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Quantifying the Need for Force Agility

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Quantifying the Need for Force Agility

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Abstract

In this paper, we address the question of the likely nature of the future conflict environment, and the need for force agility in dealing with this environment. The approach we take is to characterise this future conflict environment through five dimensions, drawn from UK work on global futures. We define metrics for each of these dimensions, and show, by looking back over the past 60 years, that it is possible to characterise these dimensions in quantitative terms. This analysis was applied across the US, UK, France and Israeli experience. It shows that in essence, random factors dominate the space, and thus agile forces are required to deal with this essentially random walk across the space of likely conflicts in the future (assuming that the future reflects this recent history). The statistics involved also show characteristics of complexity such as power law 'fat tails' in the distributions. By projecting these distributions forward, we show how it is also possible to begin to quantify the likelihood of extreme shocks of certain types in the future.

Introduction

The problem of developing an effective and capable future force structure is one that is constrained by the lack of knowledge of the future environment in which the force is going to have to operate. The UK Ministry of Defence (MoD) approach to this uncertainty is to lay down policy guidelines stating the tasks that the UK Government is most likely to require of the MoD and to define a set of representative scenarios, against which more detailed planning and evaluation of capability can be undertaken. The MoD also sponsors work to examine the likely broad features of the future operating environment using existing trends. However the future is also defined by shocks that can confound policy makers and lead to abrupt changes in policy direction. Examples of shocks with particular relevance to defence in only the last 20 years or so include the fall of the Berlin Wall and the attacks on the ‘twin towers’. The transition from one conflict to another through time can also be considered to be a sequence of shocks on a smaller scale.

The ideal future force is one that is able to cope with a world in which both trends and shocks shape the future. For the purposes of this paper, the degree to which the future force can cope with the range of possible future situations is termed *agility*. We discuss how to characterise the future environment in such a way that the agility of the force can be quantified and ultimately used as a basis for planning the future force structure.

Complex Adaptive Systems

In (Moffat, 2003), a number of defining characteristics of a Complex Adaptive System were brought together, and applied to an ‘Information Age force’ as in Table 1.

CAS Concept	Information Age Force
Non- linear interaction	Combat forces composed of a large number of nonlinearly interacting parts.
Decentralised control	There is no master "oracle" dictating the actions of each and every combatant.
Self-organization	Local action, which often appears"chaotic", induces long-range order.
Non-equilibrium order	Military conflicts, by their nature, proceed far from equilibrium. Correlation of local effects is key.
Adaptation	Combat forces must continually adapt and co-evolve in a changing environment.
Collectivist dynamics	There is a continual feedback between the behaviour of combatants and the command structure.

Table 1; Relation between Complex Adaptive Systems and Information Age warfare. The six criteria shown correspond to a characterisation of a Complex Adaptive System.

In terms of complexity, and complex adaptive systems, a parallel insight into possible future trends is also given by the work of (Alberts and Hayes, 2007). They consider a coalition force that is composed of a number of ‘contributing elements’, both military and civilian (inter-agency or whole of government) from the various NATO nations. Other contributing elements may include contributions from non-NATO countries and international organizations as well as non-governmental organizations (NGOs) and private voluntary organizations (PVOs). The heterogeneous make-up of the enterprise implies that no single element is ‘in charge’ of the entire endeavour. The interactions among these contributing elements need to be considered in terms of the Physical, Information, Cognitive and Social domains. Industrial Age Command and Control was well matched to the predominant challenges of the Industrial Age. The low agility of the command process matched the characteristics of the mission environment; specifically the familiarity of the mission, the linearity of the battlespace, the predictability of actions and effects, and its relatively small rate of change. Hence Industrial Age approaches to Command and Control have proved to be successful in simple, linear (albeit highly complicated) environments where manoeuvre was limited, and the concepts of operation employed were based on massed forces to create attrition-based effects. ‘Industrial’ approaches to Command and Control begin to break down in more complex environments where the interactions that take place are less linear, more dynamic, and less predictable. The term ‘Complex Endeavours’ has been used (Alberts and Hayes, 2007) to refer to more complex coalitions that have characteristics similar to those highlighted in Table 1.

Complex systems can thus exhibit stable structure and pattern formation, but also (as with chaotic systems) emergent behaviour that is extremely sensitive to the initial conditions and hard to predict. Moreover, a complex adaptive system is one whose complex behaviour stems from the modification of the behaviour of the components of the system according to the changing nature of the environment in which they find themselves. It is suggested here that the MoD, and the UK defence community in general, is itself a complex adaptive system. In addition to emergence, one common property of complex adaptive systems highlighted in Table 1 is their ability to self-organise, with no external input or guidance, through the interactions of the components of the system with each other and with their environment. This organisation may occur through initiative from within the system, but may also come through imitation of success or through the un-competitiveness and eventual extinction of poorly organised rival sub-systems. Therefore, given that the MoD and its predecessors have been fairly successful organisations over the past two centuries, surviving mortal threats from enemies ranging from Napoleon to the Great German General Staff, it may be that some of the existing features of the organisation are also those that give it the ability to survive and adapt effectively in its environment. In general there is a balance between the need for the system and the control sub-systems to adapt fast enough to respond to new challenges and opportunities in the environment, and the need to pace the rate of adaptation so that it is sufficient without being so fast that valuable gains are sacrificed in the process.

One of the key signatures of complex behaviour in general, and self-organised and adaptive systems in particular, is that of power law behaviour. By this we mean that the probability of an event and its magnitude are related according to a power law.

The significance of the power law, as opposed to the normal distribution, is that the probability of events occurring at the extremes (i.e. shocks) remains significant. Since data at the extreme (in the ‘tail’ of the distribution) are generally sparse, it is often difficult to clearly observe deviations from the normal distribution, which is thus often assumed to be the appropriate function for statistical convenience. Power law behaviour is often seen in conflict, including for example the observation by Richardson that the probability of a conflict of a given magnitude is inversely proportional to the power of that magnitude (Richardson, 1960). Historical analysis by, for example (Rowland, 2006), shows examples of both power law and lognormal distributions. In certain cases (for example when the variance of the data is large) the tail of a lognormal distribution can look very similar to a power law distribution (Newman, 2006)

The essential elements of MoD’s control system are shown in Figure 1, which involves a feedback loop where lessons from each successive conflict change our ideas about what the future is likely to hold. The major problem with this system is that it can take many years, or even decades to move around this ‘stimulus-response’ loop, largely due to decision and acquisition timescales. Therefore if investment and acquisition decisions are not stable against possible deviations from the anticipated future or organisational change over these timescales, then the future force will at best be sub-optimal, and at worst, inadequate.

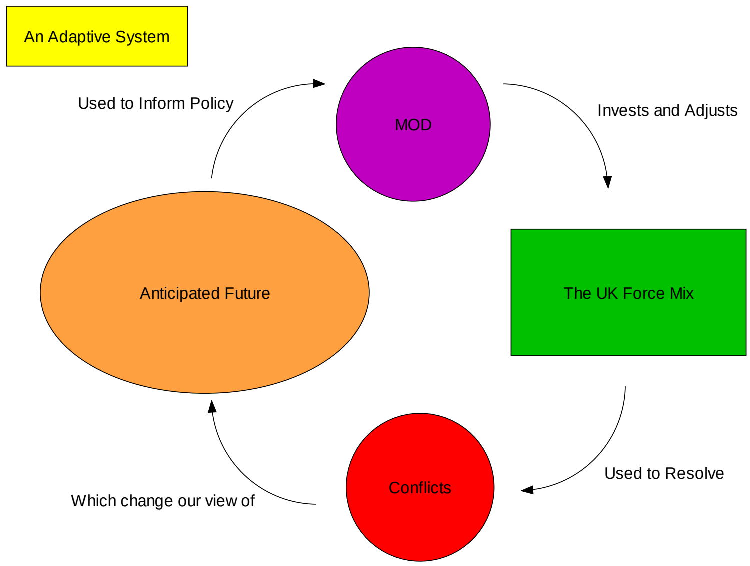


Figure 1; The MoD as an adaptive system.

The Conflict Environment

An understanding of the environment in which the MoD is operating is essential for determining the best strategy for adapting to that environment. The MoD has recently produced 'The DCDC Global Strategic Trends Programme'(Ministry of Defence, 2007), which outlines a vision of the state of the world over the next 30 years. This identifies a number of factors likely to lead to long term change, and uses subjective probability estimates for the different outcomes.

Other studies have attempted to address the same problem. For example, a recent RAND report on 'UK Military Capabilities in an Uncertain Future' (Pung and Gompert, 2006) is an attempt to investigate the possible shape of the future using an extension to Scenario Planning (a well known technique for exploring the future, first pioneered by Shell). The RAND study is a 3-dimensional version of this approach and characterises the utility of different capabilities in a world high or low on each of three dimensions:

- Heavy dependence of the global economy on energy from countries beset by extremism, turmoil, terrorism, and weapons of mass destruction;
- Cascading collapse of weak states, with mass refugees, killing, and chaos;
- Homeland threats from minority radicalism and terror's global reach.

The first problem in characterising the future environment is thus to decide what axes might be important for describing the situations to which the MOD is adapting. Our starting point is the DCDC Strategic Trends document (Ministry of Defence, 2007) which proposes five dimensions for characterising the future. These five dimensions are Military, Political, Social, Technology and Resource. The meaning of these dimensions in the Strategic Trends work has been slightly adapted to enable their use here, where the specific focus is on the kind of situations to which the MoD must respond. These dimensions have been used to facilitate qualitative assessment of the extent to which real historical conflicts could be found throughout the multidimensional conflict space, using a series of two-by-two 'Boston matrices'. The result was that in all cases all four quadrants were populated, which gave initial confidence that the axes were reasonably independent.

Quantifying the Conflict Space

To get a more quantitative grip on the problem, the next stage involved the redefining of these dimensions as quantifiable parameters. Briefly, the definitions are:

Military – Force ratio based on manpower strengths.

Political – Number of participant groups with distinct political control.

Social – GDP per capita of the conflict zone.

Technology – Geomean age of the key weapon systems on each side.

Resource – Military Killed in Action (KIA) per million total population[1].

Using these dimensions it was possible to plot UK experience of conflict since World War 2 (WW2) on a series of 2-dimensional scatter graphs representing slices through the 5-dimensional space. When each axis is plotted logarithmically, there is a fairly even scatter and distribution around the centre point in all cases. There is also no statistically significant correlation ($p<0.05$) between the values of the axes for the different dimensions, which further suggests that they are independent and are thus a reasonable choice for the axes for the conflict space.

The absence of correlations also means that the full 5-dimensional space is relevant. Given that the variance is large (5 orders of magnitude in the Resource dimension), and assuming the characteristics of future conflict mirror those of the last 60 years, the future environment can be shown to have a high degree of uncertainty, which means that armed forces will need to respond to a wide range of potential conflict situations.

By obtaining similar data sets for the USA, France and Israel, it was possible to produce a larger pooled set, and where appropriate, make comparisons between the nations. In the case of force ratios, for example, when measured as Blue/Red (i.e. own force over opponent), there was found to be good general agreement between the distributions for the US, France and Israel, but a somewhat higher distribution was found for the UK. It is suggested that this slightly higher mean force ratio for the UK may have been due to the UK having undertaken a higher number of counter-insurgency operations.

[1] This is taken as a measure of the political will to commit resources to a specific conflict.

The distributions of data for the other dimensions were broadly similar between the nations in general. Overall there is enough similarity in the distributions to suggest that these dimensions are capturing some general and enduring features of conflict, and that there may be an emerging pattern in the types and scale of conflicts that these nations have been involved in over the past 60 years. It is therefore considered reasonable to pool these data sets together, which has thus been done for much of the analysis discussed later in this paper.

The Nature of the Distribution along each of the Axes

For each of the five axes described above, we plotted the frequency distribution of the measure used for that axis, looking across the set of conflicts from WW2 to the present day. The distribution of this data on the Military (Force Ratio plotted as 'Blue/Red'), Social (GDP/Capita) and Technology (geometric mean age of equipment) dimensions are all found to have very good agreement with a lognormal distribution. When the Resource dimension is plotted as Total KIA/Million (including both Red and Blue casualties), the distribution is also very close to lognormal for the majority of the distribution. However, there is some deviation from lognormal behaviour in the tail.

The shape of the lognormal distribution is skewed to the left, with a long tail to the right. The majority of the distribution can thus be thought of as the 'business as usual' set of circumstances – those with reasonably high chance of occurrence. The long tail to the right hand end of the distribution corresponds to extreme 'shocks' which occur with low probability. In complex circumstances, this tail may actually follow a power law relationship, increasing the probability of such shocks occurring. In Figure 2 we see that the data deviates from a lognormal in the tail, however the sparseness of the data does not allow a definitive fit to a power law. Such deviations produce what is known as a ‘fat tail distribution’. Power law behaviour has been observed for this same metric, and with an exponent of 1.3 - 1.4, by (Roberts and Turcotte, 1998). Only the Political dimension (the number of participating groups) shows significant deviation from lognormality, being possibly a bimodal distribution.

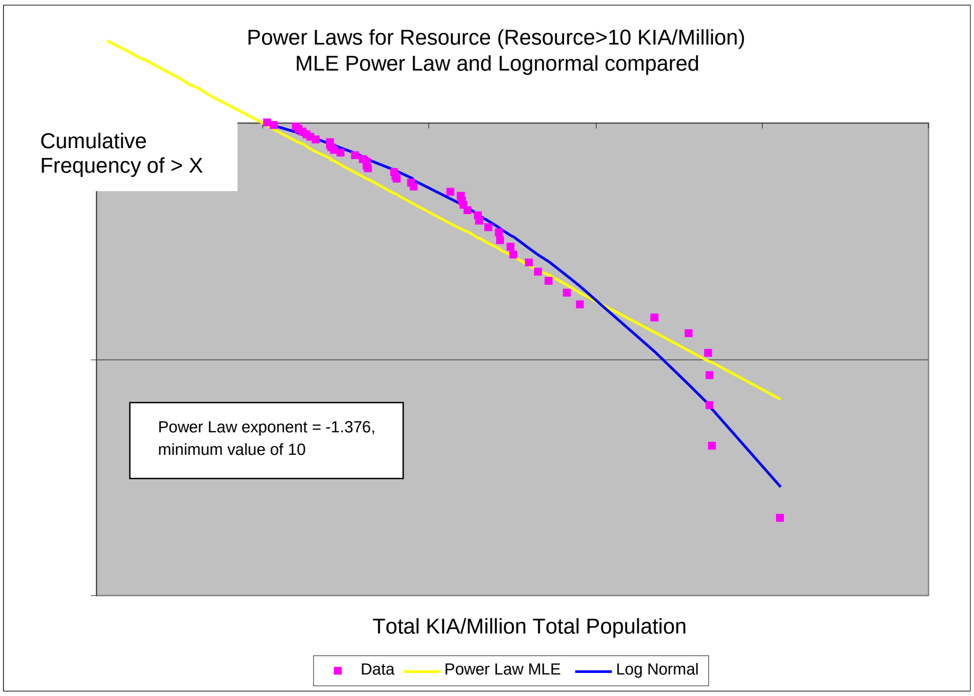


Figure 2; Power law (Maximum Likelihood Estimate – MLE) and lognormal tails compared for the Resource dimension.

Trends Through Time

Having identified quantifiable distributions in the data for most of the conflict space dimensions, an understanding of the degree to which this historical data might provide guidance on the future conflict space required analysis of trends through time.

Military – Using either of the two possible metrics for force ratio (Stronger/Weaker and Blue/Red), there is no evidence of a trend in any direction. There is thus no trend in asymmetry as measured by force ratios, although other aspects of asymmetry such as technology overmatch do show a trend, as shown below.

Resource – When analysed as Total KIA per Million Total Population, a statistically significant ($P<0.01$) trend of reduced KIA/Million is observed through time, of about 5% per year. This may be due to a reduction in the size of military forces, improved medical care, or greater political unwillingness to accept casualties.

Political – There is a general upward trend (a doubling in 50 years) in the number of participant groups (states or coherent non-state actor groupings with distinct political control) in each conflict. This represents the number of individual groups that have to come to an agreement to end the conflict. Interestingly, the trend is broadly similar to the increase in numbers of members of the UN over the same period.

Social – There is no trend in GDP per capita in the conflict zones considered, despite an overall increase in real global GDP by a factor of 3 over the same period. However, these conflict zones do not lie in disproportionately poor countries, which may be because very poor countries are unlikely to threaten vital national interests of world or regional powers. Wealthy countries are also under-represented, which may be due to political maturity or may be because they have more to lose by settling disputes by military means.

Technology Ratio – The geometric mean age of key equipment used on both sides is found to be increasing by 1% per year. However, it is relative age in equipment that is important in determining technology overmatch, and it is found here that, at least historically, geometric mean age of opponent (‘Red’) equipment is increasing faster than that of own (‘Blue’) equipment.

All of these trends are statistically significant, particularly that related to the Resource dimension, however none of the trends account for more than 20% of the variability and most for 10% or less. Thus trends in the conflict space dimensions are much less significant than random variation, although the trends may, over time, produce substantial movement in the mean of the distribution.

Movement through the space

The above trends are based on pooled data, so it is not possible to elucidate from them patterns in the movement of individual nations though the space as they move from conflict to conflict through time. In a separate analysis, Figure 3 illustrates this movement for the UK since WW2, which includes both very short jumps (e.g. Bosnia IFOR to Kosovo) and very long jumps (e.g. Malaya to Korea). The other nations (USA, France and Israel) show similar effects. In the case of Force Ratio, where the distribution is believed to be very close to lognormal, it is possible to predict the distribution in jump lengths if the sequence is random.

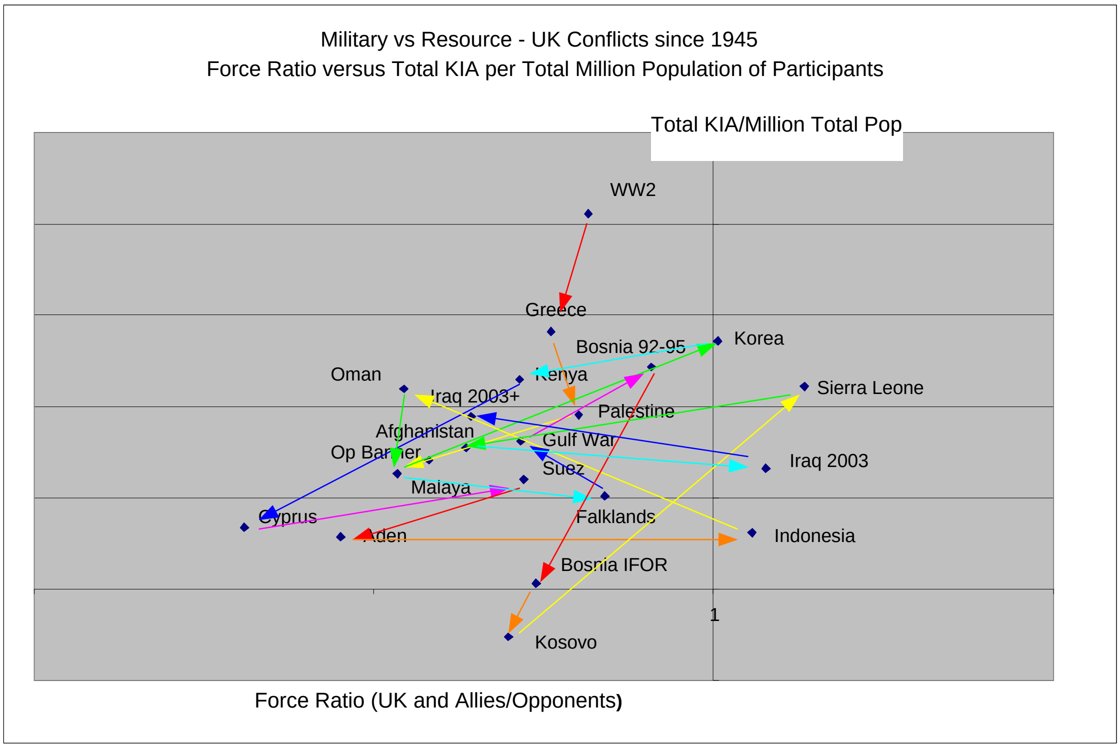


Figure 3; Progress of the UK through the Conflict Space – arrows indicate sequence of start dates of conflicts. Both axes are plotted on a logarithmic scale.

The distribution of jump lengths on a logarithmic basis (pooling the data from all four nations) does match this prediction, being normally distributed as shown in Figure 4, having a variance within 5% of that predicted by theory for completely random jumps. Thus in terms of the logarithm of Force Ratio, the move from one conflict to another forms a random walk through time. This unpredictability again emphasises the need for force agility.

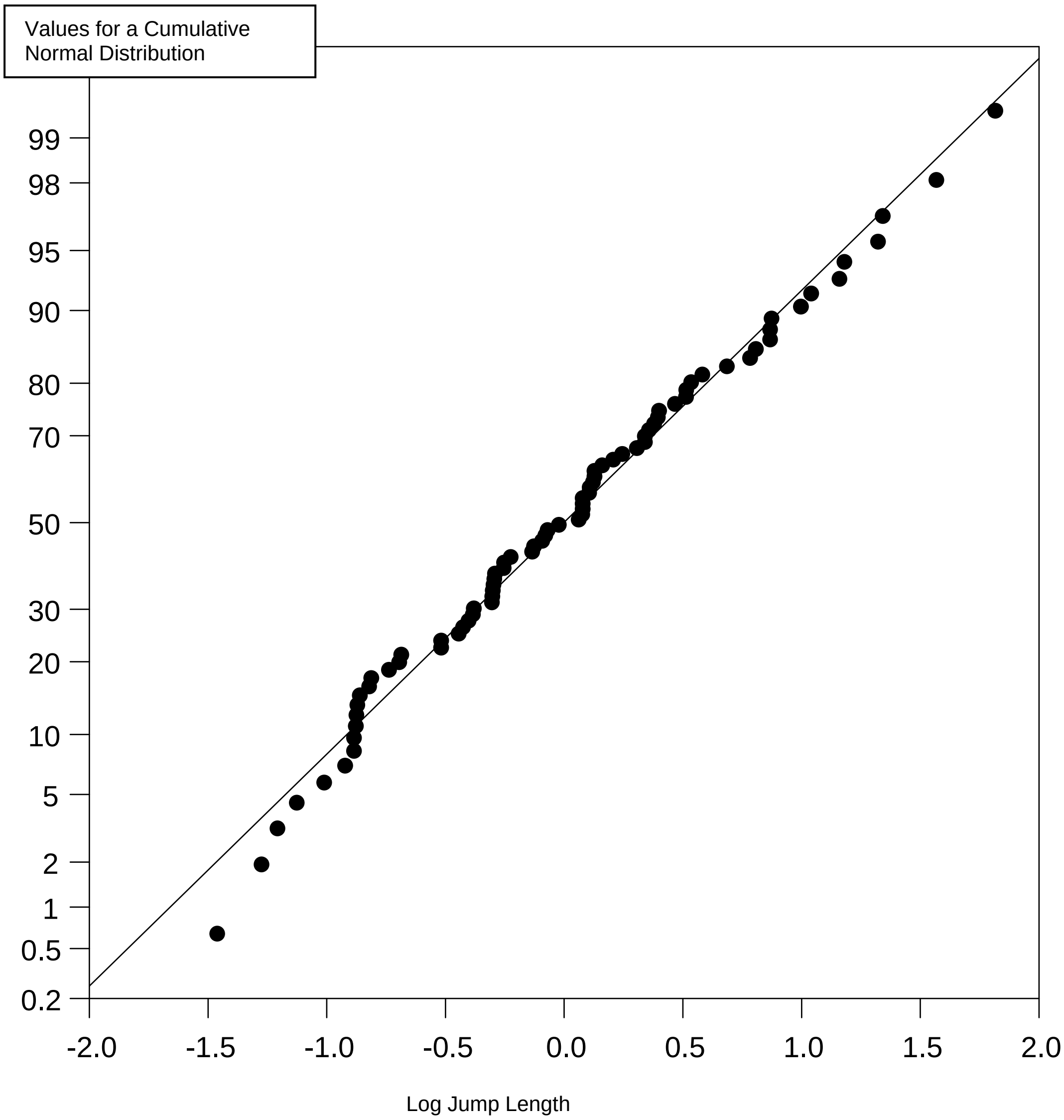


Figure 4; Cumulative frequency plot of jump lengths for Blue/Red Force ratio. This is based on pooled data from all four nations. The y-axis is such that points from a cumulative normal distribution fall on the straight line shown in the figure. The x-axis 'jump length' is the difference between successive Blue/Red force ratios on a logarithmic scale.

Frequency and Duration of Conflict

Pooled analysis of the distribution of numbers of conflicts beginning in any given year shows striking agreement with a Poisson distribution with the same mean. This result suggests that conflict occurrence can also be modelled as a random process. Analysis of the distribution of UK conflict *durations* also appears to be random, and shows excellent agreement with an exponential distribution. In summary, our analysis of the likely random nature of the future environment, based on an analysis of the past 60 years of conflict and assuming this will not change dramatically, emphasises the random nature of movement through the conflict space and thus the need for force agility. We now look at the influencing factors and constraints on the development of the force to match this requirement for agility.

Defence Cost Inflation

It is a well known fact that defence inflation is higher than normal inflation. An important driving factor on the development of the force is thus real cost growth, which can be defined as the above inflation increase in cost per platform or equipment type. Analysis indicates that such real cost growth is exponential in nature (Pugh, 1986, 2007). Thus if the increasing service life of equipment is not enough to completely offset the effects of cost growth, reductions in force size are inevitable within a fixed budget.

Agility of the Force

As already discussed, the MoD has developed a set of representative scenarios for planning purposes. The relationship between ‘Force Elements’ (coherent packages of force[2]) and their degree of utilisation in the full range of such planning scenarios is considered here to provide a potential alternative measure for the agility of the force.

[2] Similar in approach to the idea of Mission Capability Packages (MCPs).

Our analysis has shown that the relationship between the number of scenarios and the number of Force Elements used in fewer than that number of scenarios is very close to a power law (i.e. a straight line is obtained on a log-log plot). The gradient of this line describes the extent to which a high proportion of Force Elements are used in a high proportion of scenarios, and is thus a potential well-defined metric for agility. This is shown in Figure 5 below, with illustrative regression results for the years 2010 and 2020 using this measure of agility.

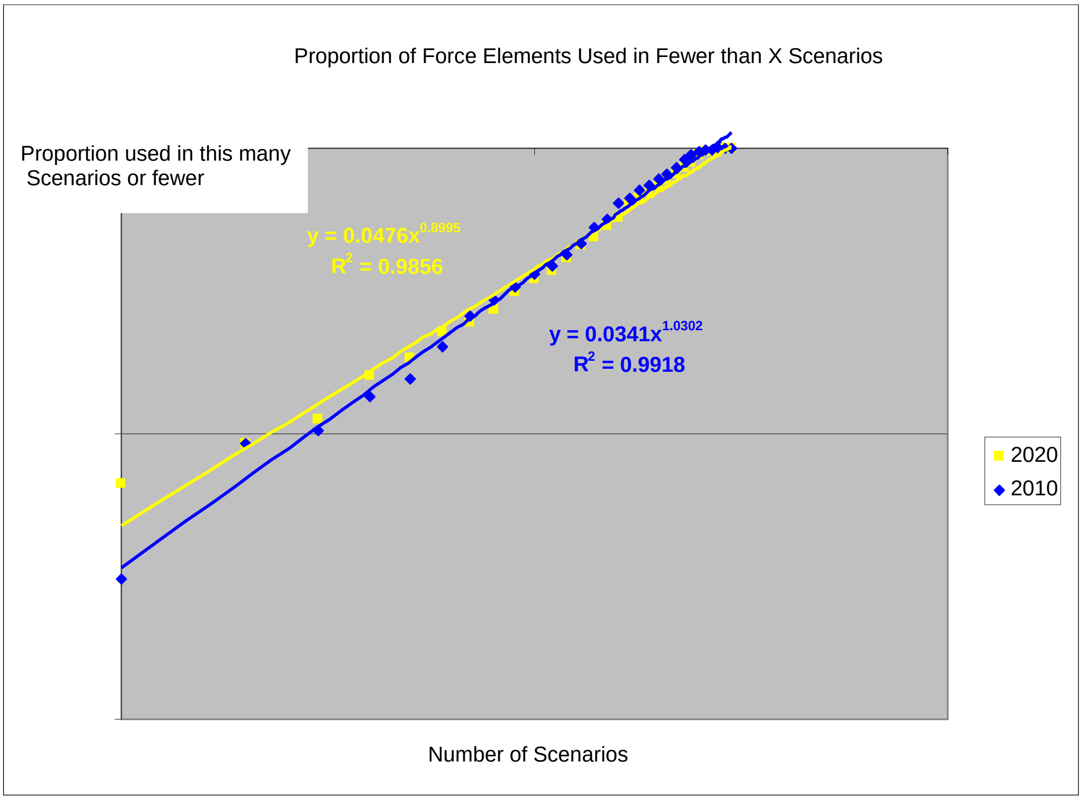
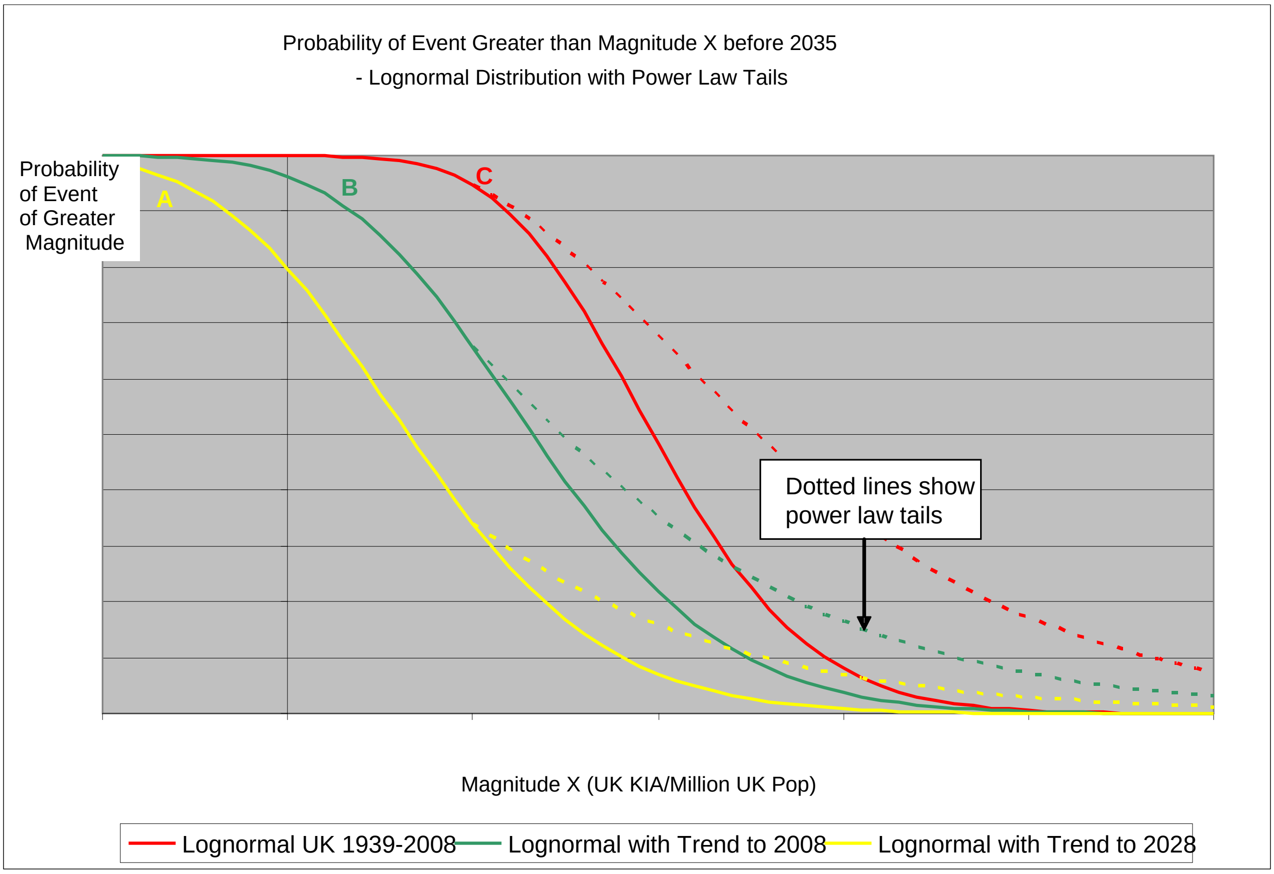


Figure 5; Proportion of Force Elements used by Number of Scenarios (Illustrative results only).

Finally, it is possible to use our relatively well-defined lognormal distributions to investigate the probability of extreme shocks in the tail of the distribution. Figure 6 illustrates the probability functions for conflicts of varying magnitude in the Resource dimension occurring before 2035, extrapolating forward from our historical data and taking account of trends over time. Line C shows the probability function based upon the mean and standard deviation of UK conflicts since 1939. Lines A and B take into account the effect of the downward trend in the Resource dimension for the specific time frames they consider. The dotted lines illustrate the effect of the tail obeying power law (rather than lognormal) behaviour, which is clearly very important for the probabilities of extreme events. Results such as these help us to assess the probability of a 'shock' occurring before 2035, on the assumption that the historic trends we have discussed continue into the future.



<u>Figure 6; The Future Risk Profile (illustrative example only).</u>

Conclusions

It is possible to map conflicts onto a quantitative five dimensional space based upon the UK Strategic Trends dimensions of the future. Doing this shows that the UK, US, French and Israeli experience of conflict over the past 60 years has shown high levels of variability in the scale and nature of conflicts. The historical record shows evidence of both complex behaviour and randomness. Though some trends exist, most notably a reduction in the level of military deaths relative to population, the trends account for only 10-20% of the variability where they exist. A key implication of these results is that randomness dominates such trends in the futures dimensions, and an agile force is required to deal with such high and random variability. In addition, it is possible to begin to quantify the likelihood of shocks of a given magnitude over the same timeframe.

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