Technical Note 1680

A Review of Building Evacuation Models, 2nd Edition

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NIST National Institute of Standards and Technology • U.S. Department of Commerce

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Abstract:
Evacuation calculations are increasingly becoming a part of performance-based analyses to assess the level of life safety provided in buildings. In some cases, engineers are using back-of-the-envelope (hand) calculations to assess life safety, and in others, computational evacuation models are being used. This paper presents a review of 26 current computer evacuation models, and is an updated version of a previous review published in 2005. Models are categorized by their availability, overarching method of simulating occupants, purpose, type of grid/structure, perspective of the occupants, perspective of the building, internal algorithms for simulating occupant behavior and movement, the incorporate of fire effects, the use of computer-aided design drawings, visualization methods, and validation techniques. Models are also categorized based upon whether they simulate special features of an evacuation, including counterflow, exit blockages, fire conditions that affect behavior, incapacitation of the occupants due to toxic smoke products, group behavior, disabled or slower-moving occupant effects, pre-evacuation delays, elevator usage, and occupant route choice.

Keywords: evacuation, evacuation models, building fire, performance-based analysis, egress, simulation

1 Introduction

Evacuation calculations are increasingly becoming a part of performance-based analyses to assess the level of life safety provided in buildings [1]. In some cases, engineers are using back-of-the-envelope (hand) calculations to assess life safety, and in others, computational evacuation models are being used. Hand calculations usually follow the equations given in the Society of Fire Protection Engineers (SFPE) Handbook [2] to calculate mass flow evacuation from any location within the building. The occupants are assumed to be standing at the doorway to the egress component on each floor as soon as the evacuation begins. The calculation focuses mainly on points of constriction throughout the building (commonly the door to the outside, transitions between egress components, or where different paths merge together) and calculates the time for the occupants to move past these points and to the outside. These calculations treat the occupants as particles that follow known rules. Aside from density, interactions with other individuals, the building conditions (including fire effects), and the decision-making processes of the individuals are ignored.

To achieve a more realistic evacuation calculation, or a more efficient solution, engineers have been looking to evacuation computer models to help assess key aspects of a building's life safety attributes. Currently, there are a number of evacuation models to choose from, each with unique characteristics and specialties. These models can range from an efficient use of the hand calculations (thus having the same limitations as the hand calculations) to models that have complex equations and occupants with decision-making capabilities. The purpose of this paper is to provide a comprehensive model review of 26 evacuation models for current and potential model users. This information can help guide users in selecting the model or models appropriate for their design.

This review categorizes the models initially by their availability; i.e. whether they are available to the public, via a consultancy basis, or not yet released. Next, information is provided for many features of each model, such as the modeling method, purpose, model structure and perspective, methods for simulating movement and behavior, output, use of fire data, use of visualization and CAD drawings. Finally, special features of the model such as counterflow, blocked exits, fire conditions that affect behavior, toxicity effects, group designations, occupants with disabilities, occupant delays, elevator use, and route choice are included.

Four evacuation model reviews are available which were significant in the terminology, organization, and data gathering found in this report. The most substantial review to date was performed by Gwynne et al. [3] at the University of Greenwich in 1999, which influenced the model review featured in this paper. The report offers a review of 16 evacuation models and is referenced throughout this section. Second, Combustion Science and Engineering released an article on a review of fire and evacuation models, as well as developed a website where this information is available to the public [4,5]. Also, a review was performed by Watts [6] which introduced early network algorithm models, queuing models, and "simulation" models and provided examples of each type. Lastly, Friedman [7] in 1992 also reviewed egress models, much in the same fashion as was performed by Gwynne et al.

In addition to the previously mentioned model reviews, there is a need for an updated, unbiased, and more detailed review to aid evacuation model users in choosing the appropriate model for their particular application. The previous four reviews listed were written before some of the newer models were developed, showing a need for a more updated review. Also, the previous model reviews could be expanded to provide additional detailed information for each model. This led to NIST developing a model review in 2005 [8]. The review presented here is an updated version of the previous NIST review and includes models that were not in existence when the first review was written as well as updates provided by the model developers for models in the 2005 review. For models that have not been updated in the period between the reviews, the reader is referred to the original review.

2 Features of Egress Models

This review covers a total of 26 computer models that focus on simulating building evacuations. Many of the models reviewed can also simulate evacuation from other types of structures; however, evacuation from buildings is the main focus of this review. The models are organized in the review by their method of availability: available to the public, on a consultancy basis, and not yet released. Those models that are no longer in use are not included in this review. Additionally, models that have not had any peer-reviewed literature published regarding their use or development since 2000 are not included in this review. Information on these models can be found in the previous edition of the review [8]. A list of the models featured in this review is provided here:

- Models available to the public: EVACNET4 [9, 10], WAYOUT [11], STEPS [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23], PedGo [24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41], PEDROUTE [42, 43, 44, 45, 46, 47, 48], Simulex [49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62], GridFlow [63], ASERI [64, 65, 66, 67, 68, 69, 70, 71, 72, 73], FDS+Evac [74, 75, 76, 77, 78, 79, 80, 81, 82, 83], Pathfinder 2009 [84, 85], SimWalk [86], PEDFLOW [87], buildingEXODUS [3, 88, 89, 90], Legion [91, 92, 93, 94, 95], SpaceSensor [96, 97, 98, 99, 100, 101, 102], Evacuation Planning Tool (EPT) [103], and MassMotion [104, 105].

- Models available on a consultancy basis: PathFinder [106], Myriad II [107, 108, 109], ALLSAFE [110, 111, 112], CRISP [113, 114, 115, 116], EGRESS [117, 118, 119], and SGEM [120, 121, 122, 123].

- Models not yet released: EXIT89 [124, 125, 126, 127, 128, 129, 130], MASSEgress [131, 132, 133, 134, 135], and EvacuatioNZ [136, 137, 138, 139, 140, 141, 142].

Each model is reviewed by providing information on a series of evacuation modeling categories. Table 1 of this report provides the main feature categorization and Table 2 provides the special feature categorization of the 26 evacuation models. The main features describe the model's availability status, purpose (as it pertains to modeling certain building types), validation strategies, and internal modeling techniques of which the user should be aware before choosing the model for a project. Internal modeling techniques include the method of moving occupants, the method of simulating occupant behavior, the incorporation of fire effects, and the method of structuring the building within the model. Section 2.1 of this document summarizes the main features that are used to categorize each of the models in Table 1.

Table 2 provides a categorization of the evacuation models via their special features. Special features are specific aspects of a building evacuation that the user may be interested in simulating for certain scenarios. The special features identify certain capabilities of the model, including the ability to simulate counterflow, exit blockages, fire conditions that affect behavior, incapacitation of the occupants due to toxic products in the smoke, groups, disabled or slower-moving occupant effects, pre-evacuation delays, elevator usage, and occupant route choice. Section 2.2 of this document summarizes the special features that will be used to categorize each of the models in Table 2.

2.1 Main Features

The models included in this review are categorized by main features. These features include the following:

- Model availability
- Modeling method
- Model purpose
- Type of grid/structure of the model
- Model view of the occupants
- Occupants' view of the building
- Behavior of the occupants
- Movement of the occupants
- Incorporation of fire effects
- The use of computer-aided design (CAD) drawings
- Visualization methods
- Validation methods

Each feature is described in more detail in the sections here, after which, all models included in this review are categorized by these features in Table 1.

2.1.1 Availability

While all of the models included in this review have appeared in peer-reviewed publications, there are differences in how these models are made available to the public. The first group is models that the users can use on their own computers. In some instances, these models are available for free and, in other cases, the user has to pay a fee to gain access to the model and then install it on his/her computer. The second group is models that the development company will use on a consultancy basis. In this group, the models are used by the consultancy company and only the results are given to the user. The third group is models that have not yet been released to the public. In Table 1, models that are available to the public for free or a fee are labeled with a "Y," models that are available only through the development company (who uses the model for the client on a consultancy basis) are labeled with a "N1," and models that have not been released for use in a commercial manner are labeled with a "N2."

2.1.2 Modeling Method

In previous reviews, evacuation models have been categorized using a primary category labeled modeling method [3]. This category describes the method of modeling sophistication that each model uses to calculate evacuation times for buildings. Under the modeling method category, models are assigned one of the following three labels:

- *Behavioral models* (B): those models that incorporate occupants performing actions, in addition to movement toward a specified goal (exit). These models can also incorporate decision-making by occupants and/or actions that are performed due to conditions in the building. For those models that have risk assessment capabilities, a label of (B-RA) is given in Table 1.
- *Movement models* (M): those models that move occupants from one point in the building to another (usually the exit or a position of safety) without accounting for human behavior. These models are useful in showing congestion areas, queuing, or bottlenecks within the simulated building. For those models that are specifically optimization models (models that aim to optimize time in an evacuation), a label of (M-O) is given in Table 1.
- *Partial behavior models* (PB): those models that primarily calculate occupant movement, but begin to simulate behaviors. Possible behaviors could be implicitly represented by pre-evacuation time distributions among the occupants, unique occupant characteristics, overtaking behavior, and the introduction of smoke or smoke effects to the occupant. These models, however, do not simulate behavioral actions and decision-making explicitly.

2.1.3 Purpose

This subcategory describes the use of the model as it pertains to certain building types as determined by the model developers. Some of the models in this review focus on a specific type of building and others can be used for a wide range of building types. The main purpose in using this as a category is to understand whether the model is intended to simulate the user's chosen building design.

The current model categories for purpose, as labeled in Table 1, involve models that can simulate any type of building (1), models that specialize in residences (2), models that specialize in public transport stations (3), models that are best suited for simulating low-rise buildings (under 15 stories) (4), and models that only simulate 1-route/exit of the building (5).

2.1.4 Grid/Structure

The subcategory of grid/structure is used to assess the method of occupant movement throughout the building. A fine network (F) model divides a floor plan into a number of small grid cells that the occupants move to and from. In a fine network, the grid cells commonly allow for only one occupant at a time, which means that they frequently measure 0.5 m by 0.5 m in size (i.e., the space required by an individual). The coarse network (C) models divide the floor plan into rooms, corridors, stair sections, etc. and the occupants move from one room/building section to another. Multiple occupants can occupy the space at a given time. A continuous (Co.) network model applies a 2-D (continuous) plane to the floor plans of the structure, allowing the occupants to walk from one point in space to another throughout the building. The occupants are not tied to a specific cell, but there are often rules that limit the minimum distance between occupants. Fine and continuous networks can have the ability to simulate the presence of obstacles and barriers in building spaces that influence individual path route choice, whereas the coarse networks "move" occupants only from one portion of a building to another. For a blockage to be included in a coarse network, the entire component has to be excluded from the egress path.

2.1.5 Perspective of the Model/Occupant

The perspective subcategory explains 1) how the model views the occupants and 2) how the occupants view the building.

1) There are two ways that a model can view the occupant; globally (G) and individually (I). An individual perspective of the model is where the model tracks the movement of individuals throughout the simulation and can give information about those individuals (ex. their positions at points in time throughout the evacuation). When the model has a global view of the occupants, the model sees its occupants as a homogeneous group of people. The model might be capable of determining density and average speed at a given location and time, but it is not possible to track individuals as they move through the different egress components. It is clear to see that an individual perspective of the occupants is more detailed since the location of each individual is known at all times, but it depends on the purpose of the simulation as to which alternative is best. If the user is not interested in knowing the position of each occupant throughout the simulation or assigning individual characteristics to the population, and is only interested in locating congestion points and knowing total evacuation time, then a global view is sufficient.

2) The occupant can view the building in either a global (G) or individual (I) way. An occupant's individual view of the building is one where the occupant is not all knowing of the building's exit paths and decides his/her route based on user-defined criteria (e.g., all occupants might know the main entrance at the start of the evacuation, but only some would be aware of the other exits), information from the floor, personal experience, and in some models, the information from the occupants around him/her. A global perspective of the occupants is one where the occupants automatically know their best (e.g., fastest, shortest, etc.) exit path and seem to have an "all knowing" view of the building. The individual approach is more computationally intensive, but it depends on the question that the user is trying to determine as to which choice is best. The global approach is best suited for buildings where all occupants are highly familiar with, and regularly use, all of the different egress paths. Also, if the user is most interested in knowing what the optimum solution would be, then the global perspective is the more appropriate choice.

2.1.6 Behavior

The behavior of the occupants is represented in many different ways by the evacuation models in this review. The labels associated with this subcategory are the following:

- *No behavior* (N) denotes that only the movement aspect of the evacuation is simulated.

- *Implicit behavior* [3] (I) represents those models that attempt to simulate behavior implicitly by assigning certain response delays or occupant characteristics that affect movement throughout the evacuation.

- *Conditional (or rule)* (C) behavior reflects models that assign individual actions to a person or group of occupants based on local conditions, e.g., structural or environmental conditions of the evacuation (as “if, then” statements or rules).

- *Artificial Intelligence* (AI) resembles the models that attempt to simulate human intelligence throughout the evacuation.

- *Probabilistic* (P) represents that many of the rules or conditional-based models are stochastic, allowing for the variations in outcome by repeating certain simulations.

Some models have the capability of assigning probabilities of performing certain behaviors to specific occupant groups. Many of the partial behavioral models allow for a probabilistic distribution (P) of the pre-evacuation times, travel speeds, and/or smoke susceptibility.

2.1.7 Movement

The movement subcategory refers to how the models move occupants throughout the building based on the underlying algorithm. Some models can allow the user to specify other methods. For most models, occupants are usually assigned a specific unimpeded (low density) velocity by the user or modeling program. The greater differences in the models occur when the occupants become closer in a high density situation, resulting in queuing and congestion within the building. The different ways that models represent occupant movement and restricted flow throughout the building are listed here:

- *Density correlation* (D): The model assigns a speed and flow to individuals or populations based on the density of the space. When calculating movement dependent on the density of the space, three sources of occupant movement data are typically used in evacuation models, e.g., Fruin [143], Pauls [144, 145], and Predtechenskii and Milinskii [146]. All three sources were collected more than 30 years ago. Fruin's data was collected from non-emergency movement in the United States, Paul's data was collected from evacuation drills in Canada, and Predtechenskii and Milinskii's data was collected from normal use in the Soviet Union.

- *User's choice* (UC): The user assigns speed, flow, and density values to certain spaces of the building.

- *Inter-person distance* (ID): Each individual is surrounded by a 360° "bubble" that requires them to have a certain minimum distance from other occupants, obstacles, and components of the building (walls, corners, handrails, etc.).

- *Potential* (P): Each grid cell in the space is given a certain number value, or potential, from a particular point in the building that will move occupants throughout the space in a certain direction. Occupants follow a potential map and attempt to lower their potential with every step or grid cell to which they travel. The potential of the route can be altered by such variables as patience of the occupant, attractiveness of the exit, familiarity of the occupant with the building, etc. (which are typically specified by the user).

- *Emptiness of next grid cell* (E): In some models, the occupant will not move into a grid cell that is already occupied by another occupant. Therefore, the occupant will wait until the next cell is empty, and if more than one occupant is waiting for the same cell, the model will resolve any conflicts that arise when deciding which occupant moves first.

- *Conditional* (C): With conditional models, movement throughout the building is dependent upon the conditions of the environment, the structure, the other evacuees, and/or fire situation. For this designation only, not much emphasis is placed on congestion inside the space.

- *Acquiring knowledge* (Ac_K): Movement is based solely on the amount of knowledge acquired throughout the evacuation. For this model, there is no real movement algorithm because evacuation time is not calculated; only areas of congestion, bottlenecks, etc.

- *Unimpeded flow* (Un_F): For this model, only the unimpeded movement of the occupants is calculated. From the calculated evacuation time, delays and improvement times are added or subtracted to produce a final evacuation time result.

- *Cellular automata* (CA): The occupants in this model move from cell/grid space to another cell by the simulated throw of a weighted die [5].

Which type of movement model is selected should be based on what the user is interested in determining. Most of the methods are related to grid structure and the perspective of the occupants. They take into account the presence of others, but the level of detail can vary.

2.1.8 Fire Data

The fire data subcategory explains whether the model allows the user to incorporate the effects of fire into the evacuation simulation. However, the models incorporate fire data in a variety of ways and it is important for the user to understand the complexity of the coupling. The model can incorporate fire data in the following ways: Importing fire data/results from another model (Y1), allowing the user to input specific fire data at certain times throughout evacuation (Y2), or the model may have its own fire model that can be run simultaneously with the evacuation model, however, the evacuation model can also be run in “drill” mode (Y3). If the model cannot incorporate fire data, it simply runs all simulations in “drill” or non-fire mode (N). “Drill” mode is the equivalent of a fire drill taking place in a building, without the presence of a fire. The user needs to understand the limitations of scenarios that the model is designed for. Aside from how the fire effects are brought into the model, the more important consideration is how the model then applies that data to the simulations.

The purpose for evacuation models to include such data is to assess the safety of the occupants, who travel through degraded conditions and how it can alter their behavior. Purser has developed a model to calculate a fractional incapacitating dose for individuals exposed to CO, HCN, CO_2, and reduced O_2 [147, 148]. Many models that incorporate a fire’s toxic products throughout the building spaces use Purser’s model to calculate time to incapacitation of the individual occupants. Purser also developed mechanisms for models to calculate certain effects due to elevated temperatures and irritant gases.

Some models use data collected by Jin [149] on the physical and physiological effects of fire smoke on evacuees. Jin performed experiments with members of his staff, undergraduates, and housewives subjected to smoke consisting of certain levels of density and irritation. He tested visibility and walking speed through irritant smoke in 1985 [149] and correct answer rate and emotional stability through heated, thick, irritant smoke-filled corridors in the late 1980s [149]. These data are used in certain models to slow occupant movement through smoke and also to change occupant positioning in certain spaces to a crawl position, instead of upright.

Bryan and Wood concentrated on the correlation between visibility distance in the smoke and the percentage of occupants within that smoke that would move through it [150]. This work was done in the US (Bryan) and the UK (Wood) and was obtained by occupant self-reporting. These data are used by some models to assess when certain occupants will turn back, instead of move forward into the smoke-filled space.

The models that include fire effects can include any (or all) of the previously described effects or include data from other sources. In many cases, the data used to develop the rules that occupants follow is relatively scarce and care should be taken by the user in knowing how the models incorporates fire effects, where the data is coming from, and the applicability of that data to the question that is posed.

2.1.9 CAD

The CAD subcategory identifies whether the model allows the user to import files from a computer-aided design (CAD) program, or other files containing the building layout, into the model. In many instances, this method is time saving and more accurate. If a user can rely on accurate CAD drawings instead of laying out the building by hand, there is less room for input error of the building. However the user needs to be more careful that all of the different elements are properly connected. If the model allows for the input of CAD drawings, the label (Y) is used in Table 1. On the other hand, the label of (N) is used when the model does not have that capability.

2.1.10 Visual

The visualization subcategory identifies whether the model allows the user to visualize the evacuation output from the structure. Visualizations of the evacuation allow the user to see where the bottlenecks and points of congestion are located inside the space. Many of the models allow for at least 2-D visualization (2-D), and recently more have released versions or collaborate with other virtual programs that will present results in 3-D (3-D). Other models do not have any visualization capabilities (N). The choice in visualization will often depend on the audience. For an audience that is unfamiliar with the building or in cases of complex geometries, visualization capabilities may provide a better understanding of what is occurring.

2.1.11 Validation

The models are also categorized by their method of validation, i.e., the process of determining the degree to which the model and underlying data are accurate representations of the real world situations. The current ways of validating evacuation models are listed here: validation against code requirements (C), validation against fire drills or other people movement experiments/trials (FD), validation against literature on past evacuation experiments (flow rates, etc) (PE), validation against other models (OM), and third party validation (3P) (i.e., another party other than the model developer validates the model – please see available references to verify which validation method was used by the third party). For some models, no indication of validation of the model is provided (N). Some of the behavioral models will perform a qualitative analysis on the behaviors of the population. Although problematic since occupant behaviors are often difficult to obtain in fire drills, past drill survey data is sometimes used to compare with model results. Before using any model, the user should evaluate the appropriateness of the validation efforts to the project involved and question how the results were obtained. Furthermore, care should be taken to ensure that the model has been validated for buildings similar to the project building.

2.1.12 Summary of Category Labels

Availability to the Public:
(Y): The model is available to the public for free or a fee

(N1): The company uses the model for the client on a consultancy basis
(N2): The model has not yet been released
Modeling Method:
(M): Movement model
(M-O): Movement/optimization models
(PB): Partial Behavioral model
(B): Behavioral model
(B-RA): Behavioral model with risk assessment capabilities

Purpose:
(1) Models that can simulate any type of building
(2) Models that specialize in residences
(3) Models that specialize in public transport stations
(4) Models that are capable of simulating low-rise buildings (under 15 stories)
(5) Models that only simulate 1-route/exit of the building.

Grid/Structure:
(C): Coarse network
(F): Fine network
(Co): Continuous

Perspective of the model/occupant:
(G): Global perspective
(I): Individual perspective
Each model is categorized by both the perspective of the model and of the occupant. If only one entry is listed in this column, both the model and occupant have the same perspective.

Behavior:
(N): No behavior
(I): Implicit
(C): Conditional or rule-based
(AI): Artificial intelligence
(P): Probabilistic

Movement:
(D): Density
(UC): User’s choice
(ID): Inter-person distance
(P): Potential
(E): Emptiness of next grid cell
(C): Conditional
(Ac_K): Acquired knowledge
(Un_F): Unimpeded flow
(CA): Cellular automata

Fire Data:
(N): The model cannot incorporate fire data
(Y1): The model can import fire data from another model
(Y2): The model allows the user to input specific fire data at certain times throughout the evacuation
(Y3): The model has its own simultaneous fire model

CAD:
(N): The model does not allow for importation of CAD drawings
(Y): The model does allow for importation of CAD drawings

Visual:
(N): The model does not have visualization capabilities
(2-D): 2-dimension visualization available
(3-D): 3-dimension visualization available

Validation:
(C): Validation against codes
(FD): Validation against fire drills or other people movement experiments/trials
(PE): Validation against literature on past experiments (flow rates, etc.)
(OM): Validation against other models
(3P): Third party validation
(N): No validation work could be found regarding the model

Table 1. Main features of egress models

Model	*Available to public*	*Modeling Method*	*Purpose*	*Grid/ Structure*	*Perspective of M/O*	*Behavior*[a]	*Movement*[a]	*Fire data*	*CAD*	*Visual*	*Valid*
EVACNET4	Y	M-O	1	C	G	N	UC	N	N	N	FD
WAYOUT	Y	M	5	C	G	N	D	N	N	2-D	FD
STEPS[c]	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	C,FD,PE
PEDROUTE	Y	PB	3	C	G	I	D	N	Y	2,3-D	N
Simulex[b]	Y	PB	1	Co.	I	I	ID	N	Y	2-D	FD,PE, 3P
GridFlow	Y	PB	1	Co.	I	I	D	N	Y	2,3-D	FD, PE
FDS+Evac[c]	Y	PB	1	Co.	I	I, C, P	ID	Y3	N/Y	2,3-D	FD,PE,OM
Pathfinder 2009[c]	Y	PB	1	Co.	I/G	I	D,ID	N	Y	2,3-D	C,FD,PE,OM
SimWalk[c]	Y	PB	1,3	Co.	I	C, P	P	N	Y	2,3-D	FD,PE,3P
PEDFLOW[c]	Y	B	1	Co.	I	C, P	ID	Y2	Y	2,3-D	PE
PedGo[c]	Y,N1	PB/B	1	F	I/I,G	I/C, P	P,E (CA), C	Y2	Y	2,3-D	FD,PE,OM,3P
ASERI[c]	Y	B-RA	1	Co.	I	C, P	ID	Y1,2	Y	2,3-D	FD, PE
BldEXO[b]	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	FD,PE,OM,3P
Legion[c]	Y,N1	B	1	Co.	I	AI, P	ID, C	Y1	Y	2,3-D	C,FD,PE,3P
SpaceSensor[c]	Y	B	3	Co.	I	C, P	C, Ac_K	N	Y	2,3-D	FD,OM
EPT[c]	Y,N1	B	1	F	I	AI	UC,C	Y2	Y	2,3-D	FD
Myriad II[c]	Y, N1	B	1	C, F, Co.	I	AI	D, UC, IP, Ac_K	Y1	Y	2,3-D	PE, 3P
MassMotion[c]	Y, N1	B	1	Co.	I/I,G	AI,P	C	N	Y	2,3-D	C,FD,PE,OM
PathFinder	N1	M	1	F	I/G	N	D	N	Y	2-D	N
ALLSAFE	N1	PB	5	C	G	I	Un_F	Y1,2	N	2-D	OM
CRISP	N1	B-RA	1	F	I	C, P	E,D	Y3	Y	2,3-D	FD
EGRESS 2002	N1	B	1	F	I	C, P	P,D (CA)	Y2	N	2-D	FD
SGEM[c]	N1	PB	1	Co.	I	I	D	N	Y	2-D	FD,OM
EXIT89[c]	N2	PB	1	C	I	I/C, P	D	Y1	N	N	FD,3P
MASSEgress[b]	N2	B	1	Co.	I	C, AI	C	N	Y	2,3-D	PE,OM
EvacuatioNZ[c]	N2	B	1	C	I/I,G	I, C, P	D, UC	Y2	Y	2-D	FD, PE,OM

[a]Only the underlying methods used by the algorithm are listed. In some instances users can define other options

[b]Model developers/NIST provided an update on the model's development in Spring 2009.

[c]Model developers/NIST provided an update on the model's development in Fall 2010.

2.2 Special Features

As a way to describe the more specific capabilities of each model, Table 2 is included to identify any special features of the model that users may be interested in simulating. This table is included for users interested in simulating certain evacuation scenarios and/or for users to understand the differences in model sophistication. It can be seen that the number of special features simulated by the model increase as the level of sophistication increases. The specific features included in the review, many of which can be enabled or disabled by the user, are as follows:

- Counterflow
- Exit block/obstacles
- Fire conditions affect behavior
- Toxicity of the occupants
- Defining groups
- Disabilities/slow occupant groups
- Delays/pre-evacuation times
- Elevator use
- Route choice of the occupants

2.2.1 Counterflow

During an evacuation, emergency responders or other individuals may need to traverse in the opposite direction as the evacuating occupants in the building. This can result in less egress width for the building occupants. The “counterflow” category identifies those models that have the capability of simulating counterflow (sometimes referred to as countraflow). Counterflow is the parallel movement of occupants in different directions. One example of this is simulating fire fighters moving up the stairs while occupants are moving down the stairs. A user would want to use a model with counterflow capabilities if the desired simulation is to include either fire fighters or other occupants that have duties to perform during the evacuation.

2.2.2 Exit Block

Not all exits may be available to occupants in a building fire. Exits can become blocked for many reasons, including environmental conditions (e.g., smoke or flames), structural building damage, or building construction. A model user could be interested in scenarios where not all egress paths can be used. The “exit block” category identifies those models that allow the user to block exits from use by simulated occupants in the scenario. Models that have this capability either allow the user to manually block the exit from use before or even during the scenario or the model will block the exit from use due to certain conditions that arise during the evacuation (e.g., smoke will block the exit). Users should understand how the occupants will view the blocked exit and if the exit can be blocked as a function of time or only at the beginning of the simulation.

2.2.3 Fire Conditions affect Behavior

In a building fire, it is likely that occupants, especially those located near the fire, will be presented with the environmental conditions produced by the fire, including dense smoke, flames, and high temperatures. Some models that incorporate fire conditions (see Table 1) have the capability of altering occupant behavior based upon those fire conditions, including the following simulated scenarios: occupants choosing another exit because there is dense smoke near the exit, occupants turning back and reversing directions away from the smoke, and/or occupants decreasing their movement speeds when/if they walk through certain densities of smoke. The “fire conditions” category identifies whether the evacuation model has the capability to alter occupant behavior due to fire conditions (not including the effect of toxic products, which is covered in the next category).

2.2.4 Toxicity

The burning of materials produces toxic gases (narcotic and irritant gases), smoke aerosols, and heat. Fires can spread smoke and hot gases throughout a building, presenting occupants with toxic gases, which can cause symptoms from slight headaches, possibly leading to decreased movement speeds, to incapacitation (i.e., where the occupants stop moving without assistance), or even death. The “toxicity” category identifies those models that simulate the incapacitation or death of occupants due to toxic products contained in smoke from fire conditions. Some models simulate incapacitated occupants when exposure to toxic products occurs for a specific length of time (based on toxicity algorithms [147]).

2.2.5 Groups

During evacuations, occupants are likely to gather into groups before evacuating and even travel through the building exits together to reach safety [151]. Groups can consist of friends, family members, coworkers, etc., depending upon the type of occupants in the building and their relationships to one another. The “groups” category identifies those models that have the ability to simulate occupants evacuating in groups. These models allow the user to define groups as individuals that are assigned similar characteristics; however, depending upon the sophistication of the model, the group members may even seek each other out and/or evacuate as a single unit. In some cases, the model may even simulate the group performing actions together (if the model is behavioral-based) and/or moving at the same speed of the slowest-moving person.

Most of the models that account for groups do so only by allowing the individuals to be assigned similar characteristics. Therefore, if a model is assigned a “Y” for the “Groups” category, the model at least defines groups of individuals that are assigned similar characteristics. Before using the group feature, the model user should understand how the model is defining groups (do they stay together or not) and, if the individuals stay together, how the individuals make their decisions.

2.2.6 Disabled/Slow Occupants

Not all occupants move at the same unimpeded speed during an evacuation from a building. Instead, occupants move at a variety of different speeds based on their movement abilities to negotiate long distances, steps, doors, etc. The type of population in a given scenario needs to be considered by the model user to determine if the standard movement speeds are appropriate for the entire building population. The "disabled/slow occupants" category identifies those models that allow the user to assign lower unimpeded speeds to a specific percentage or group of occupants to represent occupants who may move slower during the evacuation. Once an unimpeded speed is assigned to occupants in a simulation, they will move at this speed until higher density spaces, where their movement algorithm (see section 2.1.7) takes over. Just because a model has this capability, does not mean that disabled occupants or slower-moving occupants actually cause bottlenecks or congestion in smaller spaces throughout the building. The presence of congestion due to slower-movers depends upon how the model configures the building (section 2.1.4), how the model handles individuals' behavior (section 2.1.6), and how the model moves occupants throughout the building (section 2.1.7).

2.2.7 Delays/Pre-evacuation Times

Most evacuation models simulate occupant evacuation from buildings over two distinct time periods: the pre-evacuation period and the evacuation period. The pre-evacuation period begins when the occupant realizes that something is wrong and ends when s/he begins to travel an evacuation route out of the building (in some models, this time is nonexistent). The evacuation period ends when the occupant has reached a point of safety. The "delays/pre-evacuation times" category identifies those models that have the ability to simulate a time delay that occupants will wait before initiating their evacuation movement out of the building. Models can assign the entire population or portions of the building population a specific time period or a distribution of time periods to delay before beginning evacuation movement. The user needs to review the literature for pre-evacuation times and distributions that are typical for the scenario being examined.

2.2.8 Elevator Use

In certain situations, i.e., non-fire emergencies or in buildings where the elevators are equipped to operate during fire emergencies, elevators may be used for evacuation from the building. The "elevator use" category is used to identify those models that can simulate evacuation from a building via elevators.

2.2.9 Route Choice

When occupants decide to begin their evacuation, they must also decide which route to take to evacuate the building, i.e., which exit stair will they use to evacuate in buildings taller than one-story and/or which exit door they will use to leave the building. The “route choice” category identifies the options available for route choice of the occupants. These can include the following: occupants will travel the fastest route (the route that takes the shortest amount of time – labeled as “optimal” in Table 2), occupants will choose to travel the shortest route, occupants will choose to travel routes defined by the user of the model (labeled in Table 2 as “user-def.”), and occupants will choose to travel a route based upon the conditions in the building (e.g., fire conditions, actions of the other occupants, etc.) (labeled in Table 2 as “conditional). Models with conditional route choice options will typically allow occupants to change their selected exit during the course of the evacuation.

2.2.10 Summary of Category Labels

For all of these features, except route choice, the model is labeled as either having this capability or not having this capability. If the model has this capability, a “Y” for yes is placed in Table 2. If not, a “N” for no is placed in Table 2. For route choice of the occupants, the various options provided to the user for simulating occupant route choice are described in Table 2.

Table 2: Special features of egress models

Model	*Counter-flow*	*Exit Block*	*Fire Conditions*	*Toxicity*	*Groups*	*Disabled / slower*	*Delays/pre-evacuation*	*Elevator use*	*Route choice*
EVACNET4	N	N	N	N	N	N	N	Y	Optimal routes
WAYOUT	N	N	N	N	N	N	Y	N	1 route, flows merge
STEPS[c]	Y	Y	Y	Y	Y	Y	Y	Y	Conditional
PEDROUTE	N	N	N	N	Y	Y	Y	N	Shortest, optimal, or signage
Simulex[b]	Y	Y	N	N	Y	Y	Y	N	Shortest or altered distance map
GridFlow	Y	Y	N	Y	N	Y	Y	N	Shortest, random, user-def.
FDS+Evac[c]	Y	Y	Y	Y	N	Y	Y	N	Optimal, conditional
Pathfinder 2009[c]	Y	Y	N	N	Y	Y	Y	N	Shortest, user-def.
SimWalk[c]	Y	N	N	N	Y	Y	Y	Y	Shortest
PEDFLOW[c]	Y	Y	Y	Y	Y	Y	Y	Y	Shortest, conditional
PedGo[c]	Y	Y	Y	N	Y	Y	Y	N	Probabilistic/conditional, user-def.
ASERI[c]	Y	Y	Y	Y	Y	Y	Y	N	Shortest, user-def., conditional
BldEXO[b]	Y	Y	Y	Y	Y	Y	Y	N	Various
Legion[c]	Y	Y	Y	Y	Y	Y	Y	Y	Conditional
SpaceSensor[c]	N	Y	N	N	N	N	N	Y	Conditional – visual perception
EPT[c]	Y	Y	Y	Y	Y	Y	Y	Y	Shortest, conditional
Myriad II[c]	Y	Y	Y	Y	Y	Y	Y	Y	Various
MassMotion[c]	Y	Y	Y	N	Y	Y	Y	Y	Shortest, conditional
PathFinder	N	N	N	N	N	N	N	N	User's choice – 2 choices
ALLSAFE	N	N	Y	N	Y	N	Y	N	1-Choice
CRISP	Y	Y	Y	Y	Y	Y	Y	N	Shortest, user-def., conditional
EGRESS 2002	Y	Y	Y	Y	Y	Y	Y	N	Conditional
SGEM[c]	Y	Y	N	N	N	Y	Y	Y	Shortest time, conditional
EXIT89[c]	Y	Y	Y	Y	N	Y	Y	N	Shortest distance, user-def.
MASSEgress[b]	Y	Y	N	N	Y	Y	Y	N	Conditional – visual perception
EvacuatioNZ[c]	N	Y	Y	N	Y	Y	Y	N	Various

[b]Model developers/NIST provided an update on the model's development in Spring 2009.

[c]Model developers/NIST provided an update on the model's development in Fall 2010.

2.3 Overview of Model Features

The purpose of this section is to provide an overview of the changes in evacuation modeling since the first edition of this model review was published in 2005 [8]. There have been several general trends in features which the models have incorporated.

One of the principal differences between this review and the previous one is the increased complexity of the evacuation models overall. First, the modeling methods have shifted from a split between the movement, partial behavioral, and behavioral models to a concentration of models categorized as either behavioral or partial behavioral. More of the models are including behaviors and decision-making capabilities for the simulated occupants. Users should be careful, however, to ensure that the behavioral aspects of the model are supported by data and/or theory of human behavior during fires. This is not always the case. The attributes and decisions of the occupants are often defined in a probabilistic fashion which requires multiple iterations of each simulation to determine the range of expected occupant evacuation times and movement speeds. The next most common trend observed is the increased complexity of the model grids used. In the previous review, very few models incorporated a continuous grid network. In this review, the majority of the available models simulate movement on a continuous grid. The continuous grid is more complex since occupants are not assigned to a specific cell but can instead be located anywhere in the building.

Models have also increased in complexity of the modeling input. First, more models, compared to the previous review, allow the user to incorporate fire effects into the simulation. These effects should, in theory, increase the complexity of the behaviors of the occupants. Also, nearly all of the models in this review allow the user to incorporate CAD drawings. This change makes it possible for more complex designs to be studied since the ease of model use has increased. However, an increase in the ease of use can lead to more errors, so users should understand the limitations of the chosen model.

Probably the most significant change between 2005 and the current review is the complexity of the models' output capabilities. Only a few models had 3-D visualization ability in the previous review. Nearly all of them in the current review provide that capability. While this change does not alter the quality of the results from an engineering perspective, it enables the results to be better understood by the people viewing them and broadens the potential audience. It is important, however, for the user to understand the underlying assumptions that produced these visualized results.

Last, many more of the models have included all of the capabilities listed in Table 2 . These special features enable the model user to look at a wider range of scenarios and conditions that could alter egress time. Once again, the changes are increasing the complexity of the models as well as the potential scenarios that can be considered.

There are limitations that the model user should keep in mind as the models offer a wider range of features, both internally and externally (i.e., for the user to define). The evacuation modeling field seems to have advanced much further past the sets of available evacuation data [152]. Many of the newest features are based on a limited number of data sets that might not be applicable to most scenarios. While the model might be accurate in general, there could be limitations on some of the subcomponents. Therefore, it is imperative to understand how the model has been validated and to find out if the capabilities are grounded in any evacuation or pedestrian data sources and to understand the validity of that data to the desired scenario.

2.4 Additional Egress Models

In addition to evacuation models that can simulate egress from buildings, there are many other evacuation models that can simulate evacuation from different types of structures/scenarios, such as aircraft, rail systems, marine structures/ships, and cities. Although this evacuation model review focuses specifically on evacuation models that simulate building emergencies, some of the models highlighted in this review and others not mentioned are used to simulate evacuation from other types of structures. If the user has a project that involves egress from these types of structures, there are other evacuation model reviews [153, 154, 155] that would be useful to obtain before choosing a model.

3 Conclusion

This report provides model users with information to narrow down the potential selection of models to use for specific projects. It is up to the model user to review the details of particular models and make a final and informed decision as to which model(s) is best for the project at hand.

As time passes, more evacuation models will be developed and many of the current models will be updated by developers. It should be noted that this review will require updates as new models are introduced to the field and older ones retire. It is up to the user to take into account the model version, the publish date of the report, and any more recent publications on particular evacuation models when choosing the appropriate model.

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