MAGNITUDE ANALYSIS USING BRADFORD DISASTER SCALE

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ABSTRACT

Disaster consequence magnitude analysis methods utilising the Bradford Disaster Scale (BDS) previously applied to fatalities and re-insurable costs is used to analyse evacuation data for both the UK and USA. Consistent fit to the data are obtained using both exponential and Weibull probability density functions (pdf). Return periods as a function of the number of population evacuated are calculated for both the UK and USA. Examination of the estimated values of the (pdf) parameters obtained by using Maximum Likelihood suggest that even allowing for uncertainty associated with sample size, on balance significantly more people are evacuated in an emergency in the USA than in the UK.

INTRODUCTION

In order to compare disasters arising from different sources it is useful to use quantitative measures. For this purpose Keller (1) introduced the Bradford Disaster Scale (BDS) which is based on the logarithm of the number of fatalities involved in the occurrence of a disaster. It has been shown that the method is useful for disaster analysis, hazard identification and quantification; it can also be used as a tool for structured and strategic planning.

Whilst death is the most significant and most easily identified consequence associated with disaster, other consequences such as injuries, cost of damage, evacuation, social disruption, psychological trauma and environmental impact cannot be neglected. Evacuation and temporary housing of evacuees is obviously an important element in emergency planning. Due to the complexity of these consequences, a comprehensive quantitative measure to satisfy all planning needs is difficult to formulate.

The approach developed in this paper and elsewhere Keller et al (2,4); Keller et al (5) is to consider consequences existing in a multidimensional manifold and to formulate scales for each of these dimensions. Consequences of disasters can then be considered as a vector whose components are given by individual scale values for each dimension.

In accordance with this philosophy, somewhat simplistically, an initial two-dimensional consequence space was assumed Keller and Al-Madhari (7). The scales adopted for these dimensions were fatalities and re-insurable costs of disaster.

In the present paper, a third dimensional consequence is added to the above two-dimensional consequences in order to cover evacuation. The present paper also demonstrates how techniques developed for obtaining return periods for the earlier two-dimensional consequences, fatality and cost magnitudes, can be applied also to evacuation.

In order to avoid unduly large and difficult to handle data sets, a disaster is now defined as:

"An event localised both in time and space if one or more of the following consequences occur

1). 10 or more fatalities
2). damage cost exceeds US $1 million
3). 50 or more people evacuated."

This definition is an extension of the definition of disaster given by Keller and Al-Madhari (7) which is expressed in terms of fatalities and re-insurable damage costs only. The threshold values of 10 fatalities, US $1 M and 50 evacuated persons are pragmatic and not absolute and are chosen for convenience of producing clean and manageable data sets. For example, Keller et al (3); Keller et al (6) in an analysis of disasters in the oil and chemical industries, because of the relatively small number of disasters having detailed documentation, used a fatality threshold of 5. Similarly, in Keller et al (2,4), in dealing with disasters of a global nature, because of the very large number of disasters involved and the possible under-reporting of "small" disasters, a fatality threshold of 20 was assumed.

In earlier papers (2,4,6,7), a probabilistic model is developed in which inputs for the model are frequency of occurrence and magnitudes of disasters of the particular type being studied. Expressions derived from the model include the return period for disasters having magnitude equal or greater than a particular value. This method has been applied by Keller et al (2,4) to disasters of general nature that have occurred in the geographical areas of the USA, Europe and the UK. In a more structured application the method has also been applied by Keller et al (6) to the disasters referred to above which have

occurred during the period 1970-1987 within chemical and allied industries. Again this method also has been applied by Keller and Al-Madhari (7) to earthquakes, floods and climatic disasters. As described in (2,4,7) the method has since been extended to allow for analysis of re-insurable losses for disasters in both the USA and Europe and for earthquakes, floods and climatic disasters world-wide.

In the present paper the methods previously developed are applied to evacuation consequences resulting from technological disasters in the UK and USA. Data covering the years 1970-1993 were obtained from the MHIDAS database of the British Health Safety Executive (HSE).

FATALITY SCALE

On the Bradford Disaster Scale magnitude is defined by taking the common logarithm (base 10) of the number of fatalities resulting in a disaster.

A similar form of scaling based on common logarithms had been previously used by Richardson (8); further reference to this scaling technique can also be found in Marshall (9).

Supplementary to magnitude scaling a classification system, Keller (1), was introduced for analysis of large data sets where fatality data values are not necessarily precise.

COST SCALE

In a similar way to the fatality scale a cost scale can be defined where the magnitude of the cost component is the common logarithm of the re-insurable losses in US $ M

EVACUATION SCALE

In a similar way to the fatality and cost scales an evacuation scale can be defined by taking the common logarithm of the number of people evacuated as a result of the event.

DISASTER CONSEQUENCES MODELS

Fatality

It has been found that for a large number of magnitude consequence data sets analysed, an exponential distribution gives a good fit Keller et al (2,4,6); Keller and Al-Madhari (7); an example of the use of the exponential distribution indicating the degree of fit is given in Figure (1) for the case of general UK disasters which occurred during the period 1960-1990.

Re-insurable Cost

For re-insurable cost modelling, it has been previously found that the two-parameter Weibull distribution provides a good fit Keller et al (2,4); Keller and Al-Madhari (7); an example of this is given in Figure (2) for re-insurable costs of general USA disasters.

Numbers Evacuated

Using the MHIDAS database two data sets of technological disasters were compiled for the period 1970-1993 for the UK and the USA. A threshold of 50 evacuees was assumed. These data sets were analysed using both the exponential and Weibull distributions. Indications of goodness-of-fit to the data for both the exponential and Weibull distributions are given in Figures (3-6). Values of parameters of these distributions derived using Maximum Likelihood are given in Table (1). Also included in Table (1) are annual occurrence rate and normalised occurrence rate for the UK and the USA assuming a normalised population of 10^8 for both

countries. This has been done in order to be able to provide direct comparison between the UK and USA.

Table (1). UK and USA Technological Disasters Evacuation Distribution Parameters

Parameters Location	UK	USA
Annual Rate λ_e	4.5	15.7
Normalised per 10^8 Population λ_n	7.8	6.3
Exponential Parameter β	1.39	0.87
Weibull Shape Parameters η	0.93	1.31
Weibull Scale Parameter τ	0.70	1.21

CALCULATION OF RETURN PERIODS

Fatality

Values of return periods for disaster of magnitude greater than m were calculated using the formula

$$t_R = \frac{1}{\lambda R(m)} \quad (1)$$

where

$$R(m-m_o) = \begin{cases} \beta\, e^{-\beta(m-m_o)} & \text{if } m \geq m_o \\ 0 & \text{if } m < m_o \end{cases} \quad (2)$$

and λ is the annual occurrence rate of disasters classified by fatalities.

Re-insurable Cost

Values of return periods for disasters of magnitude greater than m_c is given by

$$t_R = \frac{1}{\lambda_c R(m_c)} \qquad (3)$$

where

$$R(m_c) = \begin{cases} e^{-\left(\frac{m_c}{\tau}\right)^\eta} & \text{if } m_c \geq 0 \\ 1 & \text{if } m_c < 0 \end{cases} \qquad (4)$$

and λ_c is annual rate of occurrence of disasters classified by re-insurable cost. Derivations of (1) and (3) are given in Keller et al (2,6).

Evacuation

Return periods for numbers evacuated can be calculated in a manner similar to that used for fatalities and re-insurable costs.

DISCUSSION OF RESULTS AND CONCLUSIONS

Values of the parameters β, η and τ for Figures (3-6) are given in Table (1). It can be noted from formulae (2) and (4) that for the special case of the shape parameter $\eta=1$, the Weibull distribution degenerates to the exponential which mathematically is particularly convenient to manipulate.

Table (1) indicates that preliminary adoption of an exponential distribution, until further analyses have been carried out, to describe numbers evacuated is not an unreasonable procedure; this is confirmed in Figures (3-6).

Return periods for numbers evacuated assuming an exponential distribution for the UK and USA is given in Figure (7). For comparison purposes corresponding normalised return periods using λ_n are given in Figure (8).

It is seen that taking population size into account the normalised occurrence rate for the UK and USA are directly comparable. This indicates that the two data sets used are not inconsistent.

The difference in values of β for the UK and USA appear to be greater than one would expect from sampling error and suggests a possible real difference in emergency evacuation procedures in the UK and USA with possibly up to twice as many people being evacuated on average in the USA.

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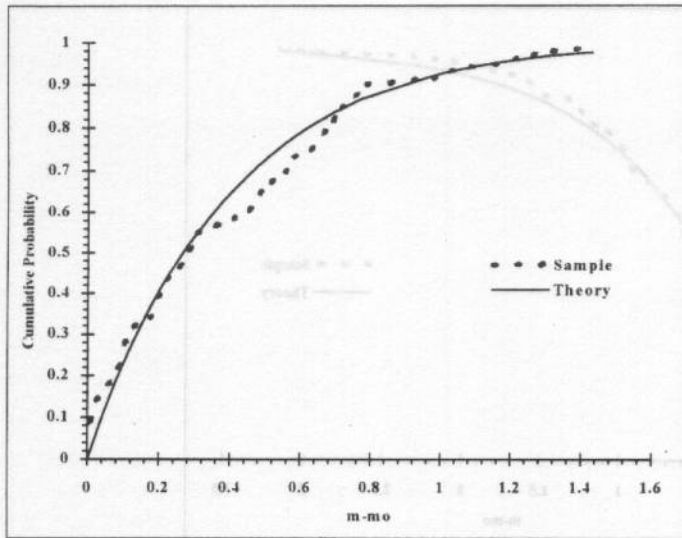
Figure (1). Fatalities UK Disasters (1960-1990)

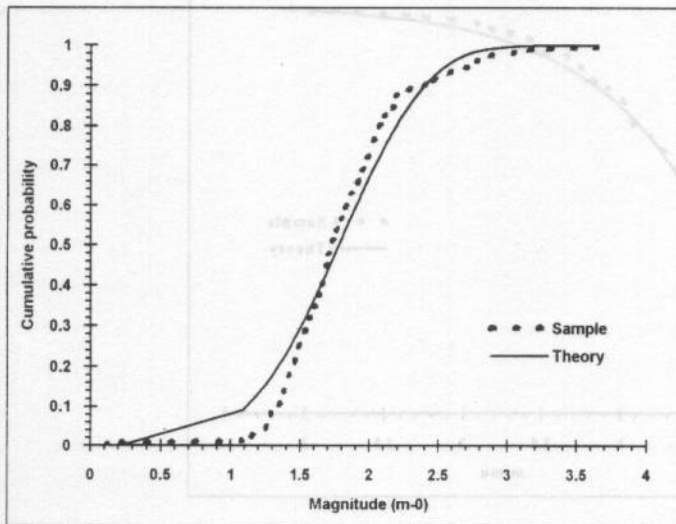Figure (2). Re-insurable Costs USA Disasters (1982-1991)

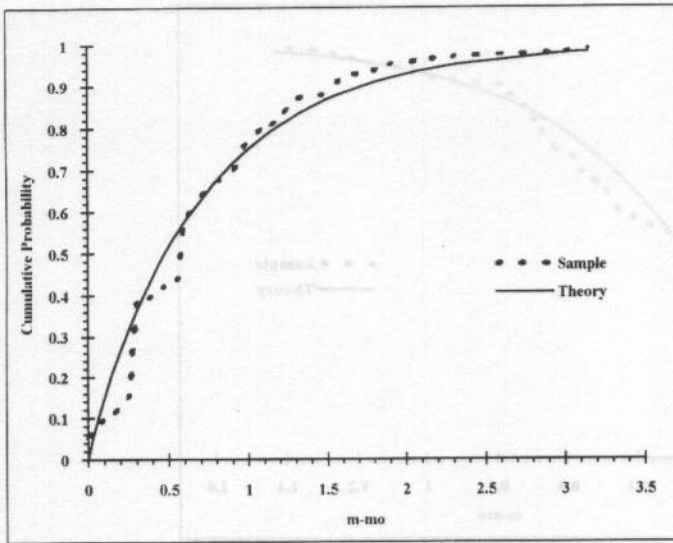Figure (3). Evacuations UK (Weibull Plot) 1970-1993

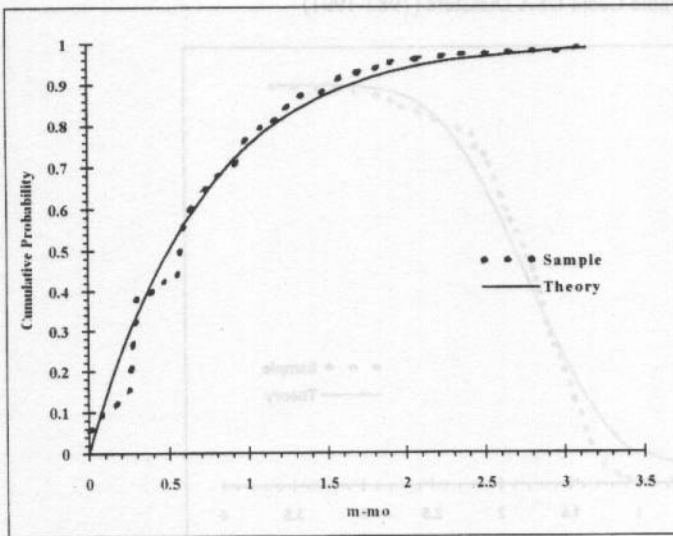Figure (4). Evacuations UK (Exponential Plot) 1970-1993

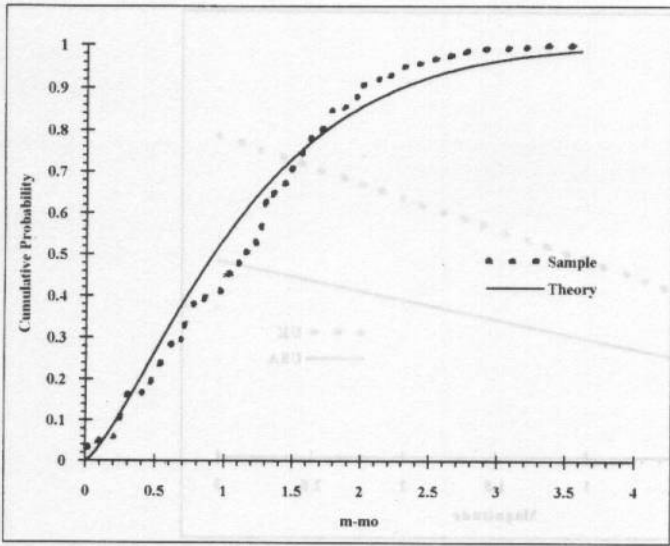Figure (5). Evacuations USA (Weibull Plot) 1970-1993

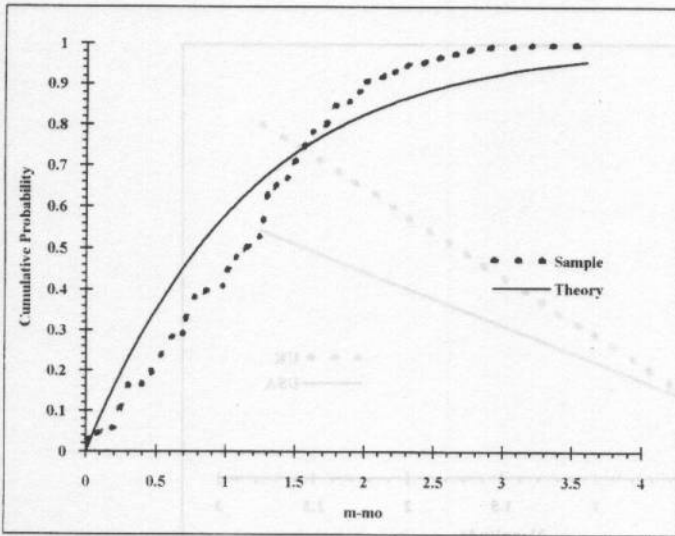Figure (6). Evacuations USA (Exponential Plot) 1970-1993
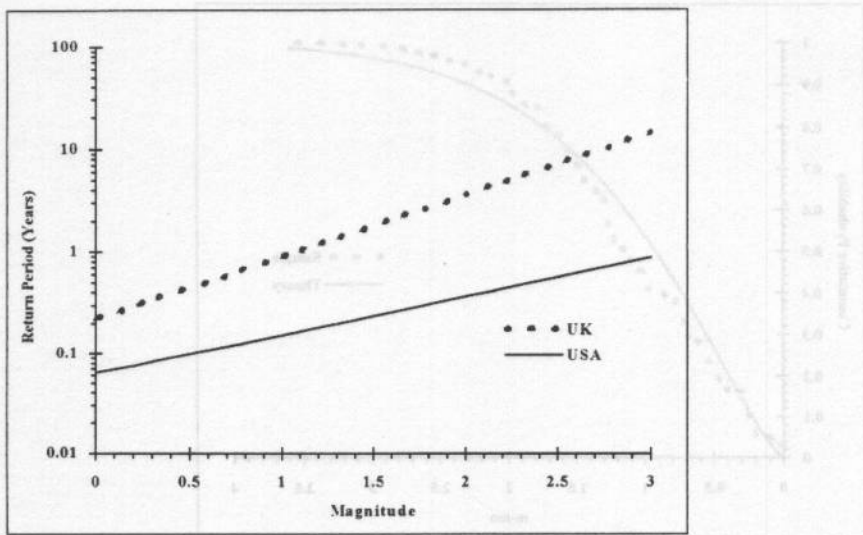
Figure (7). Evacuations Return Periods UK and USA

Figure (8). Evacuations Normalised Return Periods UK and USA