIR 84-477. National Bureau of Standards, U.S.

77 Galea, E.R., Sauter, M., Deere, S.J., Filippidis,L., Investigating the Impact of Culture on Evacuation Behaviour – A Turkish Data-Set, *Proceedings of the Tenth International Symposium on Fire Safety Science*, University of Maryland, 19-24 June 2011, pp. 709-722. ISSN 1817-4299. DOI: 10.3801/IAFFS.FSS.10-709.