Conceptual Framework for Simulating the Pedestrian Evacuation Behavior from Buildings

By

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ABSTRACT

From a social science perspective it is useful to think of the evacuation behavior during emergency, commonly referred to as emergency egress, as having four distinct analytical dimensions: the physical environment from which to evacuate, the hazard forcing the evacuation, the managerial policies and controls deployed at evacuation, and the psychological and social organizational characteristics impacting the persons that participate in the movement. It is much more common in the physics and engineering literature to find direct consideration of the first three dimensions than of the fourth.

This article reports on a conceptual framework for incorporating consideration of the latter dimension into the simulation of the pedestrian evacuation behavior. This framework can be put to great use by architects, engineers and computer scientists alike in determining the outcomes of evacuation processes. Such multi-disciplinary precedent can promote highly beneficial and enduring collaborations between the previous disciplines. The sections that follow describe the conceptual framework and its potential account into simulation software, and draft some conclusions.

INTRODUCTION

From a social science perspective it is useful to think of the evacuation behavior during emergencies, commonly referred to as emergency egress, as having four distinct analytical dimensions: the physical environment from which to evacuate, the hazard forcing the evacuation, the managerial policies and controls deployed at evacuation, and the psychological and social organizational characteristics impacting the persons that participate in the movement. It is much more common in the physics and engineering literature and in simulation models of evacuation (Fraser-Michell, 2001; Helbing, Farkas, and Vicsek, 2000; Fahy, 1999) to find direct consideration of the first three dimensions than of the fourth.

The awareness of the importance of social organization has increased in recent years particularly as a result of studies of panic. The oldest view of panic assumed that people in dire emergencies lost their humanity and became overwhelmed by fear. A second view, sponsored by Quarantelli (1954; 1977) advanced a different conceptualization of panic as a social collective or emergent behavior whereas people attended to their own needs with no consideration for the fate of others. This view was superceded in the 1980s and 1990s by the work of Norris Johnson and other scholars (Johnson, 1987; Johnson, Feinberg, and Johnston, 1994) who pointed out that people in situations of great danger did not panic, and did not abandon their ties to others. Instead, they continued to be social actors embedded in social organizations, and deeply concerned for the fate of others so that they often imperiled their own lives on their behalf.

The social science literature provides an extensive coverage of the impact of psychological and social organizational characteristics on the emergence of consensus in collectivities, albeit not necessarily at evacuation. This body of knowledge can be put to great use by architects, urban planners, engineers and computer scientists alike in determining the outcomes of evacuation processes. Such multi-disciplinary exchange of information can promote highly beneficial and enduring collaborations between previous disciplines. The need for a study of crisis evacuation anchored in social science is particularly keen nowadays as terrorist threats have increased.

This article reports on a conceptual framework from social science for incorporating consideration of the psychological and social organizational characteristics of pedestrians into the simulation of the evacuation behavior. It affords a holistic and consistent means of assessing the impact of these characteristics in spite of their inherent variability and the complexity of their interactions. The variations in pedestrian social organizational characteristics, pedestrian facilities, management mitigation policies and threat characteristics result in a complex web of interactions between these dimensions.

Pedestrian collectivities vary widely in their micro- and macro-structural organization. Micro-structural characteristics include such factors as the social bonds between individual pedestrians. Macro characteristics include the distribution of behavioral factors among individuals in pedestrian collectivities or the distribution of the same across space, in collectivities still. Pedestrian facilities vary in their layout and throughput capacities, in their ease of navigation as facilitated by displays such as exit signs, and in their provision of temporary shelters.

Variations exist as well in the management policies implemented at evacuation and in the characteristics of the threat posed. Mitigation may entail various components that attenuate the impact of the hazard, that enhance hazard awareness and perception by pedestrians through the issuance of warnings, or that guide pedestrian reactions through the deployment of control agents. Threats vary in location and time of onset, magnitude and evolution among other factors.

The sections that follow describe the conceptual framework, its potential account into simulation software and present some conclusions and recommendations. The framework ensures that socially imbedded pedestrians willingly form definitions and responses to hazards or management directives in cooperation with social group members and especially those to whom they hold primary ties.

CONCEPTUAL FRAMEWORK—AN AGGREGATE PERSPECTIVE

Fig. 1 presents an overall schematic of the proposed conceptual framework as inspired by the works of Quarantelli, 1980, on disaster evacuations. The framework uses two distinct domains: that of the inherent global variables, which describe pre-existing information; and that of the local variables, which provide the basis for how an individual or a group reacts to a specific hazard. The global community includes all initial variables of the evacuation, which are not affected by any kind of pedestrian or management behavior once the evacuation starts. This information is to be taken from empirical data gleaned from disaster-related literature, and conceivably emergency management agencies.

The global domain contains two main components, the community and the hazard. The community encompasses the physical building environment, the persons and organizations that evolve within the building, including the building management, and conceivably outside entities such as nearby firefighter stations that may impact the course of events. The hazard component contains the possible hazard agents, such as fire, flood, hostage situation or explosion and the physical effects of these hazards (Quarantelli, 1980). Other characterization parameters specific to hazard agents include onset parameters such as probability of occurrence at given location, magnitude and probability of an evolution history.

The community is characterized by a social climate, inherent social links, and numerous resources. The social climate, according to Quarantelli (1980), consists of the social, psychological, political, economic, legal, or historical factors which can affect the evacuation process. Included in this aspect of the model are the demographics of the evacuees, such as age, gender, and ethnicity. This also accounts for whether or not the evacuees have had past experience with similar hazards. Research suggests that it may be difficult for people to understand the hazard warning when they do not understand much about the specific hazard (Fitzpatrick and Mileti, 1994).

Various social links, or bonds, tie community individuals to each other. Johnson, Feinberg and Johnston, 1994, document primary, secondary or nested secondary social groups. Primary and secondary groups contain members with primary (spousal, friendship, familial) and secondary ties, respectively. Strong bonds relate primary group members whereas secondary groups constitute more loosely knit social organizations, such as those made up of co-workers or fellow travelers in a tour group. Nested secondary groups embed members holding primary ties with members holding secondary ties and vice versa. For instance, a husband and wife pair forms a nested secondary group together with a vacationing tour group.

Included within the global community are the tangible and intangible resources available to organizations and individual or group of evacuees (Quarantelli, 1980, 1984, Perry, 1994). Within the building environment tangible resources may translate for instance into surveillance, detection, mitigation and communications equipment utilized by management, and intangible ones into the evacuation plan, the training of emergency personnel, the communication processes, the available information and the knowledge of how to utilize the tangible resources. This knowledge may reside with persons or organizations.

The local domain concerns itself with the actual onset of a specific hazard, the ensuing actual vulnerability and actual exposure, the actual and perceived risk, and the end behavior. The global domain bears physically, socially and psychologically on individuals or groups, delineating the local variables. Whereas the global variables define how the group of evacuees can potentially react to a crisis, it is the local variables that affect the real-time or actual behavior of the individuals.

Tangible or intangible resources help enhance the community's preparedness and resilience, or its ability to cope with the hazard. It is these available resources that form the basis for the actual vulnerability of the individual or group of evacuees, or the pedestrians' preparedness to deal with a crisis situation as it unfolds. Hence, the actual vulnerability of the evacuee is related closely to the resources that are available through the global domain. The actual exposure of individual or group of evacuees can be interpreted as varying with the distance to the hazard and the protection from the hazard that is afforded by such things as walls, water or other obstructions.

It is the interaction of the actual exposure and the actual vulnerability that forms the actual risk inherent in the crisis situation. This variable is a function of the probability of harm and the magnitude of the damage. The actual risk drives the social and individual processes that define the perceived risk. The evacuation behavior ensues from the perceived risk. Drabek's findings suggest that those with high perceptions of risk, or those who develop high levels of perceived personal risk, tend to evacuate significantly quicker than others (Drabek, 1996). The evacuation behavior reflects the effect of the hazard on the individuals within the community at risk, and is a function of communication, coordination, and decision-making (Quarantelli, 1980).

CONCEPTUAL FRAMEWORK—A DISAGGREGATE PERSPECTIVE

A scheme outlining the relationships between the individual, and the behavior output is presented in Fig. 2. A primary motivator for the entire scope of human behavior is stress level minimization, as informed by the principles of drive reduction theory. In terms of the current application, a model based upon this principle aims to effectively replicate human behavior, with a focus on decision making and motivation.

Many factors in the physical environment (ranging from a pedestrian's proximity to a loved one, to hazard-based endangerment, to adherence to scheduled activity agenda) cause varying levels of stress in each individual. These stress levels are directly responsible for active problem solving behavior, with the immediate behavior directed towards the most intense stressor. If the problem solving is effective, this stressor becomes of less concern, and the process repeats.

Pedestrians afford a degree of knowledge and experience (both pre-assigned and accumulated), that enables them to avoid raising their current stress levels, in addition to just reducing them. As a result, preventive stress level optimization and prescriptive stress level optimization will simultaneously and competitively determine each pedestrian's actions. Prescriptive stress optimization is primarily the motivator behind problem solving behavior, while preventive determines exactly which solution strategy is chosen.

Each pedestrian is initially defined in terms of her physical ability, social bonds, personal space preferences, and assigned agenda. Physical ability is defined here as one's athletic ability, and is informed by the age and gender of the pedestrian. It outputs to the physical senses, defining their level of acuity. Physical ability can only be altered by physical damage sustained, the level of harm, during hazard conditions.

An individual’s personal space size is dynamic, varying primarily with age, gender, immediate environment, and social climate. Hall (1966) called the study of interpersonal distance *proxemics.* From his observations of Americans, Hall concluded that four interpersonal distances were important in our social interactions: intimate, personal, social, and public. Intimate distance ranges from 0 to 1.5 feet. We tend to avoid getting this close to people we are not intimate with, and will try to escape if we do.

Personal distance ranges from about 1.5 feet to around 4 feet. Touch is minimal at this distance (except perhaps when shaking hands). This is the distance used for friendly interactions. Sometimes we allow strangers into the outer limits, the inner limits are reserved strictly for friends. Social distance extends from approximately 4 to 12 feet, and includes the space required for more formal social interactions. Social distance is often experienced in the business environment, for example at a business meeting, or interviewing new applicants for employment. Finally, Public distance is between 12 and 25 feet. After 25 feet, communication is almost non-existent. This distance is utilized for public speaking situations, which is only one way communication to an audience.

It is important to consider that the above distances are only optimal when space is not limited. In crowded areas, personal distance spheres vary in size. For example, in a crowded elevator strangers may be very close, or even touching; this is acceptable for that particular situation but is not acceptable if there is room to move apart. As applied to the simulation, inappropriate sphere occupancy is directly correlated with an increase in stress, prompting corrective behavior.

Social bonds, as a function of their intensity, inform stress levels and guide behaviors that keep loved ones in close proximity and out of harms way. Each pedestrian’s agenda is user-assigned and includes a list of tasks. Each task, besides containing a set of instructions, is characterized by a time budget and a degree of importance. A level of stress ensues from these factors and impacts upon the pedestrian. Behavior always focuses on satisfying the agenda, provided no greater stressor is present. When non-agenda focused behavior does take precedence, behavior choices that are congruent with the agenda are given priority.

An individual interacts with the environment around her through three basic processes: awareness, perception, and reaction. The physical senses inform awareness, which includes the raw, objective data we extract from the environment. This is where inter-pedestrian communication and warning detection enter to be processed. Once aware of a stimulus, a perception, or subjective interpretation, is formed. Perception is influenced by many factors. Firstly, the knowledge and experience of each individual will play a strong role in how an event or stimulus is perceived. Two other important influences on perception are personal space and existing social bonds. Both contribute primarily to the interpretation of extra-pedestrian awareness. Finally, a reaction follows from perception once motivation is introduced. This motivation manifests itself through stress level optimization.

As an emergency situation develops, the model explained above remains valid, though an additional element needs to be considered. An individual’s perceived risk plays an important role in stress level fluctuation and can become the driving force behind behavior in a dangerous environment. Risk is defined as the product of probability of occurrence and magnitude of harm (Harris, 2000). The highest risk occurs when a threat is unavoidable and the consequences are great. The perceived risk of an individual is derived from her personal interpretation of magnitude and probability, as this is what influences decision making (as compared to the actual risk which is calculated objectively). A pedestrian can be at high risk, but with out knowing it she won't consider corrective action. Perceived risk is a dynamic variable that is constantly updated. It is primarily a function of proximity to resources (exits, fire extinguishers, etc.), disaster experience, knowledge of the building layout, group membership, level of harm, and physical ability. Social bonds also play into perceived risk, as a spike in perceived risk can be expected in a child who has lost her parents. Additional perceived stimuli, like communicated messages and warnings, will also affect this measure.

Perceived risk directly outputs to an individual's stress levels, and when it is moderate to high, perceived risk will generally dominate. If risk level reaches a maximum, panicky behavior can ensue. This will result in a skewing of the individual's general perception. External perceived risk (perceiving the risk of a sibling, for example) can have a similar effect on stress levels, and is a function of the same variables, but applied to the target.

The selection of the behavior chosen by the pedestrian is based upon preventive stress level optimization, and taken from a catalogue of possible actions. Inter-pedestrian communication in the forms of milling and keynoting are possible outputs here. As the model is continuously engaged, a chosen behavior will manifest until completion and/or stress levels motivate otherwise. (The reader should note that the disaggregate model presented here applies to both emergency and non-emergency pedestrian behavior.)

FRAMEWORK ACCOUNT WITHIN SIMULATION

Fig. 3 presents a generic means of accounting for the conceptual framework presented above into simulation software. Three sub-models, parameter updating, logistical and operational, interact to output the pedestrian motion parameters under both, emergency and non emergency conditions.

The logistical model takes as input the pedestrian's activity demand and the network representation. It outputs her activity schedule and her route assignment. Each pedestrian possesses an agenda of activities, to conduct through the facility within a limited time budget. The agenda consists of compulsory or mandatory activities and elective ones. A particular activity can only be conducted at one of the multiple fixed areas servicing the activity. Later areas may in turn service multiple activities. The servicing of individual activities may be subjected to equal or differing costs at differing service areas. In addition, a pedestrian typically incurs servicing and waiting costs at service areas.

Based on the layout of the facility and based at times on the directives obtained from control or service agents, each pedestrian schedules a selected set of activities through the network. The activity schedule derived must satisfy all priority constraints in the execution order of activities. For instance, an airline traveler may need to purchase her ticket or check her luggage prior to being screened. Further, activity selection and scheduling is intent on minimizing the total pedestrian costs incurred during activity conduct. Total pedestrian costs encompass the running costs associated with locomotion, the servicing and waiting costs incurred at service areas, and numerous cost penalties associated with violating mandatory activities or violating a time budget. In the absence of the awareness of hazards by the pedestrian, this module executes her initial activity agenda. Otherwise, it acts upon an updated activity agenda as explained later.

Having selected a schedule of activity, the pedestrian then chooses a route to and from activities according to their scheduled execution order. In the absence of congestion, the route choices of individual pedestrians do not impact those of other pedestrians. In the event of congestion, however, travel time increases monotonically with increases in flow and pedestrian route choices become interrelated. The marginal running costs induced by individual pedestrians are incurred by all.

The operational model determines the immediate pedestrian's motions given her route assignment, and the constraints or challenges posed by the physical environment and by other pedestrians in her immediate vicinity. To this end, the operational model optimizes her motion parameters by maximizing activity and route abidance while avoiding other pedestrians and obstacles. Motion parameters may include for instance pedestrian heading and speed.

Occasionally, assuming hazard onset, model parameters, including the network, the activity agenda and conceivably the management plan, require updating. It is the parameter updating model that undertakes the task of updating these input parameters. It bases its activity updating function on the conceptual framework earlier advanced. In essence, the stress minimization behavior exhibited by the pedestrian translates into an updated activity agenda.

It is the parameter updating model that interfaces traditional models of simulation of the evacuation behavior and the proposed conceptual framework. Hence, it constitutes the main object of the discussions within the following sections. (Needless mention that the proposed framework, notwithstanding minor modifications, can account for the motivational pedestrian behavior within the logistical and operational models as well; thereby enhancing the consistency of her behavior throughout the simulation.)

Parameter Updating Model

Each time step, this module duplicates the processes undergone by management, active hazards, pedestrians and their interactions to update, where needed, the model simulation parameters including: the active walking environment, the managerial plans and the pedestrians' activity agendas. Updates may be needed 1) following the onset of hazards or 2) following the onset of mitigation efforts by management until recovery. Update processes undergone by management include surveillance, detection, mitigation, monitoring and recovery. Those undergone by pedestrians include decision making (awareness, perception and reaction) communication and coordination. The hazard processes anticipated address the hazard onset and evolution until its removal or extinction. (Refer to Fig. 4 for a detailed display of the simulated processes.)

Updates in pedestrian activity agenda ensue from the undertaken pedestrian processes. The chief pedestrian reaction of interest consists in the changes to the activity agenda. Updates in the network environment may follow either from management or hazard processes. Management may reduce the use of portions of the walkable network as a mitigation strategy. Alternately, the hazard through its presence and evolution may render portions of the walkable network unusable or may threaten building structural stability. (Depending on network representation, updates to the physical environment translate into the unavailability of space or into missing nodes and links and possibly into the disconnection of network portions.) Only management processes may directly result in management plan updates.

The various management, pedestrian and hazard processes interact as further indicated in Fig. 4. Hazard and management processes may engender cues, emissions or warnings which impact pedestrian awareness, perception or reaction and hence pedestrian processes. Management processes such as mitigation may hinder the hazard evolution process. Alternately, pedestrian reaction may include a mitigation component which also tackles the hazard evolution. Finally, management may monitor pedestrian reactions to reinforce or counter them within mitigation. The paragraphs that follow describe the inner works of the anticipated model.

Pedestrian-Based Update Processes
Each time step, this module attempts to predict the socio-psychological and socio-organizational processes undertaken by pedestrians including the awareness of hazards or management directives and the emergent communications, perception and reactions. Following Sime, 1983, the module maintains group ties in collective flight. Socially imbedded pedestrians form hazard or directive definitions and responses in cooperation with social group members and especially those to whom they hold primary ties. Unregulated competition in collective flight occurs rarely (Quarantelli and Dynes, 1972, and Keating, 1982) and under the most severe of threats.

Following Fig. 2, the simulation endows pedestrians with vision, and conceivably other sensorial capabilities. Pedestrian awareness may arise from direct eye witness, symbolic interactions such as keynotes, or issuance of warnings and evacuation path directives by management. The simulated pedestrians who directly witness the hazard onset or evolution can be determined based on gaze directions, locations relative to each other, to obstacles and to hazards, and based on physical and visual attributes such as height, visual acuity, etc. Awareness may then propagate using keynoting and other symbolic interactions, potential disaggregate model outputs that ensue from stress minimization. Pedestrian threat perceptions could be simulated as erroneous deviations around a true mean. They could be assumed independently and identically Gumbel distributed thereby validating the use of the multivariate logit model and allowing for the ease of calibration. (Needless mention that the Gumbel distribution differs only slightly from the true Gaussian distribution of errors.)

In forming a reaction strategy, individuals seek to maintain the togetherness and the integrity of their group members. To this end, they 1) select the action choices that minimize the perceived riks of group members from the threat and 2) resolve individual differences in reaction choices within a group through symbolic interactions. Fig. 2 allows for consideration of social links in the computation of the stress level experienced by the pedestrian. They inform her perception of risk; thus interpreted in terms of the social setting, the presence of children and elders, etc.

Other factors impacting on her risk include her exposure to the hazard or her level of harm, as measured by the proximity of the hazard and the hazard severity, and her vulnerability that is not shaped by her social setting such as the safety of the present location as measured by the proximity of escape routes (Drabek, 1996, Sorensen, 1991; Ikle, Quarantelli, Rayner, Withey, 1957). Different vulnerability functions may apply to pedestrians with different threat acceptance levels. The pre-cited location variables, proximities to the hazard and escape routes, facilitate the interface with the logistical model.

Drabek, 1996, describes the sequence of behavior that culminates in the evacuation of tourists and other transients from disaster areas, albeit not building. This work further confirms that the transients responded as groups, experiencing dissention and discussing decisions. The quasi totality was involved in debates, with over one-third indicated extensive discussions. Others reported minimal discussion before reaching a decision. In confirmation of the adequacy of the above cited vulnerability and exposure variables, decision topics catalogued included severity of threat, safety of location, where to go, when to go, potential traffic congestion, or other. The majority of respondents discussed multiple topics. The differences in views reflected variations in perceptions of risks among group members. Groups with children responded to warnings more quickly and more protectively.

Following warning dissemination, Drabek, 1996, catalogued the five decisions made by transients. They encompass the decisions to do nothing, to await more information, to confirm the warning, to leave immediately, or to do otherwise. Following Drabek, 1996, pedestrian reactions within the simulation model may sway the previous list of decisions short of last. Within the building environment, each previous decision directly translates into an updated activity agenda. To do nothing is tantamount to retaining the current activity agenda. To await more information is tantamount to pausing and putting on hold the current agenda. To confirm warning is tantamount to including one additional mandatory and high priority activity in the current agenda, information gathering. This activity is typically performed at the information desk. To leave immediately is tantamount to dropping the current agenda in favor of the sole exiting activity.

Drabek, 1996, further catalogues the features and properties whereby disasters, herein hazards, differ. They include frequency, predictability, controllability, cause, speed of onset, length and uncertainty of forewarning, duration, magnitude, uncertainty and scope of impact, destructive potential, and accessibility of escape route. Depending on social setting or phase in the hazard life cycle different features or properties of disasters matter. Relevant features during the response phase may not be so relevant in recovery. Besides, different socio-environmental settings may result in different perceptions of hazard features. As earlier stated, representative hazard features within the simulation model could convey the threat severity, as a surrogate for pedestrian exposure. Later feature encompasses the hazard destructive potential, the accessibility of escape routes, the controllability, the magnitude and the scope of impact. In addition, the hazard duration should also be considered.

Hazard-Based Update Processes

This model component simulates the onset and the evolution of hazards until their removal or extinction. Past behavioral studies (Drabek, 1996) have revealed the importance to the evacuation behavior of the accessibility of escape routes, as well as the proximity and severity of the threat posed by the hazard. Further, awareness of hazard by pedestrians through eye witnessing or even keynoting much depends on hazard location over time relative to pedestrians. Yet, most pedestrian evacuation simulation models continue to ignore, and do not require as input, the characteristics of the hazard that induces the evacuation given their lack of pedestrian behavior consideration. Hazard attributes specified by the user include the time and location of onset and the shape and the dimensions of the impacted or influence area at onset, and the destructive potential at onset still. To model the hazard evolution, a prescribed hazard trajectory and hazard dimensions over time can be input as well as the time of hazard removal. Alternately, explicit models may describe or anticipate the hazard evolution given the physical building environment, the management mitigation plans and even the pedestrian resources.

Management-Based Update Processes

This model component enables user enactment of the mitigation plans derived by management. These plans may include 1) the issuance of warnings, 2) that of activity or route directives to parts or to the totality of the pedestrians at risk, 3) the deployment of trained control agents to enforce the warnings and directives or 4) the closure of sections of the physical environment. Warnings are characterized by six (6) key attributes: clarity specificity, consistency, source, number, and content (Drabek, 1996). This model component may anticipate the plans enacted by management given hazard, surveillance, detection and monitoring system characteristics, a plan catalog and managerial constraints. Seven (7) constraints guide managerial executive behavior when disaster strikes: organizational mission managerial risk perception, intra-organizational factors, number of levels of supervision or vertical differentiation, number of professional organizations in which an executive holds membership, extent of disaster planning, and official message source (Drabek, 1996). Assuming data availability from surveys or real evacuation histories, a multiple attribute decision making analysis could establish a relationship between average behavior and pre-cited attributes.

CONCLUSIONS

Because different communities differ in their vulnerability and exposure to hazards and because it is the interaction of exposure and vulnerability that forms the actual risk inherent in the crisis situation, the explicit incorporation of these variables becomes critical to the simulation of the evacuation behavior. Exposure must be specified beyond mere presence including the manner in which it is manifest. Resources must be specified whether tangible or intangible and whether residing with organizations, such as management, or with individuals or groups.

The study of building evacuation in physics and engineering (Fraser-Michell, 2001; Helbing, Farkas, and Vicsek, 2000; Fahy, 1999) has consistently ignored the managerial and human resources including mitigation and social processes and aspects of the hazard exposure that bear on the movement. Direct consequences of this oversight include the underestimation of the delays associated with the emergence of the evacuation behavior and with the propagation of the awareness of a hazard. The Beverly Hills Club Fire (Johnson, Feinberg and Johnston, 1994) illustrates the importance of awareness through formal communication means or through keynoting to the outcome of evacuation processes. A study of the 1993 evacuation of the World Trade Center illustrates the additive effect of group size and social links on the timing of evacuation.

Typically, in forming a reaction strategy to a hazard, individuals seek to maintain the togetherness and the integrity of their group members. To this end, they 1) select the action choices that minimize the perceived risks from the hazard to group members and they 2) resolve individual differences in reaction choices within a group through interactions. Only under the most severe of threats do individuals abandon their social ties. Typically as well, individuals within a community do not become instantaneously aware of a hazard.

This article proposes conceptual frameworks for incorporating considerations of both resources, whether managerial or human, and exposure in the simulation of pedestrian behavior. The proposed disaggregate framework seamlessly interfaces with existing models of pedestrian dynamics.

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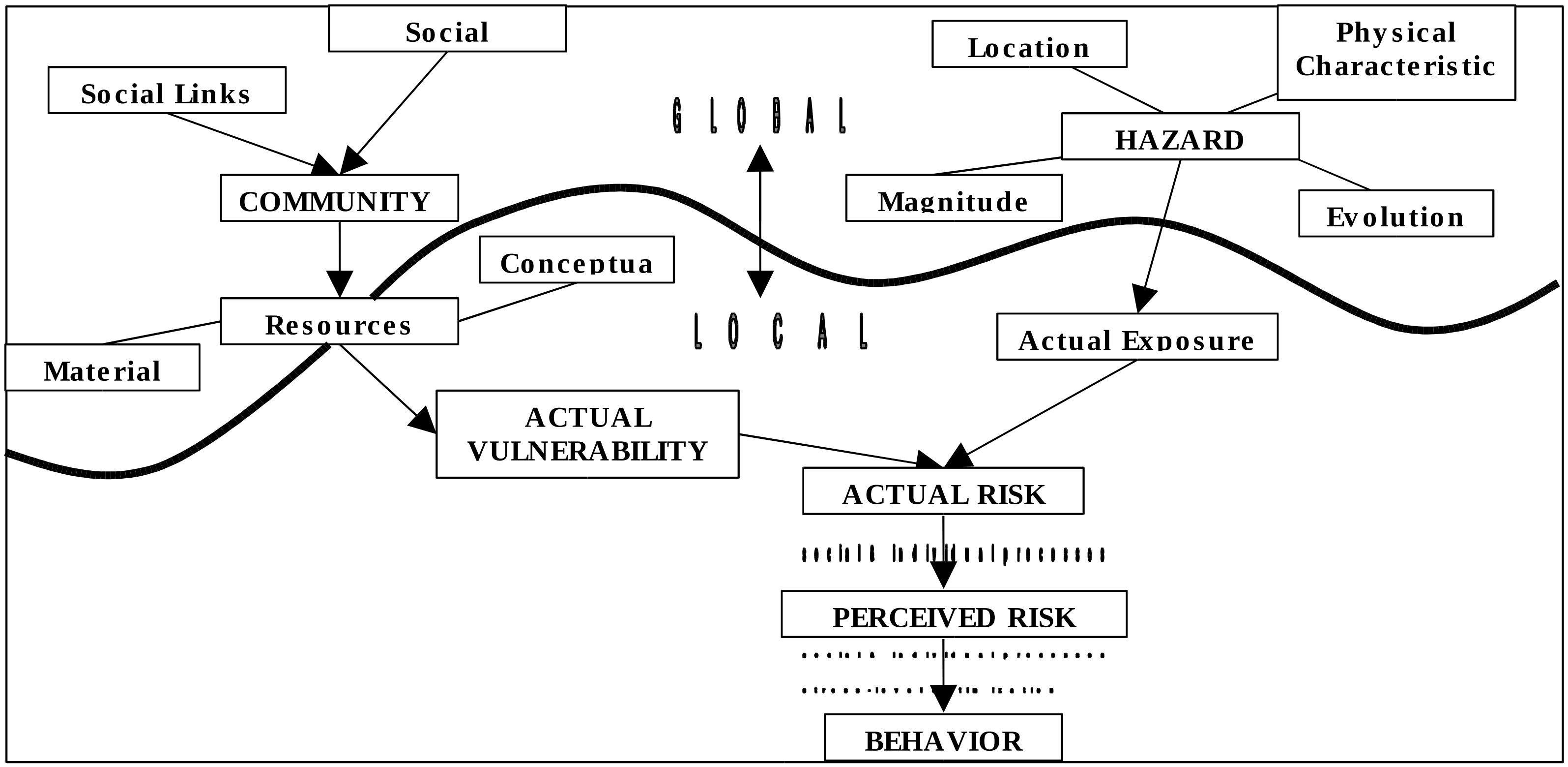
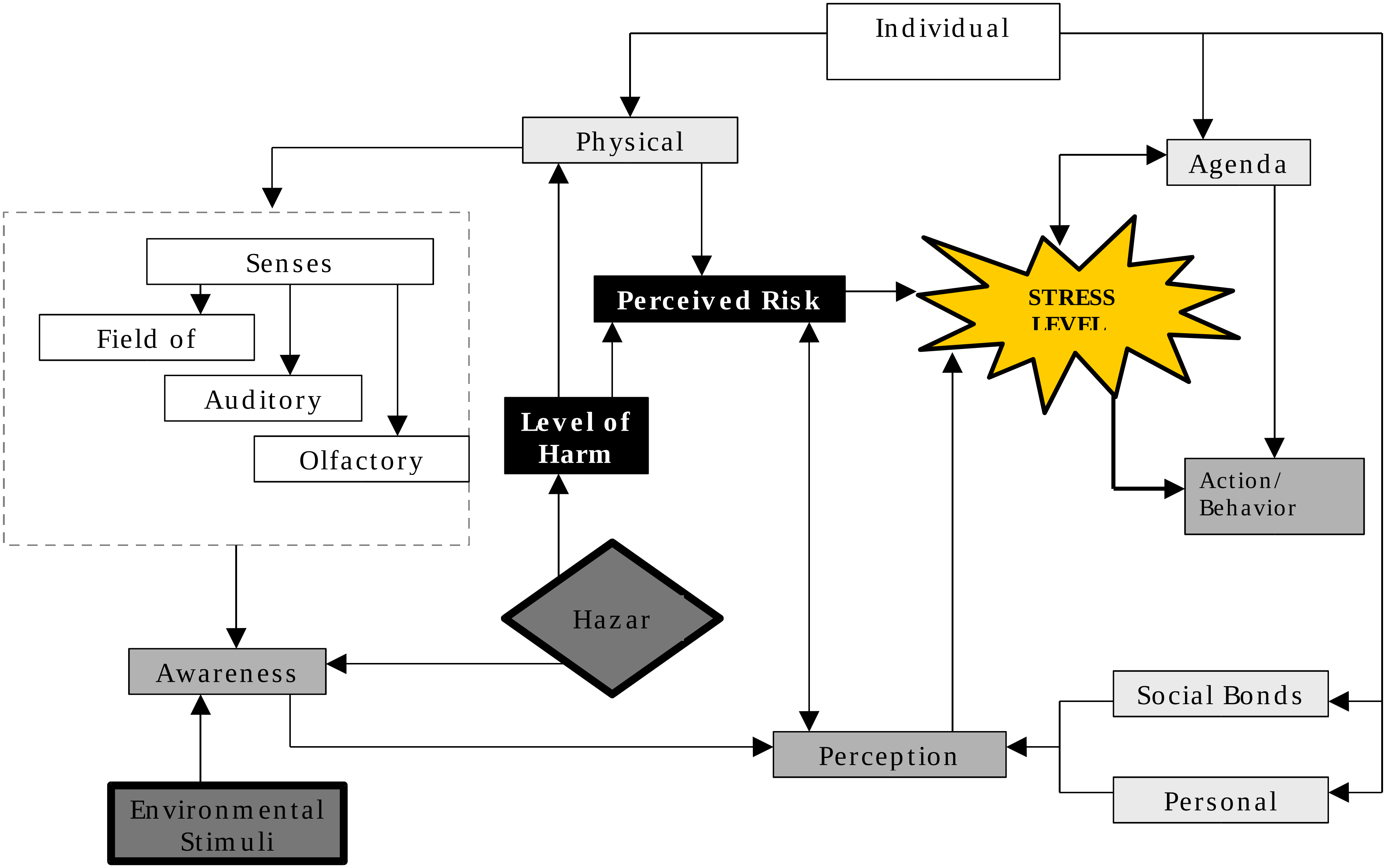


FIGURE 1 Conceptual evacuation framework- an aggregate perspective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Personal
Environmental
Stimuli

FIGURE 2 Conceptual evacuation framework- a disaggregate perspective

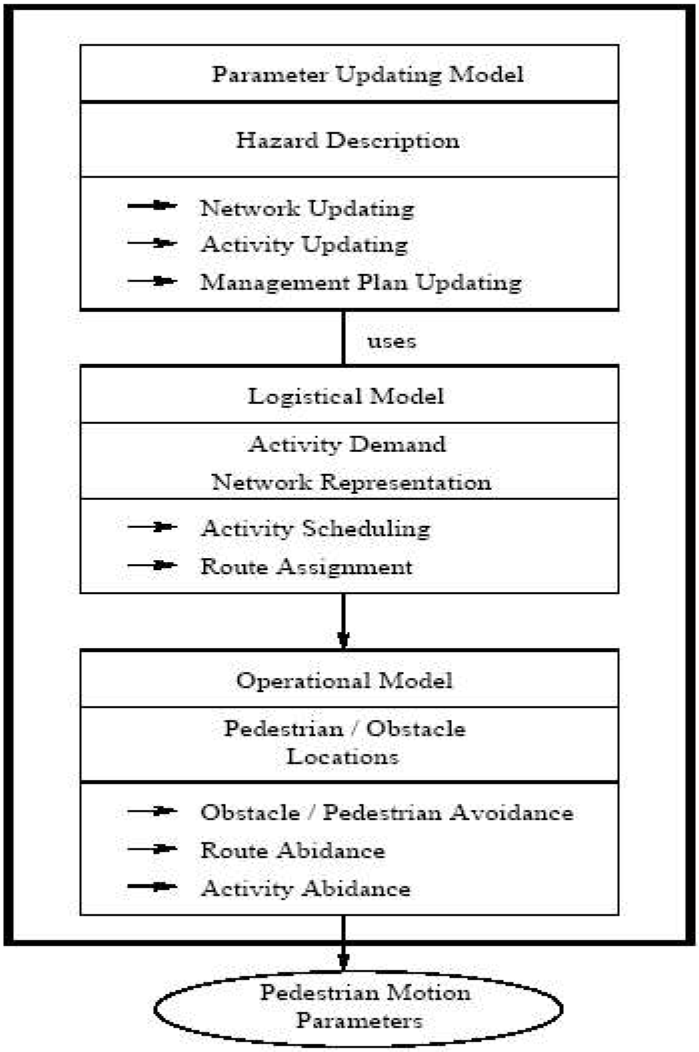

FIGURE 3 Simulation model schematic

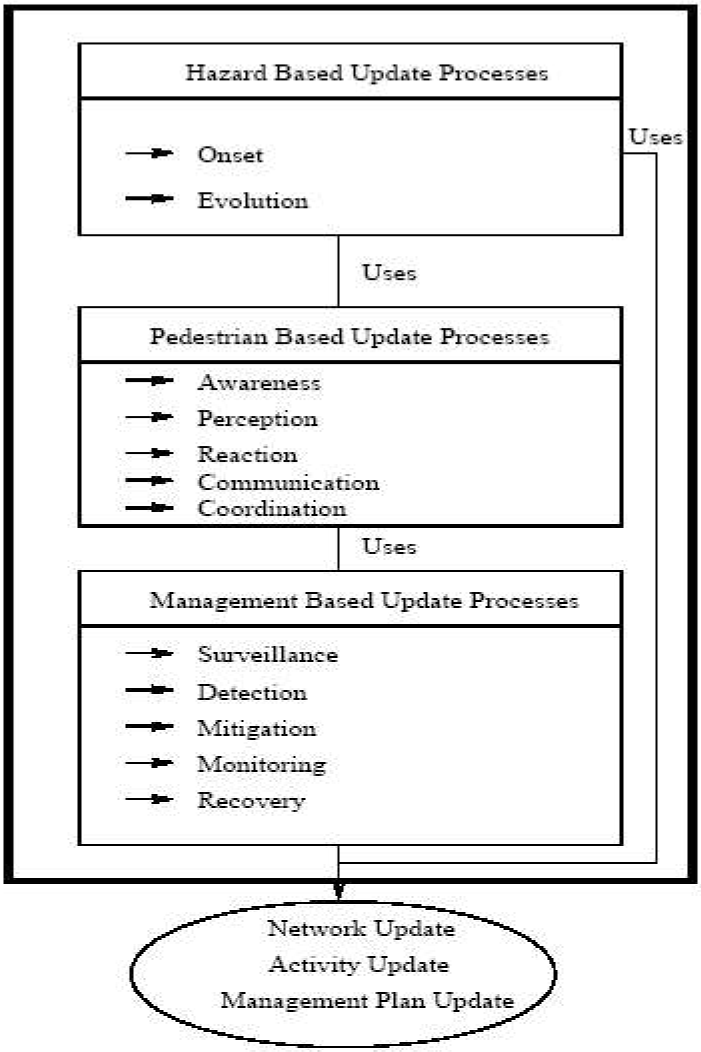

FIGURE 4 Updating model schematic