A NEW APPROACH FOR MODELING THE OCCUPANT RESPONSE TO A FIRE IN A BUILDING

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ABSTRACT

The Risk Assessment Method (RAM) has been adopted as the basic approach for evaluating the fire risk and cost associated with fires in apartment buildings, hotels and motels in Australia. It uses a systematic approach to consider a large number of scenarios which are related to fire growth and spread, smoke spread and management, detection, barrier performance, occupant response and evacuation, and fire brigade fire fighting and rescue. For each scenario, a number of submodels are required to be run in order to evaluate the performance of the fire safety system in the building. To limit the overall computational time to a reasonable period of time (hours rather than days on a PC), the computational time for each submodel must be short. The paper proposes a new approach which is termed the Expected Multi-Response Approach for the Human Response and Evacuation submodel. Using this new approach, the computational time is significantly reduced compared with using the conventional Monte Carlo Method.

INTRODUCTION

A performance-based code was introduced in Australia in July 1997. To assist in the application of the performance-based code, a Fire Engineering Guidelines[1] document has been published in which the Risk Assessment Method is recommended for life safety and fire cost evaluation of building fire safety systems. The Risk Assessment Method uses an event tree algorithm to generate a set of scenarios which includes the most important events, such as detector activated or not, fire spread or not, barrier failed or not, etc. For each scenario, a number of submodels are required to be run in order to predict the fire environment, detector activation time, smoke management performance, occupant response and evacuation, fire brigade arrival time, etc. A computer model using this methodology is being developed by the Centre for Environmental Safety and Risk Engineering at the Victoria University of Technology to evaluate the fire risk and cost in apartment buildings, hotels and motels in Australia.[2,3] The model will be used (a) to add flexibility by specifying additional prescriptive design solutions to the existing building code of Australia, and (b) to assist the designer and code officials to evaluate the life safety and fire cost for a particular proposed building design. In order to limit the overall computational time of the model to a reasonably short period of time, that is, hours rather than days on a most accessible machine—a personal computer, the computational time for each submodel must be short.

In a previous paper,[3] the Expected Response Approach (ERA) was proposed to calculate the occupant response and evacuation in a building. The ERA approach does not consider the distributional effect of the response time, which is found in real fire evacuations. Studies by Proulx & Sime[4] and Brennan[5] suggest that the response time of occupants to a cue can vary from 10 s to 15 min or more. Many factors, such as psychological factors, the type of cue, occupant condition and the environment, can affect the occupant's decision and hence time delay. The response time is defined to be from the time at which the occupant receives a cue to the time at which the occupant starts the evacuation. The most common activities for occupants during this period of time in residential buildings were found[6] to be finding a pet, gathering family, gathering valuables, getting dressed, investigating in corridor, and moving to balcony. The response time is, in most cases, much longer than the evacuation time which is defined to be the time at which the occupant starts evacuation to the time at which the occupant exits the building. Therefore, it is important to consider the distributional effect of this response time because it is often the occupants who have a long response time who will be the most vulnerable.

THE THREE-POINT APPROACH

To consider the distributional effect of a variable, Hasofer[7] used a three-point approach where each point had a probability of occurrence according to the distribution of the variable. A simple illustrative example for one evacuation scenario was given in which three variables were considered, namely, time to start evacuation (= cue time plus response time), time of evacuation and time of untenable condition as shown in Fig. 1. It was assumed that the expected number of people remaining in the enclosure was a linear function of time after the evacuation was started. The expected number of deaths in the enclosure was, therefore, the expected number of people remaining in the enclosure at the time of occurrence of untenable conditions. Hence, it can easily be seen that if the time of untenable condition is different, and is greater than A but smaller than B, for the same evacuation shown in Fig. 1, the expected number of deaths will be different. Three values of time of untenable condition[7] will thus result in three values of the expected number of deaths. Similarly, for different values of either the time to start evacuation or the time of evacuation, the expected number of deaths will be different. Three values were used for each of the variables. Hence, the total number of sub-scenarios for this three-value approach is 27. The overall expected number of deaths for the scenario is the sum of the product of the expected number of deaths for each sub-scenario and the probability of occurrence of the sub-scenario over all sub-scenarios. The results were compared with both a full Monte Carlo Simulation and a one-point approach in which the mean value of the variable is used to represent its distribution. It was concluded that the three-point approach is more favorable than the one-point approach after comparison with the Monte Carlo Simulation result, where the discrepancy between the three-point approach results and the Monte Carlo Simulation results was reasonably small.

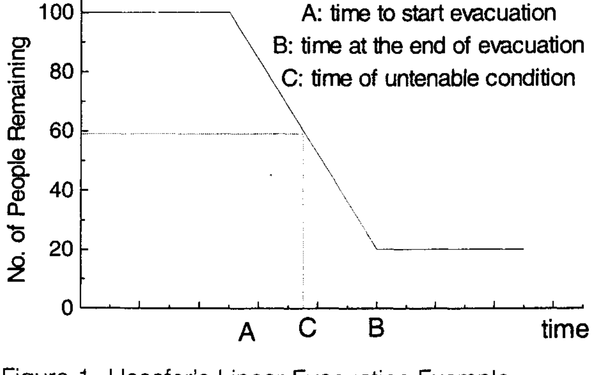

Figure 1. Hasofer's Linear Evacuation Example

As can be seen, the number of runs of the Human Response and Evacuation submodel, to determine the number of deaths for one scenario, is 27 using the three-point approach for one cue. The number of cues in a real fire situation is often more than one. The most common cues are alarm cue, sound of glass breaking cue, smoke cue, occupant warning cue, and fire brigade warning cue. The number of sub-scenarios for one scenario using Hasofer's three-point approach[7] for n number of cues is $3^{(n+2)}$. In the case of 4 cues, the number of sub-scenarios is 729. Thus, the computational time cannot be significantly reduced for many practical applications compared with using the conventional Monte Carlo Simulation where usually thousands of random trials are required. Hence, a new approach is proposed here which is aimed at significantly reducing the computational time.

THE EXPECTED MULTI-RESPONSE APPROACH

To reduce the computational time, an Expected Multi-Response Approach (EMRA) is proposed here. It assumes that there can be multiple occupant subgroups which respond to a cue with different response times. Such an occupant subgroup is called an expected response subgroup. The number of people in an expected response subgroup is a function of the number of people in the original occupant group, the probability of occurrence of the cue, the probability of response of the occupant group to the cue and the distribution of the response time. An example of the EMRA is shown in Fig. 2 in which two cues are

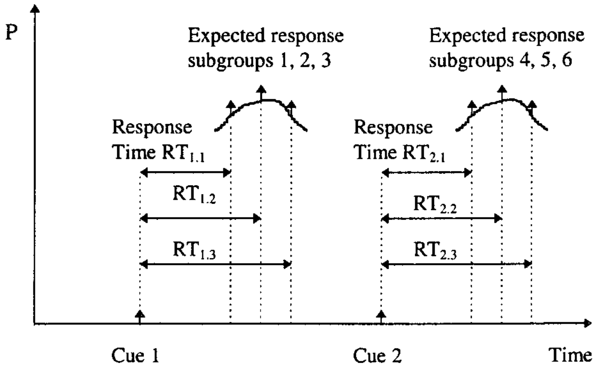

Figure 2. Illustration of the Expected Multi-Response Approach in which Three Points are Taken from the Response Time and Two Cues are Considered

concerned and three points are used to represent the distribution of the response time. The vertical axis is the probability density function of the response time.

As can be seen, the distributional effect of the response time will not increase the number of sub-scenarios, although the number of the expected response subgroups in one sub-scenario is significantly increased. The number of subgroups in each sub-scenario is the product of x and n, where x is the number of points taken from the distribution of the response time and n is the number of cues. If the distributional effects of the time of movement and the time of untenable condition are considered, the number of subscenarios using this EMRA is the product of x^2. Normally x will be 3 or 4 to have a good representation of the distribution. Thus the number of runs of the Human Response and Evacuation Submodel for one scenario is not large. Compared with a Monte Carlo Simulation where thousands of runs, or the ERA where hundreds of runs, are required, a significant time saving in the overall computational time for the fire risk and cost evaluation is expected. Given below is a description of the methodology for EMRA. For the purpose of comparison, the methodologies for the Monte Carlo method and ERA are also briefly described.

Methodologies for Monte Carlo Simulation and the Expected Response Approach

Studies[8-10] have found that the occupants within one enclosure often act as a group; that is, occupants within one apartment either all evacuate or not; and, in case of evacuation, they move together to a familiar exit. This tendency of movement towards familiar persons and places justifies the assumption made in the program, i.e., the occupants in one apartment are defined as one occupant group. Using the Monte Carlo method, if the probability of response is p%, a uniform random number can be generated from 0 to 1, and compared to p%. If the random number is smaller than or equal to p%, all people will respond to the cue. In the case where the response time is also a distributed variable, another random number is required to determine the particular response time. After a large number of such trials, the expected number of people evacuating the apartment can be obtained as a function of time, and the overall expected number of people who respond to the cue is the total number of people who respond to the cue in all runs over the total number of runs. In the Expected Multi-Response Approach, no random number is needed. The expected number of people who respond to the cue is the product of p% and the number of people in the group, and the response time is also chosen deterministically. The distributional effects of the response time are considered in the probability of the occurrence of the sub-scenario, which is a function of the probability of occurrence of the particular response time being chosen. Details of the calculation of the probability of the sub-scenario are given in Ref. [7]. While the calculation procedure for the Expected Multi-Response Approach and the Monte Carlo Simulation is different, the resulting expected number of people evacuating the enclosure should be the same. Occupant evacuation in a three-story building will be used as an example to validate this hypothesis.

Methodology of the New Expected Multi-Response Approach

As previously stated, x number of values with certain probabilities can be chosen to represent the distribution of the response time. Using the new Expected Multi-Response Approach, x expected response subgroups are formed in which each subgroup has a response time which is one of the x representative values, and the expected number of occupants in the subgroup can be calculated using the following:

$$N_{ei,j} = N_j \times P_{cue} \times P_{res} \times P_{ei} \quad i = 1, 2, \ldots x; \quad j = 1, 2, \ldots n. \tag{1}$$

where

$N_{ei,j}$ = the number of people who respond to the jth cue at ith response time,
P_{cue} = the probability of occurrence of the cue,
P_{res} = the probability of the occupant group responding to the cue,
P_{ei} = the proportion of occupants who decide to evacuate the building in the ith subgroup which has the ith representative response time, and
N_j = the number of people who are exposed to the jth cue, which can be calculated by

$$N_j = N_{j-1} \times (1 - P_{cue,j-1} \times P_{res} \times P_{e,j-1}) \quad \text{for } j > 1 \tag{2}$$

and

$$N_1 = N_0 \quad \text{for } j = 1 \tag{3}$$

where

N_0 = the initial number of people in the group.

Equation (3) indicates that the number of people who are exposed to the first cue is the initial number of people in the group. Each of the x subgroups has one of the x representative response times. Since the total expected number of occupants in the x expected response subgroups is:

$$N_e = N \times P_{cue} \times P_{res} \times P_e \tag{4}$$

where

N_e = the expected total number occupants who decide to evacuate the building, and
P_e = the total probability of occupants who decide to evacuate the building, therefore

$$N_e = \sum_{i=1}^{x} N_{ei} \quad \text{and} \quad P_e = \sum_{i=1}^{x} P_{ei} \tag{5}$$

The x-value Expected Multi-Response Approach for the human response can be graphically expressed as in Fig. 3 where the response time is assumed to be the same for the two cues.

An example of using the EMRA for a three-story building is given below. The number of points taken from the distribution, x, was chosen to be 1 and 4 to examine its effect on the accuracy of the solution. The results were compared with the Monte Carlo Simulation results.

VALIDATION

Validation Against Hand Calculation and EVACNET+

A three-story building was used for the purpose of validation of this program. A summary of the geometry of the building is tabulated in Table 1. Assuming that there are 20 apartments per floor level, and there are 2 persons per apartment. Each apartment has a length of 10 m and depth of 14.5 m. The length of the corridor is 100 m and there are 10 apartments on each side of the corridor. It is further assumed that all occupants start evacuation at the same time, i.e., at time = 0, then the evacuation time can be calculated using the method presented by Nelson and MacLennan.[11] The calculation can be performed by hand or spreadsheet. The effective width is the

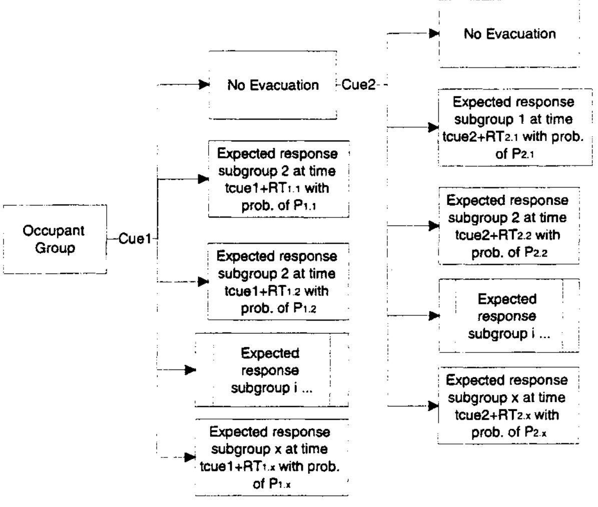

Figure 3. *x*-value Expected Multi-Response Approach for Two Cues

Table 1. Geometry of the Test Building

number of floors	3	
floor area	100 by 30	m^2
floor to floor height	3.6	m
number of stairs	1	
Stair width	2	m
Stair riser	17.8	cm
stair tread	27.9	cm
stair door	1.6	m
corridor length	100	m
corridor width	1.5	m
number of compartments per floor	20	
compartment door width	0.8	m
number of persons per floor	40	
compartment size	10 by 14.5	m^2

width of the exit route subtracting a boundary layer from the walls where 15 cm is recommended for each boundary layer in stairways or doors, and 20 cm for corridors. Thus, the effective width for the stairway is 1.7 m, for the door 0.5 m and for the corridor 1.1 m. The maximum specific flow, that is, the maximum flow of evacuating persons past a point in the exit route per unit time per unit of effective width, for corridors and doorways is 1.31 persons/s/m effective width, and for stairs, having the given risers and thread, is 1.01 persons/s/m effective width. The maximum specific flow occurs when the density is 1.9 persons/m^2 of the exit route space.

The travel distance within the compartment is assumed to be the diagonal of the compartment, i.e., $\sqrt{10^2 + 14.5^2} = 17.6$ m, and the travel speed within the compartment is assumed to be 1.4 m/s. Thus, the travel time required in the compartment is 12.6 s.

The effective width of the compartment door is 0.5 m, and the maximum specific flow for doors is 1.31 persons/s/m effective width, thus the maximum flow, the product of the maximum specific flow and the effective width, is 0.66 persons/s. The time required to go through the compartment door is 2/0.66 = 3.1 s. Similarly, the maximum flow for the stairway door and corridor can be calculated, which are 1.7 persons/s and 1.44 persons/s, respectively.

The actual density in the corridor is the number of persons on the floor divided by the corridor area, i.e., $40/(100 \times 1.5) = 0.267$ persons/m^2. The movement speed is 1.30 m/s. The actual flow F_c is the product of the movement speed S, the actual density d_c and the effective width. Thus the actual flow is $1.3 \times 0.267 \times 1.1 = 0.382$ persons/s. This is smaller than the maximum flow for the stair entry door, thus, there is no queuing up in the corridor, and the calculation of the travel time in the corridor should use 0.382 persons/s, which is the minimum value of the actual flow and the maximum flow of the corridor.

The actual flow in the stairway between levels 2 and 3 is the same as the actual flow in the corridor, i.e., 0.382 persons/s, and between levels 1 and 2 is twice that value, i.e., 0.764 persons/s. Both values are smaller than the maximum flow capacity of the stair door, thus, there is no queuing up in the stairway. The evacuation time in the stairway is 40/0.382 = 80/0.764 = 104.7 s.

Assuming that the stairway exit is connected directly to the outside, then the total evacuation time required for the building is the sum of the time required for the people entering the corridor plus the evacuation time in the corridor and stairway, i.e., 12.6 + 3.1 + 104.7 = 120.4 s.

The computer model EVACNET+[12] was also used for the purpose of validation. The model produces results that describe an optimal evacuation of the building. Each evacuation is optimal in the sense that it assumes that the time of cue and time of pre-movement is zero and, hence, minimizes the time to evacuate the building. The model EVACNET+ yields a result of 150 s for the total evacuation time using a time step of 3 s.

The present model uses the following two equations for the speed of movement as recommended by Pauls,[13] i.e., the speed of movement in the stairway:

$$S = 1.08 - 0.29d \qquad (6)$$

and the speed in corridors or doorways:

$$S = 1.4 \times (1 - 0.266d) \qquad (7)$$

where S is the speed and d is the density which is the number of people in the enclosure divided by the area of the enclosure. The program tracks the movement of all occupant groups; then records the number of people in every enclosure at each time step where an enclosure can be a compartment, corridor or stairway; calculates the density d; and further calculates S using Eq. (6) or (7) depending on the type of enclosure. The travel time required for one enclosure is the travel distance within the enclosure divided by the speed of people in the enclosure. The total evacuation time for the building is defined to be the time when all occupants have evacuated the building. Using a time step of 3 s, the present model gives a prediction of 150 s for the total evacuation time, and 148 s if a time step of 2 s is used. Further reducing the time step to 0.5 s does not alter the total evacuation time. This indicates that a converged result is achieved at a time step of less than 2 s. The overall results are in excellent agreement with the prediction by EVACNET+ where the predicted results also represent an optimal evacuation time in the

Table 2. Hand Calculation Results

1. Estimate travel time within the compartment		
travel distance	17.6	meters
travel speed	1.4	m/s
travel time	12.6	seconds
2. Estimate flow capacity through door		
effective width	0.5	meters
maximum specific flow	1.31	persons/s/m effective width
maximum flow	0.66	persons/s
travel time	3.1	seconds
3. Estimate flow capacity through stairway door		
effective width	1.3	meters
maximum flow	1.70	persons/s
4. Estimate flow capacity through corridor		
effective width	1.1	meters
maximum specific flow	1.31	persons/s/m effective width
maximum flow	1.44	persons/s
density	0.267	persons/m^2
actual flow	0.382	persons/s
5. Estimate the impact of stair entry door		
No queuing up at the stair entry door because the actual flow is less than the maximum flow		
6. Estimate flow capacity of the stairway		
effective width	1.7	meters
maximum specific flow	1.01	persons/s/m effective width
maximum flow	1.72	persons/s
actual flow	0.76	persons/s
No queuing up in the stair because the actual flow is less than the maximum flow		
travel time	104.7	seconds
7. Estimate building evacuation time		
total	120.4	seconds

sense that the pre-movement time, cue time and investigation time etc. are neglected. This model, however, can further take into account the time of occurrence of cues and the delay time, although all of these are assumed to be zero in this test case. Both the present model and EVACNET+ predicted a longer total evacuation time than the prediction by using the method presented by Nelson and MacLennan.[11]

Validation Against Monte Carlo Simulation

Introduction

A three-story building, comprising 12 apartments per level, one corridor on each level and one central stairwell, was considered. Each apartment had a floor area of 10 m × 10 m, and a height of 2.4 m. The distance from each apartment door to the stair was assumed to be 10 m. It was assumed that six types of occupant groups may exist in this building. These occupant groups had a probability of existence in the building according to the probability of their existence in Australian apartment buildings from the Australian Bureau of Statistics (ABS).[14] A summary of the data from the ABS is tabulated in Table 3.

The time of occupant response to cues was found to vary considerably from 10 s to 15 min[3]. In this study, data collected from real fires was used,[5] which is plotted in Fig. 4. Three solution techniques, namely, 1-value (mean response time)

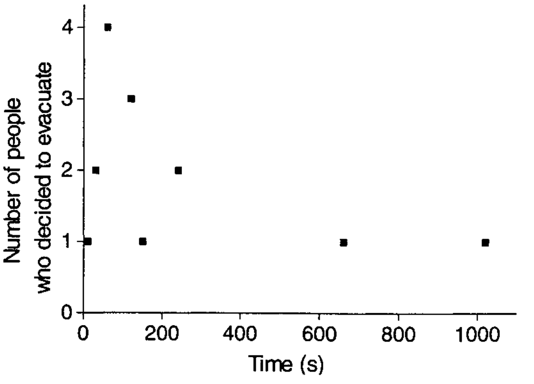

Figure 4. Occupant Response Time after Receiving a Cue

Expected Multi-Response Approach (EMRA), 4-value EMRA and Monte Carlo Simulation, were used. The mean response time was 198.7 s. To represent the distribution of time of response, the four time segments were chosen, namely, 0-2 min, 2-5 min, 5-15 min and 15 min plus. The four mean times in the four segments, that is, the four values used in the four-value EMRA, were 67, 210, 660 and 1020 s, and their probabilities of occurrence were 0.66, 0.2, 0.07 and 0.07, respectively. In the Monte Carlo Simulation, to represent the distribution of the time of response, the original data collected by Brennan,[5] that is, 10, 30, 60, 120, 150, 240, 660 and 1020 s, as shown in Fig. 4, were used. The corresponding probabilities of occurrence were 0.07, 0.13, 0.27, 0.19, 0.07, 0.13, 0.07 and 0.07, respectively.

Table 3. Occupant Groups, Frequencies and Composition

Occupant Group	Composition	Day (Persons)	Night (Persons)	Day (%)	Night (%)
OG1	Single person and age < 70 years old	93989	92051	32	31
OG2	Single person and age > 70 years old	24984	19833	9	7
OG3	2 Parents, 1 Child	60068	60068	20	20
OG4	Group of 2 related or unrelated	99546	99546	34	34
OG5	Single person, fully drugged/intoxicated	3680	10769	1	4
OG6	1 Disabled, 1 Caretaker	11555	11555	4	4
Total		293822	293822	100	100

A fire was assumed to be started on the ground floor. Six types of occupant groups were initially randomly distributed in the building according to the probability of existence in the Australian apartment building as shown in Table 3. For simplicity, the occupants in the building were assumed to be located in four locations, namely, the apartment of fire origin (AFO), the apartment of non-fire origin (ANFO) on the fire floor, the apartments at the level above the fire floor, and the top floor, i.e., the third floor of the building. After the computer pseudo-random allocation, the building had an occupant distribution as shown in Table 4. In this particular example, OG6, i.e., one disabled with one caretaker was not considered. The model, however, can consider this by varying the baseline speed in Eq. (6) or (7).

The times of occurrence of cues were assumed to be as shown in Table 5. Upon receiving a cue, all occupant groups were assumed to have a response probability of 0.6 except for occupant group OG5 for which 0.3 was assumed. The travel speeds for the six occupant groups were assumed to be as shown in Table 6. The travelling distance within the apartment was assumed to be 5 m. The stairwell at each level was assumed to have a height of 2.8 m.

Results and Analysis

Three solutions using 1-value EMRA, 4-value EMRA and the Monte Carlo method were obtained. The number of random trials in the Monte Carlo Simulation was 1000. The number of trials was increased to 2000, but no significant difference between the Monte Carlo Simulation solutions was found. Therefore, the 1000-trial Monte Carlo Simulation solution is regarded as the benchmark solution with which all the comparisons will be made.

Figure 5 shows the expected number of people remaining in the apartment of fire origin as a function of time. As can be seen, for the first 300 s, neither the 4-value EMRA nor the 1-value

Table 4. Initial Occupant Distribution in the Building

Parameter	Apartment of Fire origin	Apartment of Non-Fire Origin on the Fire Floor	Level 2	Level 3
Occupant Groups	1×OG2	2×OG1; 1×OG2; 6×OG3; 3×OG4.	1×OG1; 2×OG3; 7×OG4; 2×OG5.	6×OG1; 3×OG3; 3×G4.
No. of People	1	27	23	21

Table 5. Time of Occurrence of Cues

Parameter	AFO	ANFO	Floor above the Fire Floor	Top Floor
Time of Cue 1 (s)	30	74	159.6	237.6
Time of Cue 2 (s)	58.8	119.4	254	363

Table 6. Occupant Travel Speed (m/s)

Parameter	OG1	OG2	OG3	OG4	OG5	OG6
Horizontal Travel Speed	1.5	1.0	1.0	1.5	0.2	0.5
Vertical Travel Speed	0.75	0.5	0.5	0.75	0.1	0.25

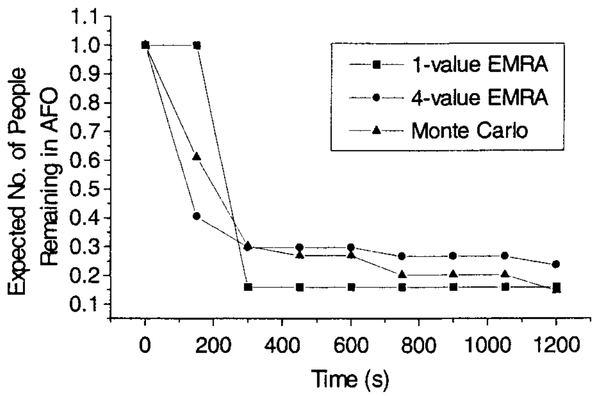

Figure 5. Expected Number of People Remaining in the Apartment of Fire Origin Versus Time

EMRA approach gives excellent agreement compared with the full Monte Carlo results. The largest discrepancy occurs at about 150 s. The errors given by the 4-value EMRA are generally smaller than the errors by the 1-value EMRA. For the first 300 s, the 4-value approach gives a non-conservative prediction, meaning that the prediction is likely to result in a prediction of a smaller number of deaths than what it should be, whereas the 1-value approach gives a conservative prediction. But, after 300 s, the 4-value EMRA approach gives a conservative prediction, and the 1-value EMRA approach gives a non-conservative prediction.

The expected number of people remaining in the apartment of non-fire origin on the fire floor versus time is plotted in Fig. 6. The 4-value EMRA prediction is in excellent agreement with the Monte Carlo Simulation results at a time of 150 to 800 s. After 800 s, there are small discrepancies, and the 4-value EMRA prediction gives conservative results. Large discrepancies between the 1-value EMRA prediction and the Monte Carlo Simulation results are found from 200 s to 400 s, and moderate discrepancies from 400 s to 800 s.

Figure 7 shows the number of people in the apartments at level 2 versus time. As can be seen, the agreement between the 4-value EMRA approach and the Monte Carlo Simulation is excellent. There are large discrepancies between the 1-value EMRA and the Monte Carlo Simulation result at times between 150 s to 750 s, and moderate discrepancies from 750 s to 1000 s. The 1-value EMRA prediction is non-conservative after 400 s.

The predictions of the expected number of people remaining in the apartments at level 3, shown in Fig. 8, by the 4-value EMRA approach agrees well with the Monte Carlo Simulation results; the prediction by the 1-value EMRA, however,

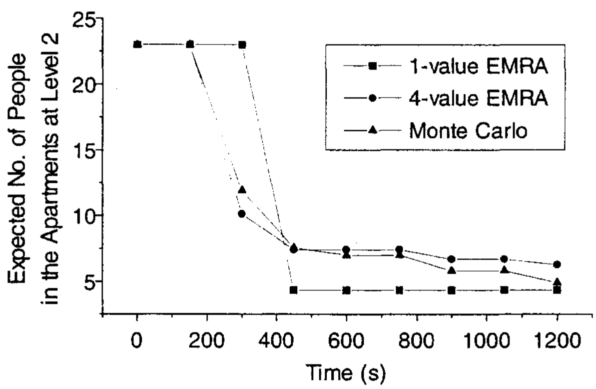

Figure 7. Expected Number of People Remaining in the Apartments at Level 2 Versus Time

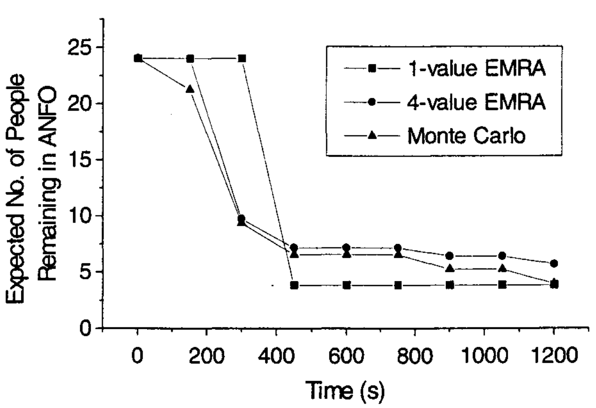

Figure 6. Expected Number of People Remaining in the Apartments of Non-Fire Origin versus Time

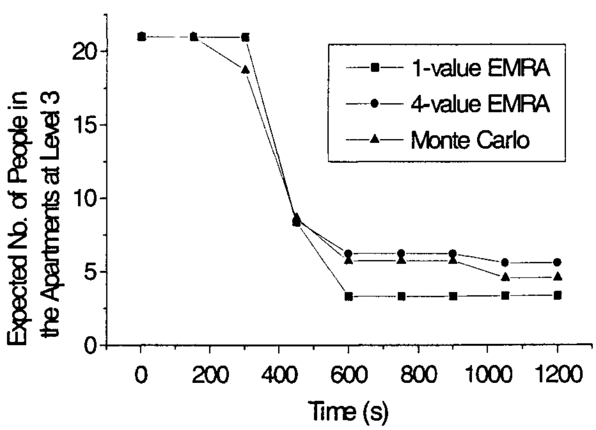

Figure 8. Expected Number of People Remaining in the Apartments at Level 3 Versus Time

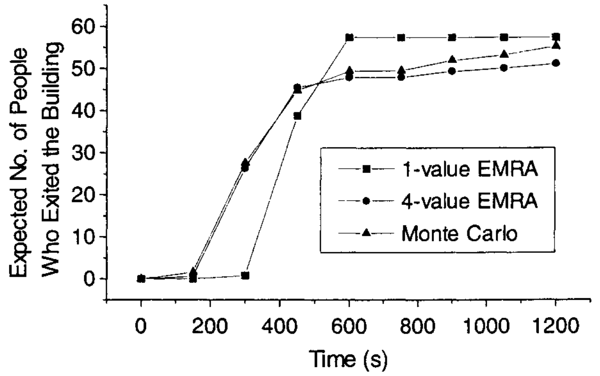

Figure 9. Expected Number of People Who Exited the Building Versus Time

has a moderate discrepancy compared with the Monte Carlo Simulation results, and gives a non-conservative prediction after 450 s.

The prediction of the expected number of people who exited the building at any given time is an important measure of the overall performance of the results. As shown in Fig. 9, the prediction by the 4-value EMRA approach gives excellent agreement with the Monte Carlo Simulation results up to 900 s, and good agreement and conservative results thereafter. The prediction by the 1-value EMRA gives conservative results for the first 500 s and non-conservative results thereafter, and large discrepancies exist compared with the Monte Carlo Simulation results at 200 s to 800 s.

Conclusions and Recommendations

The main purpose of developing the Expected Multi-Response Approach is to save computational time. The computational times for the three-story building for the three solutions, namely, 1-value EMRA, 4-value EMRA and Monte Carlo Simulation (1000 runs) solutions, were 1.2, 2.2 and 221.4 s, respectively. Thus, in the Risk Assessment Method where hundreds or thousands of scenarios are considered, the difference in the overall computational time by using the 1-value EMRA and 4-value EMRA is not significant, while savings over the Monte Carlo Simulation for either of the Expected Multi-Response Approaches is enormous. Since the results indicate that the 4-value EMRA is superior to the 1-value EMRA, the 4-value EMRA is, therefore, preferred over the 1-value EMRA.

A computer code developed using this approach has been validated against both hand calculation and EVACNET+. The results indicate that the present code predicted an almost exact solutions as the prediction given by EVACNET+, and about 25% higher than the hand calculation result using a hydraulic flow method. Unlike EVACNET+, this code can take into account various times of cues and delay times which are perhaps the most significant components in evacuations of many types of buildings.

An example of using this Expected Multi-Response Approach was given for an apartment building with an expected population from the Australian Bureau of Statistics. The study compares the human response and evacuation phase only, that is, the number of people in each location at any given time. Further work is required to compare the expected number of deaths in order to use the Expected Multi-Response Approach for the prediction of fire risk in buildings. This will involve the integration of fire growth and smoke spread into the present computer code which will be the subject of further research within the Centre.

Nomenclature

d	Density (persons/m^2)
d_c	Actual density
F	Flow capacity (persons/s)
F_c	Actual flow capacity
n	Number of cues
N	Number of people
N_e	Expected number of people in all expected response subgroups
P_{cue}	Probability of occurrence of a cue
P_{res}	Probability of occupant response to a cue
S	Speed (m/s)
x	Number of representative points for a distributional variable

Abbreviations

AFO	Apartment of fire origin
ANFO	All apartments on the fire floor except the fire apartment
ERA	Expected Response Approach
EMRA	Expected Multi-Response Approach
OG	Occupant Group
RAM	Risk Assessment Method
RT	Response Time

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