THE BENEFITS OF THE APPLICATION OF A "MONTE CARLO" METHODOLOGY TO EVACUATION MODELLING

Simon J Ham Architect MIFireE

Fire Safety Engineering Consultants Ltd.
Lincoln, UK
e-mail: simonham@fisec.co.uk

ABSTRACT

This paper compares FDS+Evac to a Ball Bearing model. It looks at behavioural aspects of escape modelling and examines the justification for integrating randomly generated numbers either as part of a Monte Carlo approach or more generally within an escape model

INTRODUCTION

It is important to recognise that aspects and components of a model as sophisticated as FDS+Evac are heterogeneous (diverse in character) rather than homogeneous (all of the same kind).

To illustrate the point I have chosen to look at the integration of the the EVAC model with FDS and to consider the Monte Carlo approach which is considered by some escape modellers to provide a means of resolving issues relating to human behaviour.

The principal merit of 'Evac' is the fact that it integrates issues of escape with the development of a fire. As a practising engineer I would use the model where a naïve enforcing authority wishes to see a graphic representation of the manner of escape. However my preference would be to always use a 'ball bearing' flow model as I consider that it is 'good enough to characterise the escape potential for a built form.

THE MONTE CARLO APPROACH

The following is an abbreviated version of the Wikipedia entry which explains what is meant by a Monte Carlo approach (I appreciate that academics will cry foul at my citing this but not being a mathematician I have included this for those who wish to know a bit about the basics. People wishing to know more can look it up and follow up on the references).

"Monte Carlo methods vary, but tend to follow a particular pattern:

1. Define a domain of possible inputs.
2. Generate inputs randomly from a probability distribution over the domain.
3. Perform a deterministic computation on the inputs.
4. Aggregate the results.

There is no consensus on how *Monte Carlo* should be defined. One statistician suggests that a simulation is a fictitious representation of reality. A Monte Carlo method is a technique that can be used to solve a mathematical or statistical problem. A Monte Carlo simulation uses repeated sampling to determine the properties of some phenomenon. Examples:

- Drawing a pseudo-random uniform variable from the interval [0,1] can be used to simulate the tossing of a coin: If the value is less than or equal to 0.50 designate the outcome as heads, but if the value is greater than 0.50 designate the outcome as tails. This is a simulation, but not a Monte Carlo simulation.

- The area of an irregular figure inscribed in a unit square can be determined by throwing darts at the square and computing the ratio of hits within the irregular figure to the total number of darts thrown. This is a Monte Carlo method of determining area, but not a simulation.

- Drawing a large number of pseudo-random uniform variables from the interval [0,1], and assigning values less than or equal to 0.50 as heads and greater than 0.50 as tails, is a Monte Carlo simulation of the behaviour of repeatedly tossing a coin."

Whilst a Monte Carlo approach within an escape model may be useful in defining the degree to which some factors influence the ability to escape, it becomes unrepresentative and therefore less useful when it considers that the range of people's behaviour may also be defined in this way.

Treating the occupants of a building like a bunch of headless chickens will not provide much insight into the behaviour of people under fire conditions.

HUMAN BEHAVIOUR

We know quite a lot about human behaviour under fire conditions: difficulties arise however when attempts are made to integrate this into an escape model.

Characterising people is extremely difficult as there is little consistency about people. Individuals vary in size, age, education, intelligence, knowledge, training , abilities and state of well being, Their state of well being may be affected by health, alcohol and other drug intake. Groups of people are inconsistent in their make up. It is recognised that these factors fall within a range which is capable of definition and statistical analysis.

The mass movement of people is neither random nor consistent, but responds to a range of external and internal group stimuli.

There are however some important principles, mostly addressed in the book "Fires and human behaviour"[5],

In no particular order, people:

> do not panic in a fire;

> do not behave irrationally except when they have a mental handicap;

> are forced to respond to a developing situation often with only limited information available to them;

> unfamiliar with a building will usually attempt to leave using the means by which they entered;

> losing normal visual references may become confused;

> have an instinct for survival;

> separated from family members instinctively seek to regroup;[6]

> respond better to simple verbal or visual messages than alarm sounders;

> respond quickly to an imminent and obvious threat, by which time it may be too late;

> are more reticent to evacuate when they are dining;[4&7]

> are strongly influenced by others around them.

Unlike smoke and fire, which respond to established physical and chemical laws, people do not respond to any given situation in a consistent manner and there are no established scientific theories, principles or laws which can be seen to govern this.

FDS + EVAC

FDS + Evac Technical Reference and Users Guide[8]clearly states its uses and limitations. It is a research tool. It is not an engineering tool yet, although it may have ambitions in that respect.

The model effectively utilises a more sophisticated ball-bearing, the dimensions of which vary within limits. The developers recognise the existence of a gathering phase before evacuation but have not currently incorporated it. The model utilises a simple logical exit selection process based on familiarity and the visibility of exits. This is influenced by the fire. Although the model allows a familiarity factor to be defined by the user, it also has a facility to incorporate a randomly generated familiarity factor. The model takes into account the physiological effects of the fire on the people.

There is an implicit assumption which is unlikely to be true, that the fire development time as calculated by FDS and escape time as calculated by Evac, are the same and synchronised.

Queueing time (congestion time) is not yet implemented. Body diameters and walking speeds are selected randomly from within uniform distribution limits.

It has been suggested that the Evac component might be extended to doors being opened and shut.

Randomly generating parameters within FDS+Evac will make the results less useful for comparing the performance of identical situations.

Influencing the fire model by having people opening and closing doors seems an inappropriate extension for Evac as decisions in this respect are easily implemented with FDS.

The use of a gimmick of this kind may look neat and help to create an illusion of reality. It does not mean it is desirable.

The randomising of physical characteristics in no way means that any population generated will be particularly representative. Using a probability factor and thereby weighting preferred exits randomly does not appear to be a particularly valid approach.

The FDS+Evac technical reference paper refers to the the use of Monte Carlo simulations under the heading 'Human Parameter Sensitivity' . It advocates the use of the technique as a means of examining the influence of physical characteristics and group interactions and not as a means of quantifying human behaviour. It suggests that the technique may be used to define the relative importance of a variation of the basic parameters to produce a series of rank correlation coefficients. This is satisfactory as far as it goes but other modellers have extended the use of Monte Carlo simulations into behavioural aspects of escape. Evac should avoid the pitfalls of such an extension.

BALL BEARING FLOW MODEL
There is probably a proper scientific term for a ball bearing model but I have been unable to locate it. What I mean by a 'ball bearing' model is representing people as if they were ball bearings who escape from a building on the basis of simple flow equations based on a standardised population, the speed at which they move is limited by their flow rate through openings or other obstructions.

This type of model takes no account of human behaviour and is used to characterise the form and configuration of the building and not the people. In effect this type of model will not produce results on how long it would take people to actually evacuate a building but indicates instead the buildings potential for evacuation.

Whilst not reflecting real escape times, it might be considered that under ideal conditions, the greater the number of people the model predicts will be able to evacuate to a place of safety in a limited time the greater the number of people who might be able to evacuate under fire conditions.

The rate at which the people can evacuate a building in this type of model is largely based on the restrictions arising from congested flow. As well as being used to evaluate stairway capabilities the technique can be extended to evaluate flow within a floor.

In the case of stairways it assumes that the population will flow through restrictions (storey exits) at the start of the evacuation process. It does not take into account the time it will take for people to reach the storey exit or any group gathering time. It assumes that flow through a floor exit starts immediately and there are sufficient people in close proximity to a floor exit to maintain flow into the stairway. Whilst it is recognised that gathering times may have a

significant influence on real times for escape, this and other factors such as 'arching' within crowds at a restriction are not considered in this type of model.

Despite it's limitations an unsophisticated version of this type of model does form the basis for acceptability of stairway sizes within the guidance in support of the England and Wales, the Scottish and Irish (both Northern Ireland and the Irish Republic) Building Regulations[1] as well as a significant number of other countries who have adopted it.

The size of a stairway is initially based on a set of acceptable minimum width criteria and then based on the formula

$$w = [P + 15n - 15]/[150 + 50n] \quad (1)$$

where:
w is the width of the stair in metres,
P is the number of people, and
n is the number of storeys served

This equation was derived from the the formula represented in Table 2 of the GLC code of practice for buildings[2] not exceeding 30 metres in height.

In my capacity as an advisor to Government on Building Regulations, I had a great deal of difficulty persuading administrators to incorporate the formula in the Approved Document in addition to the tables derived from it. The administrators considered that users of the document would struggle with its complexity.

The formula includes a component which evaluates the standing capacity s of the staircase as:

$$s = 50[w - 0.3] \quad (2)$$

Building Research Current Paper 96/75[3] suggested that this formula by lacking a w^2 term makes less allowance for the standing capacity of the landing for staircases wider than 2 metres preferring the expression:

$$s = 18w + 14w^2 \quad (3)$$

This equation assumes that the number of people who can be accommodated on stairways and landings is 3.5 persons/m², the slope of the stair is 30° and the floor to floor height is a consistent 3 metres.

The equation also assumes that the population of a building is evenly distributed on all floors, that the stairways are conventional 'doglegs' with a landing and half landing for each storey level each twice the

width of the stairway and a storey height of 3 metres. This was typical of office buildings in London at the time it was derived. The equation utilises what can only be described as the conventional time limit for people to either enter a protected stairway or exit the building of 2.5 minutes - one of the 'magic' numbers of fire safety.
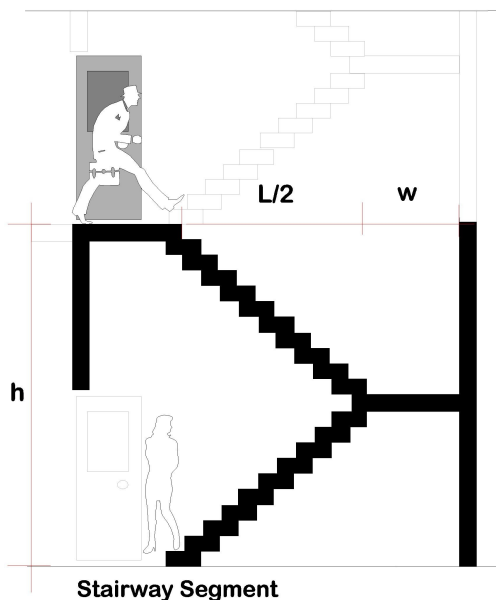
Another factor that is not fully addressed in the equation is the manner in which populations merge, as this can have a significant influence on potential escape times.

It is useful to consider three possible scenarios when two equal groups, A & B, merge. If group A blocks group B the the whole of group A will leave first with group B following on. The reverse is also true with group B blocking group A. However the more civilised way will be if the groups merge on a 1 for 1 basis so that the emerging group is a complete mixture. However this has implications for any stairway model serving a number of floors because the only place where the population leaving the floor to enter the stairway merge on a one for one basis is on the lowest floor. The rate of entry into a stairway on an upper floor is slowed in proportion to the number of mergers that occur below.

By adopting the same general principles a more flexible modified approach can be developed using a series of simple equations a zone model can be developed, using a standard spreadsheet, better tuned to reflect the buildings, population distribution, use and form.

As part of this a stair is considered as being made up of a series of discrete segments.

Each stair segment has an entry point where people enter from a floor and an exit where the people either pass into the the next stair segment or the landing for a final exit. The final exit segment is a special case whose characteristics are defined by whether people on the final exit level exit by means of the stairway or whether the exit also serves people ascending from lower levels.

Similar principles can be applied to deal with basement stairways.

For a stairway serving upper floor levels a segment has two potential states, congested or uncongested.

A segment is uncongested when there is nobody entering the segment from a level above and the segment has not reached its standing capacity.

Figure 1: A single stair segment

Once congested, a segment will return to an uncongested state when there are no further people to pass through it from above and no people entering into the stairway on a lower level.

In an uncongested state the rate of flow of people into a stairway segment will be controlled by the storey exit width.

In a congested state the rate of flow in a stair segment will be controlled by the stair width(s) or the final exit width, depending which is the narrower and the number of segments serving floors where people continue to enter below.

Using the values:

> 80 persons/metre width/minute as the rate at which people flow through a restriction,
> 3.5 persons/m² as the density of people on the stairway,
> 30° as the angle of pitch of the stairway.

The standing capacity of a stair segment

$$C_s \approx [1.732h + 2w] \times 7w \quad (4)$$

The time taken to fill the stair segment

$$F_s = C_s/w \times 80 \quad (5)$$

Stairway Segment

Rate of evacuation of a stair segment

Es = [80 x w]/ [1 + no of segments where a floor exit is discharging into the stairway below]   (6)

This equation can be utilised to fine tune the time at which the total population of a floor will have completely discharged into the stairway.

In its simplest form the model (rather than considering all stair segments individually) may treat the rate of discharge of a stair segment as either the rate of discharge of the lowest segment or the rate of discharge through the final exit from the building, depending on the configuration of the final exit level.

The rate of discharge into a stairway at a floor exit is the lesser of either the rate of evacuation of the stair segment or the rate of discharge through the floor exit.

These simple equations can be built into a very sophisticated escape model using a spreadsheet.

Floor level		units	5	4	3	2	1	Exit level
Population of floor	P	No	200	200	200	400	500	200
Floor exit width	e	M	1.10	1.20	1.20	1.80	3.60	1.20
Final exit width		M						5.00
Stair width	w	M	1.20	1.50	1.50	2.00	5.00	
Floor to floor height	h	M	2.80	2.80	3.00	4.00	6.00	
Rate of discharge through floor exit		People/minute	88	96	96	144	288	96
Standing capacity of stair segment		No	60	82	86	152	713	21
Time to fill stair segment		Mins	0.682	0.854	0.896	1.056	2.476	0.219
Time for stair segment to become congested		Mins	0.682	0.682	0.854	0.896	1.056	0.219
No to escape into segment before it becomes congested		No	60	65	82	129	304	21
No yet to discharge into segment		No	140	135	118	271	196	179
rate of discharge through final exit		P/mins						400
rate of discharge down stairway		P/mins						400
number of people to evacuate through segment after congestion		No	140	275	393	664	860	1039
Time to evacuate after congestion		Mins	0.350	0.688	0.983	1.660	2.150	2.598
Total time to evacuate		Mins	1.032	1.369	1.837	2.556	3.206	2.816

Figure 2: A simple escape stair model

Other values for rates of discharge through an opening, and/or density of people on a stairway, may be substituted if considered appropriate. As examples, the flow rate through through a restriction could be modified, if considered appropriate, for basement stairways or variations due to cultural differences based on local research as to actual flow rates and densities.

Complexity arises not from the incorporation of the basic equations, but from the logic operators that define when a segment clears and its influence on segments above.

The results of a model like this will give a reasonable representation of the escape potential for a building. By using standardised criteria the performance of one building may be directly compared with another and an equivalent level of performance may be defined by Regulators.

COMPARISON BETWEEN FDS+EVAC AND A BALL BEARING MODEL
Although the common measurement of performance for both models is based on time these times are not syncronised.

Neither model endeavours to define actual evacuation times.

A potential benefit for using a standard crowd density as opposed to a series of randomly generated body shapes is that, providing the figure for crowd density has been accurately defined and measured, it tends to be self regulating for variations in physical shape two small children perhaps occupying a similar area to a fat adult for example. The establishment of a set relevant figures for differing building types is an area that would benefit from further research.

FDS+Evac	Ball Bearing model
integrates an escape model with a fire model	No fire model component
Utilises a series of randomly generated body shapes	Utilises a standard crowd density parameter based on established data
Takes no account of group gathering times but the developers are moving towards integrating this	Takes no account of group gathering times
Evaluates movement based on decision making parameters	Takes no account of decision making
Ignores queuing or congestion.	Is largely controlled by congestion
Scant regard for human behaviour	No regard for human behaviour

Figure 3: Table comparing FDS+Evac to a ball bearing model.

CONCLUSIONS

The sophistication of a modelling technique is not necessarily a reflection of its accuracy, relevance or usefulness.

The random nature of a Monte Carlo technique generally makes it an inappropriate tool for modelling human behaviour in escape models

The Monte Carlo approach can be used to establishing the criticality of some criteria.

FDS+Evac is a useful tool for looking at issues related to means of escape especially on a fire floor.

FDS+Evac provides a useful handle on potential interactions between the people within the building

and a potential fire. It is not a fire engineering design tool but may be utilised to illustrate potential escape problems.

In setting performance standards for buildings simple ball bearing type models can provide sufficient sophistication.

The ball bearing type methodology currently in use in the UK and some other counties would benefit from further refinement.

A model that looks real may be an illusion. This may apply to both a fire model and an escape model.

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