PRELIMINARY ANALYSIS OF THE NUMBER OF OCCUPANTS, FIRE GROWTH, DETECTION TIMES AND PRE-MOVEMENT TIMES FOR PROBABILISTIC RISK ASSESSMENT

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ABSTRACT

This paper describes work recently undertaken by scientists and engineers at Arup Fire in Leeds, University of Manchester, London Fire and Emergency Planning Authority and Southbank Univeristy into the stochastic aspects of fire in shops and commercial buildings. The work is based on data from the 'Real Fires Database' which includes more detailed data on fires than has traditionally been collected. New data on the number of people, fire growth rates, detection times and pre-movement times is presented and discussed. The potential for dependencies in and the limitations of the data are also discussed.

KEY WORDS

Fire report data, shops and commercial premises, number of people, fire growth, detection time, pre-movement time, dependencies, fire risk assessment

INTRODUCTION

The most stochastic aspects of fire safety have been challenging scientists, regulators and designers of buildings for many years [1][2][3]. These aspects include the rate of fire growth, the response of the building to fire and human behaviour in fire including the number of people and their pre-movement time…etc.

Many existing fire report forms do not contain detailed aspects of the timing of many events, the behaviour of the fire or the response of occupants. New data from detailed analysis of a relatively large number of fires the Real Fires Database has allowed further investigations to be made in to four aspects not covered in other general fire reports:

1. The number of people in the building when the fire broke out;
2. Fire growth rates;
3. Detection times and;
4. Pre-movement times of occupants.

DATA

Since 1996 the London Fire and Civil Defence Authority (now known as the London Fire and Emergency Planning Authority, LFEPA) has been undertaking detailed investigations of a much larger sample of fires than would be normal. They started the initiative so that they could to attempt to record the time basis of events which together describe the total history of each fire from pre-heating to fire extinction.

The detailed fire investigation protocols include:

- Fire scene plan details
- Fire spread analysis
- Smoke spread analysis
- Initiation and development analysis
- Fire suppression analysis
- Fire detection and warning response analysis
- Firefighting facilities analysis
- Occupant egress analysis
- Performance analysis

For example, the occupant egress form covers:

- Room/space of origin
- Elsewhere on floor of fire origin
- Above the floor of fire origin
- Below the floor of fire origin
- The number of occupants
- The evacuation strategy
- The number of stairs (protected and not protected)
- Number of occupants evacuated, assisted and rescued
- Time commenced and durations
- Number and types of injuries and fatalities

Much of the data is collected after the fire by follow up interviews with those present at the time of the fire.

The data is stored on the ‘Real Fires Database’. The analysis in this paper was carried out on over 5000 non-residential fires. The data has been reviewed by Southbank University and the relative proportions of sub-sets of the sample of fires in the real fires database was found to be consistent with the profile of fires reported in the UK as a whole.

Number of people in the building

The first stochastic aspect of fire safety occur before ignition, in terms of the number of people in the building. The guidance that support fire regulations usually prescribe the occupant floor factor for various building purpose groups. For this reason, shops and commercial premises are considered together as one purpose group.

To gain a more representative understanding of the nature of fire risk in buildings, it is necessary to be able to more explicitly understand the situation for a range of circumstances. To this end data on the floor area and number of occupants in the room of origin was analysed.

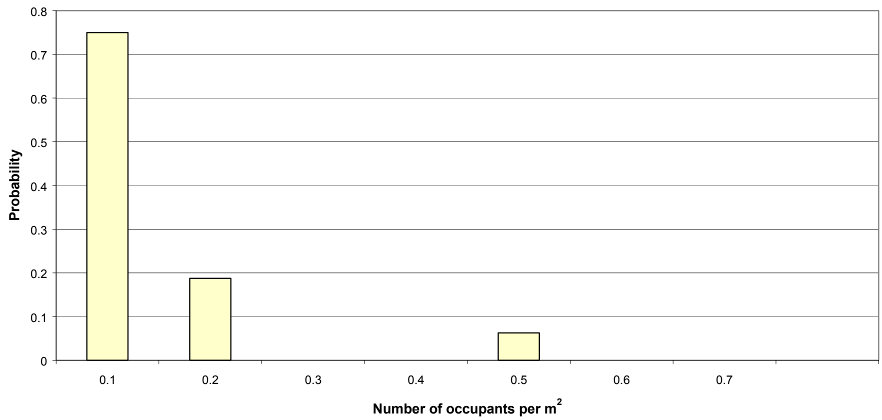

Figure 1Probability distributions for number of occupants per m² for shops and commercial premises

Figure 1 shows the occupant densities for a number of fires on the Real Fire Database. The results do not include the zero cases and so a relatively small number of fires (16) are involved. The small sample size also indicates the smaller numbers of fires occurring in some purpose groups (in this case shops and commercial premises) when people are present and information on their number is available. The graph shows that there are relatively few occupants in the room of origin in most fires, but that there may be a significantly long tail to the distribution. The results indicate how the design limits of 0.5 and 1.5 people per m^2 for shops and malls (respectively)[3] compare to those measured at the time of a fire.

Fire growth rates

For shops and commercial premises, the area of the fire when it was detected and when the fire brigade arrived was plotted against the respective times. This approach assumes that the fire is growing and in the growth stage in the few minutes it normally takes for the fire brigade to arrive. However, to counter any potential averaging of fire growth, a t^2 fire was fitted to the points and the worst case of alpha was taken by assuming an incubation period or by neglecting the point on the curve with lowest heat release.

Alpha was calculated using the formula:

$$\alpha = (q''A_f)/t^2$$

Where α = Fire growth rate (kJ/s^3)
q'' = Rate of heat release per unit area (kW/m^2)
A_f = Area of fire growth between discovery and fire brigade intervention (m^2)
t = Time between discovery and fire brigade intervention (s)

The value of q" for the various occupancies was taken from TM19 [4]. Therefore, equation (1) gives the fire growth rate for the fire based on the fire's sizes at discovery and fire brigade intervention and the amount of time between the two. Maximum time limits and the removal of outliers were used to avoid fires where fire growth ended before fire brigade intervention or fire growth occurred before discovery.

Alpha values were then grouped into the four main categories according to DD240 [5]:

Slow	0.0029 KJ/s^3
Medium	0.012 KJ/s^3
Fast	0.047 KJ/s^3
Ultra-fast:	0.188 KJ/s^3

This effectively rounded them up and once this was complete the probability distribution was plotted.

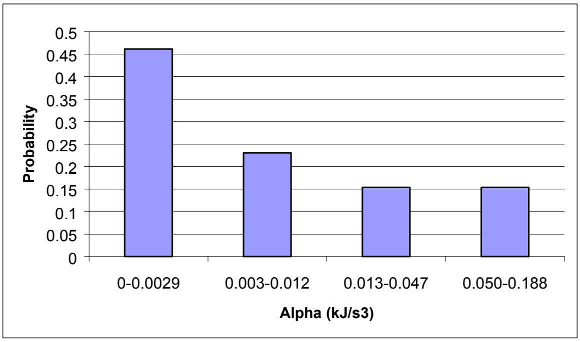

Figure 2 Shows the probability distribution of fire growth coefficients for shops and commercial premises

[Note: The two ultra-fast fire cases were in commercial cash and carry warehouses with high racked storage.]

Figure 2 shows the wide range of fire growth rates that can occur in shops and commercial premises in the 13 cases with data that could be analysed. The distribution also shows that, with the exception of high racked storage the fire growth rates observed were less than or equal to the fast fire growth rate and that the majority are likely to be slow or medium growing fires. Therefore, for general deterministic analysis, fast fire growth seems to be reasonable value, with ultra-fast fire growth for high volume storage areas with highly combustible materials. However, both of these values will produce significantly pessimistic results if used for probabilistic fire risk assessment.

Detection times

One of the other highly variable aspects of fire safety in buildings is detection time ie the interval between the time between ignition of a fire is given and the time at which the fire is detected. Detection times for automatic fire detection systems can be calculated, but methods for calculating detection time by people are limited.
For shops and commercial premises the detection time for each fire was selected and grouped according to their values in one-minute intervals and these were then plotted on a probability distribution.

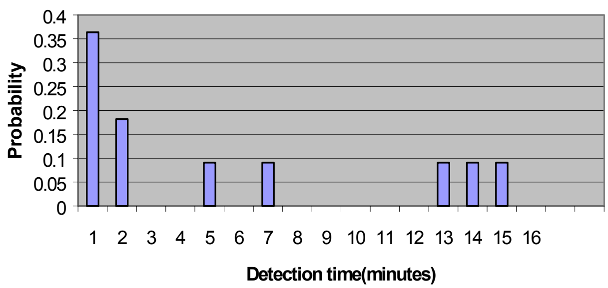

Figure 3 Shows the probability distribution of detection times from ignition (where that was known) for shops and commercial premises.

Figure 3 shows the probability distributions for 'exact time' to discovery from fire start for shops and commercial premises. 'Exact time' indicates where there is definite retrospective knowledge of the time of ignition and not simply a broad range of time in which ignition occurred (no other data was cleansed in this analysis). The distribution shows that of the eleven fires analysed, many are detected in the first few minutes and a rapidly decaying probability there after. The probability distribution shows an extended tail and these are almost always when there are no occupants (out of hours), no automatic fire detection (or auto-dial) or the fire does not spread beyond the item first ignited in an unoccupied building or part of a building.

Pre-movement time

Another highly variable aspect of fires in buildings is pre-movement time of the occupants ie 'the interval between the time at which a warning of fire is given and the time at which the first move is made towards an exit'. To gain a more representative understanding of the nature of fire risk in buildings, data on pre-movement time for shop and commercial buildings was analysed. Note warning time does not necessarily follow detection time in shops and commercial premises where an investigation period is built into the automatic fire detection and warning system.

Figure 4 shows the probability distribution for pre-movement times for 16 individuals in fires in shop/commercial buildings for people in all locations in the building. The results show that although most pre-movement times are relatively small ie about 80+% are 2 minutes or less, there are some outlying cases of 5 and 7 minutes. These are mainly for fires in other compartments/occupancies in the same building or where the fire was small and no threat was perceived.

Figure 5 shows the probability distribution for pre-movement times for seven fires in shops/commercial buildings for occupants in the compartment of fire origin. In this limited sample of seven fires, all of them are 2 minutes or below and this seems to indicate that the tail of the distribution of is more extended for occupants outside the compartment of fire origin.

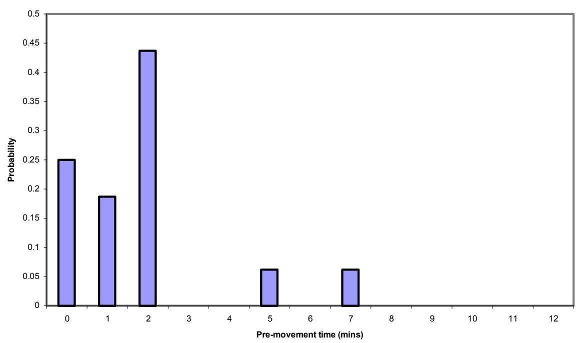

Figure 4. Probability distribution of pre-movement times for shops and commercial premises all locations in the building

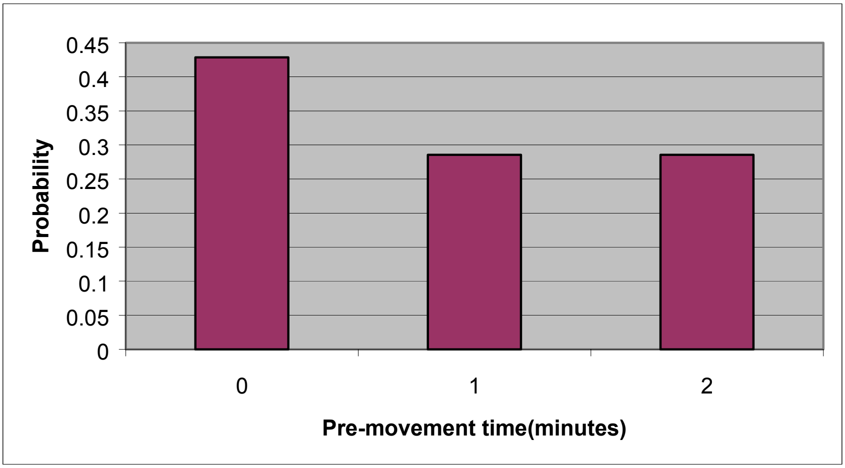

Figure 5 **Probability distribution of pre-movement times for shops and commercial premises in the room/space of fire origin**

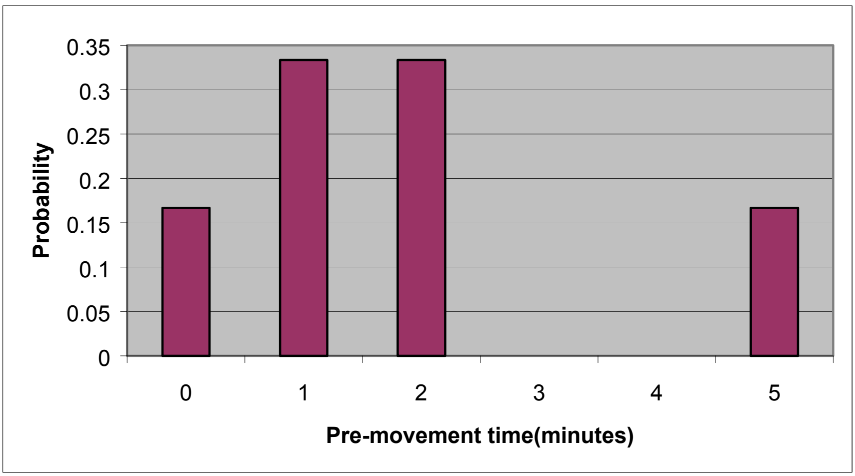

Figure 6. Probability distribution for pre-movement times for shops/commercial elsewhere on the floor of fire origin

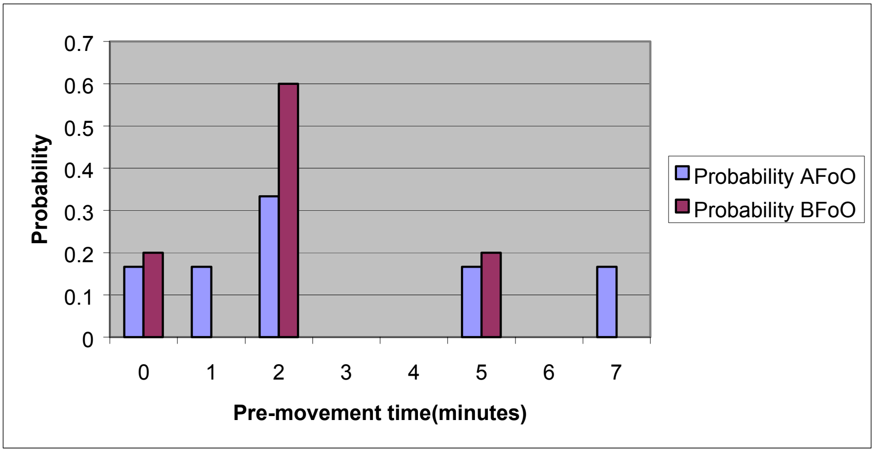

Figure 7. Probability distribution for pre-movement times for shops/commercial above (AfoO) and below (BfoO) the floor of fire origin.

Figure 6 and 7 show the probability distributions for the pre-movement times for occupants in floor of fire origin (but outside the room/space of fire origin) and for occupants in floors above and below the floor of fire origin in the building for six and 11 fires (respectively). This seems to indicate that where delayed (greater than 2 minutes) pre-movement times occur in compartments other than the compartment of fire origin. Future work should address other factors such as age, condition, level of fire training ...etc.

Some guidance[5] indicates that design values of pre-movement times for shops should be:

1.	Live directive messages	<2 minutes
2.	Pre-recorded messages	3 minutes
3.	Warning sounders	>6 minutes

Since the vast majority of shops still use warning sounders, the real fire data seems to indicate that the above values may be significantly pessimistic in the compartment of fire origin, but less so for adjacent areas.

DEPENDENCIES

The analysis so far has considered each probabilistic aspect as independent and most events are probably independent or only dependent in a minor way. This section shows some analysis to assess whether certain combinations of events or factors are independent.

There are six potential dependencies of which two are considered in this paper:

1. Fire growth rate and detection time
2. Population density and pre-movement time

Fire growth rate and detection time

Detection time may vary depending on many variables including fire growth rate, presence of people or automatic fire detection, geometry and ventilation of the space, visual access…etc. As approximately 90% of the fires were detected by observation, the data was analysed to see whether fire growth rate was important or not.

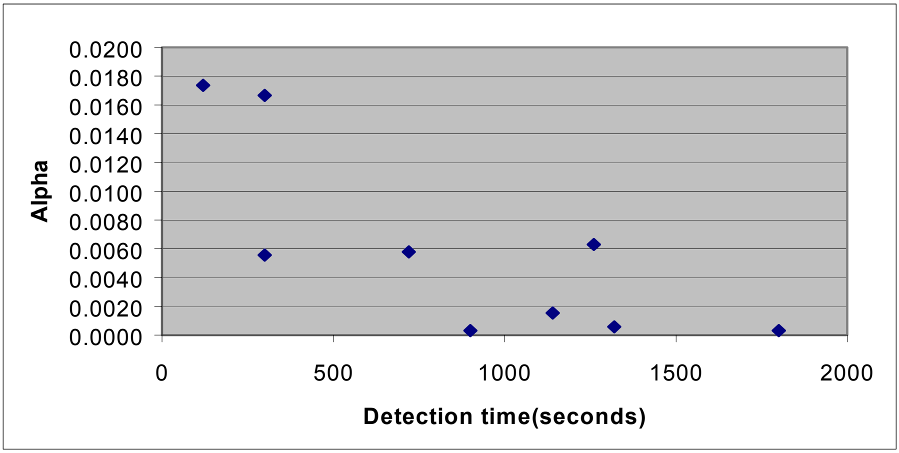

Figure 8. Correlation for fire growth coefficient against detection time for fires in shops and commercial premises

Figure 8 shows the scatter graph for the fire growth rate and detection time for 11 fires and does indicate a clear trend towards faster fire growth leading to quicker fire detection by occupants. So any fire risk assessment model should take this into account otherwise cases of fast fire growth with delayed detection will be over-predicted possibly leading to unreasonably pessimistic results and conclusions. This analysis of course does not include fires that were not reported to the fire service. This is likely to include many slow growing fires that were detected and extinguish early and this should be taken into account when interpreting Figure 8.

Population density and detection time

The scatter graph for Population density and detection time shows no evidence of the expected line between these two variables, however, this may be due to the relative small sample of data from 7 fires (See figure 9). In addition, population density may have less influence on detection time than whether the area of fire origin is populated or not in the first place.

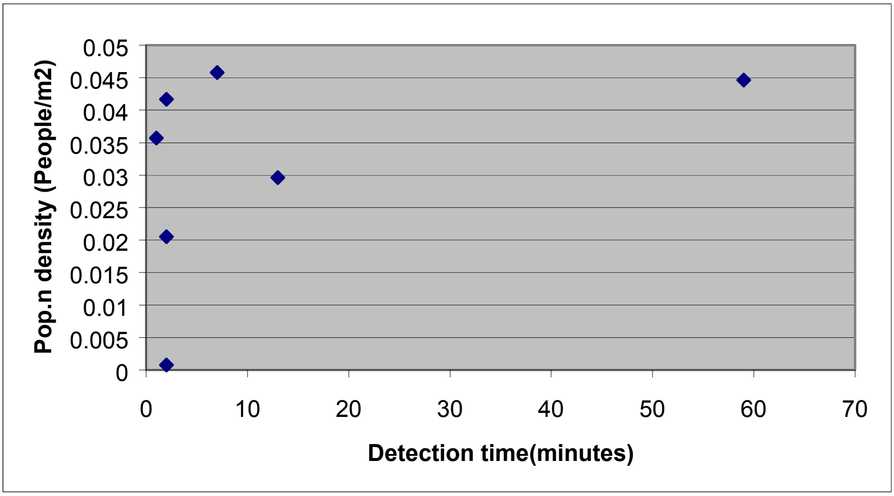

Figure 9. Scatter graph of the number of people per unit area against the detection time for shops and commercial premises

DISCUSSION

The results of the analysis illustrate one of the inherent difficulties with the use of fire report data in general and data from a more limited number of highly detailed investigations in particular, and that is sample size. To partition the data sufficiently to exclude other variables and factors usually produces small sample sizes. This means that to draw definitive conclusions about events with a low probability requires much more data and/or alternative methods.

The data is based on a sample of fires and a study comparing the data to that collected on all fire reported to fire brigade showed very little variation that would indicate significant bias or unrepresentative results. Sample sizes of the order of a few tens and in one case as low as six were used in the analysis, however even these figures can provide insight into expected values to some variables, but is limited in indicating the limits to the distributions. Further data is being collected and it is intended to up date the analysis in the near future.

The recommendations in the guidance [1][2] appear to consistently equal or exceed the worst-case points in the data for the number of people in the building, the fire growth rate and the pre-movement time of occupants. This seems to indicate that for deterministic fire analysis, the current guidance errs on the side of safety. However, for quantified fire risk assessment, if the same values are used the results will not reflect the many occasions where much less severe circumstances are pertinent.

The probability distribution for detection time indicates that most fires are detected only a few minutes after ignition. However, there are occasions where detection can be delayed (greater than 5 minutes) but that this tends to be when the fire is in an unoccupied part of the building that is not covered by automatic fire detection and/or the fire does not grow. The scatter graph for detection times against fire growth rate indicates that where observation is the main means of detecting a fire, the time to detection is lower for faster growing fires and this too should be taken into account when quantifying fire risks in shops and commercial premises. The scatter graph for other population density and detection time showed no evidence of a dependency although this may be the result of the small sample size.

Future work will include the updating of the probability distributions and further work on possible dependencies. The probability distribution data reported in this paper will be used as input to a fire risk assessment model that is currently being developed. At present, a variety of models exist for estimating the level of risk to occupants from a fire in buildings. The majority of these are largely deterministic and presume precise knowledge of the input parameters, usually using worst-case type scenarios. There is likely to be much discrepancy between the results of these evaluations and real situations.

A fire risk assessment model will combine a deterministic analysis of the various physical aspects of fire behaviour (e.g. smoke production and its movement, the amount of hazard) with a probabilistic analysis of the various stochastic features associated with fires, such as fire growth rates, detection times etc. The end result will provide an estimate of the frequency and number of fatalities and/or injuries due to fires in a building. The probabilistic analysis will use the Monte-Carlo simulation technique. Whilst fire risk assessment of this nature has been carried out by a number of organisations, a crucial difference between the authors' approach and others is that the risk assessment model should be practical and practicable and should also incorporate more detailed statistical information. Although there are certain guidance procedures that provide values for some of these stochastic variables, they are generalised and do not reflect the detailed fire statistics necessary. To enable a large number of simulations to be performed, the deterministic analysis will necessarily be simple and will make use of existing analytical equations such as those in DD240 [2] and TM19[6].

CONCLUSIONS

1. More detailed data from the investigation of real fires can provide new insights into the more stochastic aspects of fire safety in shops and commercial premises. Partitioning of the data to exclude dependent events can result in low sample sizes and limitations in the nature of data collected from real fires are important.

2. The number of people present in a shop of commercial premises is normally much less than the design value in prescriptive standards and data for the development of probability distributions are becoming available and this is crucial to the development of methods for quantified fire risk assessment.

3. The probability distribution for fire growth in shops and commercial premises indicates that most are either slow or medium. About 15% were shown to be fast and this is the value of fire growth used for performance-based design. A further

15% were shown to be ultra-fast, but these occurred in premises containing high-rack storage.

4. Detection times are normally less than 5 minutes for most fires in most buildings, however there are occasions when detection time can be of the order of 10 to 15 minutes depending on the location of the fire, the presence of people and automatic detection systems.

5. Pre-movement times can be seen to vary significantly from fire to fire. Many are well within the values presented in BS DD 240 ie less than 2 minutes, but a small proportion of pre-movement times are well outside (up to 7 minutes), particularly when people are not in the room/space of fire origin.

6. Analysis of dependencies indicated a dependency between fire growth rate and the time to detect a fire. Generally, the faster the fire growth rate, the shorter the time to detect the fire. The scatter graph for population density and detection time showed no evidence of a dependency, but this may have been due to the small size of the sample.

7. Future work will include the updating of the probability distributions and further work on possible dependencies. The probability distribution data reported in this paper will be used as input to a fire risk assessment model that is currently being developed.

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