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STATISTICAL ANALYSIS OF FIRE SPREAD IN BUILDINGS

by

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SUMMARY

Fire statistics are analysed to estimate the influence of various factors on the spread of fire in buildings. The spread of fire beyond the room of origin is considerably less likely in modern buildings, particularly in multi-storey buildings, and spread is much more likely at night time, probably because of delays in discovery. Early attendance by the brigade over the range of these data has no measurable influence on this chance of spread, probably because of the wide range of variation in the size of fire confronting the brigade.

KEY WORDS: Fire statistics, Fire spread, Building.

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INTRODUCTION

This report describes an analysis of the 1967 fire statistics aimed at assessing the influence of various factors on the spread of fire in buildings. Previously these factors, which are measures of brigade activities, building characteristics etc., have been the subject of separate studies [1,2,3,4,5] but because they are not independent of each other a more formal analysis is necessary, in which each factor is studied not in isolation, but in relation to all the other factors. This is the subject of the present paper.

The statistics of fire spread are drawn from brigade fire reports, collated and processed at the Fire Research Station. In the reports the extent of fire spread is recorded by noting whether the fire was confined to the item first ignited or to the room, floor, or building of origin. From these data the probability of important events in the fire can be estimated, e.g. the chance of fire spreading beyond the item first ignited, the chance of spread beyond the room of origin, etc.

In this paper we study the chance of fire spreading beyond the room of origin and the way in which is varies under different circumstances. It is at this stage that the structure of the building plays an important role in inhibiting further spread of fire. This is demonstrated in a recent paper by Melinek, Baldwin and Thomas[6] who have shown that if we denote the chance of spread beyond the room of origin by p_s and the chance of a fire becoming large (i.e. loss exceeding £10 000) by p_L, then

$$p_L = p_s^3$$

approximately.

Hence small reductions in p_s can lead to substantial reductions in the number of large fires and therefore in the total fire loss, since these fires account for more than 60 per cent of the annual fire loss, a strong argument in favour of improved compartmentation. An important implication of this correlation is that large fires may be studied by research on those factors which influence whether or not fire spreads beyond the room of origin, the subject of this paper.

DATA

In Tables 1 - 7, p_s, the probability of fire spreading beyond the room of origin, is tabulated in a multi-way classification for various factors associated with the fire. In choosing the factors to be included in this analysis we are limited by the information recorded in the brigade fire reports. Since the reporting system was devised some years ago, and for a quite different purpose, it is hardly surprising that the data are insufficient to assess completely the effect of varying degrees of fire protection, fire fighting or delays. However, they are currently the only information available and they do provide some useful information, however limited.

The factors chosen for this analysis are

1. Time of discovery (night or day)
2. Number of storeys (multi or single storey)
3. The age of the building
4. Fire Brigade risk classification
5. Building regulation purpose group. The composition of these purpose groups is shown in the Appendix.
6. Brigade attendance time (time from discovery of the fire to arrival of the brigade)

Each of these factors is an indirect measure of important variables associated with the fire. For example, delays in discovery are measured indirectly by the time of discovery of the fire, since delays are likely to be longer at night. Varying building controls are measured indirectly by Building regulations purpose group (which also reflects varying hazards of different types of building) and by the age of the building. They may also be reflected in the differences between multi and single storey buildings since only multi-storey buildings are subject to regulation, but once again the effect is confused to some extent by differing uses and contents.

Brigade activities are measured by the attendance time and the risk classification of the building. The risk classification is determined by the brigade in pre-fire visits on the basis of a subjective assessment of the risk of fire spread, and this classification then determines the speed and size of the first attendance. This variable therefore reflects the varying risk of fire spread in buildings of different use and with different contents, but this is counteracted by a more determined effort by the brigade where the risk of fire spread is high (the highest risk is labelled A in the tables). Brigade attendance time has not been included in the tables for reasons which will be discussed below.

Data are not available for single storey buildings for some purpose groups normally because of the few buildings at risk. For these groups the analysis will be carried out for multi-storey buildings only.

STATISTICAL ANALYSIS

The data in the tables have been analysed statistically to disentangle the combined effect of the different variables. To do this we express the value of the probability in each cell of the table as a sum of a number of independent components, each component corresponding to a different variable, and taking a different value for each level of the variable. First however, we work with a transformed variable z, instead of the probabilities p, defined by

$$z = \tfrac{1}{2} \log \left(\frac{p}{1-p} \right) \qquad = \text{logit } p$$

This transformation is expected to give approximately additive effects for many conditions, so that we can assume a linear model, and then

$$z_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + e_{ijk}$$

where μ is a mean value

α_i is the effect of the i^{th} time of discovery (i.e. α_1 is the effect of daytime discovery, α_2 nighttime)

β_j is the effect of the j^{th} risk

γ_k is the effect of the k^{th} age group

e_{ijk} is an error term

The constants of this model, together with their standard errors are estimated from the data using the method of maximum likelihood.

RESULTS AND DISCUSSION

The model described above has been fitted to the data and the constants estimated for each purpose group, multi and single storey buildings being treated separately. The goodness of fit of the model has been tested by calculating the residual chi-squared which is tabulated in Tables 8 and 9. None of these values differs significantly from its expected value, and we therefore accept the model as a reasonable representation of the data.

The estimated components of the model give additive components leading to an estimate of the logit of p_s as defined in the model. These are of no direct interest and have been omitted from this report. Trends in the data may be more readily discerned by inspection of the expected marginal percentages spreading beyond the room of origin, tabulated in Tables 10 and 11. These are the average values of p_s associated with each variable, corrected for imbalance in the data. Significant differences between the different levels of a variable are distinguished by an asterisk.

The chance of spread in industrial and storage purpose groups is significantly higher than in other groups, except in single storey buildings where the chance of spread in industrial buildings is much smaller. It is possible that rooms in

single storey buildings are larger on average than in multi-storey buildings, and this may account for the difference in spread. There are also significant differences between single and multi-storey buildings in the industrial and assembly purpose groups, but not for storage buildings or shops. These results follow from comparing the mean value in the final column of the tables.

The factor most influencing the chance of spread is the time of discovery of the fire, with spread being considerably greater at night. This reflects the longer delays in discovery at night, although there is the possibility that fires during the daytime may be of a different kind. The chance of fires becoming large is also about 4 times as great at night, underlining the importance of early discovery.

The age of a building also has a strong influence on the spread of fire, particularly in multi-storey buildings. The chance of spread in post 1950 multi-storey buildings is about one half that in pre-1920 multi-storey buildings in most purpose groups, but the difference is small in single storey buildings. There are many possible explanations for the improvement in modern buildings; for example, there may be less overcrowding in modern buildings, or older buildings may now be used for a purpose for which they were not originally designed. It is worth noting, however, that during the period 1950 - 1967 legislation for building controls was introduced, applying mainly to multi-storey buildings. Since the statistics show a very much more marked effect of age on fire spread in multi-storey buildings, it seems possible that increased building controls and improved standards of safety leading to improved building design, have played a large part in reducing spread.

There are small differences between the risk categories, but except for multi-storey industrial and residential purpose groups, the differences are not significant statistically, and could have occurred by chance statistical fluctuation. In the industrial purpose group the chance of spread in B risk is significantly lower than the other risks, and in the multi-storey residential buildings the chance of spread in D risk is significantly higher (by a factor of about two, so this difference requires further investigation). The similarity between the risk categories could imply that the brigade correctly allocate risk classification and resources, so that fire has the same chance of spread in buildings of high risk as in the lower risks. Another possible explanation is that the 'risk' of a building is not important when compared with other factors influencing fire spread.

It was pointed out earlier that the brigade attendance time (time from discovery of the fire to arrival of the brigade) has not been included as a factor in this analysis, in spite of its supposed tactical importance. It was originally included

when the data were extracted from the fire records, but inspection revealed that there were no systematic differences associated with attendance time other than those implicit in the differences between risk categories. It was found that fires attended late had no greater chance of fire spread than fires attended early. This factor was therefore excluded from this report in the interests of space.

There are again several explanations for this result, which is rather surprising at first sight. The most likely explanation is that the differences in attendance times that we are examining are relatively small, of the order of a minute or two, whereas the period from ignition to discovery is subject to variations ranging up to an hour or two. The range of variation in the time of discovery swamps any possible benefit resulting from early attendance. A similar argument results from a consideration of the size of fire confronting the brigade on arrival; because of the large variation in the period before discovery of the fire the size of the fire on arrival is also subject to considerable variations, so that the benefit of differences of a minute or two in the arrival of the brigade is unlikely to be measurable.

CONCLUSIONS

An analysis of statistics of fire spread has lead to estimates of the influence of various factors on the chance of fire spreading beyond the room of origin. There are significant differences between buildings used for different purposes, and between some multi-storey buildings and single storey buildings. The biggest single factor influencing fire spread is the time of discovery of the fire, the chance of spread at night being twice that during the day. The chance of spread is also considerably smaller for modern buildings, particularly in multi-storey buildings. The brigade attendance time has no measurable influence on the spread of fire, and there are few differences between buildings in different risk categories.

More data are required in order to understand fully the implications of these results, but it seems likely that the difference between night time and day time fires is a result of delays in discovery at night, and there are indications that the smaller spread in modern buildings may be the result of increased building control and safety consciousness. Early attendance by the brigade has no measurable influence on fire spread probably because of the wide range of variation in the size of fire confronting the brigade on arrival.

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APPENDIX

PURPOSE GROUPS

Residential	Residential clubs, colleges and schools.
	Residential ecclesiastical buildings.
	Hotels, hostels.
	Motels, lodging houses and boarding houses.
	Public Houses with residential accommodation attached.
	Children's homes, old peoples' homes.
	Hospitals, private nursing homes.
	Sanatoria, special schools for handicapped children.
Offices	including blocks of offices attached to other establishments.
Shops	including television, radio and film studios, and laboratories.
Assembly	Non-residential clubs.
	Colleges, schools, ecclesiastical buildings, meeting houses, clinics and public houses.
	Theatres, cinemas, radio and television studios to which public are admitted, concert halls, restaurants, cafes, exhibition halls, dance halls.
Industrial	
Storage	
Flats and maisonnettes	

Table 1 The chance of fire spreading beyond the room of origin in the Industrial Purpose Group

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN — AGE GROUP			NUMBER OF FIRES — AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
SINGLE	DAY	A	8	14	11	60	141	120
		B	11	14	8	93	346	355
		C	12	13	11	49	215	309
		D	35	14	11	23	79	104
	NIGHT	A	23	13	14	47	83	77
		B	15	18	11	61	219	214
		C	14	15	16	43	112	177
		D	20	21	14	10	43	57
MULTI	DAY	A	28	18	11	180	96	71
		B	15	14	9	233	132	150
		C	23	16	16	128	74	62
		D	28	25	23	25	20	22
	NIGHT	A	41	33	15	116	69	41
		B	29	35	15	164	76	110
		C	31	40	31	83	55	39
		D	36	42	14	11	12	7

Table 2 The chance of fire spreading beyond the room of origin in the storage purpose group

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN AGE GROUP			NUMBER OF FIRES AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
SINGLE	DAY	A	22	41	17	9	22	18
		B	26	28	18	19	36	39
		C	29	34	39	14	35	38
		D	60	20	0	5	15	10
	NIGHT	A	45	40	40	11	20	10
		B	50	52	48	12	23	25
		C	50	56	35	14	27	23
		D	50	44	38	2	9	8
MULTI	DAY	A	28	33	13	58	18	8
		B	49	26	54	43	19	13
		C	21	11	0	29	9	6
		D	33	25	0	9	4	2
	NIGHT	A	58	31	31	43	13	16
		B	64	40	50	28	10	6
		C	67	60	67	30	10	6
		D	71	25	100	7	4	1

Table 3 The chance of fire spreading beyond the room of origin in Shops

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN — AGE GROUP			NUMBER OF FIRES — AGE GROUP		
			Pre 1920	1920–1949	1950–1967	Pre 1920	1920–1949	1950–1967
SINGLE	DAY	A	14	11	0	7	9	5
		B	10	10	11	10	21	19
		C	17	14	3	12	43	31
		D	13	23	0	8	13	9
	NIGHT	A	25	20	22	4	5	9
		B	0	26	23	4	19	13
		C	17	17	10	6	46	39
		D	50	19	13	2	16	8
MULTI	DAY	A	18	14	9	131	44	46
		B	14	12	12	280	137	113
		C	14	10	7	263	144	113
		D	19	6	13	62	17	8
	NIGHT	A	22	4	16	122	25	44
		B	24	10	10	195	96	84
		C	18	8	5	196	135	93
		D	21	25	22	43	16	9

Table 4 The chance of fire spreading beyond the room of origin in the Assembly Purpose Group

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN			NUMBER OF FIRES		
			AGE GROUP			AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
SINGLE	DAY	A	13	17	9	15	24	23
		B	11	26	13	44	69	76
		C	16	25	17	62	136	150
		D	9	28	22	32	32	37
	NIGHT	A	100	11	33	2	9	12
		B	38	40	19	13	25	27
		C	31	59	50	16	51	48
		D	50	50	56	6	12	18
MULTI	DAY	A	20	13	10	137	40	58
		B	16	10	6	178	73	79
		C	11	14	7	174	76	76
		D	22	0	0	65	16	17
	NIGHT	A	30	38	15	50	16	13
		B	24	17	17	82	24	24
		C	33	29	13	75	31	32
		D	23	14	17	38	7	6

Table 5 The chance of fire spreading beyond the room of origin in the Residential purpose group.

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN			NUMBER OF FIRES		
			AGE GROUP			AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
MULTI	DAY	A	2	14	9	56	14	11
		B	13	8	6	139	53	32
		C	11	4	6	158	54	49
		D	18	0	0	82	10	10
	NIGHT	A	20	22	22	30	9	9
		B	16	24	5	69	17	20
		C	13	21	0	63	19	15
		D	42	33	0	38	3	1

Table 6 The chance of fire spreading beyond the room of origin in the Office purpose group

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN			NUMBER OF FIRES		
			AGE GROUP			AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
MULTI	DAY	A	5	5	7	22	22	43
		B	14	8	4	42	13	23
		C	0	14	9	14	7	11
		D	0	0	0	4	3	2
	NIGHT	A	33	8	15	21	12	27
		B	32	0	7	22	8	15
		C	43	0	13	14	3	8
		D	100	0	0	1	0	0

Table 7 The chance of fire spreading beyond the room of origin in Flats and Maisonettes

STOREYS	TIME OF DISCOVERY	RISK	PERCENTAGE OF FIRES SPREADING BEYOND ROOM OF ORIGIN			NUMBER OF FIRES		
			AGE GROUP			AGE GROUP		
			Pre 1920	1920-1949	1950-1967	Pre 1920	1920-1949	1950-1967
MULTI	DAY	A	15	12	10	481	220	252
		B	11	10	5	667	341	420
		C	11	8	7	498	441	931
		D	14	8	9	59	60	111
	NIGHT	A	20	7	8	156	54	63
		B	17	11	17	204	97	100
		C	25	14	9	140	118	194
		D	54	24	8	13	17	25

Table 8 Residual chi-squared - multi-storey buildings

Purpose group	chi-squared	Degrees of freedom
Industrial	15.3	17
Storage	21.0	17
Shops	15.3	17
Assembly	17.0	17
Residential	25.1	17
Offices	16.0	15
Flats, maisonettes	27.5	17

Table 9 Residual chi-squared - single-storey buildings

Purpose group	chi-squared	Degrees of freedom
Industrial	14.0	17
Storage	15.3	17
Shops	9.6	17
Assembly	19.9	17

Table 10 Expected marginal percentages spreading - multi-storey buildings only

Purpose Group	Time of Call		Risk Category				Age Group			Mean for the Group
	Day	Night	A	B	C	D	Pre-1920	1920-1949	1950-1967	
Industrial	18*	30*	26*	19*	25*	30*	26*	24*	15*	23
Storage	30*	56*	36	51	39	41	46*	32*	35*	42
Shops	13*	16*	16	15	12	17	18*	10*	10*	14
Assembly	13*	25*	20	15	16	15	20*	15*	9*	17
Residential	10*	19*	10*	12*	10*	21*	14	12	7	12
Offices	8*	21*	13	12	14	13	20*	6*	9*	13
Flats, Maisonettes	10*	15*	12	10	11	14	14*	10*	8*	11

* Differences statistically significant

Table 11 Expected marginal percentages spreading - single storey buildings

Purpose Group	Time of Call		Risk Category				Age Group			Mean
	Day	Night	A	B	C	D	Pre-1920	1920-1949	1950-1967	
Industrial	12*	15*	13	12	13	16	15*	15*	11*	13
Assembly	19*	44*	17	21	28	29	20*	31*	22*	25
Shops	10*	18*	16	16	12	16	16	17	10	14
Storage	28*	46*	33	34	40	29	38	39	31	36

* Differences statistically significant