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Beyond Command and Control: Sense Making under Large World Uncertainty

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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 article, 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 characterize 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 characterize these dimensions in quantitative terms. This analysis was applied across the US, UK, French, 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).

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 defense 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 article, the degree to which the future force can cope with the range of possible future situations is termed *agility*. We discuss how to characterize 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

We now consider how the concept of a complex adaptive system can help us to understand what agility really means. A number of defining characteristics of a complex adaptive system were brought together, and applied to an Information Age Force as in Table 1 (Moffat 2003).

Table 1. Relation between complex adaptive system (CAS) and Information Age warfare. The six criteria shown correspond to a characterization of a complex adaptive system.

CAS Concept	Information Age Force
Non- linear interaction	Combat forces are composed of a large number of nonlinearly interacting parts.
Decentralized 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 behavior of combatants and the command structure.

In terms of complexity, and complex adaptive systems, a parallel insight into possible future force characteristics 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 endeavor. 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 maneuver 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 Endeavors* 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 emergent behavior that is extremely sensitive to the initial conditions and hard to predict. Moreover, a complex adaptive system is one whose complex behavior stems from the modification of the behavior 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 defense 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-organize, with no external input or guidance, through the interactions of the components of the system with each other and with their environment. This organization may occur through initiative from within the system, but may also come through imitation of success or through the uncompetitiveness and eventual extinction of poorly organized rival subsystems. Therefore, given that the MoD and its predecessors have been fairly successful organizations 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 organization are also those that give it the ability to survive and adapt effectively in its environment. In general, however, there is a balance between the need for the system and the control subsystems to adapt quickly 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 behavior in general, and self-organized and adaptive systems in particular, is that of power law behavior. 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 or lognormal distribution, is that the probability of events occurring at the extremes 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 lognormal distribution, which is thus often assumed to be the appropriate function for statistical convenience. Power law behavior is often seen in conflict, including for example the observation by Richardson that the probability of a conflict of a given magnitude is proportional to the inverse power of that magnitude (Richardson 1960). Historical analysis by 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 the MoD control system for planning 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 over these timescales, then the future force will at best be suboptimal, and at worst, inadequate.

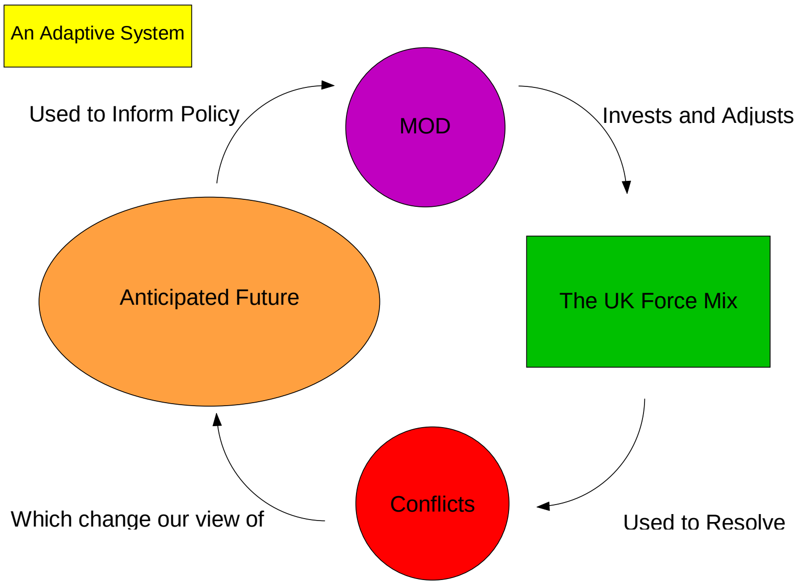

Figure 1. The MoD adaptive planning system

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* (UK 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 (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 in Shell Oil (Ringland 1996). The RAND study is a three-dimensional version of scenario planning and characterizes 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.

A similar approach is used in the current Shell futures document, (Royal Dutch Shell Group 2005), which looks at three possible worlds in 2025, one characterized by increasing globalization, a second by increased protectionism and nationalism, and a third by a *middle way*. This has recently been updated with a look ahead to 2050 with the emphasis on different scenarios in response to CO2 emissions.

The first problem in characterizing 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 (UK MoD 2007) which proposes five dimensions for characterizing the future. These five dimensions are Military, Political, Social, Technology, and Resource. The meaning of these dimensions in the Global 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*. These diagrams were useful in that they demonstrated firstly that in all of the cases, all four of the quadrants were populated. Thus, each of the dimensions seemed to be reasonably independent of the others, and in no case were there regions of the Conflict Space where conflicts did not occur. This gave some confidence that our five-dimensional characterization was a reasonable approach and that the axes selected were to some degree orthogonal, at least at a qualitative level.

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 dimension – the measure chosen was force ratio, based upon the manpower strengths of the participants in the conflict, with the peak level chosen where there were significant variations over the duration of the conflict. The force ratio was calculated in terms of military manpower with insurgent numbers, paramilitary, police, and militia forces included where appropriate. In a few cases, manpower ratios were not particularly meaningful and ship or aircraft strength ratios have been used.

Political dimension – this is measured as being the number of participants with distinct political control. This includes all participants contributing military forces to the conflict, though those contributing only non-combat forces such as medical units have been excluded. Different factions of insurgent organizations have been counted as individual participants.

Social dimension – this is measured as being the GDP per capita of the conflict zone. This has been taken as a variable that is well correlated with many of the aspects of the social dimension, such as family size, the role of women, religious observance, and social cohesion. In some cases separate figures are not available for the conflict zone, in which case sensible approximations to comparable countries have been necessary. Since many conflict zones suffer abrupt drops in GDP per capita due to the collapse of trade, the value for the first year of the conflict has usually been taken where this is available.

Technology dimension – this is measured as being the geometric mean age of the key weapon systems on each side.

Resource dimension – this is measured in terms of the total military KIA (Killed In Action) per million total population of all participants. This measure was selected as being compatible with previous work on the intensity of conflicts (Roberts and Turcotte 1998), and with work on public support for conflict (Rowland et al. 1999). It represents the clearest indicator of the amount of resources that the participants are willing to devote to the aims for which the conflict is being fought.

These five dimensions between them define the Conflict Space. This means that, for our purposes, any conflict can be characterized by the values along each of these dimensions. We define a conflict to be any significant discrete engagement involving military forces, in which at least one casualty occurred. Thus we do not include, for example, humanitarian relief operations.

Using these dimensions it was possible to plot UK experience of conflict since World War 2 (WW2) on a series of two-dimensional scatter graphs representing slices through the five-dimensional space. When each axis is plotted logarithmically, there is a fairly even scatter and distribution around the center point in all cases. The absence of correlations also means that the full five-dimensional space is relevant. Given that the variance is large (five 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.

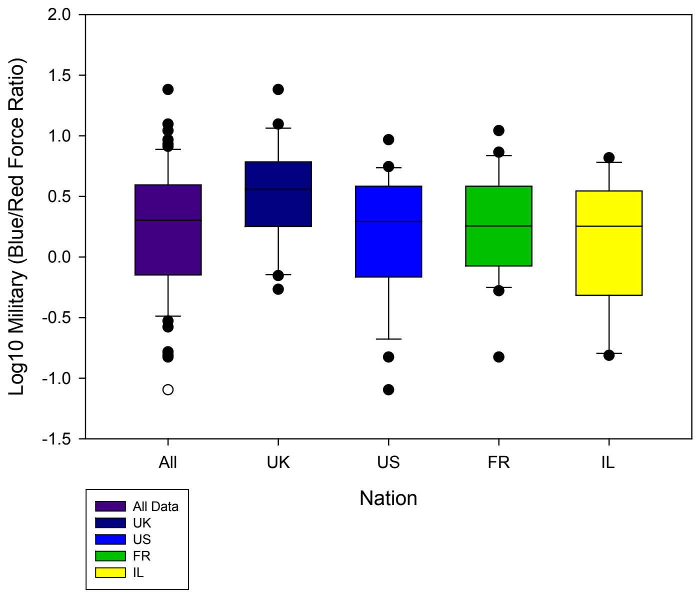

Figure 2. Distribution of the Military Dimension - Blue/Red force ratio By nation

Figure 2 shows the force ratio distribution for the four nations together with that for all data, using the *UK and Allies/Opponents* measure. The *All* data figure is for a pooled data set, where duplicate conflicts have been removed, so WW2 appears only once, despite the UK, US, and FR all having been involved. The format is that of a box plot, which shows the distribution of the data within each category. The box represents the middle two quartiles of the data, with the line inside the box indicating the median value. The lines outside the box[1] indicate the spread from the 10th to the 90th percentile of the data, and the dots represent the remaining data, shown as outliers. The

1. Sometimes termed *whiskers*, hence a *box and whisker* plot.

y-axis is shown in terms of the logarithm (base 10) of the variable. The Blue/Red force ratio data show very similar spreads for the US, FR, and IL, which are similar to that for all data, with the UK being somewhat apart. This is confirmed by a statistical significance test, which shows a significant result at the 1% level. This may reflect the fact that the UK has been involved in more conflicts at high force ratios (generally counter-insurgencies) than the other nations, or it may be due to differences in the way that the data have been compiled. The difference disappears if the alternative measure for force ratio is used (i.e., stronger/weaker).

The comparable figures for the Resource dimension are shown in Figure 3. This shows that all the datasets of the individual nations with the possible exception of the US seem to have the same characteristics as the overall data. Even the US data is very close in terms of the median, although there are more data points at the lower tail of the distribution.

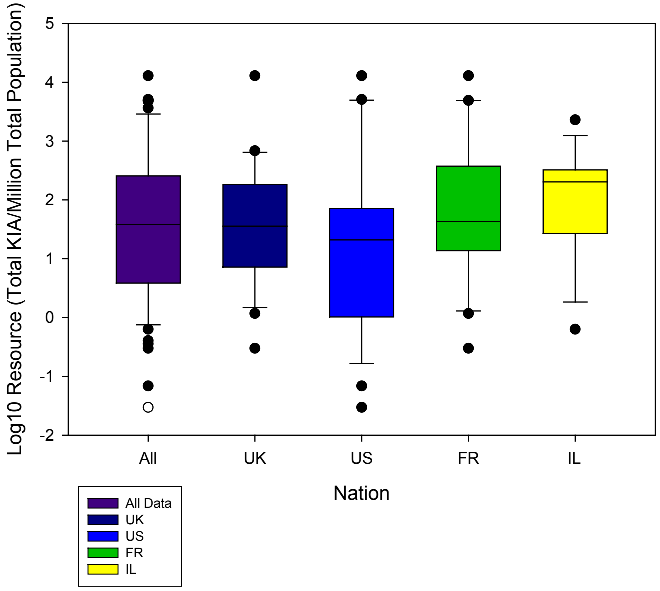

Figure 3. Distribution of the Resource Dimension - Total KIA/million by nation

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 article.

The Nature of the Distribution Along Each of the Dimensions

For each of the five dimensions described above, we plotted the frequency distribution of the measure used, looking across the set of conflicts from WW2 to the present day. The distribution of this data on the Military (force ratio) and Resource (KIA per million total population) dimensions are found to have very good agreement with a lognormal distribution as illustrated below. However, there is some deviation from lognormal behavior in the tail of the Resource dimension, possibly due to *power law* effects. If the logarithms of our data values can be shown to be drawn from a normal distribution, this opens up the possibility of using standard statistical techniques to examine the behavior of the data, including regression analysis and t-tests. The Political axis does not show this distributional effect and requires further separate analysis.

There are also some theoretical reasons for considering lognormality in the data. Firstly the lognormal distribution has been shown to be a useful hypothesis in a wide range of historical analysis work (e.g., Rowland 2006), and secondly we are here considering situations where we believe complex systems may be at work. As noted earlier, the power laws generated by complex systems behavior can be close to a lognormal distribution with large variance, and it has been demonstrated that both power law and lognormal distributions can be generated, in some cases, from similar underlying mechanisms of variability (Cont and Sornette 1997; Newman 2006).

Many complex systems are systems in which by their very nature, variability is not additive but instead multiplicative. For economies, ecologies, and conflicts alike changes in variables tend to be by multiplying factors on the parameters of interest, whether that is wealth, population, or fighting strength. The classic example is interest on capital. If a whole population starts with a given amount of money, which is multiplied by a random interest factor each year, we would expect the resulting distribution to be lognormal—irrespective of the exact nature of the distribution of the interest factors. This is by the same arguments that lead to the Central Limit Theorem, but where additive variability leads to the normal distribution, multiplicative variability will lead to a lognormal distribution.

A similar type of multiplicative variability leads to Pareto's law for the distribution of incomes in society, which has the form of a power law. The difference in the two models is that Pareto's law includes the effect of a lower limit on income. The power law calculates the proportion, in the limiting equilibrium state of income distribution, of persons having in excess of a certain income, but assumes that all incomes must be above a certain minimum value. This lower limit has the effect of a reflecting barrier and turns what would otherwise be a lognormal distribution into a power law. There are also other mathematical similarities between power laws and lognormal distributions. It is important to note, however, that multiplicative variability is not the only mechanism that can lead to power law behavior.

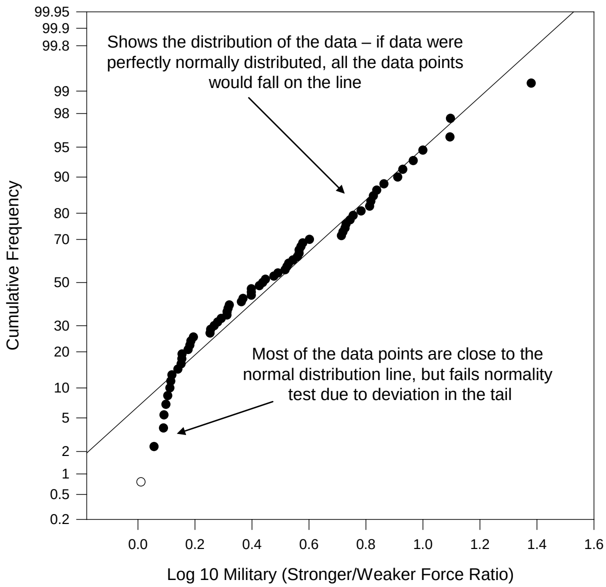

Figure 4. Normal probability plot - logged values (to base 10) of stronger/weaker force ratio

Figure 4 shows the results of plotting the distribution of the pooled force ratio data onto a normal probability plot. This plot has an x-axis that shows the value of the variable of interest—here the logarithm (base 10) of the stronger/weaker force ratio. This scale is linear. On the y-axis we have a transformation of the normal distribution onto a cumulative frequency scale. The important point about this normal probability plot is that if the data were perfectly normally distributed we would expect all the points to fall along the straight line running diagonally across the plot. Clearly the data shown here is a very good fit to the straight line for most of the data range. The data actually fails a Shapiro-Wilk test of normality, with only about a 1% chance that the data is normally distributed. Looking at the plot it is apparent however that this is entirely due to the behavior of the data in the lower tail of the distribution, as we approach the 1:1 lower limit on the possible force ratio values of this distribution.

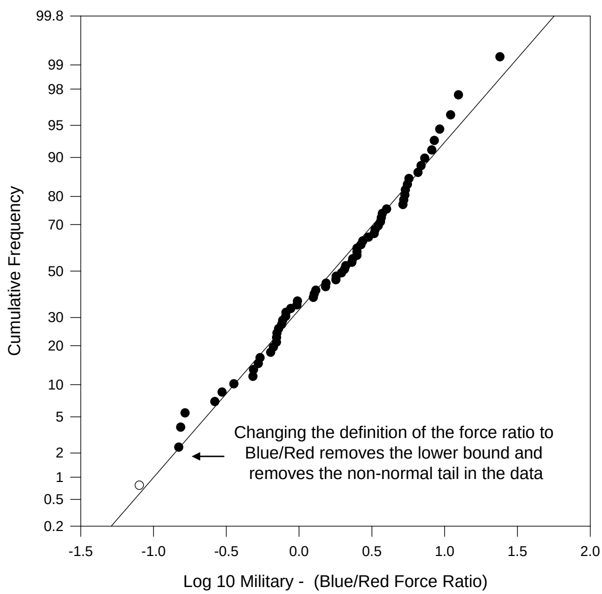

Figure 5. Normal probability plot - logged values (to base 10) of Blue/Red force ratio

This is tested in Figure 5, which shows the effect of plotting the alternative pooled Blue/Red force ratio, which does not have the lower limit on the range of the data. This logged data comfortably passes a test of normality, and can be seen to fit well to the normal line on the plot at Figure 5. This supports the view that what we are seeing may be the result of the kind of multiplicative variability discussed earlier. Certainly, removing the lower limit has turned a distribution that deviated from lognormality in the tails into a distribution that seems very close to a lognormal.

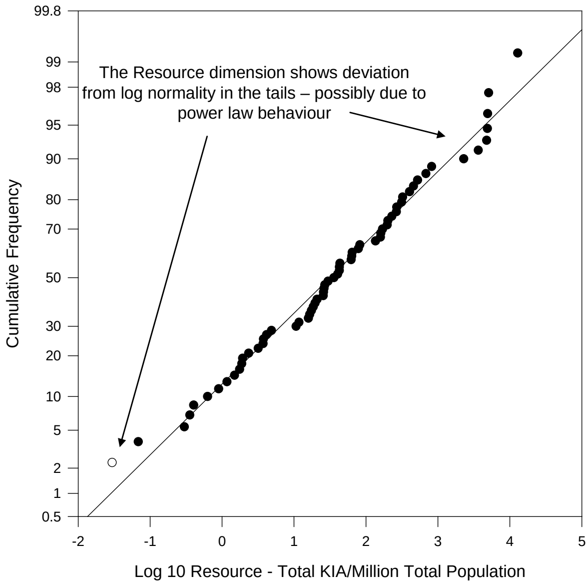

Figure 6. Normal probability plot - logged values (to base 10) of total KIA/million total population

The results of plotting the Resource dimension are shown in Figure 6. This is a dimension for which we might expect power law behavior. The work of Roberts and Turcotte (1998) has shown power law behavior for exactly this metric, based upon two separate data sets. What is interesting is how close to lognormal the distribution is for the majority of the center of the distribution, only deviating in the upper and lower tails. This distribution fails a Shapiro-Wilk test of lognormality ($P<0.001$), but again it should be emphasized that this is due to the behavior in the tails, particularly the upper tail. The data points all sit clearly along the lognormal line for the entire central part of the distribution.

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 7 we see that, for the Resource dimension, the data deviates from a lognormal in the upper tail; however the sparseness of the data does not allow a definitive fit to a power law (with an exponent of 1.38). Such deviations from lognormality produce what is known as a *fat tail distribution*. As already noted, power law behavior has been observed for this same metric, with an exponent of 1.3 - 1.4 (Roberts and Turcotte 1998). Only the Political dimension (the number of participating groups) shows significant deviation from lognormality, being possibly a bimodal distribution. Thus, we have not plotted the Political dimension distribution explicitly here.

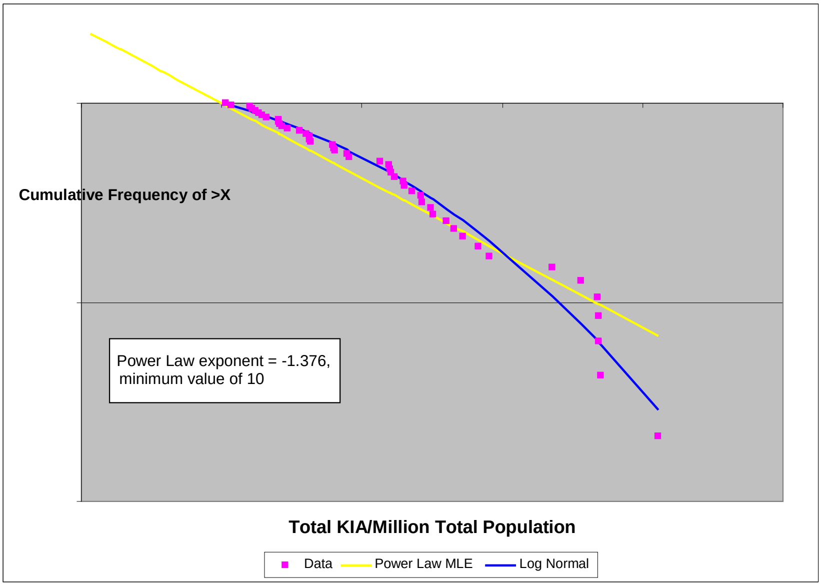

Figure 7. Power law tail (Maximum Likelihood Estimate [MLE] with an exponent of 1.38 shown as a straight line) and lognormal tail (curved line) compared for the Resource dimension.

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 analyzed 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 in each conflict with distinct political control. This represents the number of individual groups that have to come to an agreement to end the conflict.

Social – There is no trend in GDP per capita in the conflict zones considered, despite an overall increase in real global GDP per capita 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 underrepresented, which may be due to political maturity or may be because they have more to lose by settling disputes by military means.

Technology – 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 through the space as they move from conflict to conflict through time. In a separate analysis, Figure 8 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. Jump length is here defined as the difference between successive values on one of the axes, on a logarithmic scale.

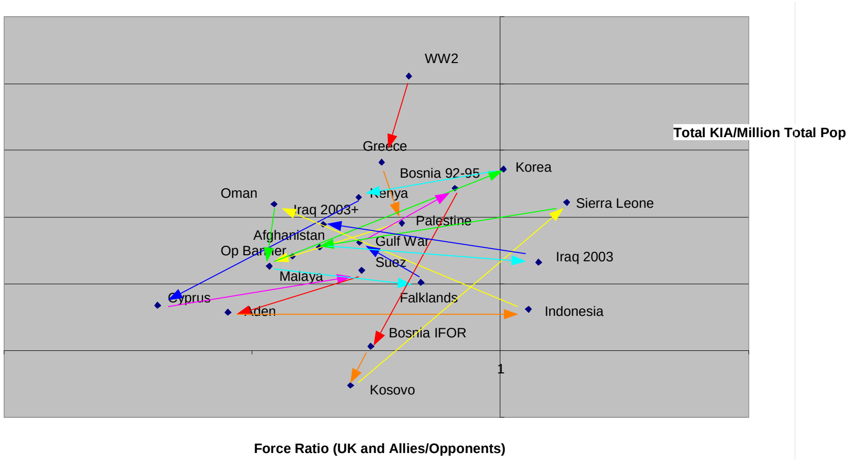

Figure 8. Progress of the UK through the conflict space - arrows indicate sequence of start dates of conflicts. Both axes are plotted on a logarithmic scale.

The distribution of jump lengths on a logarithmic basis (pooling the data from all four nations) does match this distributional prediction, being lognormally distributed as shown in Figure 9, and 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 emphasizes the need for force agility.

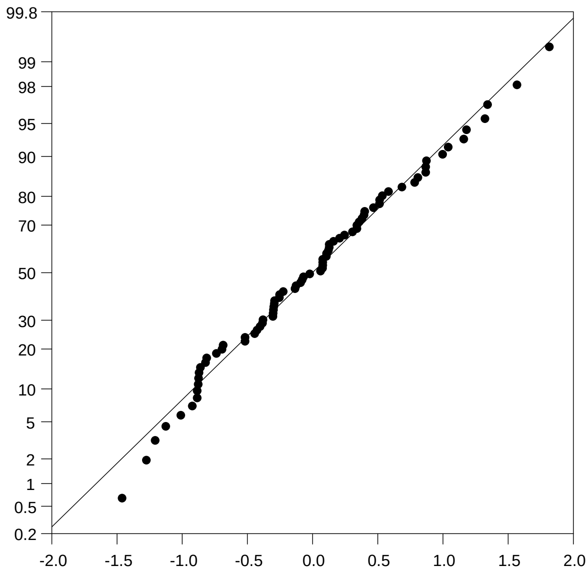

Figure 9. Cumulative frequency plot of jump lengths for Blue/Red force ratio. This is based on pooled data from all four nations. The y-axis is such that points from a cumulative normal distribution fall on the straight line shown in the figure. The x-axis jump length is the difference between successive 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 modeled 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 nature of the future environment, based on an analysis of the past 60 years of conflict and assuming this will not change dramatically, emphasizes the random nature of movement through the conflict space and thus the need for force agility. We now look briefly at the influencing factors and constraints on the development of the force to match this requirement for agility.

Defense Cost Inflation

It is a well known fact that defense 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) and their degree of utilization in the full range of such planning scenarios is considered here to provide a potential alternative measure for the agility of the force. 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 10 below, with illustrative regression results for the years 2010 and 2020 using this measure of agility. Such correlation of force elements to scenarios has to be validated, of course, by independent analysis using (for example) modeling approaches.

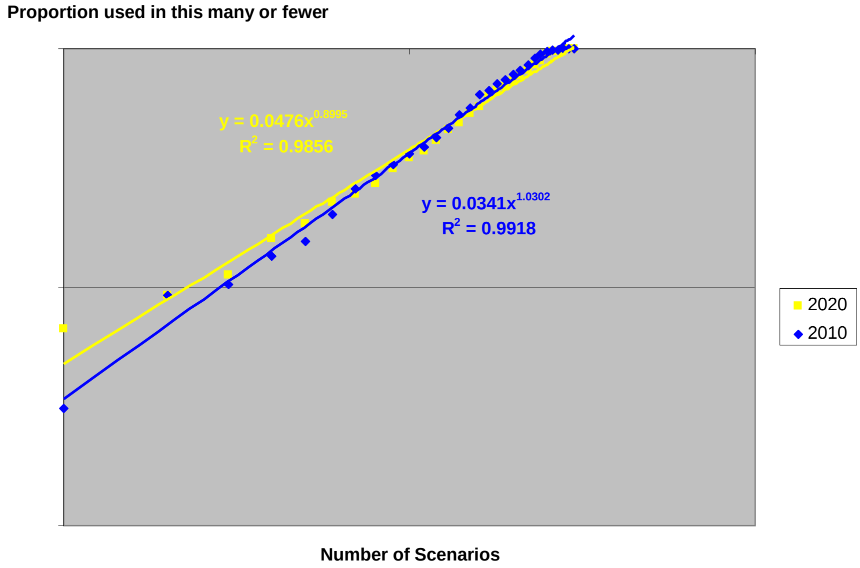

Figure 10. Proportion of force elements used by number of scenarios (illustrative results only)

Conclusions

It is possible to map conflicts onto a quantitative five-dimensional space based upon the UK Global 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 behavior and randomness. Though some trends over time 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 do 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.

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