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DEFINING A CROWD SAFETY FACTOR FOR THE DESIGNS OF ASSEMBLIES

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ABSTRACT

This paper promotes the discussion on how to minimize escape times considering the Relative Distance Between Exits (RDBE) as a "Crowd Factor" for the designs of assemblies. This study suggests that the exits' locations have an important impact for highly dense places. In order to investigate this further, this paper explores scenarios representing an assembly environment. For this purpose, People Movement Modelling Analysis (PeMMA) is performed. The results obtained from PeMMA are presented and discussed in this paper. It is expected that this study can bring some additional light to the subjects related to crowd safety and management in general as well as to the use of People Movement (PM) models for this objective.

1.0 INTRODUCTION

Events involving crowds and crowded enclosures have been present in our lives since remote times. History shows that: Mesopotamia and the great ancient Egyptian civilization where events with crowds were present in their cultures; the old Greek civilization where the Ancient Olympic Games started and the Roman Empire, well- known for its coliseums which attracted crowds. In modern times, events involving crowds and crowded enclosures are still present in our daily lives. For instance, contemporary Carnivals of different societies within the globe, music festivals, religious and sport events and many others prove the popularity of crowded places, both open and enclosed spaces.

Nowadays, according to their natures (i.e., the activity involved and the public attending), these events and enclosures can be classified into four main types, namely:
i) Sports;
ii) Entertainment/Music;
iii) Religion;
iv) Politics.
And according to where they take place, these events can be classified as:
i) Enclosed space (when they take place in specific venues, such as stadia, assembly halls, theatres etc.);
ii) Open space (when they take place in urban areas, such as streets, parks, plazas etc.).

Independently from their nature and where they take place, events involving crowds and crowded enclosures must be well planned and designed for assessing and consequently providing people's safety.

This can be said because over many years, the world has witnessed tragedies involving crowds. These tragedies have caused direct and indirect losses.

These losses when analyzed in terms of the number of fatalities (and/or number of injuries) are a crucial issue to be addressed by the local authorities. Table 1 presents data regarding the number of fatalities and injuries associated with tragedies involving crowds.

From Table 1 becomes clear to see the importance of planning and designing any venue (both enclosures and events in open spaces) where there will be crowd.

In reality, safety engineers (which can include fire safety/protection engineers) as well as designers in general are starting to recognize the real need to consider crowd safety as one of the main design factors; which will include crowd management. For instance, People Movement (PM) models are starting to be used when planning any event involving crowds and/or designing any highly dense populated enclosure.

Table 1: Number of fatalities and injuries in events involving crowds around the world.

Event	Number of Fatalities	Number of Injuries
Joseph Stalin's funeral procession (1953 in Moscow, Russia)	Hundreds (possibly thousands)	Hundreds
Rock music concert at the Ohio Coliseum (1979 in Cincinnati, USA)	11	Unknown
Football match at the Athens stadium (1981 in Athens, Greece)	24	Unknown (possibly hundreds)
Football match at the Moscow´s Lenin stadium (1982 in Moscow, Russia)	340	Unknown
Hindu pilgrimage in Hardwar, India (1986)	46	Unknown
Football match at the Hillsborough stadium (1989 in Sheffield, UK)	94	174
muslim annual pilgrimage at Mecca (1990 in Mecca, Saudi Arabia)	1426	Hundreds (possibly thousands)
Love Parade disaster (2010 in Duisburg, Germany)	21	More than 500

2.0 PEOPLE MOVEMENT (PM) MODELS

Computational simulation models which represent people's movement under emergency conditions (i.e., fires, earthquakes, flooding, bomb threats etc.) and non-emergency situations (i.e., circulation of people, urban planning etc.) have been developed largely over the last two decades. Considering their *state-of-the-art* concept, these models are still commonly called as models, egress models, crowd simulation models etc. These models can simply be designated as People Movement (PM) models, since this is what they do: they model people movement.

The PM models can be used in a wide field of applications, such as: fire safety engineering; circulation of people in open and enclosed environments; risk analysis in major events involving crowds (i.e., crowd management and crowd safety); studies on human behaviour during emergency situations etc. Figure 1 summarizes the applications for PM models.

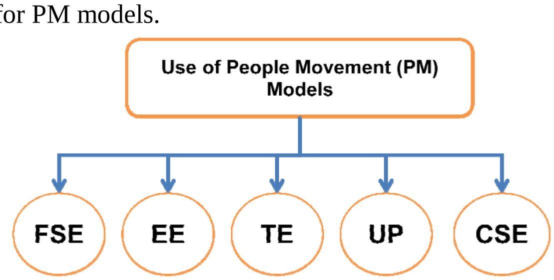

Figure 1: Examples of applications for PM models

In Figure 1, the acronyms mean:
- FSE: Fire Safety Engineering;
- EE: Earthquake Engineering;
- TE: Transportation Engineering;
- UP: Urban Planning;
- CSE: Crowd Safety Engineering.

2.1 The history behind the development of PM models

Nowadays, there are many PM models available; in fact, there are currently more than 40 PM models.

These models take into account not only the physical attributes of the occupants, but also their psychological attributes (i.e., competitive behaviour, response time etc.). Some well-known PM models are continually updated and improved to take into account new research in the field.

PM models were initially developed within the Fire Safety Engineering field for helping fire safety/protection engineers to develop their fire safety strategies based on performance-based approaches (i.e., fire engineering solutions). Indeed: "Designers and regulators are consequently turning to performance-based analysis and regulations facilitated by the new generation of people movement models" **[1].**

For instance, under this perspective, the concepts of ASET and RSET were introduced in the British Standards (BS) 7974 '*The application of fire safety engineering principles to fire safety design of buildings*' part 6 **[2]**. In section 6.7.2 of this document, it states:

"*To ensure the safety of the occupants of a building, it is necessary to establish that they are able to reach a place of safety before untenable conditions occur. The time necessary for evacuation of the occupants to a place of safety will depend on a number of factors relating to the occupants, the building and the rate at which the fire gives rise to untenable conditions. The aim is to ensure that all persons can leave a threatened part of a building in reasonable safety without assistance and the aim is generally to ensure that the time available for escape is greater than the time required for escape":*

$$ASET > RSET$$

Where:
ASET is the Available Safe Egress Time (before untenable conditions occur);
RSET is the Required Safe Egress Time.

It is possible to get a reasonable good estimation of the RSET in simple geometries (i.e., relatively low populated buildings and/or small buildings) by using the hand calculation approach suggested in this document. However, in highly populated enclosures and complex geometries, the interaction between the occupants potentially produces significant areas of congestion. For this reason, alternative methods of calculation should be considered, such as the use of computational simulation models which represent people movement: PM models. This discussion on the use of PM models within the Fire Safety Engineering field is better explored in other studies **[3-9]**; and for this reason it will not be explored in depth in this paper.

The main advantage of PM models is that they take into account the occupants' Interactions (i.e., congestions; decision-makings etc.). Besides that, most PM models allow to graphically present the information with little ''avatars'' moving around the space that resembles considerably the real environment. This helps immensely the understanding of how people move within a specific structure under emergency conditions and also non-emergency situations. For example, their appropriate use **[4]** can help designers to improve people's flow rate (i.e., elimination and/or reduce of congestions, bottlenecks, queues etc.).

More important than their sophisticated features and capabilities, the way they are used is a core-aspect **[4]**. The science behind these models is described as pedestrian dynamics and there are some websites dedicated to discuss about this topic **[10]**.

2.2 The concept of PeMMA – People Movement Modelling Analysis

The analysis before, during and after the use of any PM model should follow a logical and reasonable set of steps: (i) appropriate use of the PM model; (ii) accurate analysis of the results from the simulations; (iii) proposition of feasible and intelligent design solutions based on the PM modelling analysis.

Furthermore, People Movement Modelling Analysis (PeMMA) should be always considered. It is not only the use of the PM model itself, but the way the results are understood and analyzed which will be fundamental for assessing and addressing crowd safety.

For instance, PeMMA can include the following skills:

a) For Emergency situations:

- Simulation modelling analysis combined with fire modelling analysis (when necessary);
- Estimation of RSET (Required Safe Egress Time), considering detection times, pre-movement times etc;
- Evaluation of stairs, corridors and pedestrian tunnels widths based on their capacity in terms of occupants' flow rate for different types of scenarios and occupants' bodies and mobility;
- General investigation of deviations from the building regulation codes (i.e., travel maximum distances; maximum number of persons permitted etc.) for developing performance-based solutions.

In summary, for emergency situations, the PM models can be used for estimating the time for people to escape safely from events such as fires, terrorist attacks (i.e., bomb-treats), earthquakes, floods, hurricanes etc.

b) For Non-Emergency situations:

- Maximization of the floor area usage by people;
- Analysis of the lay-out impact on people's circulation;
- Minimization/Maximization of the time to be taken by people to move within specific areas;
- Improvements of people's flow rate (elimination and/or reduce of congestions, bottlenecks, queues etc.).

For both situations, PeMMA is capable to investigate people movement in open spaces and enclosures, for highly or lowly dense populated scenarios.

The aim of PeMMA is to address crowd safety (and comfort) in different complex scenarios: from high-tall buildings to large highly dense populated underground stations.

PeMMA can help immensely the understanding of how people move within a specific structure under emergency conditions and non-emergency situations. PeMMA can also be incorporated within the whole management strategy package, i.e., crowd management. For example, some of the benefits of PeMMA can be:

- enhanced life safety;
- avoidance of disruption (i.e., avoidance of business losses);
- building value (i.e., future sale) for enclosures;
- cost savings elsewhere in the building design and/or event planning;
- greater design freedom.

The concept of PeMMA is discussed in details in other studies developed by the author **[8,9]**.

In the next section, the scenarios which investigated using PM models are presented.

3.0 THE SCENARIOS

The scenarios investigated represented a typical assembly environment: a music concert hall/space. A summary of these scenarios is shown in Table 2.

As it is possible to see, in all of these three scenarios, the population density is high:

- For Scenario 1, the population density is 2.565 p/m^2.
- For Scenario 2, the population density is 1.5375 p/m^2.
- For Scenario 3, the population density is 2.395p/m^2.

For each scenario, the exits were placed in different locations in order to investigate their impact on the escape performance of the occupants. In other words, with this, it was attempted to see how the RDBE would influence the escape efficiency. Figures 2, 3 and 4 show these scenarios.

Table 2: Summary of the scenarios used for PeMMA

Scenarios	Geometry	Number of Exits	Exit´s Widths	Number of People
Scenario 1	Squared space (20m X 20m)	Four	1m each	1026
Scenario 2	Squared space (40m X 40m)	Four	1m each	2460
Scenario 3	Squared space (40m X 40m)	One	2m	3832

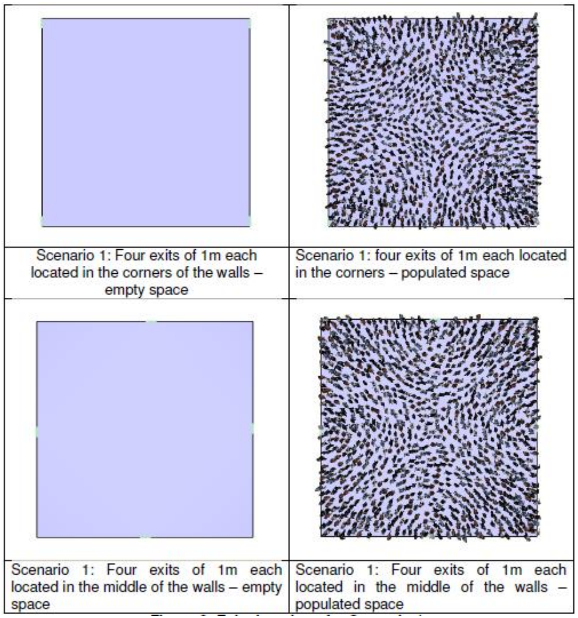

Figure 2: Exits´ locations for scenario 1

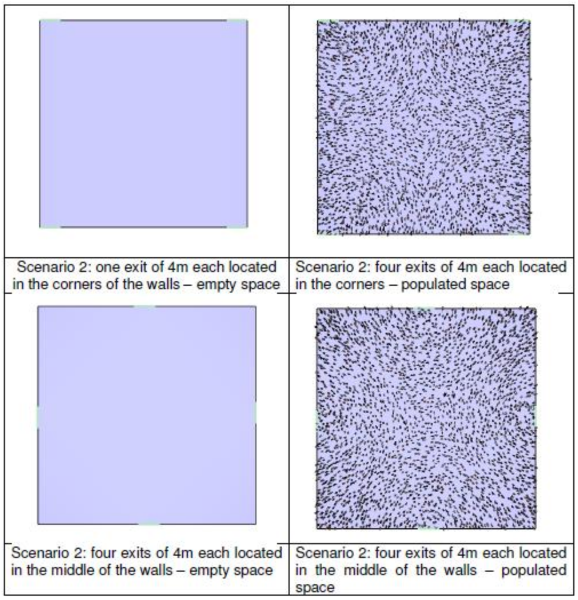

Figure 3: Exits´ locations for scenario 2

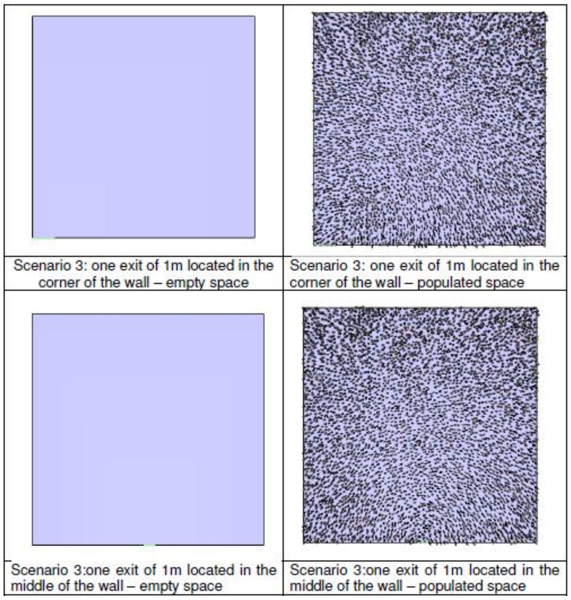

Figure 4: Exits´ locations for scenario 3

In the next section, the methodology for simulating these scenarios is discussed.

4.0 METHODOLOGY

The PM model used for performing the simulations was the Pathfinder **[11]**. There are few documents publicly available about this model **[12]** and therefore, this paper will not be discussing about the model *de per se*.

The basic parameters used for simulating the scenarios are described in the following lines.

The travel speed values adopted for the simulations followed a standard normal (Gaussian) distribution, having 1.3ms as the maximum travel speed and 0.8m/s as the minimum travel speed. With this, a heterogeneous population was considered for these simulations in order to represent realistically this type of scenario (i.e., music concert hall/space).

All the occupants ran to the nearest exit and were allowed to overtake those which were slower.

Considering also that the main purpose of this study was to investigate the interaction between people-structure, there was no delay time inserted into the model. Indeed, psychological factors were not the main concern for these scenarios, since all of them were highly populated. For this reason, people's movements were more driven in terms of physical rather than psychological aspects.

The results of these simulations are presented in the next section.

5.0 RESULTS AND DISCUSSION

The results obtained from PeMMA are shown in Table 3.

Table 3: Results obtained from PeMMA for all the scenarios

Scenarios	Exits´ Locations	Escape Times
Scenario 1	Exits located in the corners of the walls	164.78sec
	Exits located in the middle of the walls	215.73sec
Scenario 2	Exits located in the corners of the walls	96.48sec
	Exits located in the middle of the walls	104.38sec
Scenario 3	Exit located in the corners of the wall	563.33sec
	Exit located in the middle of the wall	1234.33sec

As it is possible to see, the RDBE does have a substantial impact on the people's escape performance. In reality, the "corner effect" observed in previous studies becomes more evident for high dense populated environments. With these simulations, becomes clear how its influence increases proportionally to the increase of the population density.

For example, for scenarios 1 and 2, where the population density were higher than 2, the difference between the lower and the upper escape times were higher than 30%. In fact, for scenario 3, where the complexity of the scenario also increased (since there was only one exit, constrained even more people's movement flexibility), the difference between the lower and the upper escape times was higher than 100%.

These results reveal that the way people's safety should be addressed in Crowd Safety is not necessarily the same as the way it is addressed in Fire Safety. For example, within the fire safety context, the escape time is generally thought to be (not considering human behaviour factors) a function almost exclusively dependent on the time to travel towards the exit(s). This is probably why the travel distances required in the fire safety codes is such a big concern when developing fire safety strategies.

Nevertheless, for the crowd safety context, this is not the case, since the population density is a major factor and therefore, the time spent during the congestions is a bigger issue than the time spent during the movement towards them exit(s).

For instance, for typical scenarios, such as those shown in section 3 of this paper, it is “common sense” to think that the best place to locate exit(s) would be in the middle of the wall(s), since it is more visible for the occupants. This type of understanding is also probably influenced by the fire safety codes, which do emphasize the maximum travel distance as core-factor for assessing people´s safety. Figure 5 illustrates this.

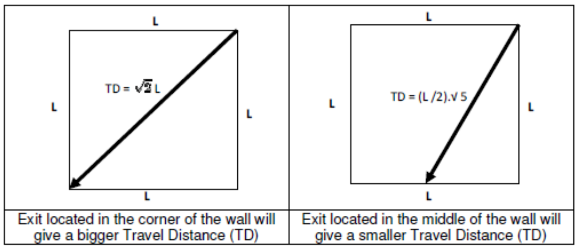

Fig. 5 Comparisons between Travel Distances for different Exits´ locations

As it is possible to see in Figure 5, for this space (no matter if it is open or enclosed), the TD when the exit is located in the corner of the wall will be bigger (i.e., approximately 1.41 times the length of the wall) than the TD when the exit is located in the middle of the wall (i.e., approximately 1.12 times the length of the wall).

Based on that, this is why the RDBE should always be considered when assessing crowd safety in open and enclosed spaces. Furthermore, the RDBE could be adopted as a crowd safety factor for designing assembly types of occupancies.

In the next section, some concluding remarks are presented.

6.0 CONCLUSIONS

This paper explored the influence of the positioning of exits on the escape performance of people within highly populated spaces. For this purpose, the investigated three scenarios which represented a music concert hall/space. These investigations were conducted through People Movement Modelling Analysis (PeMMA).
The results of the simulations revealed that the relative distance between exits (RDBE) does have a substantial impact on the escape performance of people in high dense places.

With these results were also observed that that the maximum travel distance values required to be used for fire safety code compliance does not necessarily produce the minimum escape times. In reality, more efficient escape performance (e.g., lower escape times) were found for scenarios in where the travel distances were bigger. This shows that the approach to be adopted for crowd safety should not be exactly the same as the one used for fire safety.

Additionally, it seems that the RDBE should be considered as a core crowd safety factor when assessing people’s safety in assemblies.

This paper has also demonstrated how the use of People Movement (PM) models can be extremely helpful for crowd safety and management in general.

It is expected that this paper can bring some additional light to the subjects related to crowd safety studies as well as the advantages of applying PM models for this objective.

7.0 ACKNOWLEDGMENTS

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