Fire Research Note No. 912

FIRE FIGHTING AND EXTENT OF SPREAD

by

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FIRE RESEARCH STATION

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SUMMARY

Data are presented for the variation of the probability of a fire spreading beyond the room of origin and control time with the delay in arrival of the fire brigade. This information is required in order to isolate the effects of factors connected with the building, its contents and use, etc. It is found that in most cases delay in the arrival of the brigade causes significant increases.

The probability of fires becoming large, for which data are also given, increases with the time from discovery to call of the fire brigade, but decreases with the time from call to arrival, presumably because delay time tends to be correlated with risk.

About 50 per cent of fires are fought before the brigade arrives. For these fires the mean delay before the commencement of fire fighting is of the order of two minutes. About one quarter of fires fought before the arrival of the brigade are out on arrival. For the remaining fires the likelihood of spread appears to be little altered by the earlier fire fighting. Fires are more likely to be fought before the arrival of the brigade if they are small on discovery.

KEY WORDS: Fire spread, Probability, Extinguishing

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE

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INTRODUCTION

The ease with which fires spread is an important property of buildings and varies with occupancy and other factors affecting the fire severity. Amongst these factors are the effort expended in fire fighting and the delay in the arrival of the fire brigade. To determine the effect of occupancy and other features connected with the building it is necessary to examine other relevant factors, including the influence of the fire brigade and other fire fighting. In addition, the variation of fire size with delay in arrival of the fire brigade can be used to estimate the rate of spread and the advantage to be gained from, for example, quicker discovery or earlier attendance.

The effect of various fire fighting parameters on fire size has been considered previously by Dunn and Fry[1], and Ramachandran and Kirsop[2]. In this note the data are analysed more fully. Fires in which there is fire fighting before the arrival of the fire brigade are distinguished from fires in which there is not. This factor has been shown to be important[3]. The probability of fires becoming large is also considered in greater detail.

Three measures of extent of spread have been used, P_s, P_L and t_c where

P_s = probability of fire spreading beyond the room of origin

P_L = probability of loss exceeding £10 000 (large loss fire)

t_c = time taken to control fire after arrival of fire brigade

The data are for 1967, are used to estimate these quantities and relate only to fires to which the fire brigade was called. To exclude very small fires, those confined to the appliance of origin were ignored in the calculation of P_s and P_L. Except where stated, the 1 per cent significance level has been used throughout.

EFFECT OF DELAY TIME

The relationship between fire size, delay time, t_{DA} (time from discovery of fire to arrival of fire brigade) and control time is treated theoretically by Baldwin et al[4], who also give data for:

(i) t_c vs t_{DA}

(ii) p_s vs t_{DA}

Some further data on the effect of delay in arrival of the fire brigade are presented in Tables 1 and 2. Late calls, when the fire brigade is not called until after the fire is out, have been excluded since in these cases there is often a long delay and the precise period has little relevance. Many of these fires are small. Fires starting in basements, roof space or unknown floor of origin or in derelict buildings have also been excluded to obtain a more homogeneous and well-defined population.

Figure 1 shows that p_s tends to increase with delay time t_{DA}. This increase does not appear to be due to there being different delay times for different occupancies since the average delay time is of the same order for most occupancies. Nor is there a significant correlation between p_s and the mean delay times, which are given in Table 3. Assuming a linear relationship between p_s and t_{DA} the data in Fig 1 may be represented by

$$p_s = A + B\, t_{DA}$$

where $A = 0.03$ for fires fought before the arrival of the fire brigade

$A = 0.22$ for fires not fought before the arrival of the fire brigade.

B is the rate of increase of p_s with delay time and does not differ significantly (at 5 per cent level) for fires fought and fires not fought before the arrival of the fire brigade. The average value is

$$B = 0.011 \pm 0.002 \text{ min}^{-1}$$

The variation of p_s with t_{DA} appears to be more definite for residential occupancies. Table 3 shows that for most other occupancies the variation of p_s with t_{DA} is not statistically significant, probably as a result of there being a greater scatter in the time from ignition to discovery. In residential occupancies fires are likely to be discovered quickly, whereas in other occupancies there can be long delays, particularly outside working hours.

The variation in the probability P_L of fires becoming large (in the sense of loss which will be correlated, if imperfectly, with size) is shown in Table 2 and Fig 2. The variation of P_L with delay time t_{DA} is not significant (5 per cent level). There is a negative correlation between P_L and the call to arrival time t_{CA}, probably due to the fact that fire stations tend to be placed near high risks so that t_{CA} is less although P_L is greater[5]. However, taking the time t_{DC} from discovery to call gives a positive correlation with P_L which is significant at the 2 per cent level:

$$P_L = 0.021 + 0.0013\ t_{DC}$$

TIME FROM IGNITION TO DISCOVERY

The time from ignition to discovery would be of great interest in estimating the rates of growth of fires and the potential advantages of quicker discovery. However, it is not usually known. The average value can be estimated from the intercept of p_s versus t_{DA} on the time axis[6]. From Fig 1 the intercepts are -3.4 min for fires fought before the arrival of the fire brigade and -17.7 min for other fires.

It is somewhat of a speculation to extrapolate these relationships along the negative time axis, and the data need more detailed analysis and discussion in relation to a proper model before such a procedure could be justified, but since there appears to be a reasonably linear variation of p_s with t_{DA} the resulting times are crude estimates of the average time of ignition before discovery.

FREQUENCY OF FIRE FIGHTING BEFORE ARRIVAL OF BRIGADE

It can be seen from Table 1 that about half of all fires are fought before the arrival of the fire brigade. Table 4 shows the proportion for different occupancies and materials first ignited and the methods of fire fighting used. It can be seen that the frequency of different methods varies considerably. There is less variation in the proportion of fires fought by all methods. The relative effectiveness of different methods of fire fighting is considered by Ramachandran et al[7].

Table 1 shows that the proportion, f, of fires fought before the arrival of the fire brigade increases with the delay time, t_{DA}. The overall variation of f is statistically significant.

Assume that there are two categories of fires:

i) fires people present do not intend to fight

ii) fires they will fight if the fire brigade does not arrive before they start

Let ϕ be the proportion of fires in the second category which have not been fought at time t from discovery

$$\phi = (f_\infty - f) / f_\infty$$
$$= 1 - f/f_\infty$$

where f_∞ denotes the asymptotic value of f as $t_{DA} \rightarrow \infty$

$$\phi = 1 \quad \text{when} \quad t = o$$

If the probability of an unfought fire in the second category being fought in unit time is $\lambda(t)$ then

$$d\phi / dt = -\phi \quad \lambda(t)$$
$$\ln \phi = -\int \lambda(t)\, dt$$

If $\lambda(t)$ is constant then

$$\ln \phi = - \lambda t \qquad \text{..... (1)}$$

Equation (1) was fitted by calculating χ^2 for different values of f_∞ and λ. The best fit was given by

$$f_\infty = 0.49$$
$$\lambda = 0.53 \text{ min}^{-1}$$

Figure 3 shows ln (ϕ) plotted against t_{DA}. This graph is reasonably linear, showing that λ can be regarded as constant. χ^2 is 75.48 (ν = 38) compared with 208.76 for the hypothesis that f is constant.

From equation (1)

$$\phi = \exp(- \lambda t)$$

The mean time taken to commence fire fighting is

$$\tau = -\int t\, d\phi$$
$$= \int_o^\infty \frac{t}{\lambda} \exp(- \lambda t)\, dt$$
$$= \lambda^{-1}$$
$$= 1.9 \text{ min}$$

The errors in the estimates of τ and f_∞ are of the order of 0.1 min and 0.01 respectively.

COMPARISON OF FIRES FOUGHT AND NOT FOUGHT BEFORE ARRIVAL OF THE FIRE BRIGADE

Hogg[3] has shown that fires not fought before the arrival of the fire brigade differ from those fought. They tend to become larger, apparently as a result of being larger at discovery.

Figures 1 and 4 show p_s and $\bar{t}_c$ for fires with and without fire fighting before the arrival of the brigade. It can be seen that at discovery p_s and to a lesser extent $\bar{t}_c$ are higher for fires not fought before the arrival of the brigade, indicating that these fires are bigger when discovered.

The greater size on discovery of fires not fought before the arrival of the fire brigade probably results from a longer delay before discovery. It is estimated above that the average time from ignition to discovery is about 14 minutes greater for these fires. The long delays in discovery are probably the result of there being fewer people near by. This and the larger size of the fires on discovery are presumably the reasons for these fires not being fought.

The rate of increase of p_s with delay time was found to be 0.011 min^{-1} and not to be significantly different (5 per cent level)for fires fought and not fought before the arrival of the fire brigade, which suggests that the fire fighting before the arrival of the brigade makes little difference to the rate of spread for fires not extinguished. If it is assumed[3] that fires do not continue to grow after the arrival of the fire brigade then the rate of increase of p_s with attendance time represents the rate at which fires spread beyond the room of origin.

RATE OF EXTINCTION

The rate at which fires are extinguished before the arrival of the fire brigade can be estimated from the proportion p_o going out between call and arrival. Assuming an exponential decay

$$1 - p_o = \exp(-\mu t_{CA}) \qquad \ldots\ldots (2)$$

where μ = extinction coefficient

t_{CA} = time from call to arrival

Table 1 gives p_o versus t_{DA} for fires which were fought (or burnt out). Fires were taken to be out on arrival of the fire brigade if they had zero control time. Fires out at call were classified as late calls and were excluded.

Data for t_{CA} versus t_{DA} are given in Table 3. For these data

$$t_{CA} = 0.58\, t_{DA} + 0.27 \text{ min} \qquad \ldots\ldots (3)$$

with a very high correlation coefficient of 0.998.

The extinction coefficient, μ, calculated from equations (2) and (3) as a function of the time from discovery is shown in Fig. 5. It can be seen that μ decreases rapidly. This decrease indicated that fires which cannot be extinguished within a few minutes tend to be much more difficult to extinguish.

The extinction coefficient after the arrival of the fire brigade is approximately equal to the reciprocal of the mean control time. For fires fought before the arrival of the brigade the mean extinction coefficient is 0.13 min^{-1} after the brigade arrive and 0.079 min^{-1} before. Thus the average rate of extinction after the arrival of the fire brigade is considerably higher than that beforehand.

CONCLUSIONS

1. Data presented show that the probability of a fire spreading beyond the room of origin and the mean control time is greater the later the attendance of the fire brigade.

2. Taking all fires in buildings, the probability of a fire becoming large is independent of the delay time, t_{DA} but increases with the time from discovery to call, possibly because fire stations tend to be sited near high risks.

3. About 50 per cent of fires are fought before the brigade arrives. For these the mean time taken to commence such fire fighting after discovery is about two minutes. The extinction coefficient, μ, decreases rapidly with time after discovery. The average value is 0.08 min^{-1}.

4. The mean rate of increase of p_s with delay time is 0.011 min^{-1} and appears to be little altered by fire fighting before arrival of the brigade. If it is assumed as an extreme case that fires do not continue to grow after the arrival of the fire brigade then this figure represents the mean rate at which fires spread beyond the room of origin.

5. For fires fought before the arrival of the fire brigade the mean time from ignition to discovery appears to be of the order of 3 minutes. For fires not fought before the arrival of the brigade it is of the order of 18 minutes. Thus it appears that fires fought before arrival of the brigade are smaller on average at discovery.

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Table 1. Effect of delay time, t_{DA}

Buildings, 1967 excluding late calls

t_{DA} min	Fought before fire brigade[a]				Not fought before fire brigade			$f = \frac{n}{n+n'}$
	Number of fires n	p_s	p_o	t_c	Number of fires n'	p_s	t_c	
0	0				26	0.067		0
1	13	0.142	0.385		42	0.276		0.236
2	135	0.192	0.132		186	0.211		0.421
3	710	0.088	0.210	6.3	945	0.277	9.0	0.429
4	2411	0.091	0.239		3130	0.283		0.435
5	3969	0.092	0.268		4915	0.282		0.447
6	4416	0.088			5047	0.283		0.467
7	3406	0.099			3825	0.313		0.471
8	2499	0.121	0.319	7.3	2732	0.308	10.1	0.478
9	1705	0.103			1789	0.325		0.488
10	1497	0.133			1422	0.366		0.513
11–15	3018	0.157	0.313	9.8	2892	0.358	14.8	0.511
16–20	1032	0.231	0.292	12.7	1055	0.469	19.1	0.494
21–25	403		0.238	12.5	385		21.0	0.511
26–30	153	0.268	0.221	17.3	156	0.498	27.9	0.495
31+	317		0.176	12.5	260		26.5	0.549
Total	25684	0.117	0.295	7.7	28807	0.301	10.8	0.471

Sub-occupancies coded as 25 to 35, 72 to 74, 87 and 93 to 97 excluded.

a, including fires which burn out

t_c is mean control time in minutes excluding fires out on arrival

Single compartment buildings and fires confined to the appliance of origin excluded in the calculation of p_s, but included in n and n'.

Table 2. Effect of time to arrival of fire brigade on probability p_L of fire becoming large.

Fires in buildings, 1967.
Late calls, residential and derelict excluded.

t_{DA} min	Number of fires	p_L, per cent	$\overline{t}_{CA}$, min
0	29	0.0	0.0
1	55	3.6	0.5
2	319	1.3	1.2
3	1311	2.3	1.9
4	3757	2.2	2.4
5	5451	2.7	3.1
6	5309	2.7	3.9
7	3944	2.0	4.5
8	2788	2.3	5.2
9+	9624	2.3	8.0
All	32587	2.4	4.9
t_{DC} min			
0	524	2.5	
1	6192	2.0	
2	14326	2.3	
3	5396	2.1	
4	2295	2.6	
5	1759	2.4	
6-10	1378	4.3	
11-15	335	6.6	
16+	382	3.7	
All	32587	2.4	
t_{CA} min			
0	74	0.0	
1	679	2.4	
2	4280	2.4	
3	7396	2.9	
4	6392	2.6	
5	4374	2.3	
6	2423	2.1	
7	1453	2.1	
8+	5516	1.8	
All	32587	2.4	

Table 3. Effect of Sub-group.
Multi-storey buildings, 1967

Sub-group	Number of fires	p_s	$\bar{t}_{DA}$ min
Hotels and institutions	1165	0.164*	8.0
Offices	394	0.189	5.9
Shops	3498	0.224	6.4
Assembly	1698	0.228	7.3
Industrial	2445	0.387*	7.0
Storage	557	0.488	6.6
Houses	25300	0.156*	8.7
All	35057	0.223*	8.3

*, positive correlation with t_{DA} statistically significant at 1% level. Variation of p_s with t_{DA} not statistically significant in the other cases.

Table 4. Methods of fire fighting before arrival of fire brigade

All fires in buildings, 1967

Method of fire fighting

A	physical methods (removal, smothering etc)	Code	10 to 14, 99
B	water (excluding jets and hoses) etc		15 to 1Y
C	extinguishers, jets, hoses		01, 21 to 89

Occupancy versus method of fire fighting

Occupancy	Number of fires	Method of fire fighting, per cent				
		None	Burnt out	A	B	C
Industrial	7778	41	1	5	5	48
Transport	1543	68	1	4	9	18
Wholesale	499	65	1	3	10	21
Retail	4237	68	1	7	13	12
Professional	2723	44	2	9	16	30
Entertainment	778	63	1	5	11	20
Catering	4291	49	1	10	13	28
Government	1552	60	2	6	11	21
Houses	27483	50	1	17	27	5
Flats	10659	55	1	16	25	3
Other	14290	68	1	3	12	15
Average		54	1	11	19	14

Table 4 (Contd.)
Material ignited first versus method of fire fighting

Material	Number of fires	Method of fire fighting, per cent				
		None	Burnt out	A	B	C
Unknown	11995	72	1	3	12	12
Miscellaneous	11627	64	1	4	15	16
Gases	1962	45	2	20	21	12
Liquids	5303	34	1	15	18	32
Coal etc	461	51	0	12	7	30
Crops	2041	68	0	2	15	16
Textiles	4781	44	1	9	27	19
Bedding	4410	56	0	5	34	5
Furnishings	6101	50	1	10	32	7
Structure	3393	64	1	2	19	14
Roof etc	2821	75	0	1	12	12
Fittings	2417	59	1	5	25	11
Food	10586	33	2	36	17	12
Lagging	521	46	1	6	21	26
Rubber, paper	2772	53	1	4	20	21
Insulation	4642	50	3	17	15	14
Average		54	1	11	19	14

Table 4. Methods of fire fighting before arrival of fire brigade

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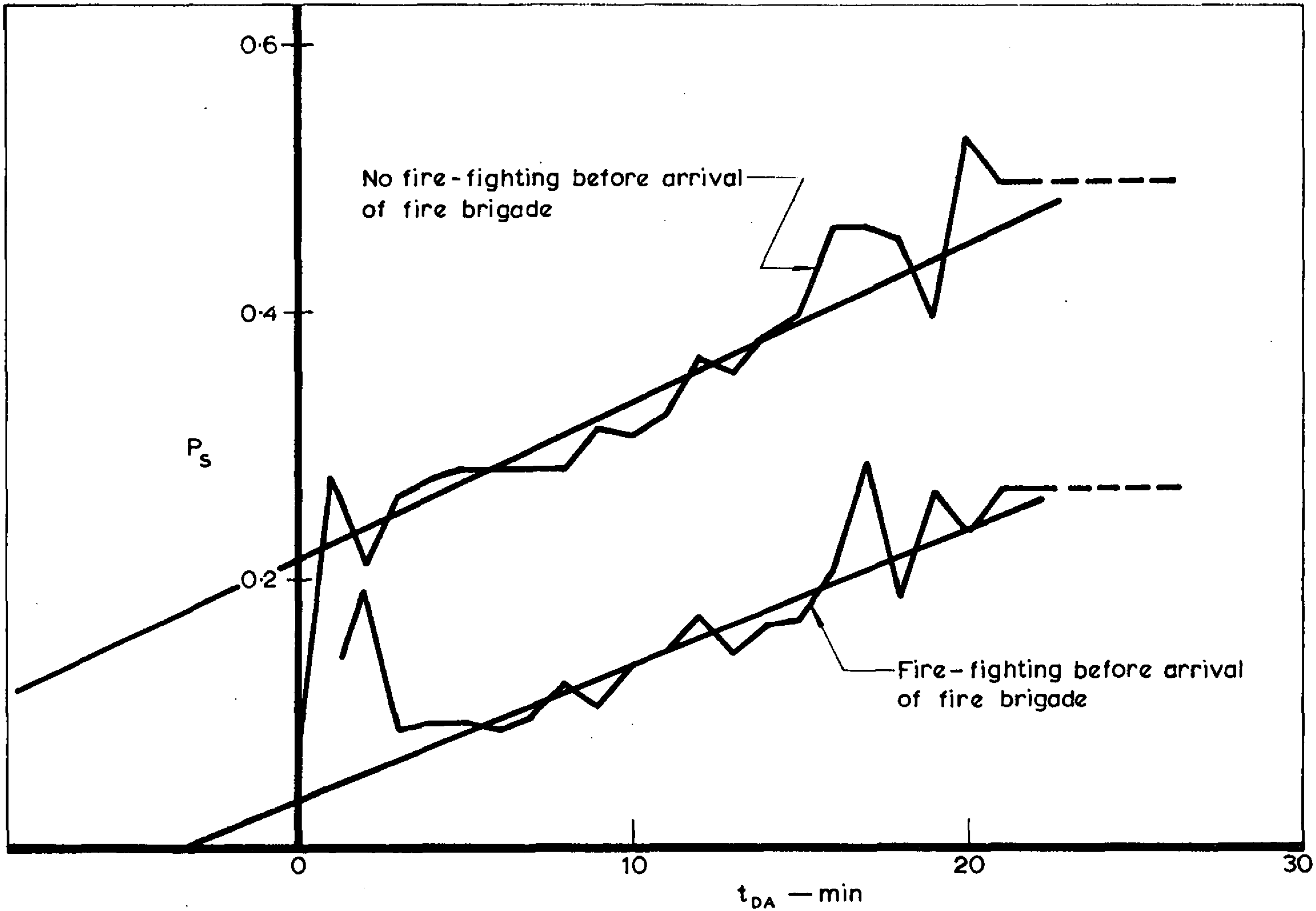

FIG.1 VARIATION OF PROBABILITY OF SPREAD BEYOND ROOM OF ORIGIN WITH DELAY TIME

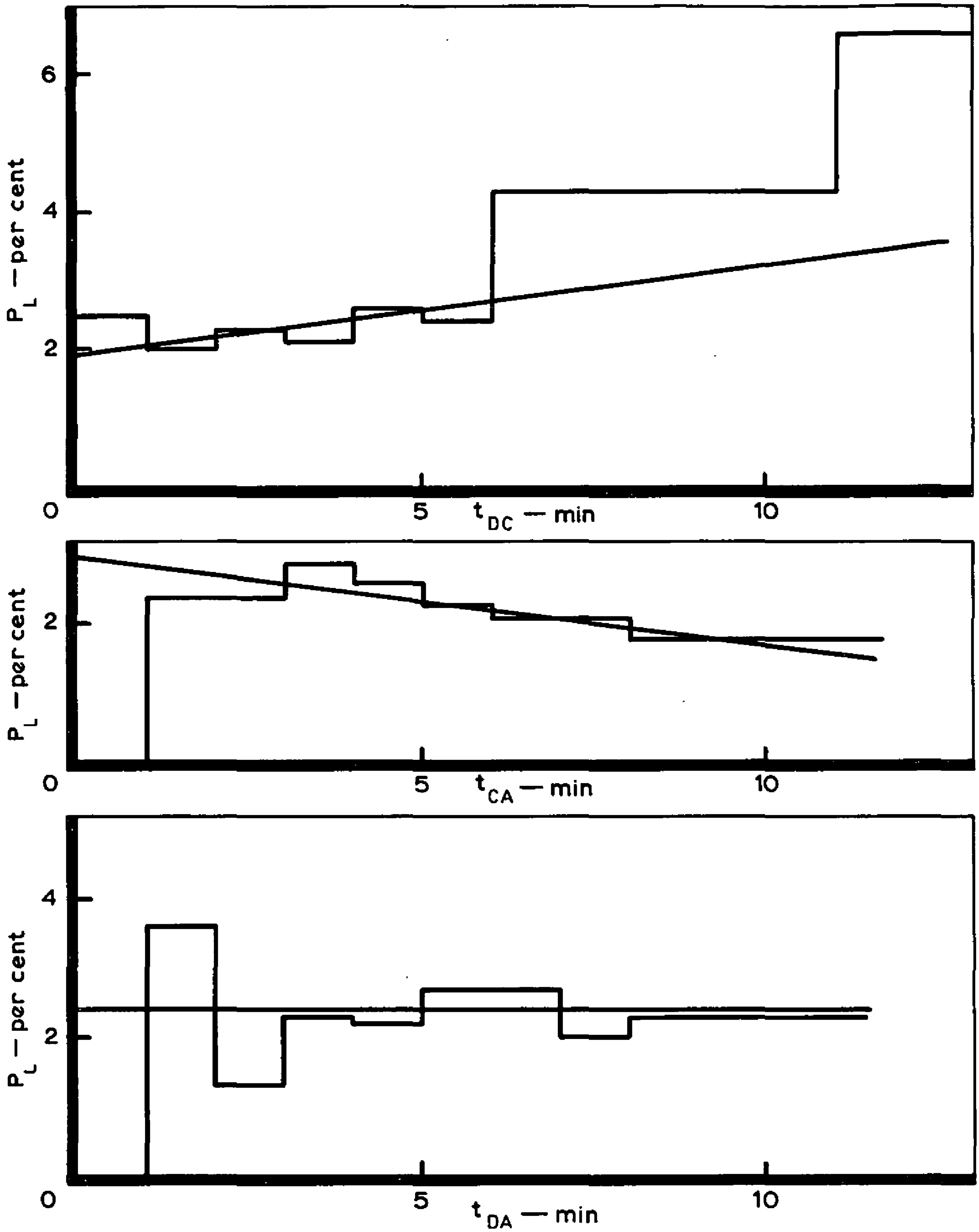

FIG. 2. VARIATION OF PROBABILITY OF FIRE BECOMING LARGE

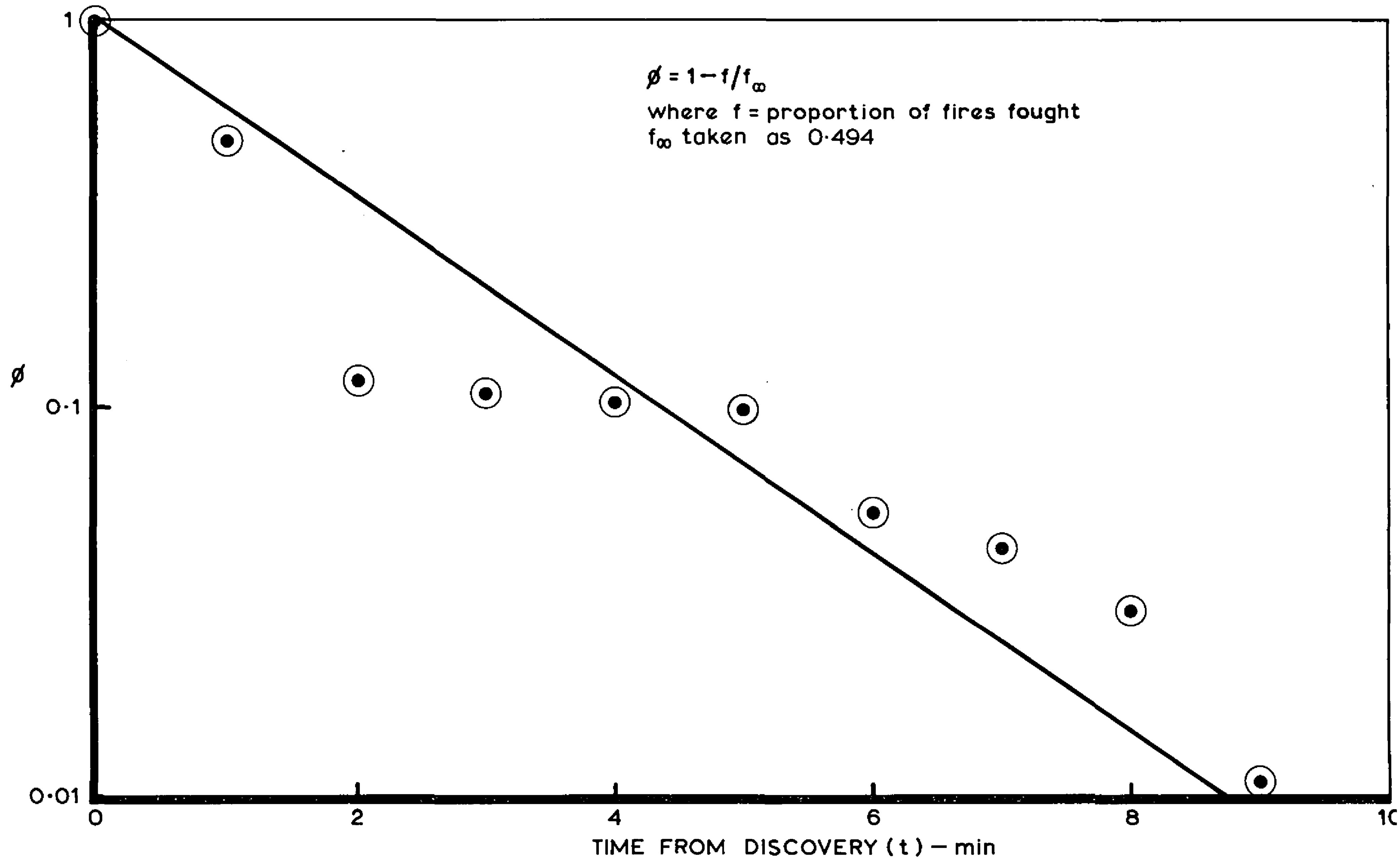

FIG. 3. VARIATION OF PROPORTION OF FIRES FOUGHT BEFORE ARRIVAL OF FIRE BRIGADE

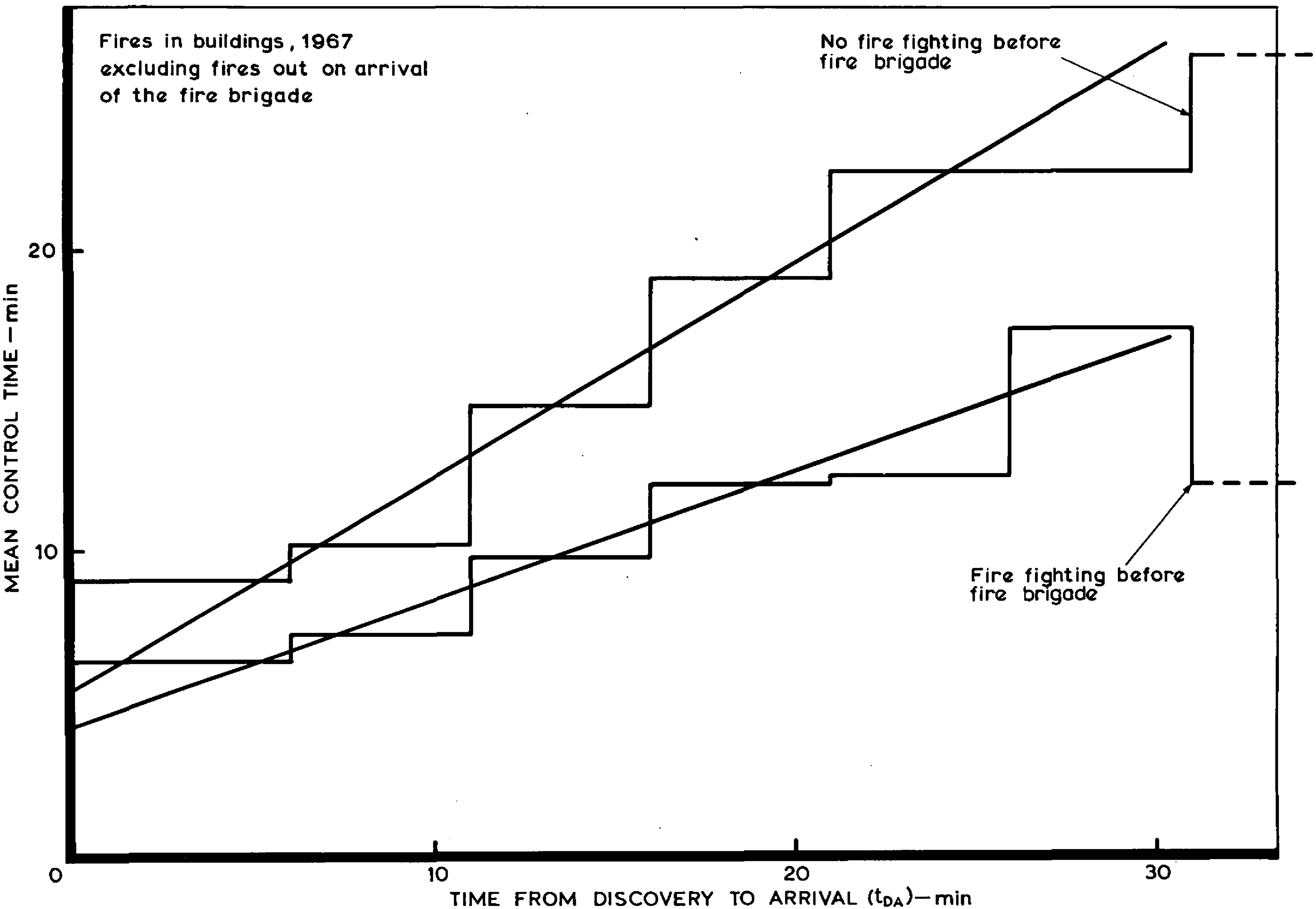

FIG. 4. VARIATION OF MEAN CONTROL TIME WITH DELAY TIME

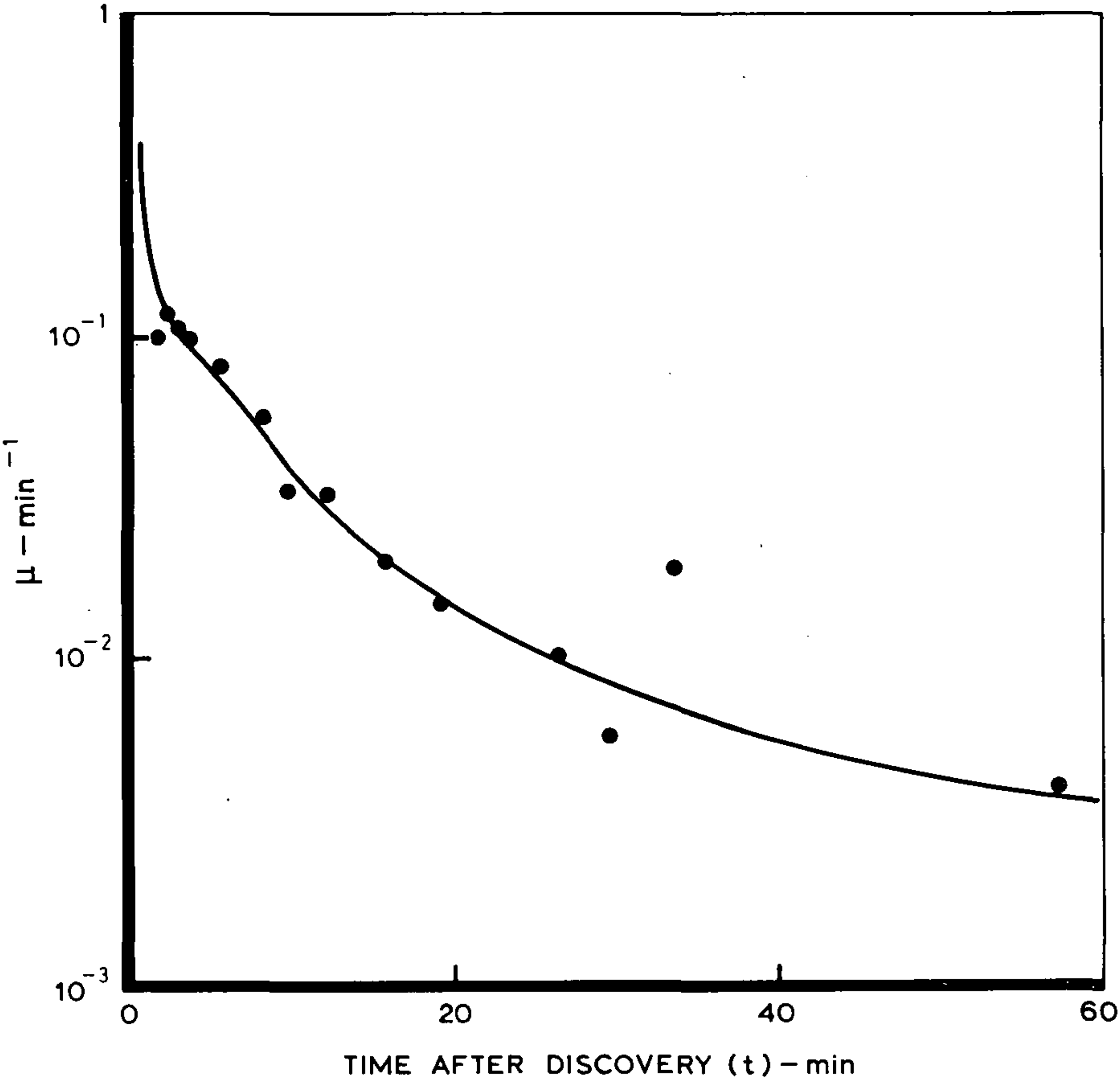

FIG. 5. EXTINCTION COEFFICIENT, μ, BEFORE ARRIVAL OF FIRE BRIGADE, FOR FIRES FOUGHT (OR BURNING OUT) BEFORE ARRIVAL OF FIRE BRIGADE