HOME OFFICE
SCIENTIFIC ADVISORY BRANCH

FIRE RESEARCH REPORT NO. 5/74

THE USE OF WATER IN THE EXTINCTION OF LARGE FIRES

by

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Director

Summary

This report is concerned with the relationship between the number of jets used by brigades to extinguish a fire and the size and other characteristics of the fire. Some published work on this relationship is discussed and comparable results have been obtained from analysis of fire reports completed by United Kingdom brigades in 1970.

These results consist of a set of equations describing the median number of jets used at fires of a given size and a statement of the variation about the median. The random variation is high and is not adequately explained by factors included in the 1970 fire reports.

The equations are needed for fire cover studies in which the probability that a given attendance will be able to extinguish a fire of given size must be estimated. The equations represent a summary of brigade practice in 1970 and are not intended as a recommendation for action at any particular fire.

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Introduction

The relationship between fire size and the force required to control it is of obvious practical importance. The officer in charge of the first attendance at a fire must make a rapid estimate of the force (in pumps, men, water supplies and equipment) required to control and extinguish that fire. This estimate is based on his assessment of the situation on arrival at the fire ground and his previous experience. The penalty for a wrong assessment in terms of increased final damage can be very high. In fire cover studies such as the calculation of the optimum number of fire appliances for a fire station, we require estimates of the size of fire that can be controlled by a given fire brigade attendance. This information coupled with a mathematical model of fire growth would permit calculations of the most effective use of fire brigade resources in a given area.

The present work is based on statistical analysis of data obtained from fire reports completed by a sample of fire brigades in 1970. Some previous papers based on experimental results and direct observations of fires are discussed in the next section.

Review of the Literature

All fires, apart from very small fires and special hazards, are extinguished by the application of water, either by the fire brigade or by automatic devices. Water ca damage buildings and their contents and so it is important to use the minimum quantity necessary. Thomas (1) showed that the relationship between the rate of application of water used and the area of the fire could be expressed in the form:

$$J = 0.1 \sqrt{A} \quad \ldots\ldots\ldots 1$$

where J is the number of jets in use at the control time and A the area of the fire damage (in sq ft) at extinction. This result was obtained from a small sample of large fires. It was also shown that the control time T was proportional to the square root of the area of fire damage and so the total amount of water used (proportional to J x T) was directly proportional to the area of fire. Although there was a large amount of random scatter in the data, reflecting the different problems encountered at the different fires, attempts to relate the number of jets used to the quantity of combustibles involved suggested that the area of fire was far more important than the fire loading in determining the necessary force.(1)

Two possible interpretations were suggested for these results. Fires are fought from the perimeter: thus one might expect the number of jets to be proportional to the perimeter size which would be correlated with the square root of fire area. Th observed relationship suggests that one jet can control about 30 ft of the perimete of the fire. Alternatively it could be assumed that jets are able to extinguish th fire at a standard rate, shown to be about 17 sq ft per minute.

A set of similar results have been published by the Illinois Institute of Technolog Research Institute (2). This survey showed that for a sample of 134 large fires attended by American brigades the rate of water application used to control the fire was given by:

$$W = 1.24 \ A^{0.664} \quad \ldots\ldots\ldots 2$$

where A is the area of fire in square metres and W the rate of application of water in litres per second. This result can be compared with the Thomas equation (1): assuming an average rate of 10 L/S for the discharge of one jet we get:

$$W = 3.3 \sqrt{A} \quad \ldots\ldots\ldots 3$$

which has been shown not to be statistically different from equation 2.

Comparison of the observed rate of water application for real fires with published data for the extinction of experimental fires shows that the rate of application is between 3 and 4 times as great for real fires (3). The published data for the extinction of experimental fires has been summarised by IITRI and have been shown to fit the expression:

$$W = 0.33 \ A^{0.64} \quad \ldots\ldots\ldots \ 4$$

with considerable scatter.

Source of data

The data used for the current work was obtained from K433 and SAF2 fire reports for 1970.

The Report of Fire, Form K433, is completed by all brigades for all fires attended except those confined to rubbish, grassland and other minor hazards. The report contains detailed information on the occupancy and construction of the building of origin, the times of discovery, call, arrival and control as well as a brief description of brigade involvement. The information from those reports has been coded, punched onto cards and copied to magnetic tape for computer analysis.

In the SAF2 project a number of brigades agreed to complete an additional report for all K433 fires, apart from late calls, fires out on arrival and fires confined to the exterior of a construction or a single item of contents of a construction. The SAF2 report contains information on the size and extent of fire at the arrival of the brigade, the arrival times of appliances and the force brought to bear on the fire. The SAF2 records for 1970 were matched with the relevant K433 records giving a sample of 22027 records of fires in buildings for that year.

The useful sample size is reduced by incomplete and inconsistent records and by excluding categories of fires that would give misleading results - for example, fires in derelict buildings, sheds, garages and building contractors huts are common and show high rates of fire spread: however life risk and losses from such fires are comparatively low and the penalty for allowing the fire to burn out is correspondingly small. Single compartment buildings must be considered as a separat category since fires in this type of building will be extremely unlikely to spread beyond the room of origin. The effective sample size is reduced considerably when these categories of fire are excluded.

Models

The brigades participating in the SAF2 project were asked to record the maximum number of jets in use at a fire and the horizontal area of fire damage at extinction In the present and previous work it is assumed that the relationship between jets used and area of fire gives a good estimate of the force necessary to extinguish the fire. This will not necessarily be true in all cases.

The estimate of fire damage is not intended to include smoke, water or heat damage: however we cannot assume that the area at extinction represents the area actually burning at any one time since part may have been extinguished or burnt out before t fire came under control. The total number of jets used does not necessarily represent the number of jets required to extinguish the fire, particularly since no all the jets may have been in use simultaneously, while limitations on water supply may have prevented the use of the desired number of jets. Furthermore, we cannot distinguish between the number of jets required to control the fire (ie prevent further fire spread) and the total number used to extinguish it.

About 85% of building fires attended by brigades in Great Britain are extinguished by the use of hose-reel jets, chemical extinguishers and other small means. Therefore the number of jets applied to the fire represents a useful measure of the fire-fighting force used only in the case of large fires. To obtain results comparable to those obtained by Thomas and IITRI the sample of fires studied was restricted to those fires over 1000 sq ft in area. In investigating the relationshi between jets used and fire size the contribution due to hose-reel jets was ignored since the rate of discharge of water obtainable with a hose-reel is considerably lower than that obtainable with a fire-fighting jet.

A larger sample of fires can be studied if we use the total rate of discharge of water at the fire as a measurement of fire-fighting force. This approach allows fire-fighting by jets of all sizes and hose-reels to be included if we use the sum of the average discharges for each type of jet as a measurement of force applied.

It is assumed that a relationship between jets (J) and area (A) analogous to equations 1 and 4 exists. The general equation 5 can be expressed in a linear form (equation 6):

$$J = a\,A^{b} \quad \ldots\ldots\ldots\; 5$$

$$\log J = \log a + b \log A \quad \ldots\ldots\ldots\; 6$$

Least squares estimates for the coefficients a and b can be found using the standar techniques of linear regression.

The data available contains additional information about the type of building on fire and there are two approaches which may be used to relate these building characteristics to the force used for control. Firstly we can divide the sample into homogenous groups based on different building characteristics and obtain separate estimates for the coefficients a and b for each group. An alternative approach is to fit a multiple regression relationship of the type:

$$\log J = \log a + b \log A + \sum_i c_i x_i \quad \ldots\ldots\ldots\; 7$$

where the x_i are a set of factors reflecting building characteristics and the difficulty of fire-fighting. If the interactions between the x_i and between log A and the x_i are not important then this approach is more satisfactory than grouping the data since we can estimate the coefficients more accurately.

In the present work the data were initially divided into four groups and regression of log J against log A were carried out. The alternative multiple regression approach was also investigated.

Results

A linear regression of log J on log A for the sample of large fires in the SAF2 data shows that, as expected, there is a strong correlation between the dependent and independent variables. The regression equation fitted was:

$$\log J = -\,2.7062 + .479 \log A$$ + log ε

where the residuals are normally distributed about the regression line with mean 0 and variance .219. The analysis of variance for this regression is shown in Table The coefficient of log (area) is not significantly different from .5.

The sample of fires was divided into four groups reflecting four different building types. The groups are single-storey dwellings, multi-storey dwellings, single-storey non-dwellings and multi-storey non-dwellings. These groups are the same as

those used in the fire spread model (4). Two regression models were fitted to the grouped data. First separate independent coefficients were calculated for each group: then an alternative model using four parallel lines was fitted. Although the independent lines must fit the data more closely than the parallel lines (ie the total residual sum of squares will be lower), the statistical significance of this improvement can be estimated. The calculations are summarised in Tables 2-3. It is shown that although the parallel lines model is a considerable improvement over a single line no significant gain is achieved by fitting independent lines to each group.

The results of the analysis of the grouped data suggest that whatever the type of building the number of jets used depends on area in the same way. This is the assumption underlying the multiple regression approach in which the dependent variable J is expressed as a linear combination of factors. In the present work we have both quantitative and qualitative factors that might be expected to affect the number of jets used for a given fire size. Examples of qualitative factors are building type (eg dwelling, non dwelling), fire extent (confined to room of origin, spread beyond room of origin or spread beyond building of origin) and risk category (a classification of buildings designed to reflect inherent fire risk). Quantitative factors are total building size (number of storeys multiplied by floor area), ceiling or roof height on floor of origin, and building age. A full list of the independent variables used together with the results of the multiple regression analysis is given in Appendix 1.

The most important factors in the multiple regression were found to be fire area, occupancy (dwelling/non dwelling), date of construction of building (expressed as a qualitative variable -1 for pre 1914, 0 for 1914-45 and 1 for post 1945), extent of fire (expressed as -1 for confined to room, 0 for spread beyond room of origin and 1 for spread beyond building of origin) and building size (expressed as log (total building area)). If these five factors are included in the regression then floor construction, risk category, ceiling height, single or multi-storey construction and whether or not the building is used for storage do not significantly affect the number of jets used to extinguish the fire. It should be pointed out that the existence of a statistical relationship does not imply a direct causal relationship: the significant variables in the regression equations may be related to a causal factor not included in the regression analysis. Some of the apparently non-significant variables may reflect causal factors already included in the regression and would show statistical significance if included in isolation. For example, if we include the following three factors only in the regression:- log A, dwelling/non-dwelling and single/multi-storey:- then the third factor becomes statistically significant. The variable single/multi-storey is not significant in the full multiple regression because the related factors affecting jets used are better represented by age, extent and building size. The model represented by the regression on three factors is analogous to the parallel lines model above and would be exactly the same if the interaction between building type and occupancy were included. The most important single factor other than area is whether or not the building is a dwelling. The expected relationship for dwellings and non-dwellings is shown in Figures 1 and 2.

An alternative method of measuring the force used by the brigade to control the fir is to determine the overall rate of discharge of water used to extinguish the fire. This quantity can be estimated from the record provided of the number of jets of various sizes used. Although the rate of discharge of any jet is a function of nozzle design, size and water pressure there is an optimum discharge and pressure for which the best jet is obtained for each nozzle size. Thus if we assume that each jet is operated at the optimum pressure(5) for that nozzle size then we can obtain the rate of discharge for the jet. The distribution of the nozzle sizes used in 1970 was as in Table 4. 35% of jets used were fitted with variable nozzles

regression analysis since it is partly dependent on the firefighting. The assumption of independence is not too important if the spread of fire after arrival is small. On average fires in dwellings spread by a factor of about 0.09 after arrival and non-dwellings by a factor of 0.25. Thus we may expect the simple model to give a reasonable estimate of the number of jets required to fight a fire of given size because the expected spread after arrival is small.

The inadequacies of the regression model make the interpretation of the less obvious results difficult. Two fires identical at arrival, could be fought with different numbers of jets leading to different areas at extinction. Thus even if area of damage was a unique and accurate measurement of the intensity of a fire a spread of data about the regression line would result. This feature could account for a large proportion of the variation observed. The multiple regression results can be interpreted in at least two ways: a group of fires may be observed to have less jets per area than the average either because they are intrinsically less fierce fires, or because the rate of spread is higher, or both.

The variation in the total rate of discharge of water used to fight fires of the same area is greater than the variation in the number of jets. This result suggests that it is more important to surround a fire with the required number of jets than it is to achieve a given rate of discharge of water.

The coefficient of log (area) in the overall regression (Table 1) is not significantly different from the value of .5 assumed by Thomas. Thus we may express the results in the form:-

$$J = .067 \sqrt{A}$$

The coefficient of $\sqrt{A}$ is significantly lower than that observed in Thomas's non-random sample of large fires: this is presumably due to the fact that the present sample is comparatively weighted by fires of just over 1000 sq ft fought by one or two jets.

The coefficient of log (area) in the regression of total discharge against area at control is likewise not significantly different from that reported by IITRI. Again the intercept value is significantly lower.

Conclusion

The number of jets used to control a fire is approximately proportional to the square root of the area of fire-damage in a random sample of large fires. Other factors with a statistically significant effect on the ratio between number of jets and area are occupancy (whether the building is a dwelling or not), the age of the building, the extent of fire (whether confined to room of origin or not) and the building size. Risk category, number of storeys, ceiling height, firefighting befor the arrival of the brigade; casualties and floor construction do not affect the relationship significantly after the first five factors have been taken into accoun The physical interpretation of the significance of these factors could be explained both in terms of the severity of the fire and the nature of the firefighting.

The variation between numbers of jets used to fight fires of similar size is considerable. This may be partly due to the fact that area of fire damage does not accurately represent the area of fire at any one time, but can also be explained in terms of the deficiencies in the regression model. The variation in total discharg of water used to fight fires of similar size is even greater than that observed in number of jets.

normally these can operate with an aperture from 0 to about 1" and an average discharge of 10 l/s has been assumed. Results of a multiple regression of discharge rate against area and other factors are tabulated in Table 5. As expected the results are similar to the results for regression of jets against area. The sample used here was fires that had spread beyond room of origin only: this does not affect the results significantly. The coefficient of area is significantly higher for the regression involving total discharge of water: it is not surprising to find that larger jets, as well as more jets, are used on larger fires. The goodness of fit as estimated by R^2 is less good for the total discharge regression and the amoun of variation about the regression surface is greater.

Analysis of residuals

A significant feature of both regressions is that however many independent variables are included the 'random variation' indicated by the error sum of squares is still high. The error mean square for the jets regression is .183. This result suggests that for any fire of given area of fire damage and building characteristics the top 5% are fought with at least twice as many jets than the average and over four times as many as the lowest 5%. The top 1% are fought with 2.7 times as many jets as those on the regression surface.

It is still possible that some of this variation can be removed by putting more independent variables in the regression equation. To test whether part of the variation could be ascribed to building use, building occupancy or variations in brigade practice plots of the residuals were obtained for the data organised into groups reflecting differences in each of these three aspects of the fires. First the data were divided into different sub-occupancies such as storage, industrial, assembly, shops etc. For the second residual plot the data were divided into different industrial classifications - mechanical engineering, electrical, retail, textiles etc. Finally the data were divided into different brigades. Details of the residual plots are shown in Figures 3, 4 and 5. The results show that sub-division of the data is not likely to significantly reduce the variation and comparison between the variation between group means and the overall variation shows that the group means do not significantly differ from zero. The first two results are similar to those obtained by Thomas in that no correlation could be observed between jets required for control and fire-loading. It is not expected that there would have been a large variation in brigade practice although the availability of water supplies in different areas might be expected to affect the number of jets used.

Discussion

Figures 1 and 2 show the relationship between number of jets and area of fire damage for dwellings and non-dwellings estimated by the regression analysis. The regression equation describes the median line: 50% of fires required more than this number of jets and 50% required less. Also drawn are the 90%, 95% and 99% confidence limits. These have a simple interpretation. A fire of about 10,000 sq ft in a non-dwelling would on average be controlled with 6 jets: 11 jets would control 90% of fires of this size and to be 99% certain of controlling fires of this area 17 jets should be available.

In practice it is likely that these confidence limits give a very conservative estimate of the probability of controlling a fire. In the present work no consideration has been given to the spread of fire between arrival of the brigade and control and the regression line represents an oversimplified model of control at a fire. For the final size of a fire must be a function of the size at arrival, the type of fire, the area unburnt at arrival and the firefighting. Thus the final area of fire damage cannot strictly be regarded as an independent variable for the

References

1. Thomas P H. Use of water in the extinction of large fires. Inst. Fire Eng. Quarterly, 19(35), 130-2, 1959.

2. Labes W G. Fire department operation analysis, final report. Illinois Institute of Technology Research Institute. Contract No N0022867 C0701, OCD Work unit 2522 F, January 1968.

3. Baldwin R. The Use of Water in the Extinction of Fires by Brigades. JFRO Fire Research Note No 803, March 1970.

4. Hogg Jane M. A Model of Fire Spread. Home Office Scientific Advisory Branch Report No 2/71, March 1971.

5. Home Office (Fire Department). Manual of Firemanship, Part 3 : hydraulics and water supplies. London, HMSO, 1972.

Appendix 1. Regression of number of jets against area and other factors

1.1 The sample. A sample of building fires over 1000 sq ft in area was obtained by using a computer to scan through the SAF2 files. Fires in sheds and garages were excluded. Miscoded and otherwise inconsistent records were excluded as far as possible: some records were excluded on the basis of internal inconsistencies such as being coded as confined to room with an area larger than the room, and others were excluded or corrected after the first regression analysis had shown extreme values for the residuals. The data for regression was written onto a disc file and used as input for a stepwise multiple regression program.(1)

1.2 Definition of variables

1. Dependent variable log. (number of jets used to extinguish the fire). Jets used does not include hose-reel jets.

2. AHRF = log (horizontal area of fire damage at extinction in square feet). Horizontal area is defined as the sum of areas of fire damage at each level of the building.

3. DND. A qualitative variable taking the value 0 for a dwelling and 1 for a non-dwelling.

4. ISTORE. Value = 1. If building of origin used for storage. 0 otherwise.

5. IRISK. Qualitative variable reflecting the risk category of the building in question. Value = -1 for special and high risks, 0 for A and B risks and 1 for C and D risks.

6. IAGE. Qualitative variable dependent on the date of construction of the building. Value was -1 for pre 1914 construction, 0 for 1914-1944 and 1 for 1945 and later construction.

7. STORYS. Value 0 for single storey construction. 1 for multi-storey.

8. IFLOOR. Value 1 if building has wooden floors, 0 if otherwise.

9. IEXT. Extent of fire. Value = -1 for fire confined to room of origin, 0 for fire confined to building of origin and 1 if spread beyond building of origin.

10. RMH. The height of the ceiling of the room of origin.

11. ABDIM = log (total building area). Here building area is defined as the ground floor area in square feet multiplied by the number of floors in the building, including basement and roof space.

In addition to the variables listed above, 3 other qualitative dependent variables were included. These were not at all significant, and have not been included in the listing of output below:

12. CASNO: qualitative variable taking on value 1 if escapes, rescues or non-fatal casualties were present at the fire.

13. IFBA: qualitative variable taking value of 1 if breathing apparatus was used and 0 if it was not.

14. PRFF: qualitative variable taking value of 1 if there was any kind of firefighting before arrival of the brigade and 0 if none.

1.3 The program calculates a series of regressions in which one independent variabl is added at each step. The variable added is the one that makes the greatest reduction in the total sum of squares. Variables included in the regression can be eliminated if the partial F value for that variable falls below a control level specified at the beginning of each run.

1.4 Information output by regression program:

a. Analysis of variance and regression equation for each step.

b. Summary table showing increase in regression sum of squares at each step. The program has been allowed to include non-significant variables in the regression equation. The relevant significance levels of the calculated partial F values are:

Significant at greater than 5% F 3.84
" " " " 1% F 6.63
" " " " 0.1% F 10.83

c. Plot of residuals against the main independent variable (loga).

```
STEP NUMBER      1
VARIABLE ENTERED      2

MULTIPLE R                        .6676
STD. ERROR OF EST.                .4676

ANALYSIS OF VARIANCE
                          DF      SUM OF SQUARES      MEAN SQUARE
          REGRESSION       1           113.575          113.575
          RESIDUAL       646           141.244             .219

                    VARIABLES IN EQUATION

  VARIABLE        COEFFICIENT  STD. ERROR  F TO REMOVE .


 (CONSTANT           -2.70621 )
 AHRF     2           .47913       .02102    519.4519  .




STEP NUMBER      2
VARIABLE ENTERED      3

MULTIPLE R                        .6995
STD. ERROR OF EST.                .4492

ANALYSIS OF VARIANCE
                          DF      SUM OF SQUARES      MEAN SQUARE
          REGRESSION       2           124.678           62.339
          RESIDUAL       645           130.141             .202

                    VARIABLES IN EQUATION

  VARIABLE        COEFFICIENT  STD. ERROR  F TO REMOVE .


 (CONSTANT           -2.79443 )
 AHRF     2           .44942       .02058    478.1822  .
 DNF      3           .37874       .05105     55.0276  .
```

```
STEP NUMBER      5
VARIABLE ENTERED    11

MULTIPLE R                     .7338
STD. ERROR OF EST.             .4280

ANALYSIS OF VARIANCE
                            DF     SUM OF SQUARES    MEAN SQUARE
        REGRESSION           5          137.208           27.442
        RESIDUAL           642          117.611             .183
                                                                     .
                    VARIABLES IN EQUATION                            .
                                                                     .
 VARIABLE  .     COEFFICIENT  STD. ERROR  F TO REMOVE .
                                                                     .
                                                                     .
 (CONSTANT          -2.81226 )                                       .
 AHRF      2          .38[illegible]79        .022[illegible]      276.9642  .
 DND       3          .38856        .04928       62.1780  .
 IAGE      6         -.11146        .01987       31.4715  .
 IEXT      9          .17[illegible]5        .03[illegible]       25.9729  .
 ABDIM    11          .05715        .01461       15.3030  .



STEP NUMBER      6
VARIABLE ENTERED     8

MULTIPLE R                     .7355
STD. ERROR OF EST.             .4272

ANALYSIS OF VARIANCE
                            DF     SUM OF SQUARES    MEAN SQUARE
        REGRESSION           6          137.831           22.972
        RESIDUAL           641          116.989             .183
                                                                     .
                    VARIABLES IN EQUATION                            .
                                                                     .
 VARIABLE        COEFFICIENT  STD. ERROR  F TO REMOVE .
                                                                     .
                                                                     .
 (CONSTANT          -2.74164 )                                       .
 AHRF      2          .38125        .02284      278.7125  .
 DND       3          .36651        .05061       52.4406  .
 IAGE      6         -.11380        .01987       32.7954  .
 IFLOOR    8         -.07625        .04128        3.4124  .
 IEXT      9          .17646        .03460       26.0018  .
 ABDIM    11          .05308        .01475       12.9531  .
```

```
STEP NUMBER     3
VARIABLE ENTERED     6

MULTIPLE R                         .7187
STD. ERROR OF EST.                 .4374

ANALYSIS OF VARIANCE
                               DF      SUM OF SQUARES      MEAN SQUARE
          REGRESSION            3            131.614           43.871
          RESIDUAL            644            123.205             .191

                    VARIABLES IN EQUATION                             .
                                                                      .
                                                                      .
   VARIABLE          COEFFICIENT   STD. ERROR   F TO REMOVE           .
                                                                      .
                                                                      .
  (CONSTANT            -2.71939 )                                     .
  AHRF      2           .43703         .02015      470.4699           .
  DND       3           .39190         .04976       62.0016           .
  IAGE      6          -.12066         .02004       36.2546           .
                                                                      .
                                                                      .
                                                                      .
                                                                      .




STEP NUMBER     4
VARIABLE ENTERED     9

MULTIPLE R                         .7263
STD. ERROR OF EST.                 .4327

ANALYSIS OF VARIANCE
                               DF      SUM OF SQUARES      MEAN SQUARE
          REGRESSION            4            134.404           33.601
          RESIDUAL            643            120.415             .187

                                                                      .
                    VARIABLES IN EQUATION                             .
                                                                      .
   VARIABLE          COEFFICIENT   STD. ERROR   F TO REMOVE           .
                                                                      .
                                                                      .
  (CONSTANT            -2.65013 )                                     .
  AHRF      2           .42441         .02020      441.3713           .
  DND       3           .41105         .04948       69.0107           .
  IAGE      6          -.12392         .01983       39.0584           .
  IEXT      9           .12509         .03241       14.9002           .
                                                                      .
                                                                      .
```

```
SUMMARY TABLE

 STEP              VARIABLE                  MULTIPLE                     INCREASE        F VALUE TO
NUMBER       ENTERED   REMOVED          R              RSQ             IN RSQ       ENTER OR REMOVE


   1         ABRF        2            .6676          .4457             .4457          519.4519
   2         ONO         3            .6995          .4893             .0436           55.0276
   3         IAGE        6            .7187          .5165             .0272           36.2546
   4         IEXT        9            .7263          .5274             .0110           14.5002
   5         ABDIM      11            .7338          .5385             .0110           15.3030
   6         IFLOOR      8            .7355          .5409             .0024            3.4124
   7         IRISK       5            .7361          .5418             .0009            1.2942
   8         RMB        10            .7365          .5425             .0007             .9331
   9         STORYS      7            .7369          .5430             .0005             .6464
  10         ISTORE      4            .7371          .5433             .0004             .5147
```

```
PLOT OF RESIDUALS (Y-AXIS)                                  ..
 VS. VARIABLE  2 (X-AXIS)                                   ..

     7.000     8.306     9.612    10.918    12.224    13.531..
          7.653     8.959    10.265    11.571    12.878     ..
      ...................................................   ..
-1.19 .     1  11                  1                        ..
      .       21                                            ..
      .                                                     ..
      .  1     1                                            ..
      . 2   11                                              ..
 -.95 .  2                                                  ..
      .                  1                                  ..
      .  21 1                   1                           ..
      .1 1  1  1 1            1                             ..
      .  11       1 1    1                                  ..
 -.71 . 11  111 111                                         ..
      . 1  341 311    2         1                           ..
      . 2 122  121                                          ..
      . 1    1 1  1   1                                     ..
      .11  1   4 11 1   21        1                         ..
 -.47 . 11   2121  1    111                                 ..
      . 31 113222    1  1  1                                ..
      .  1 12112  2 1   1 1 1         1    1                ..
      . 211144 3121     1      1      1                     ..
      . 213123 511 1  11                                    ..
 -.23 . 252 5  11 121 11 1   1                              ..
      . 22 21311-1    2                                     ..
      .1 2 1 321 123  1 112        1                    1   ..
      .123 242 22     3 1 21                                ..
      . 311134 21 111 111   1                               ..
  .00 .1112342125 2 2   1    1      1                       ..
      . 122143123   1 1   1       111                       ..
      . 6332211431 1   1    2  1                            ..
      .212312 1  21   2         2                           ..
      . 36 7:1132122  2  1 11 1         1                   ..
  .24 . 52343   33   22  11                                 ..
      .2332233112  2 1   11  1   1                          ..
      . 315442 12     1 1  1   1                            ..
      . 1511442211 1  1                                     ..
      .  4 22422122     23  1                               ..
  .48 .2133     221    1     11    1                        ..
      . 111 22 11 2 1                                       ..
      .  111112       1    1    1         1                 ..
      .    2 3 1 11   11  1                                 ..
      .  2    1  21   1                                     ..
  .72 .    1 2        1                                     ..
      .1           1      1                                 ..
      .   1 1  11      1                                    ..
      .  1  1                                               ..
      .     1   1         1                                 ..
  .95 .     1                                               ..
      . 1                                                   ..
      .                 1                                   ..
      .   1                                                 ..
      .                      1                              ..
      ...................................................   ..
     7.000     8.306     9.612    10.918    12.224    13.531..
          7.653     8.959    10.265    11.571    12.878     ..
```

REFERENCE

1. Dixon W J "BMD Biomedical Computer Programs". University of California Press. 1971

All fires greater than 1000 sq ft in area

Model 1

Source	Sum of Squares	d.f.	Mean square	F-Ratio
Due to regression of log J on log A	113.575	1	113.575	519
Residual	141.244	646	.219	
Total	254.819	647		

Model fitted log J = a + b log A

where J is number of jets in use and A total horizontal area of fire damage

Constant term a = - 2.706

Coefficient b = .479

Standard error of b = .021

Table 1. Results of regression of log J against log A

Model 3: independent regression lines

Source	Sum of Squares	d.f.	Mean Square
Due to regression	128.645	7	18.38
Residual	126.174	640	.197

Group 1:	single storey dwellings	$a_1 = -2.951$	$b_1 = .455$
Group 2:	multi storey dwellings	$a_2 = -2.478$	$b_2 = .411$
Group 3:	single storey non-dwellings	$a_3 = -2.092$	$b_3 = .399$
Group 4:	multi storey non-dwellings	$a_4 = -2.455$	$b_4 = .463$

Model 2: four parallel lines

Source	Sum of Squares	d.f.	Mean Square
Regression	128.191	4	32.05
Residual	126.628	643	.197

$a_1 = -2.577$

$a_2 = -2.671$

$a_3 = -2.386$

$a_4 = -2.229$

$b_1 = b_2 = b_3 = b_4 = .436$

Table 2 Regressions of log J against log A for grouped data

Source	Sum of Squares	d.f.	Mean Square	F-Ratio
Model 1 Regresion of log J on log A	113.575	1	113.575	519*
Improvement due to model 2 (parallel lines)	14.616	3	4.872	24.7*
Improvement of Model 3 over Model 2	.455	3	.152	.7⌿
Regression Model 3	128.646	7		
Residual	126.174	640	.197	
Total	254.819	647		

* Highly significant

⌿ not at all significant

Table 3 Comparison between Models 1, 2 and 3.

Nozzle size	Percentage of total jets used on fires >100 sq ft	Discharge at optimum pressure
⅜"	1.96	1.57 L/S
½"	14.82	2.65
⅝"	13.11	4.94
¾"	18.79	8.33
⅞"-1⅛"	3.89	18.00
1¼"-1½"	1.89	34.10
1½"	.69	40.90
Diffuser	9.39	10.00
Variable	35.42	10.00
	100.00	
Hosereel	-	1.28

Table 4. Jets used in fighting fires greater than 100 sq ft (1970)

$$\log T = a + b \log A + C\,(DND)$$

where T = total discharge of water (litres/sec) for all jets used

A = final area of fire damage (sq ft)

DND = 0 for dwelling, 1 for non-dwelling

Source	Sum of Squares	d.f.	Ms	F
Due to regression of log T on A	132.692	1	133	205
Extra due to DND	8.260	1	8.26	13.1
Residual	250.615	400	.627	
Total	391.567	402		

Regression equations: dwellings $\log T = -1.887 + .5996 \log A$

non-dwellings $\log T = -1.486 + .5996 \log A$

Standard error of b is .0453

R^2 is .36

Table 5. Regression of log (total discharge) against area of fire damage for all fires that had spread beyond room of origin

Figure 1: Number of jets used against area of fire damage (dwellings)

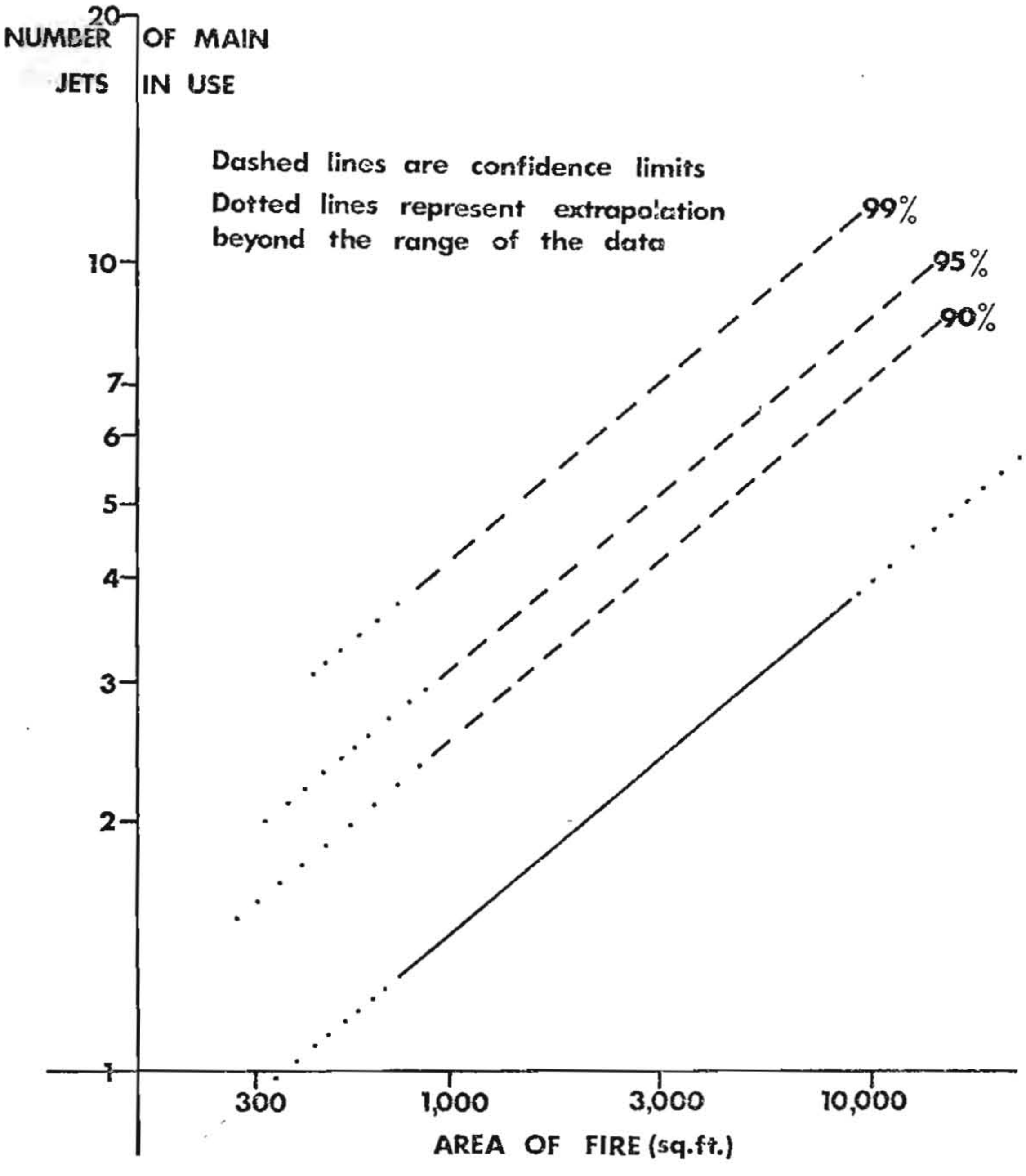


Figure 2: Number of jets used against area of fire damage (non-dwellings)

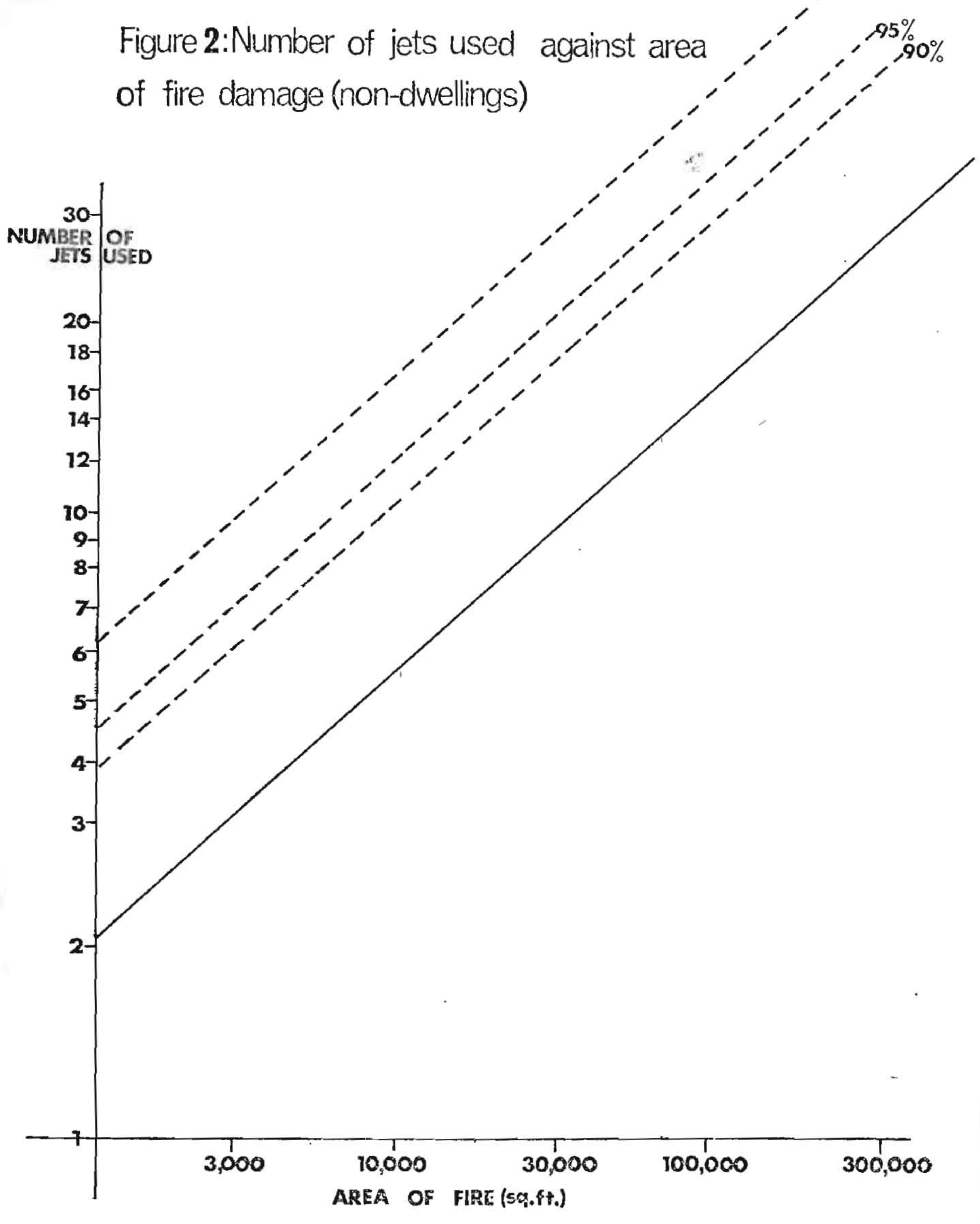


Figure 3: Histograms of residuals for groups based on sub-occupancy

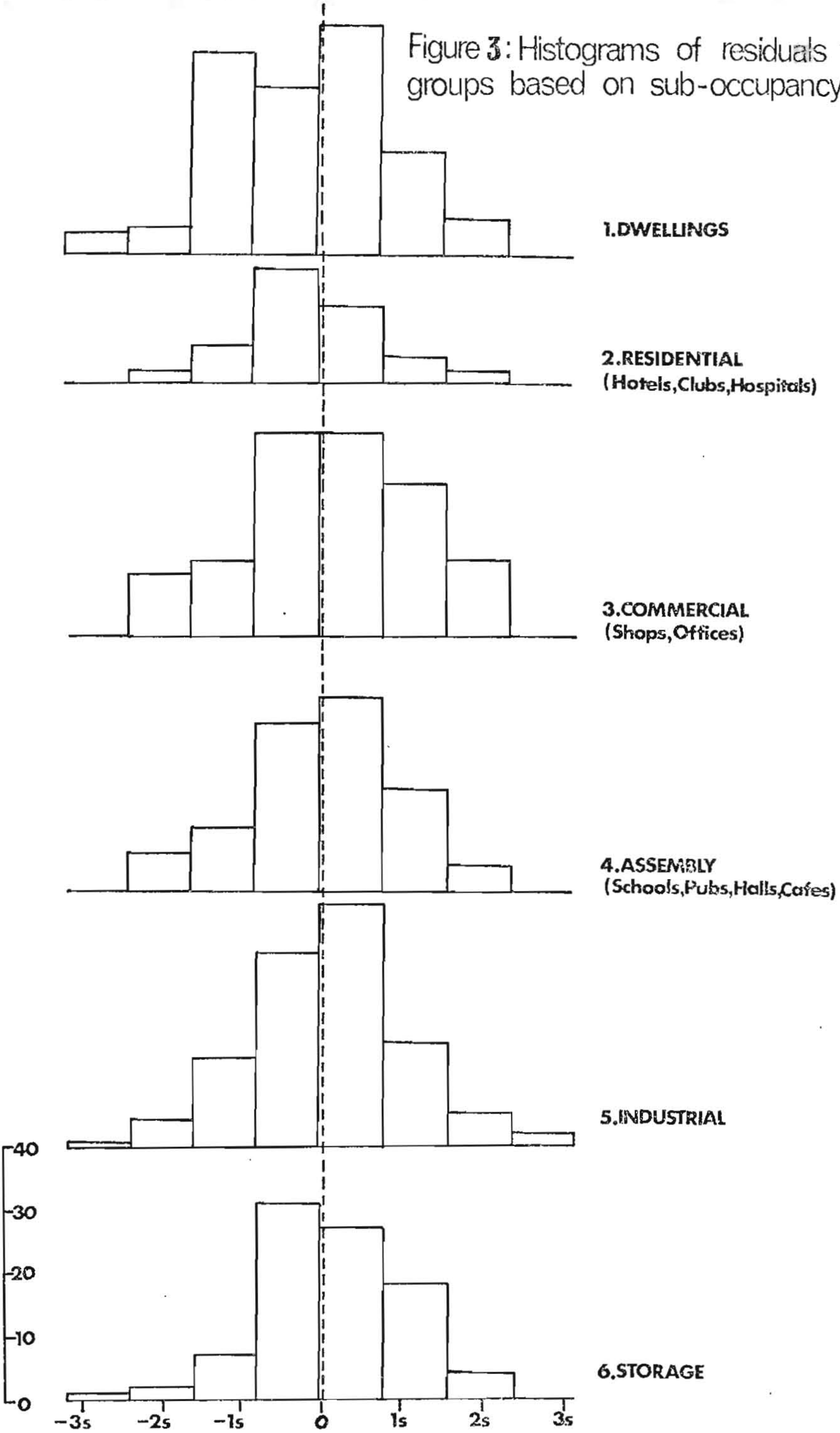


Figure 4: Histograms of residuals for groups based on Industrial Classification

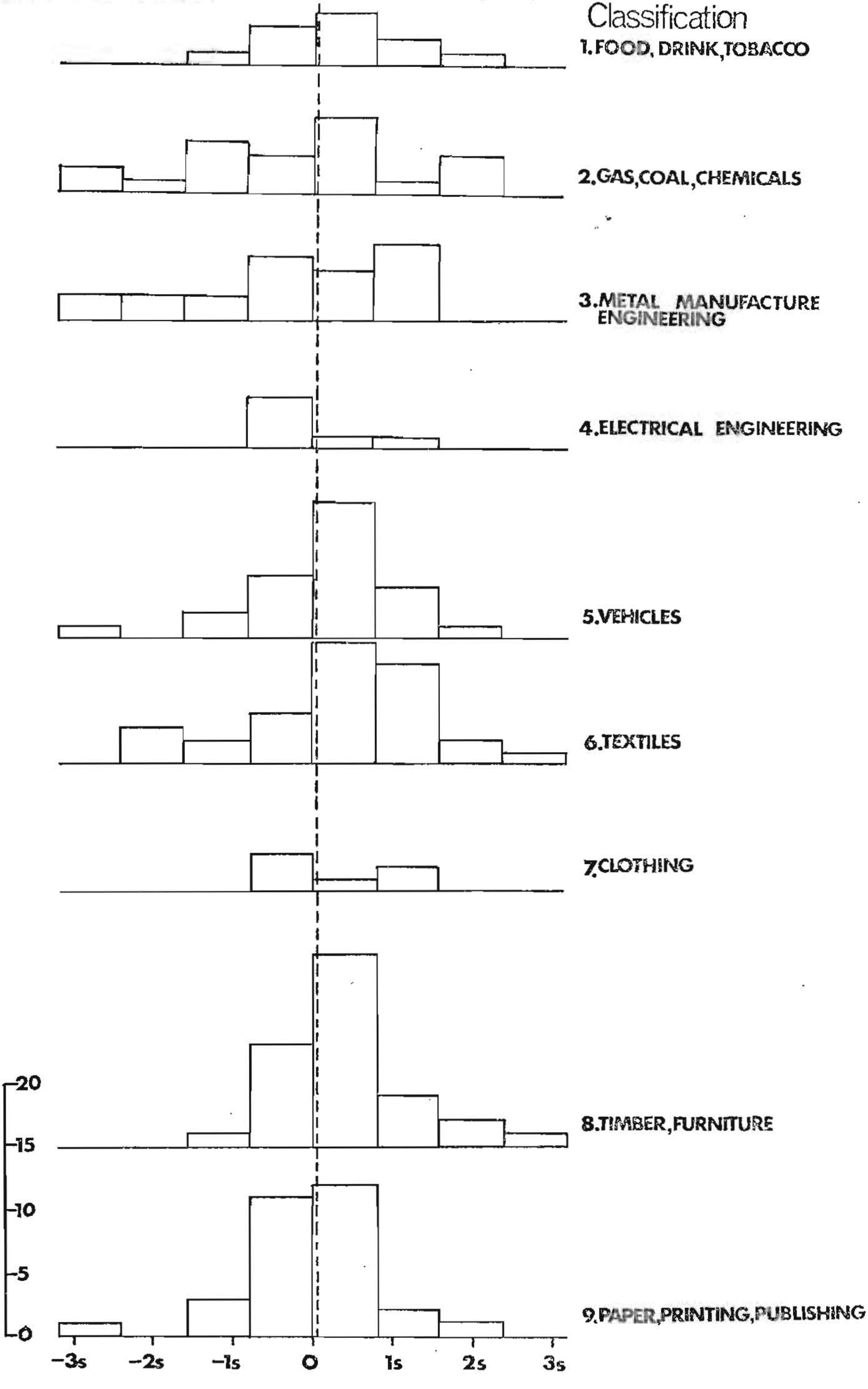


Figure 4 (continued)

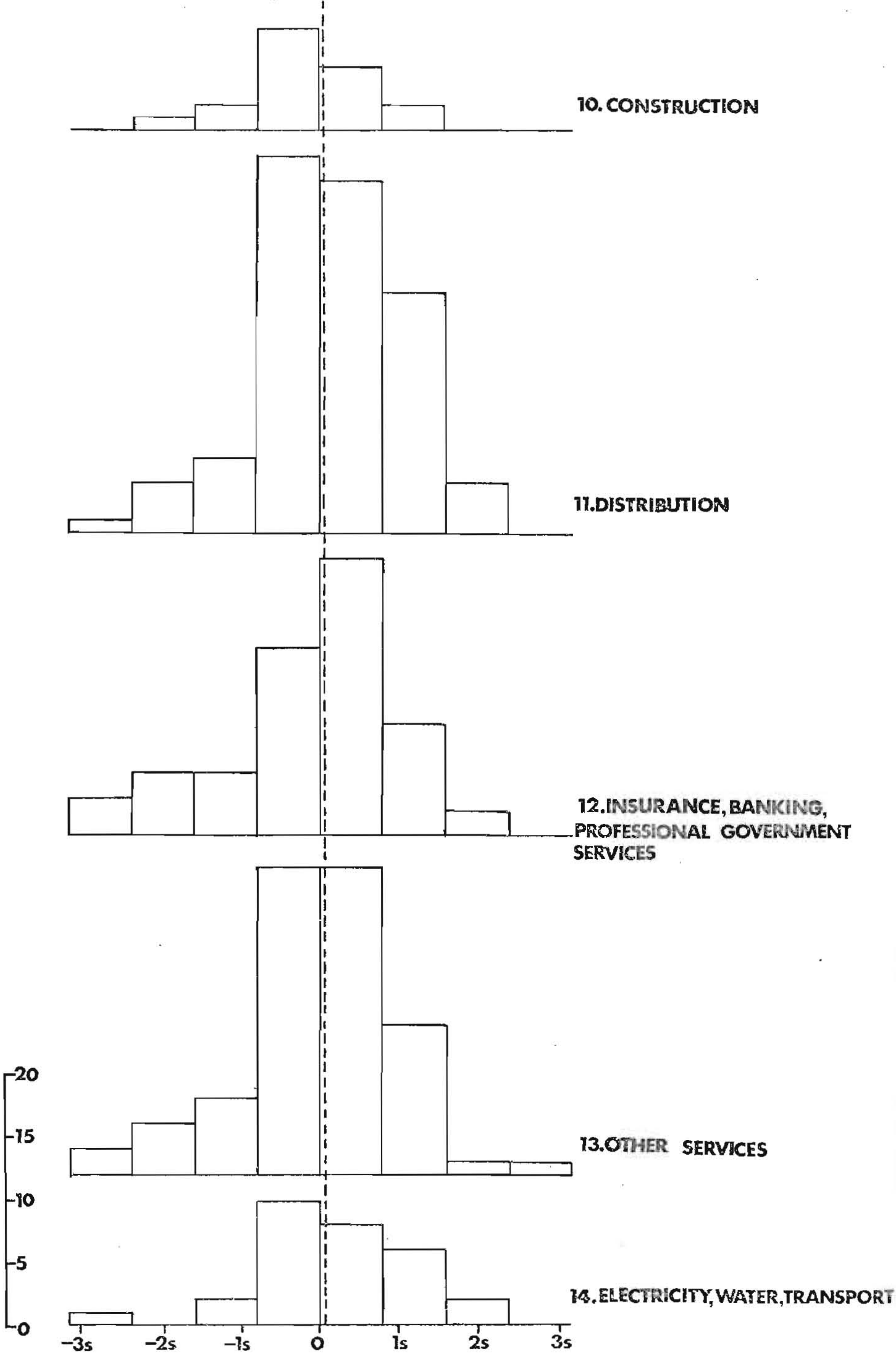
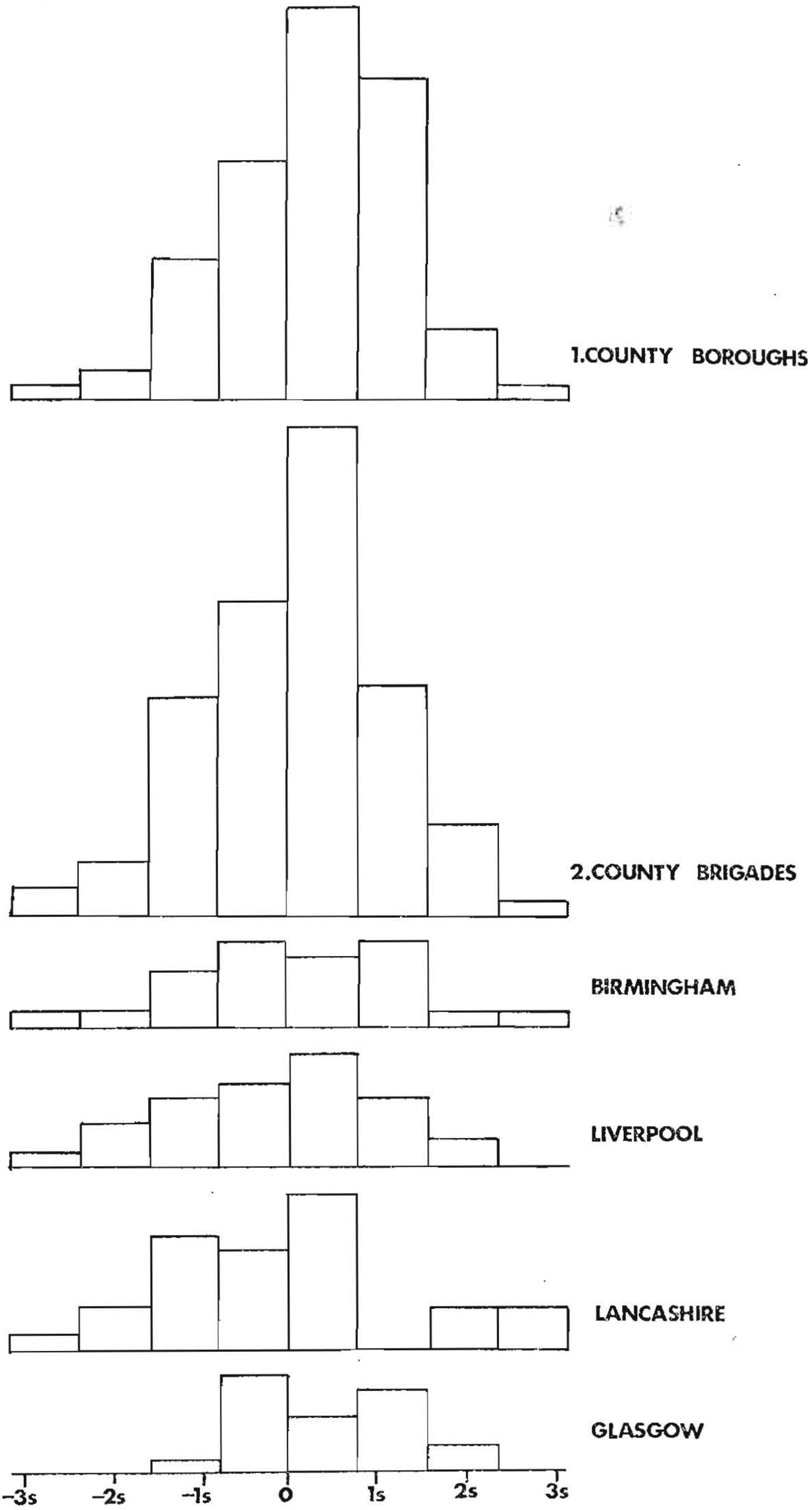


Figure 5:Histograms of residuals for groups of brigades



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