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## FIRE SPREAD IN BUILDINGS - THE EARLY STAGES OF GROWTH

by

R. BALDWIN, S. J. MELINEK, and P. H. THOMAS

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FIRE
RESEARCH
STATION

Fire Research Station,
Borehamwood,
Herts.
Tel. 01-953-6177

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DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
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## PART I - STATISTICS OF SPREAD IN THE EARLY STAGES OF GROWTH

The Fire Research Station receives and processes reports of all fires attended by the brigades, and these reports contain valuable information on the spread of fire in buildings. Previously[1,2] these data have been used to obtain estimates of the chance of fire spreading beyond the room of origin, and to study the factors which influence spread at this stage. In the present report we are concerned with earlier stages of fire growth, where fire spreads from the items first ignited to the surrounding fuel, leading eventually in some fires to flashover and spread beyond the room of origin. For this purpose we use the fire reports to obtain estimates of the chance of fire spread beyond the item first ignited, which we denote by pa. The value of pa will depend not only on the physical characteristics of fires, but also on random properties of the fuel, such as spacing and size, and on chance events such as discovery by passers-by, occupants, automatic installations, etc. A statistical model is therefore desirable.

The immediate aims of this report are to investigate:

1) the value of pa as a measure of fire spread in the early stages
2) which factors have the greatest influence on pa
3) the relationship between pa and the chance of fire spreading beyond the room of origin, ps.

## CALCULATION OF PROBABILITIES

For the purposes of this report two quantities must be calculated, ps and pa. The following conventions were adopted:

1) Only those fires were considered in which fire was initiated in a room or compartment: this means that fires confined to common service spaces, exterior components etc. were excluded. (About 75 per cent of fires in buildings start in a room). The uncertainty in ps due to those fires not starting in rooms can be eliminated to some extent by excluding fires in parts of the building where there is a high incidence of fires confined to common service spaces and exterior components. Only about 9 per cent of all fires in multi-storey buildings occur in these parts of the building which

include huts, yards, corridors, stairs, lifts and external structures, but they account for more than 95 per cent of fires confined to common service spaces and exterior components.

2) ps is defined as the chance of spread beyond the room of origin, given that it has spread beyond the item first ignited. In addition ps should be calculated for multi-storey buildings only since in single compartment buildings ps has no meaning, creating some difficulty in interpreting spread to other buildings. However, only 3 per cent spread to other buildings, insufficient to influence the conclusions, and accordingly it was assumed that these fires originated in multi-compartment buildings. A further difficulty arises with fires of unknown extent because data on the probability of fires becoming large indicate that unknowns correspond to larger fires than average[3], and not to random samples of all fires. Fires of unknown extent have therefore been included with those spreading beyond the room of origin, although once again the numbers (about one per cent) are too small to influence the results.

## DATA

To test the consistency of pa, yearly trends were examined for the period 1961 - 69. The data are given in Fig. 1. For all buildings pa decreased from 0.90 to 0.66, so that the proportion of fires confined to the item ignited first more than trebled; for chemical and textile industries this proportion increased sixfold. These trends are unlikely to be real, and recoded 1961 data for textile industries using 1969 coding procedures revealed that the observed trend could be attributed entirely to changes in coding practice, particularly where there were ambiguities in the definition of the item ignited first. It was also found that in 1969 although there was a marked increase in the proportion of fires confined to the item ignited first, this was compensated by a corresponding decrease in the proportion classified as confined to the room of origin, contents only involved.

The high values of pa observed require some comment. The apparent implication is that most fires spread beyond the item ignited first, but loss statistics show that the frequency of fires increases as their size decreases, and this agrees with the intuitive view of fires. The implication therefore, is that there are many small fires to which the brigade are not called, so that pa is a measure of the minimum size of fire to which the brigade is called.

RELATIONSHIP BETWEEN ps and pa

In spite of the limitations on the measuring of pa, discussed above, it is important to determine whether spread beyond the room of origin is related to spread beyond the item ignited first, since in theory spread depends on the ease with which the fire can develop in the early stages. This relationship, if it exists, can be explored by attempting to correlate ps with pa and to this end the data were classified by the following factors in order to produce variations in pa and ps:

a) occupancy and building purpose
b) sub-occupancy (i.e. use of room or part of building)
c) material ignited first
d) source of ignition and appliance
e) floor of origin
f) number of storeys
g) time of call
h) brigade attendance time
i) time taken to control the fire

Data for these classifications are given in Tables 1 - 11.

Significant correlations were found between ps and pa for fires classified according to time of call, brigade attendance time (discovery to arrival), time taken to control the fire, and the floor of origin. The effects of time of call and control time were investigated separately for residential buildings.

The regression lines between ps and pa are given in Fig. 2, and although they are similar in location, their slopes are different. This is to be expected because the correlation between pa and ps is produced by varying a third factor, to which both pa and ps are related, and this parameter may affect pa and ps in different ways physically. For example, the variations due to time of call are probably due to delays in discovery, but the variation with floor of origin may be due to varying fire loads and hence spacing of fuel, affecting pa, and size of room, affecting ps. Clearly, a real correlation between pa and ps will result only if the parameter chosen to produce variations in pa and ps affects the same physical component of spread for both variables (e.g. delay time). In this respect it is significant that there is no correlation between pa and ps when the data are classified according to the material ignited first, a measure of the nature of the fire load, a result of some importance from the point of view of surveys of contents.

One interesting feature of the regression lines 1 to 5 is that they all cross the pa axis (ps = o) at positive values of pa, unless the variation is extremely non-linear, and thereafter ps increases rapidly with pa. This may be interpreted as an indication of a critical value of pa (of the order 0.5) beyond which rapid spread takes place, in a similar way to that found in epidemic theory.

DISCUSSION

There are serious objections to the use of pa as a measure of spread in the early stages of fire growth. The high value of pa (of the order 80 per cent) means that there are small gains in studying variations between say 80 and 90 per cent, and that the data are seriously limited by being restricted to fires attended by the brigades. Clearly a further source of data, such as insurance claims or local authority records, is necessary to make a more useful study. Also, an examination of yearly trends in pa, and recoding of early years has shown that the statistics are sensitive to coding procedures, particularly where some are ambiguities in definition. A more profitable approach to spread in the early stages probably lies in modelling on a physical basis, taking into account statistical variations in the various parameters. This approach will be discussed in Part II.

## PART II - MODELS OF FIRE GROWTH

A variety of models are plausible for the growth of fire in compartments. In the early stages, when a small fire exists, spread to other items is primarily by radiation from the hot solids and surrounding flame. In a stochastic model, therefore, the chance of spread is related to the distances separating the contents of the compartment, thus reducing to a problem of geometric probability. These probabilities would require surveys, since it is not apparent a priori that combustibles are distributed at random (though an approximation might be for example that items in a bedroom (excluding the bed) would be randomly distributed along the bedroom walls, or items other than the table and its chairs were randomly spread around the walls of a dining room).

As more items become involved, a stage is reached when the flames reach the ceiling and the resulting flames under the ceiling, of greatly increased length, lead to a considerable increase in radiation levels. In experimental fires this stage usually marks the onset of flashover.

The simplest stochastic model of the early stages of fire growth is therefore one in which the chance of spread is determined from the chance of an item within a distance D, determined by survey data, flashover occurring when sufficient items are involved to result in flames reaching the ceiling. For simplicity it could be assumed that spread occurs if $D < D_o$, no spread if $D > D_o$ for a suitably chosen value of $D_o$.

DETERMINISTIC MODELS

Benn[4] has introduced a deterministic model

$$\frac{dS}{dt} = aS - q$$

where S is a measure of fire size, and a, q are spread and control parameters respectively, supposed constant.

This is not the simplest possible model, and to some extent it is not realistic, particularly for small fires, where no further growth would be expected after the arrival of the brigade. Furthermore, there are good reasons for regarding small area fires as different from large fires such as in industrial buildings, where the rate of growth is likely to be governed by conditions on the fire perimeter only, and control is likely to be an increasing factor of time because of build up of fire-fighting forces.

We therefore assume two alternative growth laws for S, the area of burning fire

1. $$\frac{dS}{dt} = aS$$

$$S = S_o e^{at}$$

where $S_o$ and the origin of t are undefined.

This is more likely to be true for small fires where the whole fire may influence growth.

2. In large fires where only the periphery of the fire controls spread, we assume:

$$\frac{dS}{dt} = a't$$

$$\therefore \quad S = \frac{a't^2}{2}$$

Clearly $\frac{dS}{dt} \propto \sqrt{S}$, so that growth is controlled by the fire periphery.

We also assume two models for control:

$$3. \qquad \frac{dS}{dt} = -q \qquad \text{for small fires}$$

$$4. \qquad \frac{dS}{dt} = -q' t \qquad \text{for large fires,}$$

to take account of a build up of fire fighting effort.

We have assumed that there is no propensity for $S$ to grow after arrival of the brigade, although this may not be appropriate for large fires, where the brigade initially reduce the effective rate of spread until control is achieved. Let $S_A$ be the size of the fire and $t_A$ the time at arrival, and $t_c$ the time for control after arrival of the brigade.

Combining 1 and 2 with 3 and 4 we arrive at four possible expressions for $t_c$:

$$q t_c = S_A = S_o e^{a t_A} \qquad \ldots\ldots \; 5$$

$$\tfrac{1}{2} q' t_c^{2} = S_A = S_o e^{a t_A} \qquad \ldots\ldots \; 6$$

$$q t_c = S_A = \tfrac{1}{2} a' t_A^{2} \qquad \ldots\ldots \; 7$$

$$\tfrac{1}{2} q' t_c^{2} = S_A = \tfrac{1}{2} a' t_A^{2} \qquad \ldots\ldots \; 8$$

To eliminate the unknown $S_o$ we differentiate, and then from equation 5 - 8 we have

$$\delta t_A = \delta t_c / a t_c \qquad \ldots\ldots \; 9$$

$$\delta t_A = \frac{2}{a} \cdot \frac{\delta t_c}{t_c} \qquad \ldots\ldots \; 10$$

$$\delta t_A = \sqrt{q/2a'} \; \frac{\delta t_c}{\sqrt{t_c}} \qquad \ldots\ldots \; 11$$

$$\delta t_A = \sqrt{q'/a'} \; \delta t_c \qquad \ldots\ldots \; 12$$

## DISCUSSION

The equations derived above from the initial assumptions about spread and control involve the spread parameters $a$, $a'$, $q$, $q'$, and before more progress can be made it is necessary to obtain estimates of their values. Unfortunately, there are insufficient statistics to obtain very accurate estimates, but we can find representative values as follows:

Equations 6 and 8 agree with a known result for large fires[5,6]

$$t_c = 3.3 \sqrt{A}$$

where A is the area of fire in metres$^2$.
This gives $q' = 0.18 \text{ m}^2/\text{min}^2$.

Clearly q must be of the order $q' t$, where t is replaced by a representative value for small fires, say 8 min, i.e. the mean control time $\bar{t}_c$.

Thus $q \sim q' t_c$

$= 1.5 \text{ m}^2/\text{min}$.

Also, on the basis of two U.S. fire tests, Benn[4] estimated

$$a = 0.1 \text{ min}^{-1}$$

We may also find an order of magnitude for $a'$. Consider a compartment of 'average' size, say 50 m$^2$ and a nominal value of $t_a = 15$ min (comprising an average of 5 min for attendance, 5 min for discovery to call and 5 min ignition to discovery). This is a very approximate value as the time period before discovery is highly speculative.

In Equations 7 and 8 we replace $S_A$ by its expected value $E(S_A)$. An approximate value for $E(S_A)$ may be obtained by considering the chance of spread beyond the room of origin (= 0.1 on average), which represents the proportion of large fires.

Then

$$E(S_A) = 50 \times 0.1 = \frac{1}{2} a' \times (15)^2$$

$$\therefore \quad a' \sim 10/225 \text{ m}^2/\text{min}^2 = 4.5 \times 10^{-2} \text{ m}^2/\text{min}^2$$

Another estimate of $a'$ may be obtained by calculating the rate of spread from physical considerations. For a fire large enough for the rate of spread to be regarded as independent of fire size, but smaller than one where flames beneath the ceiling are important, the rate of spread R is given[7] in terms of the bulk density $\rho$ by

$$R\rho = 8 \text{ mg cm}^{-2} \text{ s}^{-1}$$

$$= 5 \text{ kg/m}^2 \text{ min}$$

In a room we expect the mean height of the fuel to be 1 m and the fireload about 25 kg/m$^2$, so that $R \sim 0.2$ m/min

Now from Equation 2,

$$\frac{d\sqrt{S}}{dt} = \sqrt{\frac{a'}{2}} \qquad \text{for linear spread}$$

$$= R$$

$$a' = 2R^2$$

$$= 8 \times 10^{-2}\ m^2/min^2$$

which is in agreement with the above order of magnitude estimate.

A physical model of spread in forestry materials where the fire spreads by radiation within the fuel bed leads to an expression which takes the form of either Equation 1 or Equation 2, according to the size of fire. In this way the parameters $a$ and $a'$ can be related to the physical parameters of the fuel and compartment, and lead to results which are not unreasonable on physical grounds. However, this study is somewhat tentative at the present.

Using these values of $a$, $a'$, $q$, $q'$ we have

$$dt_A / dt_c = 1.2 \qquad \text{from Equation 9}$$

$$dt_A / dt_c = 2.4 \qquad \text{from Equation 10}$$

$$dt_A / dt_c = 1.5 \qquad \text{from Equation 11}$$

$$dt_A / dt_c = 2.0 \qquad \text{from Equation 12}$$

These values are in good agreement with the value of 1.8 for the statistical data shown in Fig. 3.

An average value for $dt_A / dt_c$ for large fires is $\delta t_c = 0.45\ \delta t_A$. Also Ramachandran[8] has shown that for large fires, one minute of control time is equivalent to £1,000 loss. Thus $\delta\,(\text{loss}) = 1000 \times 0.45\ \delta t_A$

$= £450$ per minute delay in arrival.

This is of the same order as that estimated directly from statistical data on loss and attendance time[9] (Hogg). Similarly, if we take the average control time as 10 min in a dwelling and the average loss as £1,000, the loss per min of control time is £100 and

$$\frac{\delta\,(\text{loss})}{\delta t_a} = 100 \times 0.74$$

$$\sim £70/\text{min},$$

also in close agreement with Hogg.

The order of magnitude agreement suggests that the deterministic model is by no means unrealistic in this respect.

## CONCLUSIONS (PART II)

A deterministic model of fire spread and control in buildings has been formulated, taking account of the differing modes of behaviour of small and large fires. Estimates of the various rates of spread and control have been obtained, although these are necessarily very approximate, and these estimates lead to results in reasonable agreement with the known characteristics of fires. This model is based on the simplest possible assumption consistent with the data and will form a useful tool for the study of factors influencing fire spread, and a starting point for more complex models.

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Table 1

Probability of spread in relation to occupancy and sub-group

| All buildings 1967 | n | pa | ps |
|---|---|---|---|
| Occupancy* | | | |
| Industrial | 7041 | 0.706 | 0.330 |
| Transport | 1445 | 0.907 | 0.355 |
| Retail | 3273 | 0.797 | 0.300 |
| Wholesale | 1310 | 0.904 | 0.458 |
| Professional | 2680 | 0.812 | 0.220 |
| Entertainment | 767 | 0.893 | 0.363 |
| Catering etc. | 3784 | 0.655 | 0.239 |
| Government | 1473 | 0.874 | 0.264 |
| Residential | 36649 | 0.808 | 0.157 |
| Sub-group | | | |
| Houses and flats | 41503 | 0.839 | 0.192 |
| Institutional | 1599 | 0.807 | 0.155 |
| Offices | 610 | 0.779 | 0.253 |
| Shops | 4328 | 0.663 | 0.234 |
| Assembly | 3207 | 0.785 | 0.276 |
| Industrial | 6974 | 0.671 | 0.299 |
| Storage | 2046 | 0.926 | 0.507 |

n = number of fires excluding fires confined to common service spaces or exterior components

*Source: United Kingdom Fire Statistics 1967, HMSO 1969

## Table 2

Probability of spread in relation to sub-occupancy

| Sub-occupancy | | n | pa | ps |
|---|---|---|---|---|
| Code | Description | | | |
| Multi-storey buildings, 1967* | | | | |
| 10 - 18 | Outdoor structures | 7 | 0.571 | 0.250 |
| 19 - 24 | Barn, shed | 474 | 0.880 | 0.551 |
| 36 - 38 | Boiler room etc | 1628 | 0.587 | 0.332 |
| 39 - 42 | Work shop etc | 538 | 0.855 | 0.359 |
| 43 - 52 | Machinery | 94 | 0.425 | 0.275 |
| 56 - 58 | Fuel store | 119 | 1.000 | 0.134 |
| 59 | Stockroom | 1371 | 0.934 | 0.392 |
| 60 - 71 | Miscellaneous | 1455 | 0.881 | 0.192 |
| 75 | Office | 553 | 0.825 | 0.252 |
| 76 - 86 | Bedsit. shop etc | 3234 | 0.579 | 0.166 |
| 88 - 92 | Domestic | 24243 | 0.807 | 0.129 |
| 98 - 99 | Unknown | 77137 | 0.834 | 0.202 |
| Private houses, 1967 | | | | |
| 5 - | Fuel store etc | 195 | 0.980 | 0.189 |
| 6 - | Scullery etc | 473 | 0.966 | 0.206 |
| 86 | Bedsit. | 60 | 0.967 | 0.207 |
| 89 | Bedroom | 5200 | 0.966 | 0.137 |
| 90 | Kitchen | 8689 | 0.741 | 0.105 |
| 91 | Lounge | 3705 | 0.832 | 0.155 |

*Fires starting in roof spaces, basements, and unknown floor of origin excluded.

## Table 3

### Probability of spread in relation to material first ignited

| Material first ignited | | Multi-storey buildings, 1967* | | | Residential houses, 1967 | | |
|---|---|---|---|---|---|---|---|
| Code | Description | n | pa | ps | n | pa | ps |
| 00 | Unknown | 4788 | 0.860 | 0.458 | 2504 | 0.717 | 0.381 |
| 01 - 09 | Miscellaneous | 3558 | 0.868 | 0.167 | 1539 | 0.895 | 0.113 |
| 10 - 19 | Gases | 1178 | 0.819 | 0.154 | 851 | 0.858 | 0.132 |
| 20 - 29 | Liquids | 2513 | 0.700 | 0.203 | 1557 | 0.705 | 0.172 |
| 30 - 39 | Carbonacious | 106 | 0.566 | 0.183 | 55 | 0.527 | 0.069 |
| 40 - 49 | Agricultural | 250 | 0.916 | 0.454 | 72 | 0.917 | 0.182 |
| 50 - 59 | Textiles | 3188 | 0.872 | 0.141 | 2017 | 0.952 | 0.122 |
| 61 | Bedding | 3955 | 0.996 | 0.110 | 2999 | 0.997 | 0.106 |
| 62 - 69 | Other Furnishings | 5105 | 0.905 | 0.132 | 3699 | 0.895 | 0.108 |
| 75 - 77 | Roof, chimney, hearth | 1043 | 0.620 | 0.207 | 1285 | 0.729 | 0.163 |
| 70-74, 78, 79 | Other structure | 1262 | 0.994 | 0.219 | 781 | 0.995 | 0.154 |
| 80 - 89 | Fittings | 1357 | 0.721 | 0.126 | 963 | 0.709 | 0.116 |
| 92, 93 | Food | 9063 | 0.660 | 0.084 | 5619 | 0.733 | 0.067 |
| 96 - 98 | Paper, packing, tyres | 1399 | 0.937 | 0.194 | 605 | 0.960 | 0.139 |
| 94, 99 | Lagging, insulation | 2765 | 0.373 | 0.201 | 1582 | 0.514 | 0.183 |

* excluding fires starting in roof space, basement and unknown floor of origin

# Table 4

Probability of spread in relation to material first ignited, further description

| Material first ignited, further description | | Multi-storey buildings, 1967 | | | Multi-storey houses, flats and maisonettes, 1967 | | |
|---|---|---|---|---|---|---|---|
| Code | Description | n | pa | ps | n | pa | ps |
| 0 | Unknown, not applicable | 33235 | 0.785 | 0.176 | 24811 | 0.811 | 0.138 |
| 1 | Wood, chipboard | 3528 | 0.803 | 0.191 | 2464 | 0.783 | 0.155 |
| 2 | Hardboard, fibreboard | 324 | 0.750 | 0.103 | 248 | 0.722 | 0.101 |
| 3 | Plastics | 359 | 0.668 | 0.092 | 210 | 0.786 | 0.073 |
| 4 | Textiles, natural | 1033 | 0.803 | 0.149 | 605 | 0.952 | 0.115 |
| 5 | Textiles, man made | 33 | 0.7273 | 0.125 | 15 | 0.933 | 0.071 |
| 6 | Lino etc. | 81 | 0.938 | 0.092 | 42 | 1.000 | 0.071 |
| 7 | Rubber | 226 | 0.513 | 0.147 | 94 | 0.972 | 0.129 |
| 8 | Paper | 2020 | 0.965 | 0.152 | 1029 | 0.972 | 0.131 |

Fires starting in roof space, basement or unknown floor of origin and fires starting in sub-occupancies 25 - 35, 72 - 74, 87, 93 - 97 excluded. (Numbers refer to JFRO code list for 1967).

## Table 5

Probability of spread in relation to source of ignition

| Source of ignition | All buildings, 1967 | | | | Residential houses, 1967 | | |
|---|---|---|---|---|---|---|---|
| | Row* | n | pa | ps | n | pa | ps |
| Electricity | 15 - 23 | 19540 | 0.697 | 0.153 | 10043 | 0.776 | 0.116 |
| Solid fuel | 1, 2, 28 - 32 | 8556 | 0.791 | 0.176 | 4681 | 0.749 | 0.124 |
| Town gas | 24 - 27 | 5551 | 0.623 | 0.132 | 2450 | 0.708 | 0.093 |
| Oil | 33 - 38 | 5061 | 0.736 | 0.231 | 2270 | 0.778 | 0.162 |
| Other and unspecified fuel appliances | 39 - 47 | 4152 | 0.699 | 0.199 | | | |
| Miscellaneous | 3 - 14, 48 | 20187 | 0.959 | 0.252 | 167 | 0.922 | 0.250 |
| Unknown | 49 | 8556 | 0.994 | 0.542 | | | |

* data from table 24A, UK Fire Statistics, 1967

Table 6

Probability of spread in relation to appliance

| Residential houses, 1967 | | | | |
|---|---|---|---|---|
| Appliance<br>Code | <br>Description | n | pa | ps |
| 010 - 019 | Cooking | 6719 | 0.726 | 0.082 |
| 020 - 059 | Domestic | 8015 | 0.834 | 0.127 |
| 110 - 119 | Central heating | 314 | 0.465 | 0.199 |
| 300 - 312 | Chimney | 2545 | 0.625 | 0.129 |
| 317 | Arson | 160 | 1.000 | 0.506 |
| 319 | Matches | 253 | 0.996 | 0.095 |
| 331 | Rubbish | 52 | 1.000 | 0.442 |
| 332 | Smokers materials | 1818 | 0.999 | 0.133 |

## Table 7

### Probability of spread in relation to floor of origin

| Floor of origin | Multi-storey buildings, 1967 | | | Residential houses, 1967 | | |
|---|---|---|---|---|---|---|
| | n | pa | ps | n | pa | ps |
| Basement | 2764 | 0.737 | 0.154 | 574 | 0.760 | 0.112 |
| Ground | 26080 | 0.754 | 0.175 | 11996 | 0.778 | 0.141 |
| First | 11903 | 0.866 | 0.196 | 5908 | 0.937 | 0.159 |
| Higher floors of buildings with more than two storeys: | | | | | | |
| A) Second | | | | 370 | 0.903 | 0.195 |
| Above second | | | | 53 | 0.830 | 0.227 |
| B) Top | 2796 | 0.813 | 0.211 | | | |
| Other | 1177 | 0.738 | 0.166 | | | |
| Roof space | 2046 | 0.925 | 0.233 | | | |

## Table 8

Probability of spread in relation to number of storeys

| Number of storeys | All buildings, 1967* | | | Houses, 1967[a] | |
|---|---|---|---|---|---|
| | n | pa | ps | n | ps |
| 1 | 18028 | 0.849 | 0.376 | 2383 | 0.198 |
| 2 | 28078 | 0.804 | 0.175 | 21192 | 0.142 |
| 3 | 8602 | 0.774 | 0.207 | 2579 | 0.170 |
| 4 | 3310 | 0.748 | 0.184 | 152 | 0.235 |
| 5+ | 1520 | 0.676 | 0.198 | 24 | 0.200 |

*Fires starting in roof space, basement or unknown floor of origin excluded.

[a] Average value of pa = 0.815. Variation not statistically significant ($\chi^2 = 6.78$, $\nu = 6$).

Table 9

Probability of spread in relation to time of call

| Time of call (hour) | All buildings, 1967* | | | Houses, 1967 | | |
|---|---|---|---|---|---|---|
| | n | pa | ps | n | pa | ps |
| 00 | 1683 | 0.874 | 0.327 | 593 | 0.875 | 0.195 |
| 01 | 1332 | 0.881 | 0.350 | 464 | 0.901 | 0.227 |
| 02 | 980 | 0.911 | 0.360 | 364 | 0.959 | 0.224 |
| 03 | 859 | 0.901 | 0.372 | 323 | 0.944 | 0.272 |
| 04 | 786 | 0.870 | 0.363 | 277 | 0.928 | 0.284 |
| 05 | 717 | 0.858 | 0.325 | 242 | 0.934 | 0.221 |
| 06 | 886 | 0.862 | 0.311 | 332 | 0.928 | 0.188 |
| 07 | 1319 | 0.811 | 0.247 | 553 | 0.855 | 0.156 |
| 08 | 1746 | 0.797 | 0.201 | 781 | 0.845 | 0.152 |
| 09 | 2220 | 0.773 | 0.184 | 1012 | 0.799 | 0.164 |
| 10 | 2693 | 0.760 | 0.189 | 1276 | 0.774 | 0.159 |
| 11 | 3260 | 0.758 | 0.177 | 1548 | 0.774 | 0.140 |
| 12 | 3720 | 0.782 | 0.177 | 1888 | 0.802 | 0.132 |
| 13 | 3499 | 0.779 | 0.196 | 1647 | 0.798 | 0.157 |
| 14 | 3433 | 0.787 | 0.215 | 1521 | 0.809 | 0.164 |
| 15 | 3588 | 0.808 | 0.209 | 1547 | 0.805 | 0.164 |
| 16 | 3987 | 0.816 | 0.193 | 1779 | 0.813 | 0.128 |
| 17 | 4496 | 0.806 | 0.182 | 2124 | 0.802 | 0.120 |
| 18 | 4047 | 0.815 | 0.187 | 1804 | 0.821 | 0.127 |
| 19 | 3735 | 0.808 | 0.206 | 1626 | 0.804 | 0.121 |
| 20 | 3329 | 0.807 | 0.201 | 1411 | 0.797 | 0.116 |
| 21 | 3145 | 0.796 | 0.234 | 1374 | 0.780 | 0.147 |
| 22 | 2647 | 0.811 | 0.217 | 1167 | 0.812 | 0.134 |
| 23 | 2249 | 0.819 | 0.249 | 891 | 0.828 | 0.165 |

*Fires starting in roof space, basement or unknown floor of origin excluded.

Table 10

Probability of spread in relation to attendance time

| Attendance time (min) | All buildings, 1967[a] | | | Houses, 1967 | | |
|---|---|---|---|---|---|---|
| | n | pa | ps | n | pa | ps |
| 1 | 60 | 0.767 | 0.308 | 9 | 0.813* | 0.000 |
| 2 | 342 | 0.725 | 0.216 | 69 | | 0.160 |
| 3 | 1770 | 0.750 | 0.203 | 521 | | 0.117 |
| 4 | 5921 | 0.774 | 0.213 | 2128 | | 0.137 |
| 5 | 9413 | 0.787 | 0.213 | 3770 | | 0.150 |
| 6 | 10069 | 0.805 | 0.207 | 4235 | | 0.141 |
| 7 | 7668 | 0.802 | 0.213 | 3494 | | 0.149 |
| 8 | 5545 | 0.815 | 0.218 | 2664 | | 0.134 |
| 9 | 3750 | 0.815 | 0.221 | 1863 | | 0.169 |
| 10 | 3103 | 0.828 | 0.228 | 1611 | | 0.158 |
| 11 | 1772 | 0.842* | 0.246 | 936 | | 0.165 |
| 12 | 1616 | | 0.275 | 817 | | 0.167 |
| 13 | 1125 | | 0.259 | 538 | | 0.155 |
| 14 | 859 | | 0.281 | 412 | | 0.181 |
| 15 | 892 | | 0.285 | 440 | | 0.209 |
| 16 -- 20 | 2204 | | 0.353 | 992 | | 0.240* |
| 21+ | 1755 | | 0.374* | 797 | | |

Late calls excluded

*, average value including fires attended at later times. Subsequent variation not statistically significant.

[a] Fires starting in roof spaces, basements and unknown floor of origin excluded.

## Table 11

## Probability of spread in relation to control time

| Control time (min) | Multi-storey buildings[a], 1967 | | | Multi-storey houses[b], 1967 | | |
|---|---|---|---|---|---|---|
| | n | pa | ps | n | pa | ps |
| 0 | | | | 3634 | 0.751 | 0.030 |
| 1 | 2275 | 0.757 | 0.058 | 994 | 0.782 | 0.058 |
| 2 | 3661 | 0.773 | 0.076 | 1534 | 0.814 | 0.071 |
| 3 | 3878 | 0.781 | 0.075 | 1665 | 0.802 | 0.076 |
| 4 | 3636 | 0.791 | 0.093 | 1559 | 0.827 | 0.083 |
| 5 | 3383 | 0.783 | 0.125 | 1385 | 0.830 | 0.113 |
| 6 | 2603 | 0.813 | 0.127 | 1047 | 0.851 | 0.145 |
| 7 | 1989 | 0.800 | 0.144 | 778 | 0.846 | 0.138 |
| 8 | 1632 | 0.833 | 0.165 | 622 | 0.879 | 0.144 |
| 9 | 1197 | 0.842 | 0.216 | 443 | 0.894 | 0.217 |
| 10 | 1160 | 0.828 | 0.223 | 418 | 0.880 | 0.217 |
| 11 | 795 | 0.818 | 0.243 | 272 | 0.879 | 0.234 |
| 12 | 672 | 0.850 | 0.310 | 232 | 0.884 | 0.302 |
| 13 | 579 | 0.836 | 0.302 | 202 | 0.886 | 0.274 |
| 14 | 462 | 0.862 | 0.299 | 141 | 0.915 | 0.256 |
| 15 | 458 | 0.860 | 0.386 | 123 | 0.894 | 0.391 |
| 16 - 20 | 1484 | 0.851 | 0.451 | 500 | 0.868 | 0.454 |
| 21 - 25 | 882 | 0.890* | 0.575 | 249 | 0.892 | 0.568 |
| 26 - 30 | 559 | | 0.643 | 132 | 0.917 | 0.669* |
| 31 - 35 | 368 | | 0.682 | 71 | 0.830* | |
| 36 - 40 | 234 | | 0.697 | 93 | | |
| 41+ | 891 | | 0.841* | 218 | | |

*, average value including fires controlled at later times. Subsequent variation not statistically significant.

Fires starting in roof spaces, unknown floor of origin and sub-occupancies 94 - 99 excluded.≠

a) Fires starting in basements and sub-occupancies 25 - 35, 72 - 74, 87, 93 excluded.≠

b) Fires first igniting structure excluded.

≠ Numbers refer to J.F.R.O. code list for 1967.

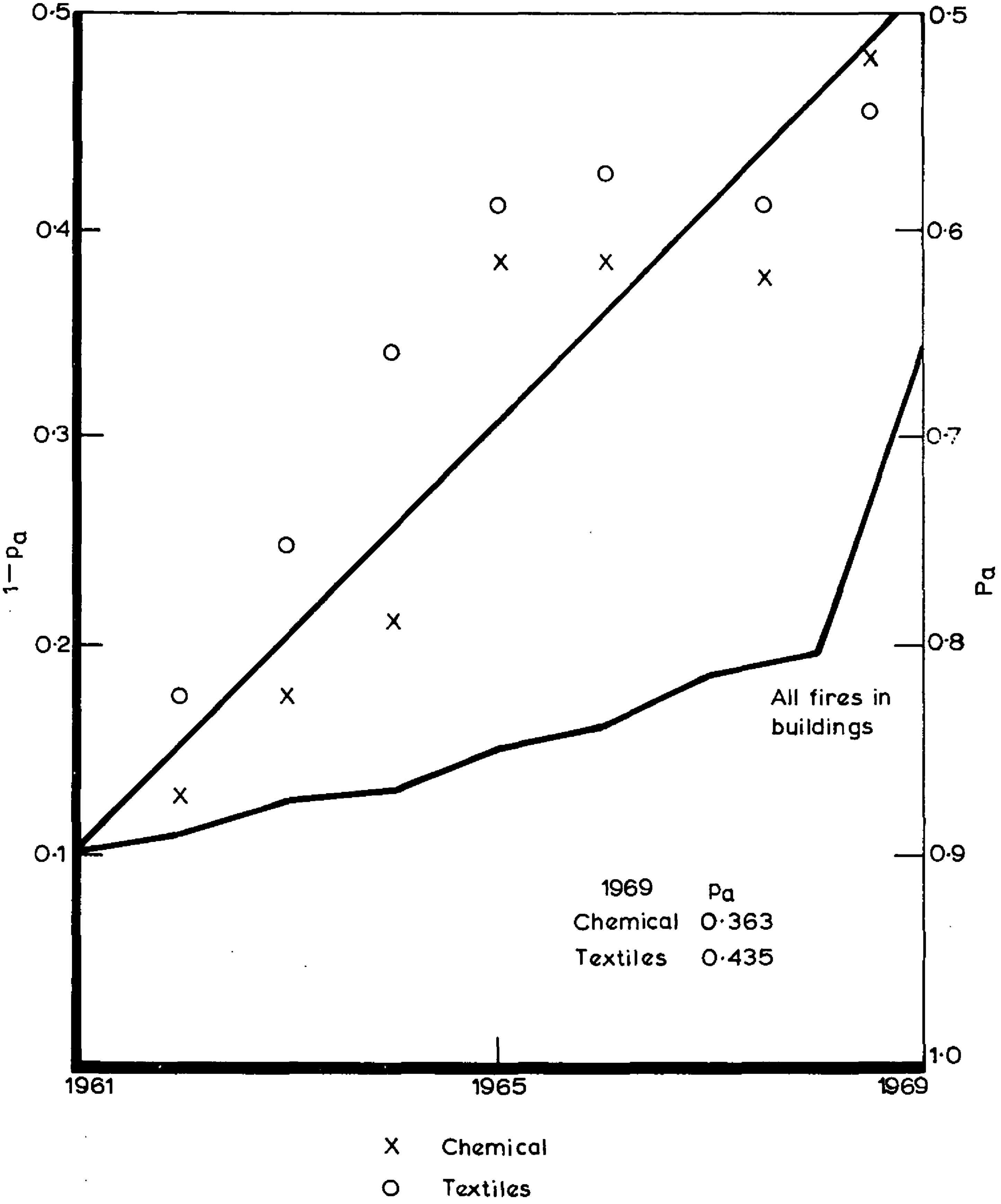

FIG.1 VARIATION OF $p_a$ FROM 1961—1969

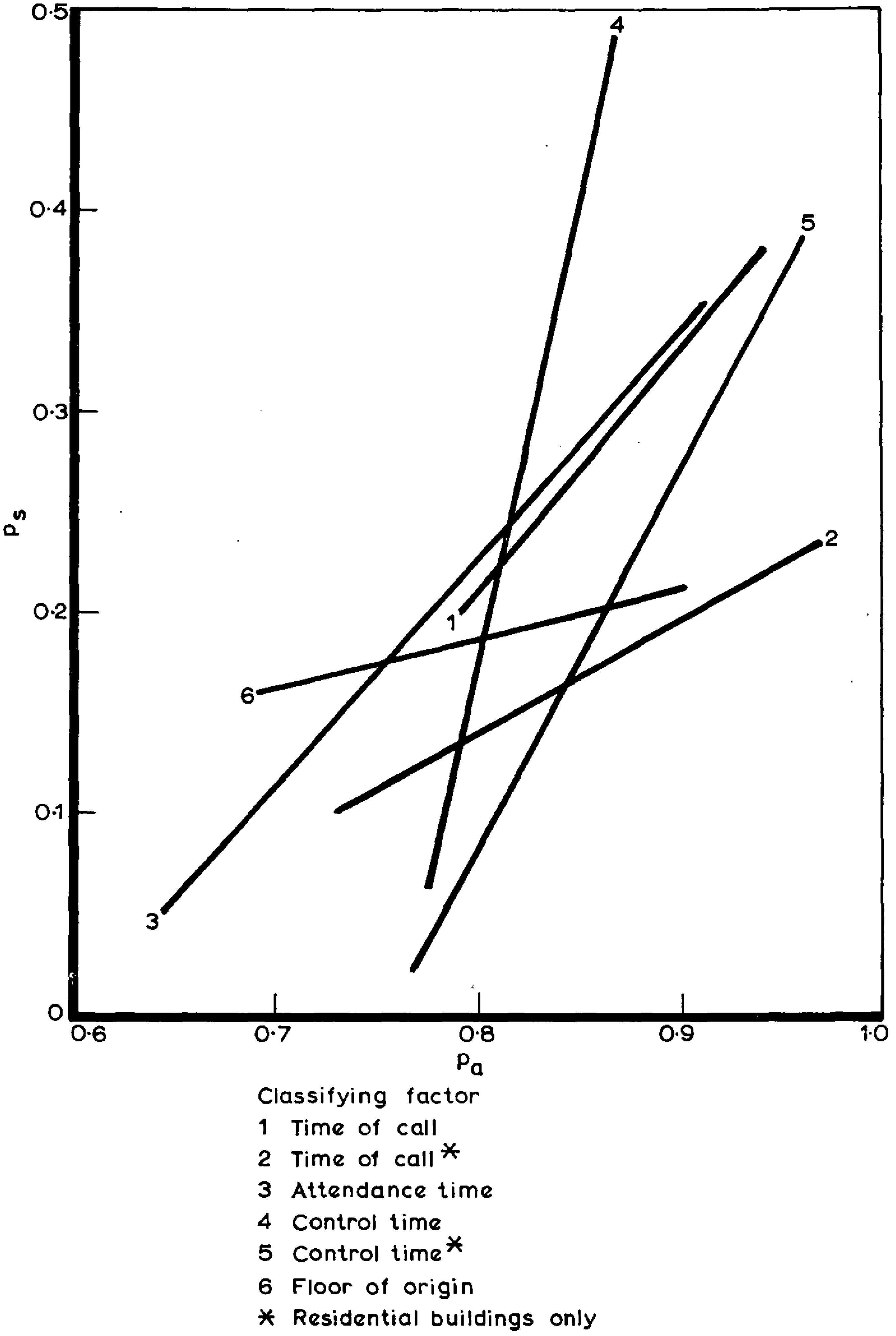

FIG.2 CORRELATIONS BETWEEN $p_s$ AND $p_a$

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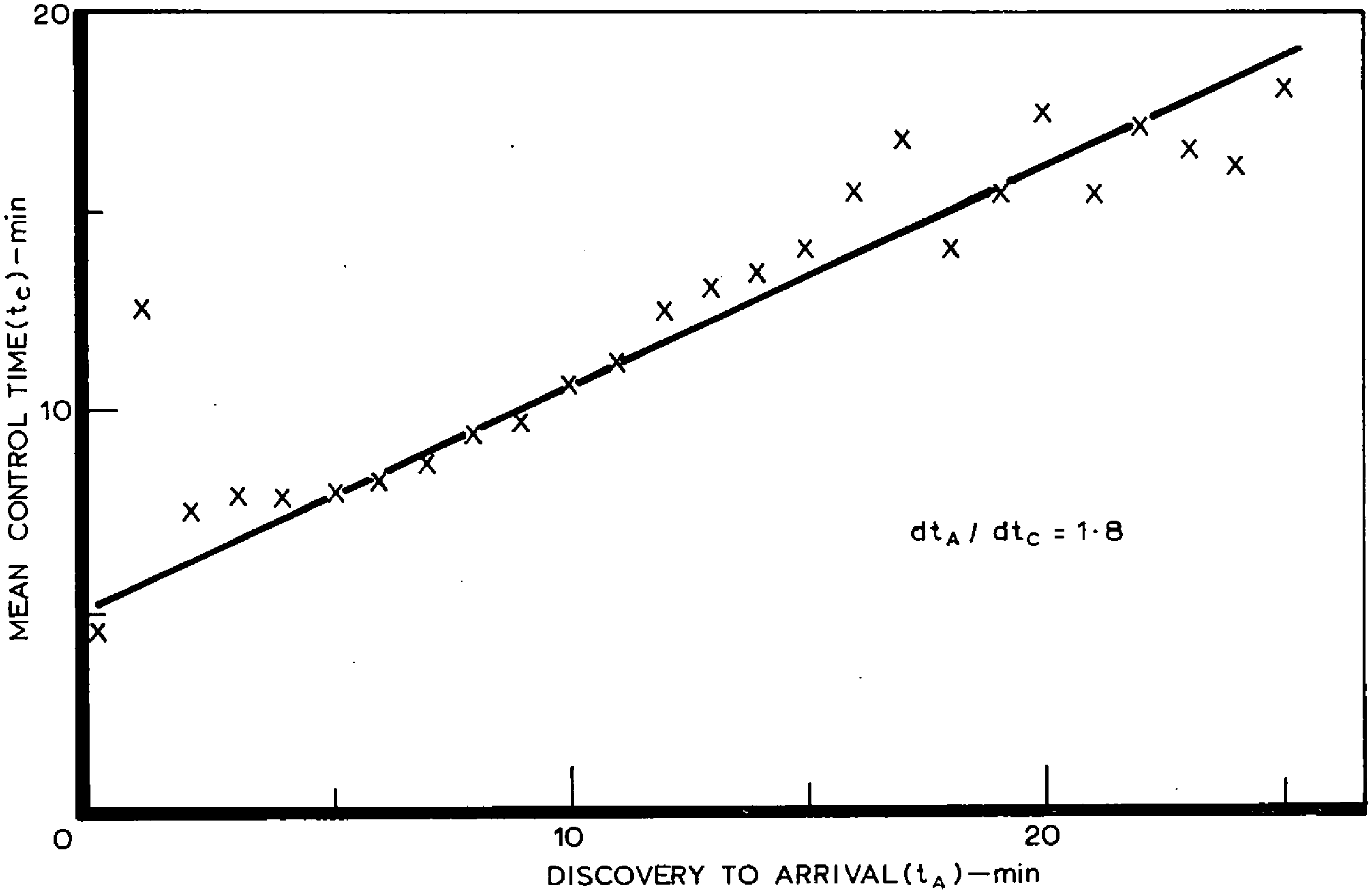

FIG. 3 SELECTED DATA 1967, EXCLUDING FIRES OUT ON ARRIVAL OF FIRE BRIGADE