EXIT89 - HIGH-RISE EVACUATION MODEL - RECENT ENHANCEMENTS AND EXAMPLE APPLICATIONS

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ABSTRACT

EXIT89 was designed to model the evacuation of a large building while tracking the travel paths of each individual occupant. In combination with a fire and smoke movement model, EXIT89 can be used to predict the effects of fire spread on evacuation. Used alone, it can provide a best-case evacuation time estimate. The model has been enhanced to allow the user to specify occupants' travel paths, to delay the beginning of evacuation by location or randomly among all occupants and to simulate the presence of disabled occupants. A beta test version of the model will be distributed by the end of 1995 and plans are to include this model in a future version of HAZARD I. This paper describes recent enhancements in more detail and includes examples that demonstrate the use of those new features.

BACKGROUND

The origin and basic features of EXIT89 have been described in previous papers.[1] This paper will concentrate on a description of recent enhancements made to the model and will present recent example applications of the model that illustrate some of its features.

PROGRAM DESCRIPTION

EXIT89 was designed to model the evacuation of a large building with the capability of tracking each occupant individually. The output of this model, in combination with a fire and smoke movement model using the same building layout, can be used to predict the effects of cumulative exposure to the toxic environment present in a structure fire.

EXIT89 requires as input a network description of the building, geometrical data for each room and for openings between rooms, the number of occupants located at each node throughout the building, and smoke data if the effect of smoke blockages is to be considered. EXIT89 uses walking speeds under normal or emergency conditions calculated as a function of density. The user selects from among three average body sizes calculated from Russian, Austrian and American population groups and between normal and emergency evacuation conditions. Queuing is handled by the decreased walking speeds that result from increased densities as more occupants move into a room or stair. The user is allowed to select among several options that are described below. The program will print out the movement of each occupant from node to node or the user can suppress this output and have the model only print out a summary showing floor clearing times, stairway clearing times and last time each exit was used and how many people used each exit.

The program is written in FORTRAN and currently running in mainframe and PC versions.

USER OPTIONS ADDED TO MODEL

Several user-specified options have been added to the model, including whether the occupants of the building will follow shortest paths out of the building or will use familiar routes; whether smoke data, if any, comes from a fire and smoke model or will be input as blockages by the user; whether there are any delays in evacuation throughout the building; whether there are any additional delays in evacuation among the occupants of the building and, if so, what percentage of the occupants will delay and what are the minimum and maximum delay times; and whether any of the occupants are disabled and if so, at what percentage of "normal" speed will each person travel. Evacuation can begin for all occupants at time 0 or can be delayed. Smoke data can be used to predict when the activation of a smoke detector would occur and evacuation will begin then or after some user-defined delay beyond that time.

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SELECTION OF ROUTING MODE

The user of this model can choose between a shortest route algorithm or can determine occupants' travel paths directly. The advantage of using the shortest route algorithm is often outweighed by the lack of realism that results. In real situations, occupants are frequently observed taking as their egress path the route they took in reaching their present location.[2] Allowing the user to enter the travel paths occupants would tend to use in exiting the building may result in an evacuation that will more closely resemble observations. This option also allows the user to simulate an observed situation, such as the Milburn House example described below.

USE OF EXIT89 IN COMBINATION WITH CFAST

EXIT89 was originally developed to be used as part of the HAZARD I fire risk assessment method.[3] This software package includes a fire growth model (CFAST), an egress model (currently EXITT) and a tenability model (TENAB). Included in the current version is a model called SURVIVAL which combines EXITT and TENAB. EXIT89 would expand the applicability of HAZARD I's occupant survivability analysis to more complex spaces. A PC-version of EXIT89 currently being tested has the linkage with CFAST, allowing the user to model a fire and then insert the outputs for that fire into the appropriate part of the EXIT89 building floor plan. This technique allows for occupant notification as a result of the modeled fire and subsequent blockages of exit paths as a result of smoke and fire spread. For a more simplified analysis, the user also has the alternative of adding room blockages due to fire effects at discrete times throughout the evacuation.

MODELING OCCUPANT DELAYS

An evacuation model that does not account for occupant behaviors will give only "best case" results. One occupant behavior that EXIT89 has been modified to handle is delaying the start of evacuation. In real life, people are not often observed instantaneously moving upon notification of a fire. There will almost always be some delay in beginning to evacuate. The user has a few options in modeling evacuation delays. All occupants at a node may delay evacuation for some user-defined period of time. The user may also have a randomly selected set of occupants delay for randomly selected additional periods of time.

The delays set for a location can be used, for example, to model the preparation time expected at a location. When doing incident reconstruction, this feature can be used to model delays in notification or delays in beginning to evacuate reported by observers or occupants. Random delays can be used to add some variability to the occupants' starting times. To use the random delay option, the user specifies what percentage of the occupants will delay evacuation and over what range of time those delays will fall. The model randomly selects the occupants who will delay and then samples the time distribution to select the delay time. The delay times currently are selected from a uniform distribution.

MODELING OCCUPANTS WITH DISABILITIES

EXIT89 calculates walking speeds as a function of density with the result that all occupants at a given density will travel at the same speed. In real life, some people are not able to move as quickly as the general traffic flow. The model now has the option of including occupants who travel at a rate of speed at variance with the general population. This option is used by specifying the number of occupants at a node who are "disabled" and for each such person setting the percentage of "normal" walking speed at which the person will travel. Anyone who will travel at a different speed can be modeled using this option, including someone who would travel at a higher rate of speed. People moving at reduced rates of speed would include not only those with disabilities but also people traveling with people with disabilities or with children. For those people, the user sets an adjustment value less than 1.0. To model a person moving faster than the general population, the user enters an adjustment value greater than 1.0.

COMPARISON OF OBSERVED AND PREDICTED TRAVEL SPEEDS

To check the results of the model, a comparison of travel speeds calculated by EXIT89 with travel speeds observed in studies of people movement was undertaken. The simplified floor plan used consisted of four rooms on each side of a corridor. There were two occupants in each occupied room and a total of 16 occupants in the one-story structure. The model was run twice -- once with emergency travel speeds and once with normal travel speeds. In both runs, the largest body size was specified.

In the emergency velocity example, the fastest calculated travel speed (1.29 m/s) was undertaken by two occupants with a 9.5-foot travel distance to an empty corridor node. The slowest speed (0.94 m/s) was calculated for four occupants traveling to the outside from a corridor node holding eight people.

In the normal velocity example, the fastest calculated speed (0.87 m/s) was undertaken by the same two occupants with the 9.5-foot travel distance to an empty corridor node. The slowest speed (0.65 m/s) was calculated for two occupants traveling to the outside from a corridor node holding eight people.

Ideally, we would have travel speeds in actual emergencies to compare with the speeds calculated by EXIT89, but such data collection in any real incident is unlikely. As a substitute, a check of the literature was undertaken to find observed travel speeds in real, non-emergency situations.

Fruin[4] reports on several studies. Surveys of 1,000 non-baggage-carrying pedestrians in bus and train terminals in New York City indicated average walking speeds of men, women and all pedestrians of 1.37, 1.29 and 1.35 m/s, respectively. Speed was apparently a function of age, but fast and slow walkers were found in each age group. Fruin concluded from these studies that almost all pedestrians have free-flow walking speeds of at least 0.74 m/s. Other studies he reported showed that walking speed also varied with time of day, outside temperature and trip purpose.

Based on his research, Fruin used the level of service concept and defines six levels of service, based on crowdedness of spaces and each with its own average pedestrian flow volume under non-emergency conditions. This converts to an unimpeded walking speed of up to 1.27 m/s and a walking speed under crowded conditions of no more than 0.61 m/s.

Predtechenskii and Milinskii[5] reference several studies done in the Soviet Union. One study included almost 200 series of observations of traffic flow in public places and concluded that flow speeds on horizontal paths were not slower than 0.28 m/s and recommended 0.27 m/s for design calculations.

Pauls[6] provides a table of reasonable movement rates ranging from 250 ft/min (1.27 m/s) for minimum crowding to less than 60 ft/min (0.30 m/s) for crushing crowds.

In EXIT89, the maximum possible calculated walking speed under "emergency" conditions is 1.36 m/s and under "normal" conditions is 0.91 m/s. The minimum possible calculated walking speeds are 0.18 m/s and 0.15 m/s, respectively.

EXAMPLE 1: MODELING ALTERNATIVE TRAVEL PATHS

An application of the model was done using data from a seven-story office building in Newcastle-on-Tyne (UK)[7]. The data used in this analysis were provided by the Tyne and Wear Fire Brigade and were obtained during a fire drill they conducted with the cooperation of building management. In the course of designing the fire drill, the fire brigade decided to challenge the occupants by denying the use of one of the stairways as if it were blocked by fire. They counted and timed the occupants using different exits and surveyed the occupants after the drill to ask them where they started, which exits they used and how long they delayed before beginning to evacuate.

There was one particularly interesting finding from the fire drill. The building is built into the side of a hill, so there are exits directly to the outside on several floors. The third floor has an exit to the parking lot at the rear of the building. The building's evacuation plan calls for the occupants to meet in that parking lot. During the evacuation, most of the occupants headed for the most direct route to the back of the building, even if that meant that they had to climb stairs or ignore closer exits that did not go there.

The model was first run using the shortest route option. The calculated time to building evacuation was shorter than that observed at the drill, but, of course, the model did not send most occupants to one exit. The observers reported that occupants throughout the building followed paths within the building that took them directly to the assembly area instead of taking the actual shortest route from the building and then walking around the building and up the hill to the assembly point. Congestion at that exit reportedly occurred almost immediately as a result. In contrast, the model used shortest routes from each location.

The second run of the model sent the occupants along the paths observed in the drill to the extent possible. In this case, both the model and the observed results show the heavy use of the exit closest to the assembly point. Although the predicted time to complete evacuation was longer than for the previous data set, the time is still one minute faster than that observed in the evacuation. One explanation of this is the delays that occur during the course of evacuations -- this phenomenon was well-reported in the evacuation drills used in the following example. The model does not add delays after movement to the exit has begun beyond those that result from queuing.

EXAMPLE 2: MODELING DISABLED OCCUPANTS

A series of evacuations conducted by the University of Ulster tested the effect of disabled persons on occupant flow in mixed ability populations.[8] One of these evacuations took place in a hotel with a daytime scenario. Using this scenario, some of the features of EXIT89 were tested.

In the first daytime scenario, estimated delays in evacuating bedrooms ranged from one to 30 seconds. In addition, 14 out of 27 able-bodied occupants observed by cameras delayed at some point in the corridors during their evacuation. Among the 22 non-disabled occupants observed by cameras in this evacuation, the times to reach the exit ranged from 16.6 to 60.0 seconds with a mean time of 37.1 seconds.

The first run of this evacuation used reported and estimated delay times in the rooms for these occupants and resulted in evacuation times that ranged from 23.1 to 60.1 seconds with a mean time of 39.5 seconds. A second run of this evacuation added random delays of one to 30 seconds to half of the occupants. In this case, the predicted evacuation times ranged from 23.1 to 79.1 seconds with a mean time of 45.8 seconds. A closer look at the movement of the occupants showed that many of the occupants actually reached the exit sooner because the delays reduced congestion in the corridors and allowed them freer and more rapid movement. Since most of the reported delays during evacuation actually lasted less than 10 seconds, the example was run a third time with random delays of one to 10 seconds distributed among half the occupants. This resulted in predicted evacuation times that ranged from 23.1 to 65.8 seconds with a mean time of 41.8 seconds.

Building on the final results of that first test, four disabled occupants were added to the modeled population. Two wheelchair occupants traveled at speeds close to the average for able-bodied occupants (1.15 m/s vs. 1.52 m/s). The other two disabled occupants were a wheelchair user who traveled at about one-eighth of the average speed of the able-bodied occupants, as a result of impedance from a walker user who traveled at about one-fifteenth of the average speed of the able-bodied occupants.

The model was rerun with these four disabled occupants added. As was observed in the actual evacuation, there was no effect on the travel times of the able-bodied evacuees. The travel times observed in the actual evacuation for these four people were 51.0 seconds, 56.9 seconds, 174.0 seconds and 222.0 seconds. The times estimated for them in the model were 58.0 seconds, 61.7 seconds, 182.3 seconds and 295.4 seconds, respectively.

CURRENT WORK

EXIT89 is currently being tested by 15 individuals at a variety of fire protection firms and academic institutions. Depending on the results of this testing, modifications may be made to the model with the ultimate goal of incorporating it into the next version of HAZARD I.

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