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APPLIED TECHNOLOGY

FORECASTING RELATIVE COMBAT EFFECTIVENESS

A Feasibility Study

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JULY 1991

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A Feasibility Study

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EXECUTIVE SUMMARY

Using computer models to predict combat outcomes requires assembling large amounts of authoritative data. Yet, describing all of the factors that influence combat outcomes cannot be done without explicitly representing the quality of opposing forces. Unfortunately, reliable empirical methods for measuring troop quality do not currently exist.

To address this critical issue, this feasibility study examined one methodology for developing values of relative troop quality. The methodology sought to compare historical levels of combat effectiveness (troop quality) with basic measures of societal conditions. If strong relationships between the societal factors and the level of combat effectiveness could be established, then such measures might be useful for predicting combat effectiveness in other cases.

By using the Quantified Judgment Model and historical data on World War I and World War II combat engagements, values for relative combat effectiveness were established for Germany, the United States, the United Kingdom, and Russia/Soviet Union. Archival research produced data for numerous societal measures for the corresponding time periods. Using statistical analyses, the relationships between the societal factors and the level of relative combat effectiveness were examined.

The analyses found that measures indicating the degree of industrialization were most closely related to the level of relative combat effectiveness. That is, in World War I and World War II, by knowing the degree of industrial sophistication, the level of relative combat effectiveness for the major participants could be predicted. This may not be surprising, because the conditions and characteristics that lead to industrial growth -- advanced education, technological and economic development, cultural work ethics and motivations, etc. -- are in many ways critical to successful modern combat operations. From this conclusion it was possible to develop predictive equations and estimate the recent US/USSR combat effectiveness ratio as about 1.75 to 1.0 in favor of the US. This result does not appear to be beyond the range of plausibility.

The feasibility study was not pursued in enough detail and breadth to ensure its validity, generality, and applicability to other nations. It simply demonstrated that it may be possible to do so with further study that generates enough quality data on combat engagements and societal factors. This study serves as promising initial research that offers useful results if pursued on a larger scale.

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1. INTRODUCTION

Using computer models to predict combat outcomes requires assembling large amounts of authoritative data. Yet, describing all of the factors that influence combat outcomes cannot be done without explicitly representing the quality of opposing forces. Unfortunately, reliable empirical methods for measuring troop quality do not currently exist.

1.1 PURPOSE OF THE STUDY

This initial feasibility study was commissioned to determine if it is possible to establish a general method of estimating current relative combat effectiveness values among the armed forces of various nations using current societal data as a predictor. If this general approach were determined to have some merit, it could be applied to make estimates of relative combat effectiveness in planning for future combat with potential adversaries.

1.2 PURPOSE OF THE REPORT

This report provides an overall view of the way in which the study was accomplished and a summary of the results that were produced. As is appropriate for a feasibility study, the report illustrates measures and estimates of relative combat effectiveness for the armed forces of the nations used to test the method, but results are not presented as definitive.

1.3 ASSUMPTION

This study was based on an understanding of combat effectiveness that was developed in conjunction with the Quantified Judgment Model (QJM).[1] The QJM's Combat Effectiveness Value (CEV) is seen as a reasonable proxy measure for the impact of behavioral factors on overall combat outcomes. No other combat model assesses combat effectiveness in this way. The authors postulate that QJM-derived CEVs reflect first order effects reasonably well.

1.4 ORGANIZATION OF THE REPORT

The report is organized into nine major sections. Section 2 is a background discussion of the concept of combat effectiveness. Section 3 is a general discussion of the methodology of the study. Section 4 describes how the combat engagements were selected for inclusion and presents the relative combat effectiveness values estimated from the results of those engagements. A listing of selected characteristics of these engagements is appended. Section 5 describes the independent variables chosen for the study and the values of those variables.

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[1] The Quantified Judgment Model (QJM) is proprietary to Data Memory Systems, Inc. (DMSi), and has been licensed for use by several organizations, including the Office of Net Assessment, Office of the Secretary of Defense (OSD), the sponsors of this study.

Section 6 presents the results of the statistical analyses of the variables and their relationship with relative combat effectiveness values. Section 7 uses the results to predict US versus Soviet CEVs. Section 8 presents the conclusions and findings from the work accomplished. Section 9 consists of the Appendices, containing the data and a summary of the project planning conference.

2. BACKGROUND

Relative Combat Effectiveness is a term used to describe the abilities and fighting quality of a military unit or force compared to an opposing unit or force. While relative combat effectiveness in general may be considered a function of the totality of factors -- including strength, weapons, and tactics -- it is most often restricted to those intangible or human factors that cause some troops to stand and fight while other troops break and run. This work was done using the narrower, limited sense of combat effectiveness as a human or behavioral matter.

2.1 THE CONCEPT OF RELATIVE COMBAT EFFECTIVENESS

Most modern military analysts have recognized the importance of relative combat effectiveness in determining combat outcomes. Napoleon implied that the "moral is to the physical as three is to one." Military historian Trevor N. Dupuy goes further and says that the moral is the equivalent of the physical squared.[2] Whatever the exact nature of the relationship, it is possible that relative combat effectiveness is as important -- and may be more important -- than technology, weapons effectiveness, or sheer numbers in influencing combat outcomes.

History provides numerous examples of smaller forces defeating larger adversaries through sheer determination, fighting ability, or enthusiasm. The Spartans at Thermopylae defeated a larger Persian force, and they died doing it. The small but well-disciplined and well-trained light cavalry of Genghis Khan defeated larger European armies. A few English bowmen at Crecy defeated a larger number of French heavy cavalry. Some of these victories by smaller forces are the result of superior technology -- the long bows at Crecy, for example. But many of these battles have been fought between forces employing the same technology and the same tactics, and in these instances, the quality of the troops -- their relative combat effectiveness -- was clearly the deciding factor. What other explanation can there be for the ability of the German Army in World Wars I and II to fight outnumbered and win consistently -- even though losing the war in the end because of lack of resources or sheer numbers of the foe? How else can the ability of the Israeli Army in 1947, 1956, 1967, and 1973 to defeat well-equipped and more numerous foes be explained? It is clear that relative combat effectiveness is an important element in the outcomes of combat engagements.

However, it is not clear what is responsible for better relative combat effectiveness. Though many of its components may relate to the quality and depth of military training, experience, and preparedness, it seems reasonable to believe that basic societal characteristics have an effect on CEV or at least move in coincident directions and therefore will reflect a high degree of correlation with CEV. Economic and technological development, educational achievements, cultural and historical legacies and motivations, and political or religious ideology and participation may all have some impact on how well the people of a nation will perform in combat. In fact, many of these basic societal conditions may be responsible for superior military training and preparedness, given that these factors have both direct and indirect influences on

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[2] Trevor N. Dupuy, *Understanding War*, Paragon House Publishers, New York, 1987, p. 11 and p. 23. Dupuy explicitly modifies the Napoleonic statement.

relative combat effectiveness. It remains an open question in regard to which of these factors has the most overall influence and is therefore the best predictor of a nation's expected combat effectiveness.

If, as most believe, the quality of the troops is an important factor in combat, knowing in advance the relative combat effectiveness of the various combatants would be of great value in planning and waging war. Military planners could use knowledge of greater relative combat effectiveness to economize on the number of troops and weapons used against a particular foe. This could be applied to mass overwhelming force in another sector of the battlefield or theater of war. It could be used as a "force multiplier" to secure victory with smaller forces. It could be used as a margin of safety when planning campaigns or fighting battles. Knowing how well troops will perform against opposing troops would be a great advantage.

Military commanders have been estimating relative combat effectiveness since war began. Indeed, one of the major aspects of the art of the general has been the ability to assess the relative strengths and weaknesses of the opposing troops realistically. A lot of mistakes have been made in these assessments. Because of the intangible nature of the factors comprising relative combat effectiveness, attempts to make this estimation in a scientific manner have not been very successful.

In recent years much has been written on relative combat effectiveness. Most authors address the subject in qualitative terms from a sociological or psychological viewpoint.[3] The leading proponent of quantifying relative combat effectiveness has been Trevor N. Dupuy,[4] who used the QJM to estimate the relative combat effectiveness of the German Army in World Wars I and II against the United States Army and the British Army. Martin van Creveld essentially used the Dupuy quantitative results as a starting point for his explanation of the reasons for German superiority against the Americans in World War II.[5] Although van Creveld and Dupuy agree that the Germans fought better than the Americans, their reasons differ. Dupuy has also applied the QJM to estimate the relative combat effectiveness of the Israeli Army against the Egyptian and Syrian armies during the 1967 and 1973 Arab-Israeli Wars.[6] The Dupuy approach to quantifying relative combat effectiveness has been used in this feasibility study.

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[3] Typical of these are William Darryl Henderson, *Cohesion: The Human Element in Combat*, National Defense University, Washington, DC, 1985; and Sam C. Sarkesian, Editor, *Combat Effectiveness: Cohesion, Stress, and the Volunteer Military*, Sage Publications, Beverly Hills and London, 1980.

[4] See *A Genius for War: The German Army and General Staff, 1807-1945*, HERO Books, Fairfax, VA, 1985.

[5] Martin Van Creveld, *Fighting Power: German and US Army Performance, 1939-1945*, Greenwood Press, Westport, CT, 1982.

[6] Trevor N. Dupuy, *Elusive Victory: The Arab-Israeli Wars, 1947-1974*, HERO Books, Fairfax, VA, 1985.

2.2 THE COMBAT POWER RELATIONSHIP[7]

Mankind has been fighting since the earliest days, and military analysts have been trying to define the nature of combat from about the same time. A formula or equation for describing the mechanics and outcomes of combat would be advantageous, because it would then be possible to know exactly the number of troops, numbers of weapons, and the supplies needed to assure victory in combat. Deriving such an equation has also proven to be most difficult because combat is a complex matter in which chance and human factors play as much or even more of a role than mere numbers of troops or weapons. Although the dynamics of combat do not reduce well to a single, simple equation, they can be represented by some general mathematical forms for which factors values can be derived empirically.

While there is no one formula that represents the equation of combat, it is reasonable to express the relationship between two adversaries as a ratio of their relative combat power. One simple statement of this ratio is shown in Eq. (1).

$$\frac{P_1}{P_2} = \frac{S_1 \times F_1 \times Q_1}{S_2 \times F_2 \times Q_2} \tag{1}$$

Where: P = Combat Power
S = Force Strength
F = Factors Affecting the Combat
Q = Quality of the Troops

Force Strength, S, is a function of the number of troops, the numbers and types of their weapons, and their intrinsic mobility. The environmental and operational factors affecting combat, F, include weather, terrain, mission or posture (attack, defend, delay), surprise achieved, and preparations (e.g., fortifications). The quality of the troops, Q, is a function of behavioral factors, such as morale, esprit de corps, training, leadership, and will of the troops.[8]

The product of these three quantities -- S, F, and Q -- is the Combat Power, P, for each side. The ratio of the combat power of the two sides is an indicator of the way in which combat has or will proceed. The side with the greater combat power will inflict more casualties, move or hold more successfully, and accomplish the assigned mission. In simplified terms, the side with the greater combat power will "win." The extent of the ratio of combat power will determine the extent of the victory. Thus, if a combat power ratio could be calculated for any combat engagement or battle, the outcome could be predicted.

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[7] The discussion in this paragraph is based on two books by T. N. Dupuy, *Understanding War*; and *Numbers, Predictions, and War*, HERO Books, Fairfax, VA, 1985.

[8] These behavioral factors seem to be derivative of the larger societal conditions that underlie the country and therefore implicitly include these more basic conditions. For example, the degree of military training is, in part, a function of the country's educational system, cultural legacy, and economic and technological sophistication.

All methods of calculating the force strength (S) of adversaries in combat engagements use various counting schemes that assign weights to different kinds of weapons and munitions. The aggregation schemes derive from engineering data and the physical characteristics of weapons. Defining force strength is a matter of aggregating the combatants' physical resources. In this analysis, the QJM method for calculating force strength based on Operational Lethality Indices (OLIs) was used.

Similarly, it is possible to estimate the impact of the environmental factors (F) -- weather, terrain, cloud cover, etc. -- or operational factors -- mission, posture, fortifications, etc. -- on combat outcomes. This can be done using an engineering approach or a historical approach.

It is far more difficult to estimate the quality of the troops. This is because the quality factor depends almost exclusively on human factors that are generally believed to be difficult to quantify. This would require introduction of substantial analytical judgment in subjectively estimating the aggregate impact of these factors.

In theory, the estimation of troop quality could be based on an ideal standard of troop proficiency. Each nation's forces could be measured against this standard and rated accordingly to produce values for Q. While an absolute measure of troop quality may be possible and certainly would be desirable, no empirical method using objective data currently exists for authoritatively measuring troop quality in this manner.

Because war is a two-sided (at least) affair, it is the relative combat power for a particular combat engagement that is important. This is also true for the quality of the troops. The resulting estimate of relative troop quality is the ratio of their respective qualities, which is defined as their relative combat effectiveness value, CEV. (The symbol $CEV_{1/2}$ is used because it is the ratio of side 1 to side 2, generally attacker over defender.) This definition is shown in Eq. (2).

$$CEV_{1/2} = \frac{Q_1}{Q_2} \tag{2}$$

If the two absolute values of troop quality could be estimated independently, the ratio of the respective quality estimates would be the CEV and could be expressed as a single number.

The Combat Power relationship may be rewritten to reflect the single-number ratio of CEV as the measure of relative quality, as shown in Eq. (3).

$$\frac{P_1}{P_2} = \frac{S_1 \times F_1}{S_2 \times F_2} \times CEV_{1/2} \tag{3}$$

Given the methodology described above, the CEV can be calculated for historical engagements. The numbers of troops and numbers and types of weapons are known, so that the force strength, S, may be calculated for each side. The environmental and operational conditions of the engagement are known, and the proper values assigned to F for each side. The historical combat outcome is known and can be translated (using the QJM) mathematically so that a combat power ratio that led to that outcome may be estimated as well. Working from these known quantities, it is possible to estimate the relative CEV that existed for that particular historical engagement from the equation below. Until a method is devised to estimate an absolute value of troop quality, Q, this is the only practical method for quantifying combat effectiveness that does not rely exclusively on judgment or subjective measures. The calculation is shown in Eq. (4).

$$CEV_{1/2} = \frac{S_2 \times F_2 \times P_1}{S_1 \times F_1 \times P_2} \qquad (4)$$

This method was used in this study to develop relative combat effectiveness values for historical combat engagements. For predicting future combat outcomes, however, a CEV ratio is required in advance as one of the combat power equation inputs. This leads to the search for a methodology to calculate or estimate CEV ratios prior to combat. When a CEV ratio can be derived, it can be plugged into Eq. (3). Note that when predicting combat outcomes, P_1 and P_2 are calculable only as an overall ratio of P_1/P_2, not as separately and independently derived values.

3. METHODOLOGY

By using the QJM and historical data on World War I and World War II combat engagements, values for relative combat effectiveness were established for Germany, the United States, the United Kingdom, and Russia/Soviet Union. Archival research produced data for numerous societal measures for the corresponding time periods. Using advanced statistical analysis, the relationships between the societal factors and the level of relative combat effectiveness were examined.

3.1 CALCULATING COMBAT EFFECTIVENESS VALUE RATIOS PRIOR TO COMBAT

There are essentially three methods that can be used to develop numbers for CEV ratios between two adversaries.

1. Recent Direct Combat Experience: Historical analysis has shown that CEV ratios tend to have a rough constancy over time. Therefore, CEV ratios determined from recent previous combat between two nations can be used for predictions of future combat between those same nations. However, the currency of such ratios is uncertain because basic societal conditions that affect troop quality do fluctuate over time.

2. Recent Indirect Combat Experience: The same process as above can be used in cases where two nations have previously fought against a common opponent. The common opponent effectively becomes a constant and the difference in CEV ratios for the two target nations can be used to estimate what a direct matchup would be.

3. Indirect Measures of Combat Effectiveness: For predicting the CEV ratio between two potential future combatants, there are often no recent direct or indirect combat experiences applicable to the countries selected. More indirect measures of troop quality must be found so the CEV ratio can be estimated. It is not unreasonable to expect that some independent variables of societal or national characteristics would correlate closely with, and thus suggest or indicate, a country's relative troop quality versus an adversary.

This study examined the indirect measures method in greater detail. To pursue this method, it was necessary to analyze a historical data base of combat outcomes and societal conditions. Analysis helped to determine if there were significant relationships between any societal measures and relative combat effectiveness values. It was a question of how much societal issues and which specific factors are at the root of combat effectiveness differentials.

3.2 COMBAT EFFECTIVENESS VALUE RATIOS AND SOCIETAL CONDITIONS

The basic assumption underlying this study is that there is a close relationship between certain characteristics or conditions of both the nation and the nation's armed forces, especially with regard to the combat effectiveness of the armed forces. The study was designed to be a pioneering effort in interdisciplinary research involving military science, historical analysis of combat, military sociology, economics, psychology, and mathematical analysis to determine if presumably independent societal conditions could be used as indicators of a military's combat effectiveness. All of these disciplines played a role in the initial feasibility study.

The general approach was to estimate relative combat effectiveness between several pairs of opponents, establish military and societal factors to serve as independent variables, and compare the two sets of numbers to determine if there are any relationships. The concept was to determine which factors appear to be most influential in determining relative combat effectiveness.

3.3 STAGES IN THE PROCESS

The work was accomplished in four general, overlapping stages as follows:

1. Estimates of relative combat effectiveness for historical combat were obtained using the QJM. Data for both sides of the combat engagements were compiled to include troop strength, weapons, environmental conditions, operational circumstances, and outcomes. The outcomes were defined in terms of mission accomplishment, attrition of personnel and weapons, and opposed distance advance. Where possible, data were obtained from existing data bases maintained by Data Memory Systems, Inc. (DMSi). In a few cases, additional historical research was performed.

2. The next step was to select several factors as independent variables. These had to satisfy the criteria of relevance and availability. The method used to compile the list of potential independent variables was to consult recognized experts in several fields and obtain their judgments in a structured manner. Archival research was accomplished to provide values for factors to be used in the initial feasibility study.

3. The CEVs and independent variables were correlated statistically to determine if there were any relationships. Strong correlation would indicate co-variation between independent and dependent variables, indicating that a significant relationship might exist between them. Some more sophisticated analyses were performed to indicate the type of results possible with a larger data base.

4. Finally, some general conclusions were drawn with regard to the pros and cons of the methodology and the general feasibility of using this approach to provide estimates of future relative combat effectiveness.

4. ESTIMATING HISTORICAL RELATIVE COMBAT EFFECTIVENESS

Although the study could have used any reasonable set of combat engagements to derive CEV ratio data, it was decided to use major participants in World War I (WW I) and World War II (WW II).[9] Using combat engagements and relative combat effectiveness scores from both wars provides a larger set of engagements from which to draw and would allow testing with two sets of independent variables rather than one set only. This would serve as a partial validation of any results if they were found to be consistent across both wars. It also offered the added advantage of providing the opportunity to examine US and UK forces vs the Russians/Soviets using the indirect combat experience method outlined in Sect. 3.1 above.

QJM analysis of historical combat requires detailed knowledge of the circumstances of combat on both sides. Accurate data for much of the US, UK, and German experience is available in archives, and the DMSi Land Warfare Data Base includes numerous combat engagements between US and German forces and UK and German forces for both world wars. However, accurate data on Russian or Soviet experience is hard to obtain, and there is a general lack of QJM engagements between German and Russian (WW I) or Soviet (WW II) forces. So one of the challenges of the feasibility study was to obtain adequate data on Russian and Soviet combat engagements. This was done by consulting leading experts on the Soviet Army and performing additional research on the Eastern Front in World War I. The difficulty in obtaining division level data for the Russian and Soviet experience explains why some of the combat events analyzed are corps- or even army-level battles lasting many days.

For the feasibility study, QJM analyses were conducted for a total of 56 combat engagements, arrayed as shown in Table 1. Some details of these combat engagements are provided in Appendix A, including the CEV ratio for each.

[9] Historical analysis of combat is performed preferably at the level of combat engagements. The term "combat engagements" is defined as a combat event involving units from company to division size lasting one to five days. This is in accordance with the hierarchy of combat presented in Dupuy's *Understanding War* (page 67). In this terminology, a battle is a larger combat event consisting of several engagements, involving larger units up to army corps and extending over a longer period of time up to several weeks. Most of the combat events used in this study are combat engagements, however, some of the combat events for Germany vs US (WW I) and Germany vs Russia/USSR (WW II) are battles because data on individual engagements are not yet available.

Table 1. Number of Combat Engagements and Battles

	Germany vs US	Germany vs UK	Germany vs Russia/USSR
WW I	10	9	9
WW II	10	9	9

For one set of analyses, the results of these engagements were condensed into a single CEV ratio that represented the overall CEV ratio for those two opponents for the entire war. After the CEVs were calculated for each engagement, the arithmetical mean was computed for use as the representative CEV for each war and pair of opponents. The mean CEVs computed for each pairing are shown in Table 2.

Table 2. Mean Combat Effectiveness Value Ratios for Opponents

	Germany vs *Itself*	Germany vs US	Germany vs UK	Germany vs Russia/USSR
WW I	1.0	0.492	1.219	3.154
WW II	1.0	1.227	1.540	2.848

To simplify the analysis and presentation, all CEVs are shown for Germany relative to the other nations. Though QJM CEVs are generally presented as attacker over defender, this would provide confusing results because there was no consistency in which side was attacking. However, since CEV is a ratio (Q_a/Q_d), it can be inverted when necessary to allow for consistency in presenting the results and still correctly reflect the magnitude of the ratio. Therefore, CEVs are shown as $Q_{Germany}/Q_{Other}$ regardless of which side was attacking or defending.

A CEV of greater than 1.0 means that the Germans (in this case) had higher combat effectiveness than their opponent; a CEV of less than 1.0 means that the Germans had lower combat effectiveness than their opponent. The size of the number also represents the size of the combat effectiveness disparity. To be able to include German societal data in the statistical analysis, a hypothetical German vs German CEV ratio was included for each war. This ratio was assigned as 1.0 to 1.0 and increases the number of pairings (cases or dependent values) to eight for performing correlation analysis.

The mean CEVs were calculated to provide a simple comparative measure that could easily demonstrate the analytical concepts under study. They show that the Germans had higher combat effectiveness than their opponents in both wars, except against the United States in World War I.[10] It also shows a rough constancy of CEV ratios for the UK and USSR across both wars. However, more advanced statistical analyses are possible using the individual CEVs for all 56 combat engagements and battles (plus hypothetical German vs German cases).

[10] This result may be explained by the circumstances of the combat between Germany and the US in WW I. The first engagement used in this study between US and German troops was in June 1918, after the Germans had just barely failed to win victory by a massive offensive and only five months before the Armistice. The German troops were dispirited and certain of defeat; the US troops were fresh and eager to fight.

Clearly this explanation causes problems with certain of our assumptions: the $Q_{Germany}$ value is assumed constant to allow estimation of Q_{US}/Q_{Russia}, etc., and the use of the same $Q_{Germany}$ for WW I and WW II might cause statistical errors. However, for the purposes of this study - feasibility - these effects are ignored. A more detailed study would need to address this issue.

5. SELECTION OF HISTORICAL INDEPENDENT VARIABLES

Selection of suitable independent variables that might establish or influence relative combat effectiveness was accomplished by convening a multidisciplinary panel of experts at a Planning Conference on October 11, 1989. The group of military analysts and experts, including sociologists and Soviet experts, drew up a list for use in the study. A summary report of the conference proceedings and a list of participants is in Appendix B. After considerable discussion, general agreement was reached that relative combat effectiveness would depend on the six general categories listed in Table 3.

Table 3. Categories of Factors Affecting Relative Combat Effectiveness

Societal Factors
Manpower Quality
Military Leadership
Military Doctrine and Theory
Military Training
Readiness for Combat

For the purposes of this initial feasibility study, it was decided to investigate only the category of Societal Factors. Although the other categories of independent variables may be equally valid for measuring and explaining relative combat effectiveness, the consensus was that societal factors were more fundamental -- in some sense primary factors -- and provided the basis for the other categories.

It was hypothesized that a nation's capacity to wage war -- its overall performance in combat -- was demonstrably related to or influenced by a number of discrete societal factors for which numerical data could be compiled. In general, these factors fell into six distinct categories as listed in Table 4. A total of 33 separate factors were used. Other factors were investigated but discarded because of a lack of authoritative data.

Table 4. Categories of Societal Factors

Industrial Production
Agricultural Production
Transportation and Communications
Educational System
Financial Activity
Vital Statistics and Health

For the initial feasibility study it was decided to use data for a single year just prior to the outbreak of each war. The year chosen for World War I was 1913 and for World War II, 1938. To eliminate differences due to sheer size, the factors were calculated on a proportional basis of the total population of each nation in the year of measurement. These are expressed as a per capita number, the number of items per one million population. Per capita values of the factors used in the analysis are provided in Appendix C.

6. ANALYSIS OF DATA

Several statistical techniques were used to analyze the data. Simple correlations were used to identify potentially important factors. More complex techniques were used to indicate methodologies that could be used for a complete investigation of the problem.

6.1 CORRELATION

Correlation is a statistical method for measuring the degree of linear co-variation between the two variables being analyzed. This means that as one variable changes, the other changes proportionately. The more closely the two co-variate, the stronger the relationship.[11] The strength of the relationship is indicated by the correlation coefficient. If there is no connection (random association) between the values for the two variables, they will not co-variate and will have a low correlation coefficient. If two variables have a high correlation, then it means that by knowing the value for one variable, a confident prediction can be made as to the value for the second variable.

A correlation coefficient of 1.0, either positive or negative, indicates a perfect relationship between the two variables. A correlation coefficient of 0.0 indicates no relationship. The closer the correlation coefficient is to either 1.0 or -1.0, the stronger the relationship. A positive correlation coefficient indicates a direct relationship and a negative coefficient indicates a negative direct relationship (one variable increases proportionally as another decreases).

The relationship being analyzed can also be represented graphically using a scatterplot. In a scatterplot the values for each pair of variables are plotted on an XY chart. The alignment of the points indicates visually if a relationship exists. For each set of points, a "best fit" line can be drawn that minimizes the total squared distance that all of the points lie off of the line. In a perfect correlation of 1.0 (or -1.0) all of the points would fit precisely on the line. The value of the correlation coefficient indicates how closely the points come to lying exactly on the best fit line. The positive or negative sign indicates whether the best fit line has a positive or negative slope, respectively. If the correlation is low, then the points should appear to be randomly distributed on the graph.

6.2 FACTOR VERSUS MEAN COMBAT EFFECTIVENESS VALUE CORRELATION RESULTS

In the first stage of the analysis, each of the societal factors (independent variables) was correlated with the mean CEVs (dependent variable) for that war. To facilitate the correlation analysis, the data were utilized in two ways. First, data for each war were separately analyzed with four cases for each war (Germany, UK, US and Russia/USSR). To validate the significance

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[11] A well-known statistical adage is that "correlation does not prove cause and effect." However, a strong correlation suggests that the analyst should at least investigate the possibility of causal linkage or other form of relationship.

of relationships that were found and to show consistency across both wars, a correlation that combined all eight cases into one data set was used.

In this combined effort, the data for each factor were "normalized" according to Germany, so that the German values served as a standard for each war. For the independent variables, normalization allows data to be utilized without regard to specific units of measurement because it converts all absolute data into ratios. In these ratios, the value for Germany is set at 1.0 and data points for other nations are calculated based on their relative value vs Germany. Therefore, a value less than 1.0 for another nation indicates real values lower than Germany's and normalized values greater than 1.0 mean values higher than Germany's. Table 5 illustrates this process.

Table 5. Presentation of Factor Data

Steel Production per Capita

Absolute / Normalized

$$\text{WWI:} \quad \frac{\text{Germany}}{\text{Russia}} = \frac{270.9}{35.1} = \frac{1.00}{0.13}$$

For CEVs, normalization effectively inverts the CEV ratios because it sets Germany's Q value to 1.0. This process is illustrated in Table 6.

Table 6. Presentation of Combat Effectiveness Value Ratio

Original / Normalized

$$\text{WWI:} \quad CEV_{\text{Germany/Russia}} = \frac{3.14}{1.00} = \frac{1.000}{0.318}$$

$$CEV_{\text{Russia/Germany}} = \frac{.318}{1.00}$$

Normalization allows combining data from both wars because it eliminates disparities or distortions that might exist because of wide variance in absolute data values. Normalization allowed for correlation of all eight cases at once, though the two German cases were identical with all values equal to 1.0. Factors for which data could not be found for both wars were not used in the combined correlation effort. Normalized per capita factor values can be found in Appendix D. Presentation of individual factor correlation coefficients follows below.

6.2.1 Industrial Production

There appears to be a general, strong positive relationship between per capita industrial production and relative combat effectiveness, as shown in Table 7. Nations with greater per capita industrial output tended to be the nations with the higher CEVs. The question as to whether and how this industrial production advantage translated into better performance from the troops remains to be answered. Figure 1 shows the normalized correlation scatterplot for electrical production vs mean CEV.

Table 7. Correlation of Industrial Production Factors and Combat Effectiveness Values

	Correlation Coefficients		
Independent Variables (per capita)	World War I	World War II	Combined
Coal Production	.394	.735	.564
Iron Production	.931	.108	.539
Steel Production	.872	.926	.783
Sulfuric Acid Production	.725	.931	.712
Electrical Production	.990	.823	.921
Motor Vehicles Registered	n/a	.360	n/a

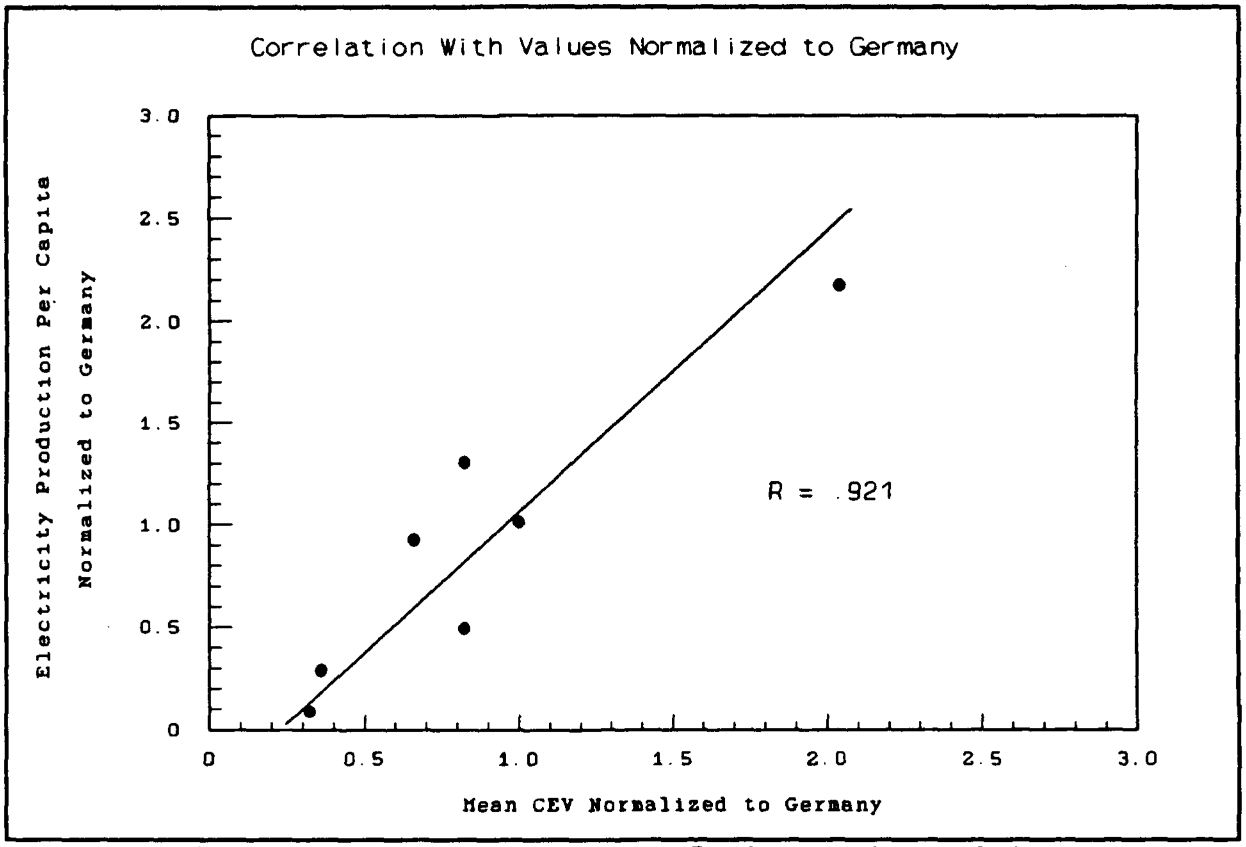

Fig. 1. Electrical production vs mean Combat Effectiveness Value.

6.2.2 Transportation and Communications

Authoritative data for transportation and communications factors were difficult to obtain and therefore limit the generalizations and conclusions that can be drawn. To the degree that these factors relate to industrial activity, they should have the same high correlations with CEV. The actual correlations are shown in Table 8.

Table 8. Correlation of Transportation and Communications Factors and Combat Effectiveness Values

Independent Variables (per capita)	Correlation Coefficients		
	World War I	World War II	Combined
Railway Mileage	.942	.342	.720
Rail Passengers	n/a	.591	n/a
Ships, Numbers	.292	n/a	n/a
Shipping Tonnage	-.259	.060	.119
Mail Items, Numbers	n/a	.606	n/a
Telegrams, Numbers	.071	.195	-.050

6.2.3 Agricultural Production

Agricultural production comparisons send a mixed message. Table 9 shows the correlations. Nations with extensive effort and production of cereal grains show a contradictory relationship with combat effectiveness. Conversely, nations with large numbers of livestock, show modest positive relationships with combat effectiveness. Except for pigs, there is also a distinct difference with respect to livestock between the two wars. On this basis, it would be imprudent to conclude that a high per capita level of agricultural production in general is a positive factor in having high combat effectiveness. Use of a single factor such as pigs, though it shows a strong correlation across both wars, could be of suspect value as it may easily be an anomaly that will not be consistent across time and space. Figure 2 shows the scatterplot for the number of pigs factor.

Table 9. Correlation of Agricultural Production Factors and Combat Effectiveness Values

	Correlation Coefficients		
Independent Variables (per capita)	World War I	World War II	Combined
Wheat Hectares	.142	-.542	-.070
Barley Hectares	-.553	-.540	-.418
Oats Hectares	.328	-.354	-.032
Wheat Output	.276	-.509	.106
Barley Output	-.720	.446	-.273
Oats Output	.399	.251	.271
Horses, Numbers	.477	-.365	.399
Cattle, Numbers	.912	.269	.666
Pigs, Numbers	.867	.760	.796
Sheep, Numbers	.145	-.532	-.086

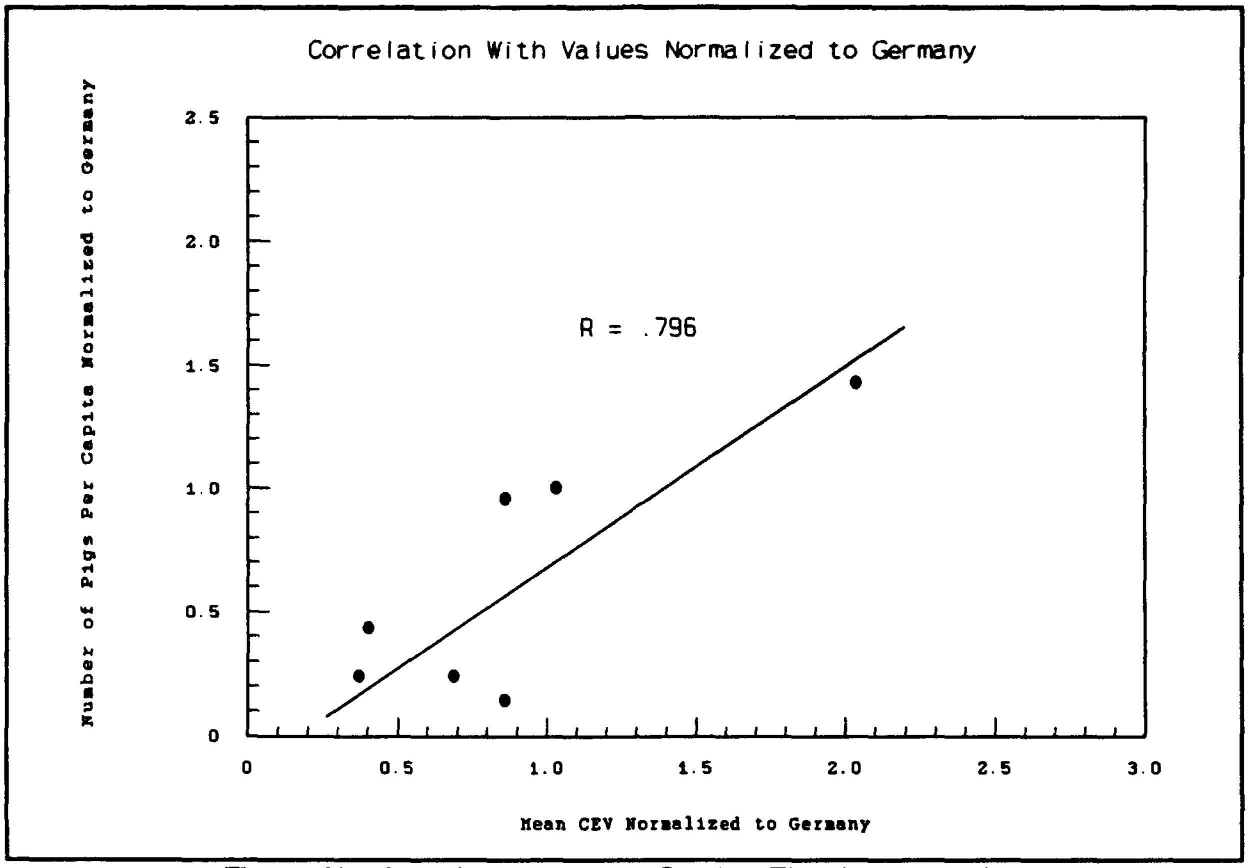

Fig. 2. Number of pigs vs Mean Combat Effectiveness Value.

6.2.4 Educational System

Relatively incomplete data on national educational systems show little consistent pattern of relationship with combat effectiveness (Table 10). The relationships for World War I are positive and strong. The relationships for World War II are largely reversed. Though in both wars there are relatively strong correlations, their inverse nature reduces their validity as predictors of CEV. The normalized value for primary school pupils shows that these inverse values tend to cancel out when combined.

Table 10. Correlation of Educational System Factors and Combat Effectiveness Values

Independent Variables (per capita)	Correlation Coefficients		
	World War I	World War II	Combined
Primary School Pupils	.842	-.721	.152
Primary Teachers	n/a	-.906	n/a
Secondary School Pupils	.528	n/a	n/a
University Students	n/a	.054	n/a

6.2.5 Vital Statistics and Health

There is a strong negative correlation between the vital statistics and combat effectiveness, as shown in Table 11. Whereas high values for industrial production indicate national strengths, high values for infant mortality and death rate indicate national weaknesses (e.g., poor health care system). Therefore, the negative direct relationship shows that a better health care system is related to better combat effectiveness. The strong negative correlation between birth rate and CEV may reflect the trend that as nations industrialize, their birth rates tend to decrease. In general, these societal conditions closely match the level of industrialization. Figure 3 shows the scatterplot for the infant mortality rate factor.

Table 11. Correlation of Vital Statistics and Health Factors and Combat Effectiveness Values

Independent Variables (per capita)	Correlation Coefficients		
	World War I	World War II	Combined
Infant Mortality Rate	-.751	-.825	-.628
Death Rate	-.451	-.732	-.427
Birth Rate	-.690	-.842	-.627

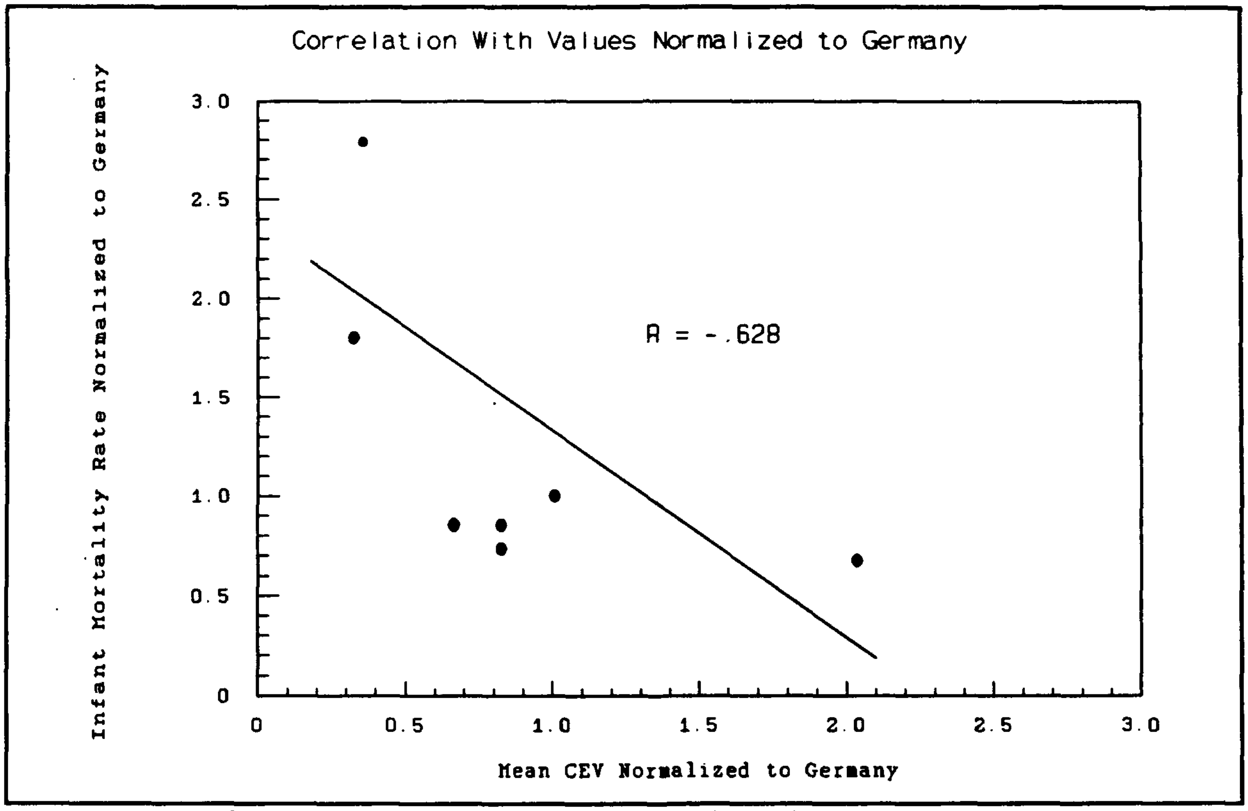

Fig. 3. Infant mortality vs Mean Combat Effectiveness Value.

6.2.6 Financial Activity

There is a consistent and moderate positive relationship shown in Table 12 between measures of financial prosperity (money flow and spending) and combat effectiveness. On the other hand, there is a moderate negative relationship shown between high taxes and combat effectiveness.

Table 12. Correlation of Financial Activity Factors and Combat Effectiveness Values

Independent Variables (per capita)	Correlation Coefficients		
	World War I	World War II	Combined
Banknote Circulation	.688	.124	.421
Bank Deposits	.896	.472	.451
Government Spending	-.388	n/a	n/a
Tax Revenues	-.320	-.842	-.354

6.3 ADVANCED STATISTICAL ANALYSIS

The simple correlations shown above demonstrate the ability of statistically comparing mean CEVs with broad national factors. However, the small sample sizes (four or eight cases) provide low confidence in the results and makes the correlation unduly affected by even one outlying value. This tends to skew the results unnecessarily; however, more advanced procedures can help to reduce this impact.

6.3.1 Correlation Using All Engagements

Determining the mean CEV for a pair of nations for a given war is useful for making simple comparisons, but the process of calculating the mean discards valuable information. This information can be retained by using the individual CEVs from all of the combat engagements as the cases of dependent values. So instead of having a total of only eight cases from both wars, the analysis used 58 cases. (This includes the 56 separate combat engagements/battles plus two additional cases representing a German baseline case for each war.[12]) As was done for the mean CEVs, each war could have been examined separately, but this was not done

[12] This does imply a constancy of German CEV across both wars, but there is no basis for assuming otherwise. Making an assumption of this kind cannot be avoided if data from both wars are to be included in a single analysis.

because of the desire both to increase the data set being used for added confidence and validity, and to find the best results across both wars for the sake of generality.

The calculated CEVs shown in Appendix A demonstrate a spread, or variance, around the mean values. This variance may be based on one or more of several factors. One factor is error, common to all measurements. If this were the only factor, it could be assumed that there is one true CEV for all engagements between two nations in one war and that the mean is the best approximation to this value. Another possibility is that the CEVs fluctuate during a war, perhaps because of the progress of the war or special circumstances of given battles or campaigns. If this is the case, it is probably better to use all of the individual CEVs in the correlation analysis.

Correlations using mean CEVs did not use the information contained in CEV variances, though they could have. Generally speaking, correlations based on the complete data will be lower than for the means alone because the spread of data is greater. Figure 4 illustrates this concept. The top portion of the figure is a replication of Fig. 1 where the mean CEV value was used against normalized values for electrical production. However, the bottom portion shows all of the CEV values for a given opponent in a given war, rather than just the mean. Thus each point in the top portion is expanded to a row of points at the same level of electrical production in the bottom portion. The spread of data shows the uncertainty in the CEV value, which is important for predicting CEVs from societal data.

6.3.2 Correlation Using All Engagements and Logarithms

Not only does Fig. 4 show the variance of CEVs, but it shows an apparent nonlinear trend. The arcing dashed line indicates a possible curve that has a better "fit" than the straight line. If this is true, and that curve can be defined, then it would serve as a better predictor of points than the equation of the straight line.

An examination of the variables yields a possible explanation for the apparent curvilinear nature of the relationship between electrical production and CEVs. The CEV range covers all possible positive numbers, but in some sense a CEV of 1.0 is the center of the range because this indicates equality of effectiveness. This causes all of the instances of low CEV to clump together between 0 and 1.0 and all instances of high CEV to spread from 1.0 to infinity. A way to adjust for this uneven spreading is to use the natural logarithm of CEV. This would tend to equalize the spread of CEV values above and below 1.0 and straighten out the curve from Fig. 4.

Figure 5 shows the correlation scatterplot of the natural logarithm of CEV (called LnCEV) vs electrical production. This produces a clearly more linear trend and higher correlation coefficient than shown in the bottom of Fig. 4. In a larger data base, it might make sense to use the natural logarithm of the normalized values for the independent variables as well because their normalization tends to produce the same "clumping" problem.

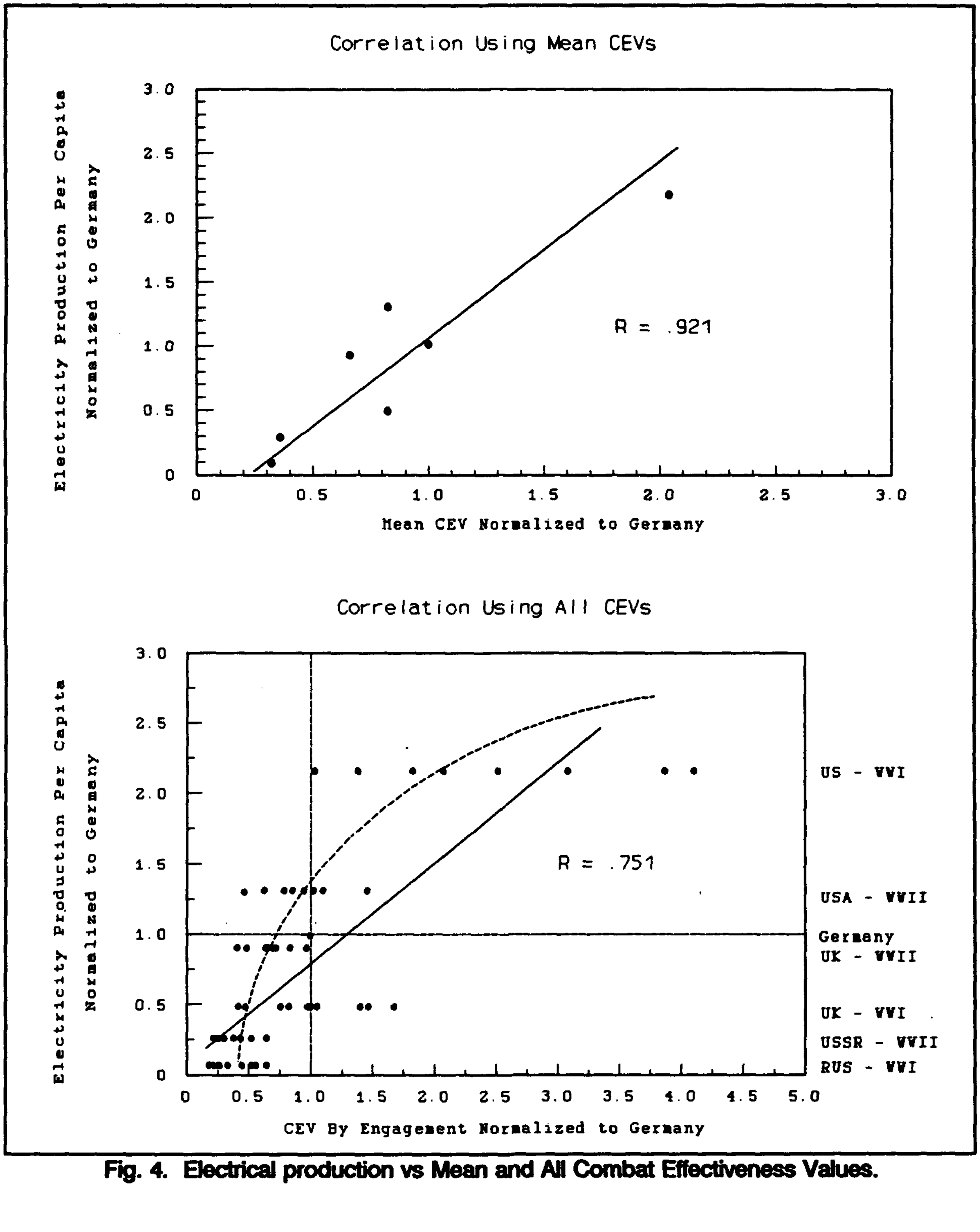

Fig. 4. Electrical production vs Mean and All Combat Effectiveness Values.

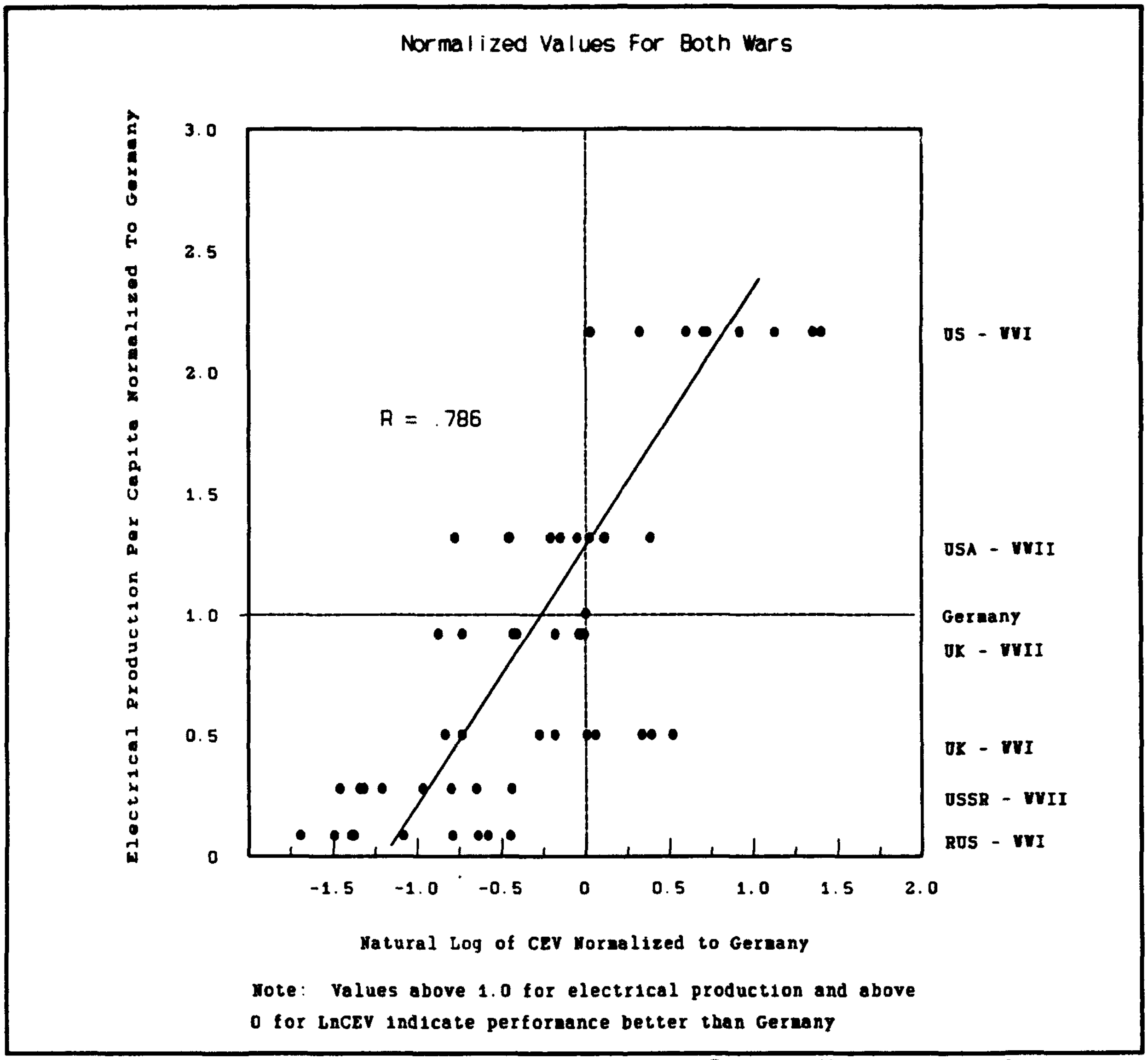

Fig. 5. Electrical production vs Natural Log of All Combat Effectiveness Value.

6.3.3 Comparing Correlation Results

As explained above, the correlation coefficients for cases when the CEVs from all combat engagements are used will generally be lower than when the mean CEV was used. However, use of the natural logarithm of CEV should generally produce stronger correlation coefficients than without doing so, and may even produce a stronger correlation coefficient than when using the mean CEV. A full list of correlation coefficients for all three methods is provided in Table 13.

Table 13. Alternative Correlation Coefficients

Normalized Societal Factors	Normalized CEVs for Both Wars		
	CEV Means	All Battles CEVs	Log of All CEVs
Coal Production	.564	.426	.563
Iron Production	.539	.436	.561
Steel Production	.783	.637	.767
Sulf Acid Production	.712	.580	.748
Electrical Production	.921	.751	.786
Wheat Hectares	-.070	.016	-.158
Barley Hectares	-.418	-.313	-.509
Oats Hectares	.032	.079	-.049
Wheat Output	.106	.167	-.037
Barley Output	-.273	-.251	-.401
Oats Output	.271	.199	.104
Horses	.399	.421	.220
Cattle	.666	.555	.528
Pigs	.796	.664	.640
Sheep	-.086	.027	.143
Railway Mileage	.720	.658	.670
Shipping Tonnage	.119	.162	.268
Telegrams	-.050	-.037	.185
Prim School Pupils	.152	.121	.167
Infant Mortality Rate	-.628	-.509	-.668
Death Rate	-.427	-.322	-.528
Birth Rate	-.627	-.495	-.689
Banknote Circulation	.421	.317	.274
Bank Deposits	.451	.375	.557
Tax Revenues	-.354	-.241	-.326

The lack of consistency as to the method producing the strongest correlations prevents drawing a firm conclusion about the nature of the general relationship between CEVs and societal factors. While the tendency of strong correlations between natural logarithms of CEVs and societal factors (when using all of the individual cases) suggests that the general relationship is nonlinear, it would take more data and more cases to confirm this.

6.3.4 Multiple Regression

Correlation is not the last step in the analytical process because it is not the most advanced statistical tool that could help to predict CEVs given societal data. This is because correlation considers only one factor at a time and is insufficient if it is believed that several factors are at work simultaneously to explain CEVs. Regression analysis can be used to overcome these limitations.

Whereas correlation analysis provides only the strength of co-variation between two variables, regression analysis provides a linear equation that allows calculation of dependent variable values given data for the independent variable(s). The calculation of this best fit line is based on the principle of least squares, which means that the squared distance between all of the data points and the line is at a minimum. Similar to correlation analysis, the regression coefficient, R^2, indicates the "goodness" of fit for the line and varies from 0 to 1.0 with 1.0 being a perfect fit.

Another way to look at the R^2 value is through the concept of explained variance. The dependent variable, in this case CEV levels, has a range of values that is known as its variance. The challenge is to determine what accounts for this spread in values. In theory, the more that is "known" about the dependent variable, the more of the variance that can be explained. Data on related independent variables provide this increased knowledge about the dependent variable. The R^2 value indicates just how much of the variance in the dependent variable is explained by the independent variable(s) used. If the independent variable(s) have a complete and direct relationship to the dependent variable then all of the variance is explained and R^2 equals 1.0.

One problem in using regression analysis is the tendency for several independent variables to correlate highly with each other. But if two or more independent variables correlate well with each other, then they may not be able to explain much more variance than any one can alone because they simply serve as proxies for each other. The key is to find two or more independent variables that explain different portions of CEV variance so that their simultaneous inclusion through regression analysis provides stronger results than using either separately.

When provided with a large number of independent variables for possible inclusion in a regression equation, the procedure of stepwise regression offers the ability to test each variable and select the best combination of variables to explain the variance in the dependent variable. First the process finds the variable that explains the most variance on its own, then it seeks the variable that explains the most additional variance, and so on. The process is stopped when no further statistically significant increase in variance explanation is achieved by adding an additional variable.

Regression analysis is the primary means by which current values for CEVs can be estimated. It is also possible to use these equations to validate historical mean CEVs. Regression analysis was performed for all three sets of independent variables used in the correlation analysis: mean CEVs, individual CEVs, and natural logarithms of individual CEVs. For the analysis, data for the variables were in normalized form so that both wars could be included. Table 14 shows the equations that are the results of the regressions.

Table 14. Regression Results and Equations for $CEV_{Other/Germany}$

Using Mean CEVs:

Explained Variance: $R^2 = 0.92$
Best Fit Line:

$$CEV = 0.1902 + 0.7528 \times ELECT \quad (5)$$

Using Individual CEVs:

Explained Variance: $R^2 = 0.69$
Best Fit Line:

$$CEV = 0.33 + 0.98 \times ELECT + 0.15 \times SHIPS - 0.169 \times TELEGRAMS \quad (6)$$

Using Natural Logarithm of Individual CEVs:

Explained Variance: $R^2 = 0.72$
Best Fit Line:

$$\ln(CEV) = -1.19 + 0.83 \times ELECT + 0.16 \times SHIPS \quad (7)$$

Or

$$CEV = e^{-1.19} \times e^{0.83 \times ELECT} \times e^{0.16 \times SHIPS} \quad (8)$$

(Notice that to calculate a CEV, the factors are now multiplied, rather than added.)

The exceptionally strong R^2 result and the use of only one independent variable in the regression equation for the mean CEV approach reflects the fact that use of the mean reduces the spread of CEV values so that it is easier to explain the variance in CEVs. When CEVs from individual engagements are used, they are more spread out making a good "best fit" line (high R^2 value) harder to obtain. In the other approaches, two or three independent variables were included because the additional variables -- ships or telegrams -- tended to supplement electrical production by explaining different pieces of CEV variance. Although the R^2 value for the latter two approaches is not as high as that for the mean CEV approach, inclusion of further variables will not yield statistically significant explanations of any additional variance.

However, it is clear that the regression results are relatively strong for all three methods and that electrical production is an important variable in all three cases. Because of co-variation, use of other variables representing industrial production in place of electrical production would show similar results.

6.3.5 Another Possible Analysis

All of the above approaches to correlation and regression use the societal variables as separate factors for study. Though the point of the study was to determine which, if any, of these variables could perform as good predictors of CEVs, there is a danger in relying on just one or two key indicators. The problem is that it is possible that those indicators, while valid for the nations and wars under study, might not be equally reliable for different times or different nations. To develop results with more generality -- applicable across a wider range of places and times -- it might be more useful to develop aggregated measures as independent variables. Instead of using the level of electrical production, the predictor would be a broader measure of industrial production that included electrical production, steel production, and other relevant factors.

Use of simple composite variables -- such as additive measures of agricultural production -- was attempted in the regression analysis. However, the regression results were higher when using the individual variables as opposed to the composites. Part of the problem was the small data set that did not offer enough cases or variables to make these types of manipulations useful. Another problem was that aggregating variables often requires weighting schemes to ensure that variables with small values or ranges do not get "masked" by other variables. This adds a level of complexity that was deemed to be unjustified at this time, though the approach may prove to be significant in future efforts of this type. In theory, composite variables seem to present the best case for producing an equation for predicting CEV that could be applied to many nations.

7. ESTIMATING COMBAT EFFECTIVENESS VALUES

Though the results of the statistical analysis suggest a good predictive ability for determining current CEVs, the actual predictive ability of societal factors – at this time – to estimate current and future CEV ratios is limited. The method is sound, but more data need to be accumulated and analyzed before there is high confidence that the results are valid and can be used for other countries. For illustrative purposes, the CEV ratio between the US and USSR have been estimated using the analyses of this study.

For historical battles, there are two ways to do estimate the CEV ratios. One is to use the experienced mean CEV values relative to Germany, where a US/USSR mean CEV can be estimated by using the German mean CEV as a constant baseline[13]:

$$CEV_{US/USSR} = \frac{CEV_{Germany/USSR}}{CEV_{Germany/US}} \qquad (9)$$

This would produce the following values:

World War I:

$$CEV_{US/USSR} = \frac{3.154}{0.492} = 6.411 : 1 \qquad (10)$$

World War II:

$$CEV_{US/USSR} = \frac{2.848}{1.227} = 2.321 : 1 \qquad (11)$$

The other method, and the only method applicable for predicting current (or future) CEVs, would be to use the equations that were generated during the regression analysis. These can also be compared to experienced CEVs that were calculated as means from the historical combat engagement data from World Wars I and II. The calculated CEVs are also extended to the most current data.[14]

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[13] This, however, assumes that the German component of CEV is constant against both sides. Especially in the WW I case this may not be entirely accurate. The German/Russian battles date from 1914 and the German/US battles date from 1918. During this time the German Army was exhausted through four years of hard combat and had lost most of its early cadre of top forces. Its quality in 1918 almost undoubtedly was less than in 1914, but the exact amount of degradation in German combat effectiveness during those years is unknown.

[14] Additional research provided current (early-1980s) data for factors used in the regression equations. Data are shown in Appendices C and D. Telephones per thousand was substituted for telegrams, since the latter data were not readily available (or may not have been applicable).

Table 15 shows the various CEV estimates. The "Experienced CEV" entries for Germany/US and Germany/USSR entries are the mean value CEVs. The experienced CEV entries for US/USSR are those calculated in Eqs. (10) and (11). The CEVs calculated from the means were derived using Eq. (5) in Table 14. The CEVs calculated from "All" were derived using Eq. (6) in Table 14. The CEVs calculated from "Log All" were derived using Eq. (8) in Table 14.

The derivations of the entries involve four steps.

1. The appropriate (normalized) values were substituted into the equations for Germany, the US, and Russia/USSR.

2. Because the equations produce CEVs for the given country over Germany, they are inverted in step 2.

3. Because the equations are approximations, the calculated CEVs for Germany over Germany are not 1.0. To maintain the normalization convention, the calculated CEVs are renormalized by dividing by the calculated Germany over Germany CEVs.

4. The US/USSR CEVs are calculated using Eq. (9).

Interestingly, the results generated from all three methods are remarkably close for US/USSR CEVs, with the exception of the value of 21.24 for World War I using the logarithm method. This abnormally and unrealistically high value may be the result of the peculiar behavior of exponential mathematics where seemingly small variances in data values (outliers) can become especially magnified and produce large values. Overall, the results as shown in Fig. 6, indicate a trend (the average line) where US/USSR CEV has fallen from around 7.65:1 in WW I (excluding the logarithm data) to about 2.75:1 in WW II to about 1.82:1 for the mid-1980s.[15] This trend and the similarity between methods provides a degree of validity to the overall approach, especially since this seems to be largely in concert with expected results.

There is a cautionary note in this process. Although electrical production was the single strongest correlation and regression factor for explaining CEV variance, other factors of industrial production were also strong and co-varied closely with electrical production in the historical data. However, the historical realities of industrialization have undercut some of this co-variation. Because of this, had some of these other factors been used in the regression equations instead of electrical production, the projected CEV ratio for the current period between the US and the USSR would have come out much different. For example, while US electrical production per capita is nearly double Soviet levels, current US coal production per capita is only 70% greater than Soviet coal production and the Soviets actually outproduce the US in steel per capita by nearly two-to-one. Use of steel values, therefore, would have suggested that the US/USSR CEV ratio should be seen to favor the Soviets.

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[15] In general, Quantified Judgment Model rules cap CEV ratios at 6.0:1.0, and it would probably be difficult to come up with historical cases that demonstrated higher CEV ratios than that. The calculated WW I figures for US/USSR CEV should be understood in that context. Though it does seem clear that the US would have had a significant advantage against the Russians, it would likely not have been above the 6.0:1.0 cap.

Table 15. Estimating Combat Effectiveness Values

World War I	Germany/US	Germany/ Russia	US/Russia
Experienced CEV:	0.49	3.15	6.41
CEVs Calc From Means:	0.52	3.73	7.20
CEVs Calc From All:	0.36	3.35	9.30
CEVs Calc From Log All:	0.10	2.21	21.24
Average:	0.37	3.11	11.04
Average Without Log:	0.46	3.41	7.64
World War II	**Germany/US**	**Germany/USSR**	**US/USSR**
Experienced CEV:	1.23	2.85	2.32
CEVs Calc From Means:	0.80	2.36	2.96
CEVs Calc From All:	1.05	2.57	2.43
CEVs Calc From Log All:	0.63	2.07	3.29
Average:	0.93	2.46	2.75
Current (Mid-1980s)	**Germany/US**	**Germany/USSR**	**US/USSR**
CEVs Calc From Means:	0.64	1.17	1.84
CEVs Calc From All:	0.71	1.07	1.52
CEVs Calc From Log All:	0.58	1.22	2.10
Average:	0.64	1.16	1.82

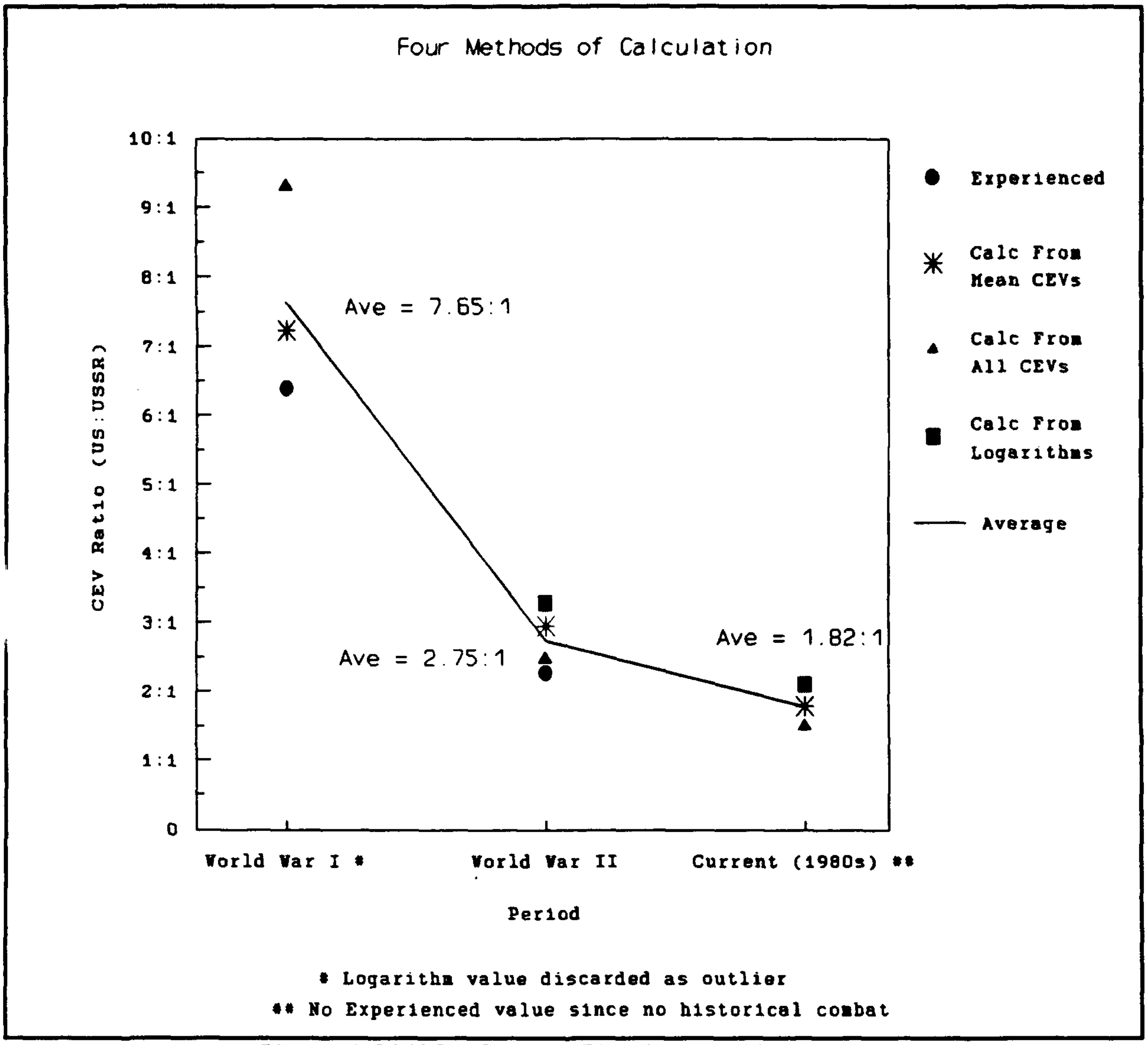

Fig. 6. US/USSR Combat Effectiveness Value trend.

In further studies, regression analysis using more countries and more engagements (needed for higher confidence of the results) might yield different factors as being more stable predictors. The instability of single factors reinforces the value of using composite factors that should limit the chance that nonrepresentative factors could skew the results.

8. CONCLUSIONS

The feasibility study was not pursued in enough detail and breadth to ensure its validity, generality, and applicability to other nations. The study simply demonstrated that it may be possible to produce valid, general, and widely applicable results with a further study that generates enough quality data on combat engagements and societal factors.

8.1 RESULTS

Analysis of the correlation and regression results between CEVs and the societal factors selected for the initial feasibility study shows limited conclusions. Factors related to industrialization, such as electrical production, generally showed strong positive correlations with (R = .90+) and implied good predictive ability for relative combat effectiveness. Other factors, particularly those related to agriculture, showed inconsistent and inconclusive results. The CEV/industrialization link is not surprising because many of the characteristics necessary for military prowess are also important in industrial activities and vice versa.

The three different analytical approaches produced differing results, but the most advanced approach (and arguably the most reliable and accurate) using logarithmic values for CEVs still produced significant results ($R^2 = .72$) for the nations and wars under study. In fact, it would have been surprising if the societal factors could explain even more CEV variance than was observed since it is assumed that some portion of CEV derives from military factors (like training) that should not be directly related to or subsumed by the societal factors under study.

The analysis also illustrates the different types of statistical techniques that could be used and the kinds of answers they would provide in studies of this type. It is premature to conclusively attempt to select the best among these approaches. It does seem that a model for predicting CEVs with relatively high accuracy could be developed over time.

This initial feasibility study has produced several tentative methods for calculating (and cross-validating) CEV ratios for combatant nations given key societal data about those nations. Using recent data, these methods were applied to develop estimates for the CEV ratio that existed between the US and the USSR during the mid-1980s. There is no reason this method could not be used to forecast or project future CEV ratios as well as to measure current ratios. The significant needs are forecasts, projections, or estimates of values for the key independent variables, such as per capita electrical production. In instances where only projection ranges for this data are practical, then CEV ratio ranges can be derived as well. Because of remaining unexplained variance in CEVs ($R^2<1.0$) it may be best to express all projected or estimated CEVs in range format. (There is a statistical procedure for calculating confidence ranges for regression equations.) In broadest terms, the project indicates the possibility of ascertaining relative combat effectiveness values by exploring the underlying state of the adversarial nations.

Overall, the study produced some interesting results for the particular cases examined and hinted at some important relationships that may exist. Drawing more general conclusions about the basis of troop quality and combat effectiveness from this small effort would appear to be premature without substantial validation through further study. The high correlations that were found between industrialization and combat effectiveness seem to suggest that other secondary issues of combat effectiveness (training, leadership, morale, etc.) provide little extra explanation for disparities in the performance of troops in combat. This finding seems to contradict longstanding military intuition, though in and of itself might justify additional study to probe its implications. Other variables that were not studied may have relevance to combat effectiveness equal or beyond that of industrialization.

8.2 COMMENTS ON THE METHODOLOGY

This project was simply a feasibility study to examine a methodology, not a definitive attempt to implement that methodology. As such, the study uncovered several areas of interest and concern for further pursuing this methodology. These include the following:

1. The use of the QJM to establish estimates of relative combat effectiveness between two adversaries was convenient and gave consistent results. Even if the QJM produces estimates with inherent small random errors, the process of aggregating large numbers of engagements would tend to offset the errors.

2. Combat engagement sample sizes were too small. Nine or ten engagements for each pair of combatants is insufficient to allow high confidence that the estimated CEVs in the sample represent the population. In addition, these 9-10 engagements were picked on the basis of availability and convenience rather than in a way calculated to provide a representative sample. In some instances, the sample set of engagements is obviously nonrepresentative. Thus, the computed mean CEV may be somewhat different from the real mean CEV. This error can be decreased by using a larger sample of engagements and by picking the engagements to be used in a way that guarantees they are representative of the population.

3. The number of CEV pairings was too small to draw fully general and valid conclusions. With such small sample sets of four or eight cases, the correlation results were skewed significantly by one or two outlying points in the factor values that resulted from unusual historical conditions. Additional cases are needed to validate the approach. Additional factor values and methods of aggregating separate factors into larger, broader categorical factors would likely be helpful.

4. The normalization process, using Germany as the norm separately in World War I and World War II, causes potential comparison problems. A single justifiable norm would be needed for a more complete study. This is more easily done for the human factors than for the CEVs.

5. The research to establish credible values of societal factors was time-consuming and difficult. These relatively commonplace numbers are hard to find, and they must be defined carefully to assure consistency. The process of quantifying the societal and (in future work military) factors needs to be given more consideration before the data research is started.

8.3 OUTLOOK FOR CONTINUED ANALYSIS

The original research plan, for which this feasibility study is intended to be the forerunner, envisaged a three year study consisting of six discrete but interrelated sub-studies leading to a comparative analysis of relative combat effectiveness and its six constituent elements. This coordinated approach would provide a clear demonstration of whether these elements were truly interrelated or not and would provide some indications of the extent to which they contribute to combat effectiveness.

Major effort would have to be placed on improving the representation of the each war by increasing the number and diversity of combat engagements from which to estimate CEVs. To the extent possible, the larger battles used in the feasibility study would be disaggregated into their constituent engagements, and QJM analysis would be performed separately for each engagement. The time and location of engagements would be broadened as much as possible to provide CEVs that will represent the wars as entire entities, rather than just small parts of them. A methodology for comparing CEVs for the normalizing country (e.g., Germany) over time will need to be developed. Combat engagements from the Arab-Israeli Wars, the Falklands Campaign, and other modern combat would be added to provide a larger base of dependent variables.

It was envisaged originally that two parallel analytical approaches -- one quantitative and the other qualitative -- would be used more or less separately, but with each designed to test the relationships between combat effectiveness and other factors. In this feasibility study, however, the method used was to perform quantitative analysis and then apply qualitative judgments to the results of that analysis to interpret the results. This latter, integrated method has proved to be quite satisfactory and would be continued in a larger effort.

The original analytical question revolved around comparative US and Soviet combat effectiveness. The new world situation reveals a need for a broader scope, addressing comparisons with all other potential adversaries.

The method used in the feasibility study shows sufficient promise to warrant continuation of the effort. The conclusion is that the work should continue. The problems and deficiencies of the feasibility study were largely those resulting from insufficient data: insufficient numbers of engagements and spotty data on societal factors. These faults can be corrected in a follow-on effort designed to provide a larger and better sample of engagements and allow adequate time for research and analysis of the independent variables. On balance, the study team believes that the general methodology is sound and shows promise. The team would like to have the opportunity to expand on the work it has already performed and to investigate this problem on a more rigorous and scientific basis.

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APPENDIX A. DATA ON COMBAT ENGAGEMENTS

Table 16. World War I: Germany vs United States

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/US CEV
1. Belleau Wood	6 Jun 1918	US	1	14,000	0.723
2. Vaux	1 Jul 1918	US	1	23,000	0.259
3. La Roche Wood	1 Jul 1918	US	1	10,000	0.246
4. Cravancon	18 Jul 1918	US	1	13,000	0.324
5. Saint Mihiel	12 Sep 1918	US	4	500,000	0.483
6. Meuse Argonne	26 Sep 1918	US	5	490,000	0.491
7. Blanc Mont I	3 Oct 1918	US	4	39,000	0.398
8. Hill 212	5 Oct 1918	US	1	8,000	0.546
9. Bois de Boyon	5 Oct 1918	US	1	8,000	0.484
10. Blanc Mont II	8 Oct 1918	US	1	28,000	0.967
				Mean:	0.492

Table 17. World War I: Germany vs United Kingdom

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/UK CEV
1. Neuve Chapelle I	12 Mar 1915	GER	1	21,000	0.597
2. Neuve Chapelle II	12 Mar 1915	GER	1	30,000	0.683
3. Hill 60	1 May 1915	GER	1	22,000	2.095
4. Fortuin-Turco Farm	2 May 1915	GER	1	32,000	1.320
5. Frezenberg Ridge I	8 May 1915	GER	1	79,000	2.409
6. Frezenberg Ridge II	9 May 1915	GER	1	29,000	0.989
7. Shell Trap Farm	13 May 1915	GER	1	29,000	0.951
8. Loos, Chalkpit Wood	8 Oct 1915	GER	1	19,000	0.717
9. Loos, Big Willie	8 Oct 1915	GER	1	22,000	1.206
				Mean:	1.219

Table 18. World War I: Germany vs Russia

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/RUS CEV
1. Stalluponen	17 Aug 1914	RUS	1	75,000	1.557
2. Gumbinnen	20 Aug 1914	GER	1	221,000	2.207
3. Orlau-Frankenau	24 Aug 1914	RUS	1	68,000	1.796
4. Tannenberg	26 Aug 1914	GER	6	383,000	3.964
5. Masurian Lakes	9 Sep 1914	GER	6	453,000	5.485
6. Lodz	11 Nov 1914	GER	15	610,000	2.966
7. Winter Battle	7 Feb 1915	GER	15	331,000	4.494
8. Gorlice-Tarnow	2 May 1915	GER	3	233,000	4.025
9. Lake Narotch	8 Mar 1916	RUS	4	103,000	1.898
				Mean:	3.154

Table 19. World War II: Germany vs United States

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/US CEV
1. Sele Calore	11 Sep 1943	US	1	25,000	2.177
2. Tobacco Factory	13 Sep 1943	GER	2	27,000	1.230
3. Triflisco	13 Oct 1943	US	2	26,000	1.578
4. Dragon I	15 Oct 1943	US	3	22,000	1.059
5. Factory Ctr-Atk	11 Feb 1944	US	1	20,000	0.977
6. Bowling Alley	16 Feb 1944	GER	4	62,000	0.894
7. Campoleone	29 May 1944	US	3	46,000	0.903
8. Lanuvio	29 May 1944	US	4	23,000	1.181
9. Chartres	16 Aug 1944	US	1	18,000	0.684
10. Sauer River	16 Dec 1944	GER	2	18,000	1.592
				Mean:	1.228

Table 20. World War II: Germany vs United Kingdom

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/UK CEV
1. Port of Salerno	9 Sep 1943	UK	3	17,000	2.090
2. Battipaglia I	12 Sep 1943	GER	4	26,000	1.558
3. Francolise	20 Oct 1943	UK	3	22,000	1.925
4. Monte Camino I	5 Nov 1943	UK	3	26,000	3.858
5. Monte Camino III	2 Dec 1943	UK	4	24,000	3.361
6. The Factory	27 Jan 1944	GER	1	33,000	3.772
7. Campoleone	29 Jan 1944	UK	3	33,000	2.647
8. Ardea	28 Man 1944	UK	3	23,000	2.234
9. Tarto-Tiber	3 Jun 1944	UK	2	49,000	1.932
				Mean:	2.848

Table 21. World War II: Germany vs USSR

Engagement Name	Start Date	Atkr	Days	Aggregate Strength	GER/USSR CEV
1. Rovno	21 Jun 1941	GER	6	282,000	4.346
2. Leningrad	12 Jan 1943	USSR	7	150,000	1.558
3. Kursk I	5 Jul 1943	GER	1	205,000	1.925
4. Kursk II	6 Jul 1943	GER	4	299,000	3.858
5. Kursk III	6 Jul 1943	GER	2	315,000	3.361
6. Kursk IV	11 Jul 1943	GER	2	210,000	3.772
7. Nikopol I	31 Jan 1944	USSR	2	33,000	2.647
8. Nikopol II	2 Feb 1944	USSR	2	32,000	2.234
9. Nikopol III	4 Feb 1944	USSR	2	32,000	1.932
				Mean:	2.848

APPENDIX B. SUMMARY OF PLANNING CONFERENCE

A planning conference to initiate the feasibility study on forecasting relative combat effectiveness was held on February 11, 1989 at Fairfax, Virginia. The participants were as follows:

Table 22. Planning Conference Participants

NAME	AFFILIATION	FIELD
Brian R. Bader	DMSi, Director of HERO	Military Historian
Col John R. Brinkerhoff	USA Retired	Military Analyst
Col Trevor N. Dupuy	USA, Retired	Military Historian
Dr. Dean S. Hartley III	DSRD	OR Analyst and Mathematician
Vincent B. Hawkins	DMSI, Research Assoc.	Military Historian
LTC Andrew Krepinevich	OSD Net Assessment	Project Monitor
Robert S. McQuie	USA CAA	Operations Research Analyst
Maj Gen Adrian von Oer	German Army Retired	Military Analyst
Keith J. Posen	DMSi Project Director	Military Analyst
David Rowland	UK Def Oper Anal Estab	Operations Research Analyst
Harriett F. Scott		Soviet Specialist
Dr. William F. Scott		Soviet Specialist
Dr. David R. Segal		Military Sociologist
LTC John F. Sloan	USA Retired	Soviet Specialist
Lewis Sorley		Military Analyst
Dr. Abraham Wolf		Psychologist

After extensive discussion the group decided that there could be several factors that might account for a relative combat effectiveness differential between the armed forces of two nations. There was a consensus that historical combat did demonstrate the importance of combat effectiveness and that it appeared there were cases in which the forces of one nation fought consistently better than did the forces of opposing nations. The German edge in combat superiority in World Wars I and II and the Israeli dominance in the Middle-East Wars were cited as examples of this phenomenon. There was general agreement that the use of the Quantified Judgment Model (QJM) to provide estimates of the relative combat effectiveness values (CEVs) for historical combatants would be useful. These CEVs would provide the dependent variables against which independent variables could be compared to determine which, if any, might influence future combat effectiveness and thus provide a basis for prediction.

Although there were many different views on how to aggregate the factors, the group agreed that the following six general factors would be a reasonable way to approach the problem:

Societal Factors were considered to be the primary bases for national combat effectiveness. The idea is that the primary attributes of the nation itself in terms of industry, agriculture, education, and societal characteristics could be influential in establishing the values and background that might cause high (or low) combat effectiveness.

Manpower Quality was defined as the basic raw material for the armed forces provided by the nation in the form of young men and women. The strength, stamina, aptitude, education, and attitude of the civilian population from which the soldier volunteers or draftees are drawn were thought to be primary candidates for determining combat effectiveness. To the extent that these attributes could be quantified, they could be related to relative combat effectiveness values.

Military Leadership was considered by all to be a primary factor in determining combat outcomes. While the presence of a genius like Napoleon cannot be forecasted, the overall quality of the officers and enlisted leaders might be quantified in terms of years of education and ages of the leaders (as a surrogate for experience) and compared to relative combat effectiveness values.

Military Doctrine and Theory was suggested as another major set of factors that have influenced relative combat effectiveness. There was much discussion on the ways in which this elusive area might be quantified in a form suitable for comparison with the CEVs.

Military Training was considered to be a strong influence on relative combat effectiveness. The length of training, its emphasis, and perhaps other attributes could be quantified and compared with CEVs.

Readiness for Combat was also considered to be an important factor in relative combat effectiveness. This was defined to include not only the status of units (proportion of troops and equipment on hand) but also the extent to which the unit was capable of doing its intended job.

The planning conference adjourned after a day of earnest discussion leaving behind more questions than answers, but it did provide the intellectual basis for the research program. Detailed notes on the conference are available upon request.

APPENDIX C: PER CAPITA FACTOR VALUES[16]

Table 23. World War I (1913) societal factor values

FACTOR	Germany	United Kingdom	United States	Russia
Population (millions)	65	41	97	140
INDUSTRIAL PRODUCTION				
Coal (thousands metric tons)	4266.80	7122.98	4403.86	257.50
Iron (thousands metric tons)	440.12	396.44	638.97	68.12
Steel (thousands metric tons)	270.91	189.93	313.76	35.13
Sulf. Acid (thou. met. tons)	26.57	26.39	28.49	2.09
Electricity (terawatt hours)	0.12	0.06	0.26	0.01
AGRICULTURAL PRODUCTION				
Wheat (thousands hectares)	34.55	17.34	217.00	239.29
Barley (thousands hectares)	25.45	17.34	32.01	97.14
Oats (thousands hectares)	68.28	28.76	155.39	140.71
Wheat (thousands metric tons)	78.37	38.20	210.73	200.00
Barley (thousands metric tons)	56.51	35.05	35.69	93.57
Oats (thousands metric tons)	149.45	49.22	155.48	130.00
Horses (thousands)	70.12	39.20	216.58	162.86
Cattle (thousands)	322.98	169.85	583.42	228.57
Pigs (thousands)	394.75	54.49	554.09	96.43
Sheep (thousands)	84.94	583.68	417.98	295.71
TRANSPORTATION AND COMMUNICATIONS				
Railway Track (kilometers)	975.05	795.68	6259.93	501.11
Merchant Ships (thou. of tons)	6.92	295.61	62.97	5.59
Telegrams (millions)	0.80	2.12	1.12	0.70
HEALTH AND SOCIAL				
Infant Mortality (per thou.)	151.00	108.00	100.00	269.00
Birth Rate (per thousand)	28.00	24.00	30.00	43.00
Death Rate (per thousand)	15.00	14.00	14.00	27.00
Primary Sch. Students (thou.)	158.62	149.29	180.14	68.97
FINANCIAL ACTIVITIES				
Currency Circ. ($ millions)	10.63	3.41	10.86	5.50
Bank Deposits ($ millions)	110.92	157.76	220.54	15.54
Tax Revenues ($ millions)	7.68	23.46	9.92	12.57

[16]Figures are per million population, except infant mortality, birth and death rates.

Table 24. World War II (1938) societal factor values

FACTOR	Germany	United Kingdom	United States	USSR
Population (millions)	66	45	130	170
INDUSTRIAL PRODUCTION				
Coal (thousands metric tons)	5775.32	5125.24	2393.85	783.90
Iron (thousands metric tons)	168.86	267.76	218.82	156.38
Steel (thousands metric tons)	343.27	234.78	375.81	106.22
Sulf. Acid (thou. met. tons)	34.27	21.33	37.17	9.08
Electricity (terawatt hours)	0.83	0.76	1.09	0.23
AGRICULTURAL PRODUCTION				
Wheat (thousands hectares)	31.73	17.29	215.35	244.12
Barley (thousands hectares)	25.35	8.84	33.03	54.12
Oats (thousands hectares)	40.86	18.87	112.20	105.29
Wheat (thousands metric tons)	94.70	44.22	192.62	240.00
Barley (thousands metric tons)	70.80	20.33	43.04	48.24
Oats (thousands metric tons)	106.11	38.42	121.60	100.00
Horses (thousands)	52.17	22.27	84.58	95.29
Cattle (thousands)	301.68	178.44	501.92	299.41
Pigs (thousands)	355.77	84.93	342.50	151.18
Sheep (thousands)	72.86	575.16	345.94	337.06
TRANSPORTATION AND COMMUNICATIONS				
Railway Track (kilometers)	907.30	715.91	5062.45	500.00
Merchant Ships (thou. of tons)	37.73	237.82	85.75	7.49
Telegrams (millions)	0.33	1.29	1.43	0.25
HEALTH AND SOCIAL				
Infant Mortality (per thou.)	60.00	53.00	51.00	167.00
Birth Rate (per thousand)	20.00	15.00	19.00	38.00
Death Rate (per thousand)	12.00	12.00	11.00	18.00
Primary Sch. Students (thou.)	113.44	112.98	147.24	173.89
FINANCIAL ACTIVITIES				
Currency Circ. ($ millions)	52.15	52.82	35.57	44.47
Bank Deposits ($ millions)	159.44	328.73	495.86	5.01
Tax Revenues ($ millions)	107.35	109.31	55.58	386.46

Table 25. Current (early 1980s) societal factor values

FACTOR	Federal Republic of Germany	United States	USSR
Electricity (terawatt hours)	6.00	10.30	4.90
Merchant Ships (thou. of tons)	125.	82.	87.
Telephones (thousands)	464.	788.	89.

APPENDIX D: NORMALIZED PER CAPITA FACTOR VALUES

Table 26. World War I (1913) normalized (to Germany) societal factor values

FACTOR	Germany	United Kingdom	United States	Russia
Population	1.000	0.631	1.492	2.154
INDUSTRIAL PRODUCTION				
Coal	1.000	1.669	1.032	0.060
Iron	1.000	0.901	1.452	0.155
Steel	1.000	0.701	1.158	0.130
Sulf. Acid	1.000	0.993	1.072	0.079
Electricity	1.000	0.500	2.167	0.083
AGRICULTURAL PRODUCTION				
Wheat	1.000	0.502	6.281	6.926
Barley	1.000	0.681	1.258	3.817
Oats	1.000	0.421	2.276	2.061
Wheat	1.000	0.487	2.689	2.552
Barley	1.000	0.620	0.632	1.656
Oats	1.000	0.329	1.040	0.870
Horses	1.000	0.559	3.089	2.323
Cattle	1.000	0.526	1.806	0.708
Pigs	1.000	0.138	1.404	0.244
Sheep	1.000	6.872	4.921	3.481
TRANSPORTATION AND COMMUNICATIONS				
Railway Track	1.000	0.816	6.420	0.514
Merchant Ships	1.000	42.718	9.100	0.808
Telegrams	1.000	2.650	1.400	0.875
HEALTH AND SOCIAL				
Infant Mortality	1.000	0.715	0.662	1.781
Birth Rate	1.000	0.857	1.071	1.536
Death Rate	1.000	0.933	0.933	1.800
Primary Sch. Students	1.000	0.941	1.136	0.435
FINANCIAL ACTIVITIES				
Currency Circ.	1.000	0.321	1.022	0.517
Bank Deposits	1.000	1.422	1.988	0.140
Tax Revenues	1.000	3.055	1.292	1.637

Table 27. World War II (1938) normalized (to Germany) societal factor values

FACTOR	Germany	United Kingdom	United States	USSR
Population	1.000	0.682	1.970	2.576
INDUSTRIAL PRODUCTION				
Coal	1.000	0.887	0.414	0.136
Iron	1.000	1.586	1.296	0.926
Steel	1.000	0.684	1.095	0.309
Sulf. Acid	1.000	0.622	1.085	0.265
Electricity	1.000	0.916	1.313	0.277
AGRICULTURAL PRODUCTION				
Wheat	1.000	0.545	6.787	7.694
Barley	1.000	0.349	1.303	2.135
Oats	1.000	0.462	2.746	2.577
Wheat	1.000	0.467	2.034	2.534
Barley	1.000	0.287	0.608	0.681
Oats	1.000	0.362	1.146	0.942
Horses	1.000	0.427	1.621	1.827
Cattle	1.000	0.591	1.664	0.992
Pigs	1.000	0.239	0.963	0.425
Sheep	1.000	7.894	4.748	4.626
TRANSPORTATION AND COMMUNICATIONS				
Railway Track	1.000	0.789	5.580	0.551
Merchant Ships	1.000	6.303	2.273	0.199
Telegrams	1.000	3.909	4.333	0.758
HEALTH AND SOCIAL				
Infant Mortality	1.000	0.883	0.850	2.783
Birth Rate	1.000	0.750	0.950	1.900
Death Rate	1.000	1.000	0.917	1.500
Primary Sch. Students	1.000	0.996	1.298	1.533
FINANCIAL ACTIVITIES				
Currency Circ.	1.000	1.013	0.682	0.853
Bank Deposits	1.000	2.062	3.110	0.031
Tax Revenues	1.000	1.018	0.518	3.600

Table 28. Current (early 1980s) normalized (to Germany) societal factor values

FACTOR	Federal Republic of Germany	United States	USSR
Electricity	1.00	1.72	.82
Merchant Ships	1.00	.65	.70
Telephones	1.00	1.70	.19

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