4.4 Review of 28 Egress Models

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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, evacuation models are being used. Hand calculations usually follow the equations given in the Emergency Movement Chapter of the Society of Fire Protection Engineers (SFPE) Handbook[2] to calculate mass flow evacuation from any height of building. The occupants are assumed to be standing at the doorway to the stair 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) and calculates the time for the occupants to flow past that point and to the outside.

To achieve a more realistic evacuation calculation, engineers have been looking to evacuation computer models to assess a building's life safety. Currently, there are a number of evacuation models to choose from, each with unique characteristics and specialties. A concern with current evacuation models is whether they can accurately simulate the unique scenarios that accompany a certain type of building. How would a user know which model to choose for his/her design?

To aid with the difficult task of choosing an appropriate model, a comprehensive model review of 28 past and current egress models has recently been completed[3]. This model review was completed with large influence from the work done by Gwynne and Galea at the University of Greenwich[4] and Olenick from Combustion Science and Engineering, Inc[5]. The model review provides information on model purpose, availability, modeling method, model structure and perspective, methods for simulating movement and behavior, output, use of fire data, use of visualization and CAD drawings, etc. The model review organizes the evacuation programs into three basic categories that aim to describe the models' level of sophistication in simulating behavior of the occupants. These categories are movement models (no behavioral capabilities), partial-behavioral models (implicit behavior is simulated[4]), and behavioral models (occupant decision-making and behavior is simulated).

Available Egress Model Reviews

Three evacuation model reviews are available, which were significant in the organization and data gathering found in this chapter. The most substantial review to date was performed by Gwynne and Galea[4] at the University of Greenwich. This 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[5, 6]. Also, a review was performed by Watts[7] where he introduced early network algorithm models, queuing models, and "simulation" models and gave examples of each type. Lastly, Friedman[8] also reviewed egress models, much in the same fashion as was performed by Gwynne and Galea.

However, there is a still a need for an updated, unbiased, and more detailed review to aid evacuation model users in choosing the appropriate model for their particular project. The previous three reviews listed were written before some of the newer models were developed, showing a need for a more updated review. Also, the previous three model reviews can be expanded as far as providing additional detailed information for each model. Therefore, more explanation was given in this review to the details of interest to model users, the inner workings of each model, and each model's validation methods and limitations.

Features of Egress Models

In developing any model review, it is important to first list the features and capabilities that are of interest to potential users. Each of the following evacuation models reviewed were categorized according to the following list of features and capabilities.

- Purpose
- Availability for public use
- Modeling method; movement, partial-behavioral, behavior
- Structure of model
- Perspective of model and perspective of occupants
- Occupant behavior
- Occupant movement
- Use of fire data
- Output
- Use of CAD drawings
- Visualization capabilities
- Validation studies
- Special Features
- Limitations

This review covers a total of 28 computer models that focus on providing evacuation data from buildings. Many of the models reviewed can also simulate other types of scenarios; however evacuation from buildings is the main focus of this review. The models are organized in the review by modeling method; movement models, partial behavioral models, and behavioral models. However because of its uniqueness, the model, Myriad, is not categorized with a particular movement method (even though it resides in the behavioral models section below). A list of the models in the review is provided here in the order that they appear in the detailed review:

- Movement models: FPETool[9], EVACNET4[10, 11], Takahashi's Fluid Model[12], PathFinder[13], TIMTEX[14], WAYOUT[15], Magnetic Model[16], EESCAPE[17], EgressPro[18], ENTROPY Model[19, 20], and STEPs[21-25].

- Partial Behavioral models: PEDROUTE/PAXPORT[26-32], EXIT89[33-39], Simulex[40-47], GridFlow[48], and ALLSAFE[49-51].
- Behavioral models: CRISP[52-55], ASERI[56-59], BFIRES-2[60-62], buildingEXODUS[4, 63-68], EGRESS[69-71], EXITT[72, 73], VEgAS[74-76], E-SCAPE[77], BGRAF[78-81], EvacSim[82, 83], Legion[84-86], and Myriad[75, 76] (uncategorized).

For each model, a special feature section is included in this review. These are included as features of interest for model users who are searching for the appropriate model to simulate a certain type of scenario or set of scenarios. The special features section verifies whether the model is capable of simulating at least one of the ten specialized features. It is of interest whether or not the model can simulate the first nine features listed and lastly, how the model simulates occupant route choice. However, just because a model attempts to simulate a feature does not always mean that there is adequate data to support the feature. The specific features included in the review are as follows.

- Counterflow
- Manual exit block/obstacles
- Fire conditions affect behavior?
- Defining groups
- Disabilities/slow occupant groups
- Delays/pre-movement times
- Elevator use
- Toxicity of the occupants
- Impatience/drive variables
- Route choice of the occupants/occupant distribution

For each model in the review, the feature is listed and described only if it is apparent that the model has the capability of simulating it. Also, for each model, the method of simulating route choice is listed and described.

This report provides only a summary of the full-length model review[3], which describes the features and capabilities of 28 different evacuation models individually.
This report aims to summarize the full-length review by providing a series of quick reference tables for model users to identify the models with which they should research further. Due to lack of information in the designated categories of interest for certain models, two models are included in the detailed review but will not be included in the following summary and tables. These models are FPETool[9] and Myriad[76]:

- FPETool is not included in the tables due to the fact that it is not primarily an evacuation model, but more so a total package fire model with an egress calculation. It is included in the review for completeness. However, since FPETool lacks many of the features that other egress models contained, it was determined unnecessary to include its features in Tables 1-3.
- Since Myriad is very different from the other evacuation models, focuses on crowd movement, and lacks information on the important categories outlined in the review, it is also not included in the conclusion tables. Because of the difference in modeling method as well

as lack of detailed data on the inner workings of the model, only the categories for which data was obtained are included in the Myriad write-up section.

The reference tables, Tables 1 through 3, organize the detailed data presented from the full length report[3] as summary guides. Table 1 details the overall organization of the categorical data for each model. Tables 2 and 3 focus on the special features of each model. The features of evacuation models and the corresponding abbreviations used throughout Table 1 are explained in the following paragraphs.

Purpose:
This subcategory describes the use of the model, as it pertains to certain building types. Some of the models in this review focus on a specific type of building and others can be used for all building types. The main purpose in using this as a category is to understand if the model can 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 capable of simulating low-rise buildings (under 75 feet) only (4), and models that only simulate 1-route/exit of the building (5).

Availability to the Public:
The subcategory of availability becomes important if the user is interested in modeling the building in-house or hiring the developing company to provide evacuation results. In this subcategory, some models are available to the public for free or a fee (Y). Others are not available due to the following circumstances; the model has either not yet been released (N1), the model is no longer in use (N2), or the company uses the model for the client on a consultancy basis (N3). If the status of the model is unknown, it is labeled as (U) in Table 1.

Modeling Method:
Past and current evacuation models have been categorized using a primary category labeled modeling method[4]. This category describes the method that each model uses to calculate evacuation times for certain types of building. 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.
- Movement models (M): those models that move occupants from one point in the building to another (usually the exit or a position of safety). These models are key in showing congestion areas, queuing, or bottlenecks within the simulated building. For those models that are specifically optimization models, a label of (M-O) is given.
- Partial behavior models (PB): those models that primarily calculate occupant movement, but begin to simulate behaviors. Possible behaviors could be implicitly represented by pre-movement time distributions among the occupants, unique occupant characteristics, overtaking behavior, and the introduction of smoke or smoke effects to the occupant. These

are models capable of simulating an entire building, and occupants' movements throughout the model are based on research of observed human behavior data.

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. The coarse network (C) models divide the floor plan into rooms, corridors, stair sections, etc. and the occupants move from one room to another. A continuous (Co) network applies a 2D (continuous) space to the floor plans of the structure, allowing the occupants to walk from one point in space to another throughout the building. Fine and continuous networks 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.

Perspective of the model/occupant:
The perspective subcategory explains how 1) the model views the occupants and 2) how the occupants view the building.

1) How the model views the occupants:
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 moving to the exits. It is clear to see that an individual perspective of the occupants is more detailed, 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, than a global view is sufficient.

2) How the occupant views the building:
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 occupants are not all knowing of the building's exit paths and decide their route based on information from the floor, personal experience, and in some models, the information from the occupants around them. A global perspective of the occupants would be one where they automatically know their best exit path and seem to have an "all knowing" view of the building.

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:
The behavior of occupants is represented in many different ways by the evacuation models in this review. The organization associated with this sub category is the following: no behavior (N), implicit behavior (I), rules or conditional behavior (R/C), functional analogy (FA), or artificial intelligence (AI). Also, 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 of the pre-evacuation times, travel speeds, and/or FED or smoke susceptibility.

- *No behavior* (N) denotes that only the movement aspect of the evacuation is simulated
- Implicit behavior[4] (I) represents those models that attempt to model 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 that are affected by structural or environmental conditions of the evacuation (as an "if, then" behavioral method)
- *Functional Analogy* (FA) resembles models that apply a set of equations to the entire population. Usually the equations are taken from another field of study, such as Physics, to represent occupant movement.
- *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.

When incorporating fire conditions, several models use the data from Bryan and Wood[87], and Jin[88] to develop rules for occupants faced with such conditions. These behaviors involve turn back behavior, slowing of occupant movement, and the physical movement of crawling, based on the changing environmental conditions.

Movement:
The movement subcategory categorizes how the models move occupants throughout the building. For most models, occupants are usually assigned a specific unimpeded (low density) velocity by the user or modeling program. The 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 key players come to mind from which the data originated that is used in current evacuation models. These three sources of occupant movement data for evacuation models are Fruin[89], Pauls[90, 91], and Predtechenskii and Milinskii[92]
- *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 allows them only 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 they travel to. 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.
- *Functional analogy* (FA): The occupants follow the movement equations specified by the topic area, such as fluid movement or magnetism. In some cases, the equations (such as fluids) depend on the density of the space.
- *Other model link* (OML): The movement of the occupants is calculated by another model, which is linked to the evacuation model reviewed.
- *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.

Fire Data:
The fire data subcategory explains whether or not 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 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 simultaneous fire model (Y3). If the model cannot incorporate fire data, it simply runs all simulations in "drill" mode (N). "Drill" mode is the equivalent of a fire drill taking place in a building, without the presence of a fire.

The purpose for evacuation models to include such data is ultimately to assess the safety of the occupants who travel through such conditions. Purser has developed a model to calculate a fractional incapacitating dose for individuals exposed to CO, HCN, CO_2, and reduced O_2 [93, 94]. 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 heat and irritant gases.

Some models also go as far as to use data collected by Jin in Japan[88] 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[88] and correct answer rate and emotional stability through heated, thick, irritant smoke-filled corridors in the late 1980s[88]. This data is 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[87]. This work was done in the United States (Bryan) and the UK (Wood) and was obtained by occupant self-reporting. This data is used by current models to assess when certain occupants will turn back, instead of move forward into the smoke-filled space.

There is a limited amount of information or data available on the validity of these optical density and occupant behavior requirements.

CAD:
It is important to note whether or not the model allows the user to import files from a computer-aided design (CAD) program into the model. In many instances, this method is time saving and more accurate. If a user can rely on the CAD drawings instead of laying out the building by hand, there is less room for input error of the building. If the model allows for the input of CAD drawings, the label (Y) will be used in Table 1. On the other hand, the label of (N) is used in cases where the model does not have that capability. In some instances, the model developer is in the process of upgrading their model to include this capability, which is labeled as (F).

Visual:
Visualization allows the user to see where the bottlenecks and points of congestion are 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).

Validation:
The models are also categorized by their method of validation studies. The current ways of validating evacuation models are included 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), and validation against other models (OM). 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.

Table 1. Overall features of egress models detailed in Appendix A.

Model	*Purpose*	*Available to public*	*Modeling Method*	*Grid/ Structure*	*Perspective of M/O*	*Behavior*	*Movement*	*Fire data*	*CAD*	*Visual*	*Valid*
EVACNET4	1	Y	M-O	C	G	N	UC	N	N	N	FD
Takahashi's Fluid	1	N2	M-O	C	G	N/FA	FA-D	N	N	2-D	FD
PathFinder	1	N3	M	F	I/G	N	D	N	Y	2-D	N
TIMTEX	4	Y	M	C	G/I	N	D	N	N	N	PE
WAYOUT	5	Y	M	C	G	N	D	N	N	2-D	FD
Magnetic Model	1	U	M	F	I	FA/I	FA	N	N	2-D	N
EESCAPE	5	N3	M	C	G	N	D	N	N	N	FD
EgressPro	5	N2	M	C	G	N	D	Y2	N	N	N
ENTROPY	5	U	M/PB	C	G/I	N	Ac K, FA	N	N	N	OM
STEPs	1	Y	M/PB	F	I	FA	P, E	N	Y	3-D	C
PED/PAX	3	Y/N2	PB	C	G	I	D	N	Y	2,3-D	N
EXIT89	1*	N1	PB	C	I	I/C(smk)	D	Y1	N	N	FD
Simulex	1	Y	PB	Co.	I	I	ID	N	Y	2-D	FD,PE
GridFlow	1	Y	PB	Co.	I	I	D	N	Y	2,3-D	FD, PE
ALLSAFE	5	N3	PB	C	G	I	Un F	Y1,2	N	2-D	OM
CRISP	1	N3	B-RA	F	I	R/C, P	E,D	Y3	Y	2,3-D	FD
ASERI	1	Y	B-RA	Co.	I	R/C, P	ID	Y1,2	N, F	2,3-D	FD*-
BFIRES- 2	4	N2/U	B-RA	F	I	R/C, P	UC**	Y2	N	N	N
BldEXO	1	Y	B	F	I	R/C, P	P, E	Y1,2	Y	2,3-D	FD
EGRESS 2002	1	N3	B	F	I	R/C, P	P,D	Y2	N	2-D	FD
EXITT	2	Y	B	C	I	R/C	C	Y1,2	N	2-D	N
VEgAS	1	N2/U	B	F	I	AI	ID	Y1?	Y	3-D	N
E-SCAPE	1	U	B	C	I	R/C, P	OML	Y2	N	2-D	N
BGRAF	1	N1	B	F	I	R/C, P	UC?	Y1,2	N, F	2-D?	FD
EvacSim	1	N1	B	F	I	R/C, P	D	Y2	N	N	N
Legion	1	Y	B	Co.	I	AI	D,C	Y2	Y	2,3-D	FD,OM

*Especially for high-rise buildings; **User specifies # of time frames, an occupant moves to a grid point during each time frame; *- Fire drills and sensitivity analyses on the model

? indicates that a category is unclear or unknown

Table 2. Movement models

Characteristics/Model	*Evacnet4*	*Fluid*	*PathFinder*	*TIMTEX*	*WAYOUT*
Avail to public	Y	N2	N3	Y	Y
Method	Movement-O	Movement-O	Movement	Movement	Movement
Structure	Coarse	Coarse	Fine	Coarse	Coarse
Perspective of M/O	Global	Global	I/G	G/I	Global
People Beh	None	N-FA	None	None	None
Import CAD drawings	N	N	Y	N	N
Visual Simulation	N	Y	Y	N	Y
Counterflow	N	N	N	N	N
Manual exit block	N	N	N	N	N
Fire Conditions	N	N	N	N	N
Defining Groups	N	N	N	N	N
Disabl/Slow Occ grps	N	N	N	N	N
Delays/Pre-evacuation	N	Y	N	N	Y
Rte. Choice	Optimal	Optimal	2 Choices	Split choice	1 route, flows merge
Elevator use	Y	N	N	N	N
Toxicity to occ	N	N	N	N	N
Impatience/Drive	N	N	N	N	N
Occ. Distribution	Optimization	Optimization from rooms and to exits	UC – 2 choices	User chooses flow split	1 choice only

Characteristics/Model	Magnetic Model	EESCAPE	EgressPro	ENTROPY	STEPs
Avail to public	U	N3	N2	U	Y
Method	Movement	Movement	Movement	Movement/ PB	Movement/ PB
Structure	Fine	Coarse	Coarse	Coarse	Fine
Perspective of M/O	Individual	Global	Global	G/I	Individual
People Beh	FA/I	None	None	None	FA
Import CAD drawings	N	N	N	N	Y
Visual Simulation	Y	N	N	N	Y
Counterflow	N	N	N	N	N
Manual exit block	N	N	N	N, Y with improvements	Y
Fire Conditions	N	N	Y	N	N
Defining Groups	Y	N	N	N	Y
Disabl/Slow Occ grps	Y	N	N	N, Y with improvements	Y
Delays/Pre-evacuation	Y	N	Y	N	Y
Rte. Choice	3 choices	1 route	1 route	1 exit	Score
Elevator use	N	N	N	N	Y
Toxicity to occ	N	N	N	N	N
Impatience/Drive	N	N	N	N	Y
Occ Distribution	UC – 3 choices	1 choice only	1 choice only	1 choice	Score/user chooses target

Table 3. Behavioral models

Characteristics/Model	*PED/PAX*	*EXIT89*	*Simulex*	*GridFlow*
Avail to public	Y/N2	N1	Y	Y
Method	Partial Behavior	Partial Behavior	Partial Behavior	Partial Behavior
Structure	Coarse	Coarse	Continuous	Continuous
Perspective of M/O	Global	Individual	Individual	Individual
People beh	Implicit	Implicit/C (smk)	Implicit	Implicit
Import CAD drawings	Y	N	Y	Y
Visual simulation	Y	N	Y	Y
Counterflow	N	Y	N	Y
Manual exit block	N	Y	Y	Y
Fire conditions	N	Y, CFAST	N not yet	N, only FED input
Defining groups	Y	N	Y	Y
Disabl/Slow occ grps	Y	Y	Y	Y
Delays/Pre-evacuation	Y	Y	Y	Y
Rte. choice	Quickest route, optimize, or follow signs	Shortest distance or user-defined	Shortest distance or altered distance map	Shortest distance, random, or user-defined
Elevator use	N	N	N	N
Toxicity to occ	N	N	N	Y
Impatience/Drive	N	N	N	N
Occ. distribution	3 choices?	2 choices	2 choices	3 choices

Characteristics/Model	**ALLSAFE**	**CRISP**	**ASERI**	**BFIRES-2**
Avail to public	N3	N3	Y	N2/U
Method	Partial Behavior	B-RA	Behavioral-RA	Behavioral-RA
Structure	Coarse	Fine	Continuous	Fine
Perspective of M/O	Global	I	I	I
People beh	Implicit	Conditional	Conditional	Conditional
Import CAD drawings	N	Y	N, F	N
Visual simulation	Y	Y	Y	N
Counterflow	N	Y	N	N
Manual exit block	N	Y	Y	Y
Fire conditions	Y	Y – not in drill mode	Y	Y
Defining groups	Y	Y	Y	N
Disabl/Slow occ grps	N	Y	Y	Y
Delays/Pre-evacuation	Y	Y	Y	Y
Rte. choice	All to 1 exit	Shortest, user defined door difficulty	Shortest or user-defined, then conditional	Conditional
Elevator use	N	N	N	N
Toxicity to occ	N	Y – not in drill	Y	Y-smk tolerance
Impatience/Drive	N	N	N	N
Occ distribution	1 choice	Conditional	Various	Various

Table 3. Behavioral models, cont.

Characteristics/Model	*EXODUS*	*EGRESS*	*EXITT*	*VEgAS*
Avail to public	Y	N3	Y	N2/U
Method	Behavioral	Behavioral	Behavior	Behavioral
Structure	Fine	Fine	Coarse	Fine
Perspective of M/O	I	Individual	Individual	Individual
People beh	Conditional	Conditional	Conditional	AI
Import CAD drawings	Y	N	N	Y
Visual simulation	Y	Y	Y	Y
Counterflow	Y	Y	N	N
Manual exit block	Y	Y	Y	Y
Fire conditions	Y	Y	Y	Y
Defining groups	Y	Y	Y	Y
Disabl/Slow occ grps	Y – mobility	Y	Y	N
Delays/Pre-evacuation	Y	Y	Y	Y
Rte. choice	Conditional	Conditional	Conditional	User-dfnd/Cond
Elevator use	N	N	N	N
Toxicity to occ	Y	Y	N	Y
Impatience/Drive	Y	N	N	N
Occ distribution	Various	Various	Various	Various

Characteristics/Model	**E-SCAPE**	**BGRAF**	**EvacSim**	**Legion**
Avail to public	U	N1	N1	Y
Method	Behavioral	Behavioral	Behavioral	Behavioral
Structure	Coarse	Fine	Fine	Continuous
Perspective of M/O	I	Individual	Individual	Individual
People beh	Conditional	Conditional	Conditional	AI
Import CAD drawings	N	N, F	N	Y
Visual simulation	Y	Y	N	Y
Counterflow	N	N	N	Y
Manual exit block	N	N	Y-locked doors	Y
Fire conditions	Y	Y	Y – user	N, not yet
Defining groups	Y	Y	Y	Y
Disabl/Slow occ grps	N	Y	Y	Y
Delays/Pre-evacuation	Y	Y	Y	Y
Rte. choice	Conditional	Conditional	Conditional	Conditional
Elevator use	N	N	Y	Y
Toxicity to occ	N	Y	N	N
Impatience/Drive	N	N	N	Y – alternate naming of variables
Occ distribution	Various	Various	Various	Various

Summary of Egress Model Features

The purpose of this section is to generally describe the three categories of modeling methods and identify general trends in the model features for each category. Table 1 to Table 3 outline this type of data and are to be used as a quick-reference guide to the details included in the full-length report[3].

The division of models into categories; movement, partial behavioral, and behavioral, classify evacuation models primarily by the sophistication of their modeling techniques. In this context, sophistication is used to describe the complexity of the modeling techniques used to simulate the egress situation and the occupant behavior throughout the evacuation. The movement models are labeled as the least sophisticated and the behavioral models are labeled as having the most modeling sophistication. However, it should be noted that a high modeling sophistication does not necessarily indicate that the evacuation model uses and/or provides the appropriate data to model such behaviors. The user should be aware of the validation methods and associated limitations of each model used.

Overall, the use (purpose) of the models range from use on only one exit (5) to use for all types of buildings (1). The movement models section contains models used for 1-exit building arrangements, low-story buildings, and all types of buildings. As sophistication in modeling increases (partial-behavioral models), only one model requires a 1-exit arrangement, one model is used for transport stations, and the rest can be used for all types of building. Lastly, as sophistication increases to an additional behavioral level, these models can be used for all types of buildings (with the exception of one used for residences and one used for low-story buildings).

Also provided in the tables is the availability of each model to the public. In some cases, the model is available to the public for personal use for free or for a fee (the fee varies depending upon the model). On the other hand, some models are labeled as unavailable, i.e. not yet released, discontinued, or used by the company on a consultancy basis.

For many of the older models in this review, their availability is either unknown or they are no longer available. These older models are found in all three of the modeling categories. Some of the more sophisticated models, EvacSim and BGRAF for example, have not yet been released. The majority of the models in Table 1 are either available for use by the public or by the consulting agency that developed the model.

Movement Models

Movement models are those models that focus on the movement of occupants from one point in the building to another (usually the exit or a position of safety). The main types of output include the total evacuation time, locations of bottlenecks inside the building, and flow through openings.

A distinct feature simulated by two models in this category is that of optimizing the evacuation results. This is noted by "M-O" in the Modeling Method column and is used to describe EVACNET4 and Takahashi's Fluid model. Optimization is a movement technique whereby the occupants are moved in a certain direction (not necessarily their shortest distance) only to achieve occupant distributions that produce a minimal evacuation time. The optimization technique is inherent in these models, instead of a users' choice. This is a unique simulation technique, since most models move occupants the shortest distance.

Table 1 shows the many characteristics of movement models. Many times with a low sophistication model, the structure and perspective of the model follow suit. Most of the movement models represent the structure with a coarse network, instead of a fine network. This involves the use of nodes (representing rooms or sections of rooms) connected by arcs (the distance from the middle of one node to the middle of the next), which can be a crude representation of the building. Also associated with most of the movement models is a global perspective of the model as well as a global perspective of the occupants. A global perspective of the model describes models that view the occupants as a homogeneous mass, instead of individuals. Also, a global perspective of the occupants describes the occupants as "all knowing" of the building exits and the quickest way to exit the building.

The movement models all lack high behavioral simulation and contain generally the same technique for moving occupants throughout the structure. Almost all of the movement models in this review lack behavioral simulation capabilities and move occupants throughout the building with the use of density vs. speed correlations (as density increases, the velocity of the occupants in the space slows via an empirical relationship from collected data). However, an exception to this behavioral and movement simulation trend is the Magnetic Model. The Magnetic Model offers a complex queuing system for special building types, such as airports, railway stations, office buildings, and department stores. The three types of queuing behaviors available are 1) queuing in front of a counter; 2) queuing in front of a gate; and 3) queuing in front of vehicles, such as a train. These behaviors originated from observed behaviors in different types of buildings. Also unique to the Magnetic Model is the movement technique. Instead of moving the occupants under empirical density vs. speed relationships, this model uses Columb's Law to move occupants as magnetic objects in a magnetic field. More information on this model can be found in the full-detail report[3].

None of the movement models allow for the inclusion of fire data, with the exception of Egress Pro. This unique model incorporates a limited amount of (user-supplied) fire data to the program to simulate the time of the alarm sounding. Also, none of the models, with the exception of PathFinder, allow the use of CAD drawings to define the building structure.

Many times it is easier to review data from the model visually. Half of the movement models has a 2-dimensional visualization capability, while the other half does not provide this feature.

Two evacuation models found in Table 1, ENTROPY and STEPS, are labeled as both movement and partial-behavioral models. This is due to the special features included in both models (shown in Table 2), that require an increased level of modeling sophistication. In the case of the ENTROPY model, the use of acquired knowledge to move occupants was unique in nature and can be categorized as partial-behavioral. In STEPs, the use of groups with different characteristics, pre-evacuation times, and visualization could categorize this model as a partial-behavioral model. However, due to the basic movement and behavioral techniques used in both of these models, the movement category still applies.

Partial-Behavioral Models
Five models in Table 1 fall under the category of partial-behavioral models. These models primarily calculate occupant movement, however begin to simulate behaviors in a less complex way. These models simulate behaviors implicitly by simulating pre-evacuation time distributions among the occupants, unique occupant characteristics, overtaking behavior, and the introduction of smoke or smoke effects to the occupant. These are models capable of simulating an entire building, and occupants' movements throughout the model are frequently based on research of observed human behavior data.

As shown in Table 1, partial-behavioral models contain a mix of coarse, fine and continuous networks, as well as a mix of global and individual perspectives. Depending upon the needs of the user, the appropriate combination of characteristics should be chosen for each project. All partial-behavioral models simulate behaviors implicitly, which is essentially the characteristic that defines this category. And, similar to the movement models, density correlations are a popular mode to simulate occupant movement throughout the structure.

Different from the movement models, the partial-behavioral models contain more sophistication in the areas of fire data, CAD, and visualization. More of the models in this category can incorporate fire data and CAD drawings to describe the structure. Also, almost all of the partial-behavioral models have the capability of visualizing the evacuation.

The main difference between this category and the behavioral category is that the "behaviors" in this category are implicitly modeled by providing inputs of body size, occupant characteristics, the inclusion of pre-evacuation times, fire data, etc. This category begins to apply the effects of individual movement toward a goal for the evacuation.

Behavioral Models
Ten models fall under the category of behavioral models (Table 1); which are labeled as the most sophisticated type of models for evacuation. Again, the user should be aware of the limited amount of data (or the lack of data) supporting some of the more sophisticated simulation techniques.

Behavioral models are those models that incorporate occupants' decisions and behaviors, in addition to movement toward a specified goal (exit). Many of these models can incorporate decision-making by occupants and/or actions that are performed due to conditions in the building. Most of these models represent the building with a fine or continuous network and all of these models incorporate an individual perspective of the model and the occupants.

In all models, except VEgAS and Legion, occupants exhibit behaviors based on rules specified in the model and/or the conditions of the situation. For instance, if there is a layer of smoke residing in front of a stairway, this represents a smoky condition that the occupant is faced with. It is possible that the model will contain the following rule, "if the smoke contains a density of ___, the occupant will turn around and walk to the next nearest exit stair." The behavior of models in this section is mostly dominated by "rules" and conditions of the environment, including the fire environment (if the model has this capability).

Along with the rules and conditional behavior, almost all behavioral models have the capability of assigning probabilities to activities performed by each occupant. These probabilities are associated both with the likelihood of performing the action and a probable distribution of the time assigned to each action.

All of the behavioral models described in this section are capable of accepting some type of fire data, and most are capable of providing a visualization of the evacuation simulation and using CAD drawings to represent the structure.

Although there is an increase in sophistication and simulation capabilities, the user must be aware of the kinds of validation performed on the model, as well as the documented data used to support various types of simulation. A note of the validation work done on each model is included in Table 1, and a more detailed version of the validation for each model is included in the detailed report[3].

Special Features
As an additional way to describe the capabilities of each model, Table 2 and Table 3 are included to identify any special features of the model that users may be interested in simulating. These tables are 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.

Among the special features are the capabilities of the models to simulate occupant characteristics, elevator use, toxicity, pre-evacuation delays, fire conditions, and exit block. Also of importance, which is shown in Table 2 and 3, is how the models simulate occupant route choice and occupant distribution to exits. Again, as model sophistication increases, the route choice of occupants is conditional upon the situation (behavioral models) instead of a "1 route" possibility.

Additional Egress Models

In addition, not all of the available models are explained in this review. Since development of this review, two additional models have been developed and will be mentioned briefly in this section. The first model, PedGo[95], is available through the TraffGo Company. It is discussed as an individual, cellular automaton evacuation model that can be used for any type of layout. The second model, the SGEM[96, 97] package, was developed in City University of Hong Kong. Similar to PedGo, SGEM is also an individual, cellular automaton model; however route choice can also be affected by situational changes of the environment, such as familiarity and signage effects.

Conclusions

As this egress model review has shown, even within model categories, each model is unique due to the various choices and modeling methods used to calculate evacuation output. This report provides model users with the information to narrow down choices on the appropriate model to use for specific projects. It is then up to the model user to then review the detailed guide[3] and make a final and informed decision as to which model is best for the project at hand.

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

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