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Report of Project MICHIGAN

Evaluating Surveillance Systems

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ABSTRACT

The first phases of a long range project for developing models for evaluating intelligence systems in terms of measurable outputs can now be reported. In making such evaluations, the number of correct identifications, number of false alarms, number of displacements, and number of complete misses must be measured, in each of several categories (such as infantry, artillery, armor, supply lines), each of a number of sectors (front line, rear, far rear) and in each of several situations (such as attack or defense, good or poor mobility). The major results to date are (1) the development of experimental techniques, (2) the formulation of an analytical model, (3) the development of analysis techniques for evaluation of parameters in the model in terms of empirical results, (4) the preliminary evaluation of parameters (rank order correlations of 0.8 and higher have been established between some of the analytic predictions and the empirical results), and (5) formulation of several concrete unsolved problems out of the over-all problem. Plans for continued study are discussed in Sections 8.2 and 8.3.

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PREFACE

Project MICHIGAN is a Joint Service supported project at the Engineering Research Institute, The University of Michigan. Its general mission is the conduct of research and development of systems and components for combat surveillance. It operates under the cognizance of the Chief Signal Officer, Department of the Army.

The aims of Project MICHIGAN are: to supplement the functions of the Technical Services in the research and development of equipment for surveillance, target detection, target location, and data transmission; to make maximum use of the techniques and equipment developed by the Technical Services and to emphasize their ultimate use in the combat surveillance system; and to engage in such research and development as may be found necessary to fill gaps in the existing programs leading to combat surveillance.

1
GENERAL CONSIDERATIONS

1.1 INTRODUCTION

In both war and peace military leaders are forced to make decisions regardless of whether they consider themselves fully prepared to do so. Although intuition has often been the sole basis for choices, much current research is devoted to the study of decision processes. Some of this research concerns statistical and game theoretical techniques for arriving at decisions under conditions of uncertainty, and other research concentrates on techniques for reducing the amount of uncertainty. The work here reported falls primarily into this second category.

This study is the beginning of a long range attack on the problem of building a model for evaluating an intelligence system in terms of its total outputs as presented to the decision making officers (at all levels). The parameters in the model serve as measures of the relative importance of various types of information and so will aid in preliminary evaluation of proposed equipment for gathering information. It seems clear from what has been done already that a suitable model can be built, although its final form can be developed only after further study. As regards theory, analysis has not as yet gone far beyond dealing with single components. Results are encouraging and justify continued research.

The basic idea of the model is to achieve a good linear approximation for a nonlinear situation by splitting a large problem into many small pieces. The score given to an intelligence picture will be a linear combination of the scores assigned to each of its small pieces. The score assigned to a small piece must be computable in terms of the basic variables: hits, false alarms, displacements, and misses. The model does not require that the score assigned to each small piece be linear in these basic variables, but it does seem desirable to keep this scoring as nearly linear as possible.

A central feature of the model is the use of judgments of experienced officers for determining the parameters in the scoring equations. One of the main contributions of the work thus far is the development of procedures for obtaining the necessary judgments.

One of the most difficult aspects of the problem of evaluating a surveillance system is the measurement of the accuracy and the importance of the information it provides.

A battlefield-surveillance system includes many components which are sources of information about the enemy, such as aerial photographs, prisoner of war interviews, heat detectors, patrols, and radar. The output of each component takes the form of information (correct or incorrect) on such items as the identification of enemy units, their location, and their strength. The output of one component results in intelligence which will not in general be identical with that resulting from another component. For this and other reasons there arises the difficult problem of evaluating a component or even an entire system.

There are many criteria which should enter into the comparative evaluation of such systems. These may be classified under the headings of performance, military feasibility, technical feasibility, and logistics. Many considerations under these classifications, such as speed, all weather capability, mobility, and manpower requirements, are objectively observable and not very difficult to measure. Much more difficult is the determination of how to combine judgments based on these many considerations to yield an over-all evaluation of a component or a system.

1.2 SCOPE FOR THE MODEL

The model, which is formally presented below, was designed to be used in solving problems of the following type: given an enemy situation and an estimate of it, how may one determine (measure) the merit of the estimate. An estimate may (1) correctly identify and locate certain enemy units, (2) report some nonexistent units, (3) report certain actual units but give an incorrect location for them, and (4) fail altogether to detect certain units. These are called, respectively, hits, false alarms, displacements, and misses and each is a basic variable in the model. They must be combined to obtain a measure of accuracy that enters into the final "value" of an intelligence estimate. Each is monotonically related to the value, but its relative contribution is not known (a priori) For instance, increasing the sensitivity of a detector might not only increase hits and decrease misses (which would contribute to value) but could also increase false alarms (which diminishes value). The value of the detector and its optimum sensitivity then depends in part on the relative importance of hits, false alarms, displacements, and misses.

In addition to constructing parameters which measure the relative importance of hits, false alarms, displacements, and misses for a given category of information such as infantry units or artillery units, there is the problem of measuring the relative importance of information in the several categories. Such measures are needed to judge between two systems, one of which is, for example, superior in detecting personnel and the other of which is superior in detecting motor vehicles.

Finally, there is another group of factors which must be taken into account in determining the value of an intelligence display. This group has to do with the character of the terrain and the depth of the sectors to which the display refers. It is reasonable to expect that the relative weights of hits, false alarms, displacements, and misses within a category of information, and the relative importance of the several categories of information, will vary from sector to sector. For example, an enemy airfield on the front line, where it is unusable, is relatively unimportant compared with an active light artillery concentration in the same area, but the reverse is true fifty miles to the rear.

In summary, then, the major aspects of a surveillance system which will be considered here as contributing to the value of its intelligence display will be:

(1) the relative weights of hits, false alarms, displacements, and misses within a given category of information and within a given sector;

(2) the relative importance of the several categories of information within a given sector; and

(3) the effect of the nature of the sector upon (1) and (2).

It is the purpose of our model to provide analytic expressions for these relative values. The basic parameters of the model are derived from subjective judgment made by military officers with considerable combat and staff experience. Consequently, a statistical procedure has been set up for converting the subjective judgments of high-level military personnel into a numerical scale which is used in determining these parameters. This procedure also contains built-in statistical checks on the feasibility and validity of the model.

2
THE MODEL

2.1 SECTORS AND CATEGORIES

The first step in building the model is to specify the various types of sectors and categories of information.

It is clear that the class to which a sector belongs is determined in part by depth (e.g., distance from the front line), trafficability, and cover. However, interest in a given enemy sector also depends upon whether our mission is attack, holding, or withdrawal. In this first study only the attack mission is considered.

Additional distinctions might be introduced, but each new distinction greatly increases the labor of experimentally determining the parameters of the equations without affecting the theoretical aspect of the model. It is to be hoped, for purely practical reasons, that no great variety of situations need be considered.

The subdivision into sector types must first be made on an *a priori* basis. When equations have been fitted to each sector type it may be observed that the parameters do not differ significantly among certain of them, in which case these sector types may be identified. On the other hand, a poor fit of the equation for some sector type may indicate the need for a further breakdown into sub-types. So the model is set up with a preliminary categorization into sector types with the expectation that modifications will be made as experience with the model dictates.

Initially, depth is divided into four intervals; 0-3,000 yds (battalion and regiment), 3,000-15,000 yds (division), 15,000-40,000 yds (corps), 40,000 yds-200 mi (army and theater). Trafficability is divided into three degrees: (1) very good, as in open flat country with a road network; (2) medium; and (3) very poor, as in marshy country. Similarly, cover is divided into three degrees: (1) heavily wooded, (2) some cover, and (3) open and unprotected. Thus there are, potentially, 36 (4 × 3 × 3) distinct types of enemy sectors. However, it is anticipated that some of these distinctions will be unimportant and therefore some of the types can be combined. Sectors are designated by superscripts and the number of sectors is denoted by m. (Note that there may be many sectors of a given type.)

The items about which information is obtained are broken down into categories. Subscripts are used to designate these categories and the number of categories is denoted by n. These categories include such items as artillery, tanks, infantry units, and airfields. Experience with the model will reveal whether some categories may be merged and others need to be divided further.

2.2 THE BASIC EQUATION

The general model is built around certain measurable integers which refer to information by category and sector.

For a fixed sector j, t_i^j denotes the number of units of category i (i = 1,.....,n) in this sector, and the true situation vector in sector j is defined to be

$$T^j = (t_1^j, t_2^j, \ldots, t_i^j, \ldots, t_n^j). \qquad (1)$$

In a given intelligence display c_i^j denotes the number of units of category i in the sector j which are correctly identified and located, and the correct identification vector in sector j is defined to be

$$C^j = (c_1^j, c_2^j, \ldots, c_i^j, \ldots, c_n^j). \qquad (2)$$

In this same display there may be some indications of targets which in fact are not present. Such an error is called a false alarm and a false alarm vector is defined by

$$E^j = (e_1^j, \ldots, e_i^j, \ldots, e_n^j), \qquad (3)$$

where e_i^j is the number of false identifications of category i in sector j.

A displacement vector is defined by

$$S^j = (s_1^j, \ldots, s_i^j, \ldots, s_n^j), \qquad (4)$$

where s_i^j is the number of units of category i in sector j which are correctly identified but incorrectly located. These four types of vectors are the variables in the model.

The number of misses is now given by the vector

$$M^j = (m_1^j, \ldots, m_i^j, \ldots, m_n^j), \qquad (5)$$

where $m_i^j = t_i^j - c_i^j - s_i^j$.

Two further vectors serve as weighting factors . The first of these is

$$P^j = (p_1^j, \ldots, p_i^j, \ldots, p_n^j), \qquad (6)$$

where p_i^j measures the relative importance of knowledge of a unit of category i in sector j. The second is

$$D^j = (d_1^j, \ldots, d_i^j, \ldots, d_n^j), \qquad (7)$$

where d_i^j gives a categorywise evaluation of a display in terms of hits, false alarms, displacements, and misses. The equation for d_i^j,

$$d_i^j = c_i^j - f_i^j e_i^j + g_i^j s_i^j - h_i^j m_i^j, \qquad (8)$$

was constructed after some preliminary investigations discussed below, in which the displacement term was not included. In Equation 8 the coefficients 1, f_i^j, g_i^j, and h_i^j are parameters for the relative weights of hits, false alarms displacements, and misses. The number d_i^j is the net score for a category of information in a given sector.

Equation 8 was normalized so as to make the coefficient of c_i^j be 1. The effect of this is to choose as the unit of measurement the value of a correct identification of one unit of the given category.

This unit of measurement is of course arbitrary. For example, the unit of measurement for infantry might be in terms of platoons or companies, or any other military unit. If for some displays companies were used as units in determining the d_i^j and for others platoons were used, it would be necessary to determine a conversion factor to make the d_i^j from one set of displays comparable with the d_i^j from the other. In the initial stages of constructing this linear model, the conversion factor may be chosen a priori on the basis of relative manpower of the respective units.

2.3 VALUATION INDICES

A series of indices may now be constructed representing evaluations of the outputs of a surveillance system or its components:

$$p_i^j \, d_i^j \tag{9}$$

is the net importance score for a category of information in sector j;

$$z^j = P^j \cdot D^j = \sum_i p_i^j \, d_i^j \tag{10}$$

is the net importance score of all information in a given sector;

$$w^j = P^j \cdot T^j \tag{11}$$

is the worth of a sector;

$$v^j = \frac{z^j}{w^j} \tag{12}$$

is the score on information in a given sector; and

$$v = \frac{\sum_j z^j}{\sum_j w^j} = \frac{z}{w} \tag{13}$$

is the score for a theater.

The value or importance of information about a particular category of information in a particular sector will depend on the command echelon evaluating the information. Information about a platoon of enemy infantry is of great concern to a front line commander and of less concern to the divisional commander. Conversely, the precise location of an enemy airfield 100 mi in the rear is of much greater value to higher command echelons than to lower ones. The importance vector P^j represents the relative importance of the several categories of information within a given sector from the point of view of a command echelon which is concerned with the welfare of all its subordinate units.

However, it is reasonable that a particular surveillance device may yield information more valuable to one command echelon than to another and it is therefore desirable to construct an index which represents the relative values of an intelligence display to different command echelons. The distinction lies primarily in the weighting of different sectors corresponding to their relative importance to different command echelons. The weighting vector is defined as

$$A(k) = \left[{}^1a(k), \ldots, a^j(k), \ldots, a^m(k)\right], \tag{14}$$

in which a command echelon is represented by k and the sector designation by the superscript j.

The worth of a total intelligence display to a particular command echelon, k, is expressed by

$$u(k) = \sum_j a^j(k) \cdot z^j. \tag{15}$$

Analogues of Formulas 11, 12, and 13 would be needed in a complete development of this topic. In the present paper the treatment of echelon measures is limited to this brief introduction and no further use is made of Equations 14 and 15.

These equations define a linear model with the vectors T^j, C^j, E^j, S^j objectively observed and with the vectors P^j and D^j to be empirically determined. Equations 8 and 10 are the basic equations. The parameters and range of applicability of these equations must be estimated from empirical data.

3
EXPERIMENTAL AND MEASUREMENT PROBLEMS

3.1 EXPERIMENTAL DESIGN

A number of special problems arise in applying the abstract model presented above.

In order to solve for the parameters of Equation 8 it is first necessary to obtain numerical measures of the d_i^j. There is, of course, a variety of direct and indirect methods by which this might be done. The most direct method is to present a true situation and an estimate of it to qualified and experienced military personnel and to ask for a numerical rating of the net score for that category of information in that sector. A highly indirect method would be to prepare detailed operational plans based on the estimate of the situation alone and then have these operational plans evaluated independently in the light of the true situation. In the pretest to be described below, this method was explored and temporarily abandoned for practical reasons. It is now being given further consideration. On the other hand, the direct rating of estimates requires the assumption that a stable origin and unit of measurement exists which can be applied uniformly by all officers. Such a broad assumption does not seem justified here. Consequently a relative method was used for evaluating the estimates, rather than such an absolute method.

This problem of obtaining a measure of the worth of a display of an estimate of a true situation for a given category of information (the d_i^j) is a problem in psychological scaling. A method which involves minimal assumptions and yet insures a solution for the d_i^j is to collect the data by the Method of Paired Comparisons and to compute the scale values by Case V of the Law of Comparative Judgment*

In this comparative method of evaluating, given two estimates each with its true situation, the basic judgment requested from the officer is a decision about which estimate gives the better picture of its own true situation. Note that he is not asked also to evaluate the importance of this situation. Hence, in determining the coefficients in Equation 8, some adjustment must be made which replaces d_i^j by a related quantity which represents what is really being judged. This substitution is discussed in Section 7.

Because of the amount of labor required from the military personnel by the Method of Paired Comparisons, a simplified variant, the Method of Rank Order, was adopted. In this method the overlay containing the estimate and the map of the true situation constitute the "object" to be judged and a set of these is ranked in order from best to worst with respect to how well the estimate approximates the true situation. The worst display is given the number 0, the next worst 1, and so on. The number thus assigned to the h-th display by the p-th officer is designated by b_i^j (h, p).

These rank orders are obtained from each of a number of officers and averaged over the sample of officers for each display. The measure of the value (designated $\tilde{b}_i^j$ (h) of display number h is taken as

$$\tilde{b}_i^j(h) = \left[\frac{1}{(N-1)M}\right] \sum_{p=1}^{M} b_i^j(h, p) \quad h = 1, 2, \ldots, N, \quad (16)$$

in which N is the number of displays and M is the number of officers used as judges. The range of $\tilde{b}_i^j$ (h) is 0 to 1; a perfect estimate would be given the score 1.

This system is not completely satisfactory. For example, for M = 1 the difference between the values assigned to any two objects is some multiple of $\frac{1}{N-1}$ regardless of how small the "psychological distance" between these objects may be. Obviously, for M small, Equation 16 will not adequately represent the relative values of two objects. However, as M increases, it is reasonable to expect that the percentage of judges who rank one object

*Thurstone, L. L. "A Law of Comparative Judgment;" Psychol. Rev., 1927. No. 34, 273-286.

ahead of another will be a function of the "psychological distance" between them. That is, if two objects, A and B, have a sufficiently small "psychological distance" between them, one could expect the number of judges ranking A ahead of B to approach M/2 as M becomes large. In this case,

$$\left|\tilde{b}(A)-\tilde{b}(B)\right|$$

becomes small.

Another defect with this method becomes evident if an estimate of the corresponding situation is perfect. Then, presumably, every judge will rank this "object," which we may call A, as best, so b(A) = 1. Now suppose B is another object which, ranked on an absolute scale, would rank as almost perfect. By the above method, since b(A) = 1, $b(\tilde{B}) \leq 1 - \frac{1}{N-1}$, so that Equation 16 would distort the "psychological distance" between objects A and B. However, this defect is easily remedied by designing the experiment so that no estimate is perfect. In the present experiment one estimate of an artillery situation was taken as perfect. In a redesigned experiment no perfect estimates will be included.

4

THE PRETEST

4.1 NATURE OF PRETEST

In order to test the general feasibility of the operations necessary to determine the parameters in the model, a test model was prepared over a limited range of categories of information within one situation. In preparation for this a pretest was run to try out the materials, test the instructions, estimate time limits, and obtain some preliminary notions of how well the model might work. The results of this pretest are given in Section 4.5 and the more intensive studies carried out at Fort Benning and Fort Sill are discussed in Sections 5 and 6.

4.2 TEST MATERIALS

Two categories of information were chosen for this preliminary exploration: infantry companies and artillery batteries, (i = 1 or 2), within a single sector, j = 1.

The situation was an attack mission on the part of our forces, the terrain had very good trafficability with moderate cover, and the sector was a regimental front with a depth of 3000 yds. The actual terrain chosen was in the neighborhood of Fort Bragg, North Carolina, and three separate instances of the terrain were used: terrain instance I was the Marston map; II, Silver Hill; III, Millstone Lake.

For each terrain instance a number of overlays were prepared, each of which displayed a true enemy situation showing various dispositions of infantry companies only, of artillery batteries only, or of both infantry companies and artillery batteries. With each of these true situation overlays was paired another overlay which was the estimate of the true situation. Figure 4.2-1 shows in red two examples of intelligence estimates of enemy situations and in black the corresponding true enemy situations. Each of such pairs will be referred to as a "stimulus"; more precisely, the "stimulus" may be regarded as the psychological difference between the estimate and the true situation. The model is designed to provide an objective basis for computing this pyschological magnitude, the "distance" between the true situation and an estimate of it.

There were eight stimuli prepared for terrain instances I and II respectively, and seven for terrain instance III. Within each terrain instance these stimuli were designed so that each component (hits, false alarms, displacements, and misses) would cover a reasonable range. The table presented in Appendix C shows the composition of each stimulus.

4.3 SUBJECTS

Eleven officers were used as judges in the pretest. Nine were Army officers ranging in grade from captain to colonel and varying in military experience from exclusively technical and service to considerable combat command experience. One was a Navy captain and another was a colonel in the Marines. Although so varied a selection is not desirable for the determining of the parameters of the model, it served the purposes of the pretest quite well. Three of the officers were used as judges in the experiment a second time after interval of two weeks or more.

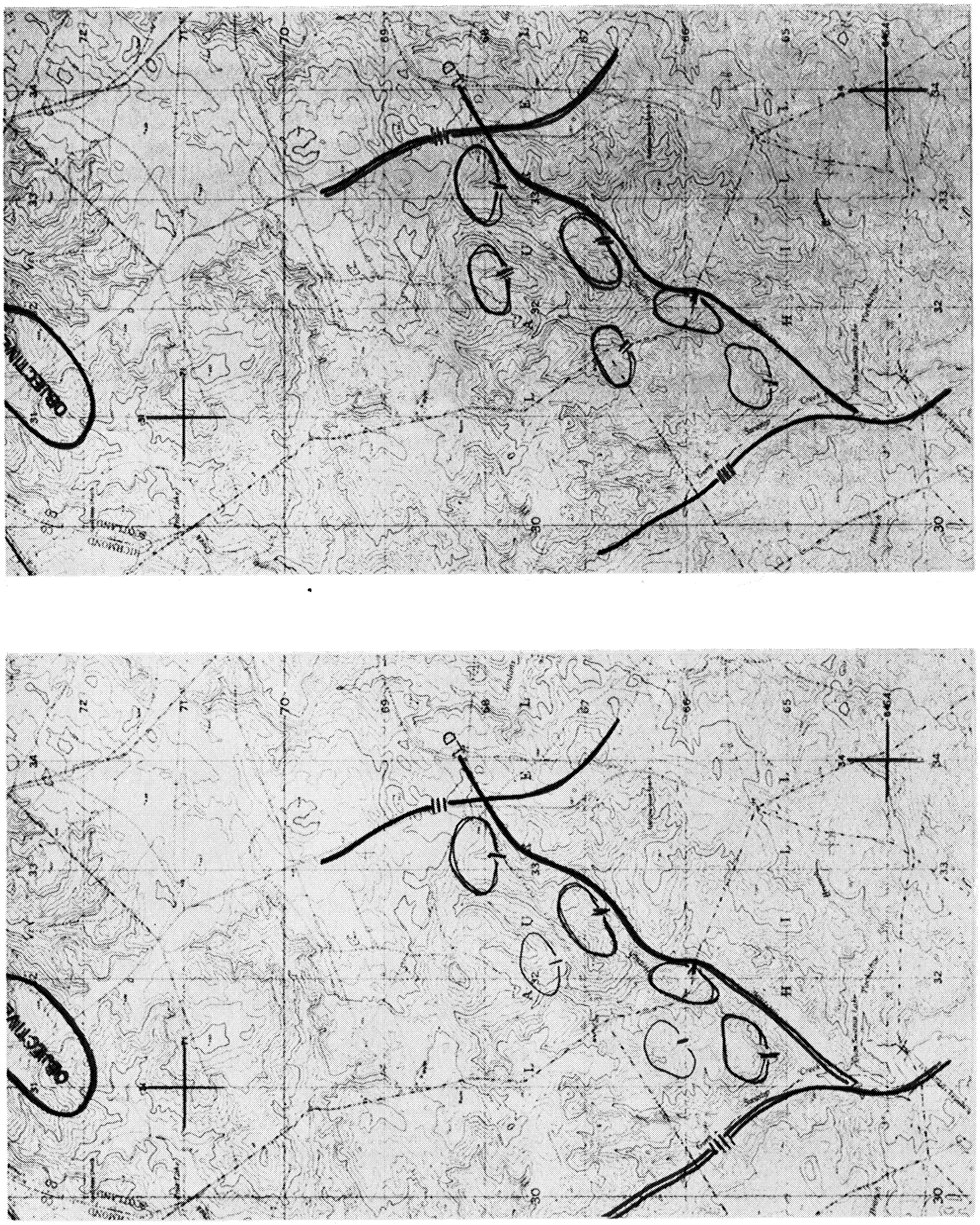


FIG 4.2-1 ACTUAL AND ESTIMATED SITUATIONS Terrain and location of enemy units in black. Intelligence estimates of number and location of enemy units in red.

4.4 INSTRUCTIONS AND PROCEDURE

The officer was first informed of the purpose of the procedure. He was told that he would be given a number of estimates of an enemy situation with their respective true situations and that he would be asked to make comparative evaluations of how nearly the several estimates approximated their respective true situations.

He was then given a copy of the terrain map and an overlay of one of the estimates, chosen at random, and was asked to consider generally what his operational plans would be to attack and achieve the objective shown on the overlay. He was informed that he was a regimental commanding officer, that his capabilities and forces were reasonably adequate to accomplish his missions, and that he could, of course, request additional support from higher headquarters.

After he had familiarized himself with the terrain, the officer was presented the set of eight stimuli for terrain instance I, with infantry units only, and asked to rank order them from best to worst. The best was that for which the estimate most nearly approximated the true situation and the worst was that in which the estimate most poorly approximated the true situation. Having completed these, he did the same thing for terrain instance II, and then for terrain instance III. Next these three ordered sets of stimuli were placed in three rows in front of him and he was required to pick successively the best one remaining in the three sets. In this way all twenty-three stimuli were ranked. Each set was arranged in front of the officer so that he could see two successive stimuli in the set. Thus, he could easily reconsider and amend his ordering within each set as he proceeded.

Next, this procedure was followed in detail with the stimuli showing artillery units alone and finally was carried out with the stimuli showing both artillery and infantry units.

4.5 RESULTS

For each judge a rank ordering of the twenty-three stimuli in each of the three sets (infantry alone, artillery alone, combined infantry-artillery) was obtained. Kendall's τ (App. B), a rank correlation coefficient, was obtained among judges for each set. These are presented in Tables 4-1, 4-2, and 4-3. Table 4-1 presents the τ coefficient among judges for infantry alone, Table 4-2 for artillery alone, and Table 4-3 for combined infantry-artillery

TABLE 4-1

INFANTRY DISPLAY ONLY

Officer	1	2	3	4	1*	5	6	2*	3*	7	8	9	10
1													
2	.636												
3	.644	.636											
4	.660	.612	.660										
1	.715	.573	.810	.565									
5	.723	.668	.747	.660	.668								
6	.700	.692	.787	.715	.771	.676							
*2	.747	.739	.636	.542	.644	.660	.621						
*3	.581	.526	.668	.787	.573	.589	.739	.470					
7	.708	.621	.684	.723	.636	.628	.731	.628	.715				
8	.589	.549	.676	.771	.581	.708	.628	.447	.644	.597			
9	.763	.613	.597	.636	.644	.597	.573	.668	.534	.692	.526		
10	.739	.668	.573	.486	.557	.621	.581	.779	.383	.526	.487	.581	
11	.621	.660	.455	.478	.439	.613	.470	.700	.312	.526	.462	.573	.692

*Officers 1, 2, and 3 served as judges twice.

TABLE 4-2

ARTILLERY DISPLAYS ONLY

Officer	1	2	3	4	1*	5	6	2*	3*	7	8	9	10
1													
2	.708												
3	.510	.502											
4	.518	.581	.407										
*1	.478	.644	.439	.494									
5	.146	.320	.225	.518	.209								
6	.138	.296	.217	.589	.534	.708							
*2	.700	.731	.399	.407	.549	.099	.138						
*3	.621	.542	.810	.455	.423	.162	.186	.455					
7	.542	.565	.652	.613	.462	.368	.407	.447	.715				
8	.202	.320	.502	.455	.415	.407	.526	.186	.415	.564			
9	.597	.423	.565	.415	.249	.154	.083	.391	.628	.455	.225		
10	.368	.542	.241	.708	.534	.573	.628	.336	.257	.462	.415	.186	
11	.613	.549	.549	.478	.415	.360	.273	.470	.676	.613	.360	.605	.407

*Officers 1, 2, and 3 served as judges twice.

TABLE 4-3

INFANTRY-ARTILLERY COMBINED

Officer	1	2	3	4	1*	5	6	2*	3*	7	8	9	10
1													
2	.312												
3	.399	.375											
4	.375	.320	.581										
*1	.470	.494	.605	.510									
5	.320	.621	.470	.510	.510								
6	.209	.415	.581	.399	.605	.415							
*2	.605	.534	.494	.439	.518	.486	.312						
*3	.462	.304	.597	.534	.644	.455	.391	.431					
7	.431	.407	.494	.660	.549	.565	.415	.573	.447				
8	.170	.289	.534	.518	.399	.320	.352	.312	.344	.510			
9	.542	.107	.273	.407	.344	.217	.123	.368	.209	.399	.344		
10	.526	.581	.462	.360	.518	.549	.375	.478	.431	.415	.202	.304	
11	.700	.494	.455	.304	.415	.478	.273	.636	.328	.391	.225	.502	.660

*Officers 1, 2, and 3 served as judges twice.

displays. The standard error* of these τ's is of the order of 0.3, so the probability that τ will exceed 0.588 by chance is 0.05 and the probability that τ will exceed 0.744 by chance is 0.01.

Three officers were used a second time as judges after an interval of at least two weeks. The τ coefficients among the three officers as compared with the τ coefficient between the two repetitions of each of the three officers shows that the officers on the average agreed with themselves little more than they agreed with each other, whether for infantry stimuli, artillery stimuli, or the combined infantry-artillery stimuli. Nevertheless, approximate test of significance indicates that the differences are far from significant. However, it should be recalled that τ coefficients have rather large standard errors.

Because of the intermittent character of the data collection in this pretest, only the judgments of the first seven officers were used in this analysis. The officers whose judgments were utilized were: 1, 2, 3, 4, 5, and 6, and a second run on 1. So, the measure of the value of a display $\tilde{b}_i^j$ was based on the rankings of this sample of officers.

Kendall's W coefficient* was used as a measure of the conformity of agreement within the sample of judges. The W coefficient may be converted into an average rank order correlation, ρ* average.

TABLE 4-4

Community of Agreement in Ranking

	W	ρ_{av}
Infantry	0.86	0.83
Artillery	0.63	0.57
Infantry-Artillery	0.67	0.61

5
FORT BENNING STUDY

5.1 NATURE OF FORT BENNING STUDY

After the pretest but before all the data had been analyzed, some revisions were made in the stimulus materials and in the instructions, and arrangements were made with the Infantry School at Fort Benning for a number of officers with combat experience in World War II and in the Korean War to act as judges.

5.2 TEST MATERIALS

Some slight changes were made in the number of hits, false alarms, and misses on a few of the stimuli. The values used are shown in Appendix C. However, a considerable change was made in the test materials themselves. A number of maps of each terrain were secured and the true situation for each stimulus was put directly on a map. Then the estimate of the situation was printed on an overlay and the pair were always kept together to constitute the stimulus for judgment.

5.3 SUBJECTS

The judgments of 19 officers at Fort Benning were secured. There were four lieutenant colonels, fourteen majors, and one captain. In a post-test interview with each officer it was learned that their combat command experience ranged from a minimum of 3 months up to 40 months with an average of 12.6 months. (See Appendix F for copy of questionnaire.) They were also asked about their staff experience, particularly in Intelligence (G-2) or Operations (G-3) sections. Seven officers had no experience in G-2 or G-3 sections and one had 40 months. The mean was 6 months. Most of their experience had been at the company and battalion level but, being field grade officers in the regular army, they were now orientated toward regimental levels. However, their lack of regimental command experience raises a question about whether their judgments should be exclusively relied upon for determining the parameters of the equations.

5.4 INSTRUCTIONS AND PROCEDURE

After the experience with the pretest, a detailed and uniform set of instructions and procedures were prepared for the Fort Benning study. The officers were scheduled for the test two at a time at intervals of two hours at 8 and 10 AM and 1 and 3 PM. There were two complete sets of test materials and the entire procedure rarely took more than four hours for any one officer.

*Appendix B.

The two officers beginning the test procedure at a particular time were first given a briefing covering the instructions and describing the procedure. This briefing was read to them in a casual and informal manner with discussion of questions if they arose. The prepared instructions are included as Appendix E.

5.5 AGREEMENT BETWEEN JUDGES

The analysis of the Fort Benning data follows the same pattern as that of the pretest with some modifications in detail. As there were 19 judges, the conformity of agreement among the judges was measured by computing the τ coefficient between the rank order of the stimuli by each judge and the average of the rank orders by the other judges. This was done separately for infantry, artillery, and for the combined infantry-artillery. These coefficients are reported in Table 5-1.

To see whether the agreement of an officer with the average of the other judges was specific as regards whether infantry or artillery units were being judged, the rank order of the officers on infantry was correlated with their rank order on artillery. The τ coefficient was 0.105, not significant, indicating that the degree of agreement of an officer's rank order of the infantry stimuli with the consensus of the remaining officers is not related to his degree of agreement on artillery stimuli. The corresponding τ coefficients between infantry on the one hand and artillery on the other with combined infantry-artillery stimuli were 0.462 and 0.129 respectively.

The W coefficient for all 19 judges together was computed on infantry, artillery, and infantry-artillery combined. The results, presented in Table 5-2, indicate a significant degree of agreement.

None of these results provided any secure basis for eliminating any of the officers from the sample; however, the considerably lower correlations of the last three officers (17, 18, and 19 in Table 5-1) suggests the possibility that eliminating the data from them would improve the validity of the results.

TABLE 5-1

AGREEMENT OF EACH JUDGE'S RANK ORDER WITH THE AVERAGE RANK ORDER OF THE REMAINING JUDGES

Officer	Infantry	Artillery	Combined
1	0.874	0.708	0.648
2	0.874	0.621	0.688
3	0.842	0.731	0.672
4	0.818	0.628	0.731
5	0.814	0.723	0.771
6	0.802	0.623	0.632
7	0.794	0.668	0.561
8	0.791	0.605	0.731
9	0.787	0.727	0.664
10	0.779	0.648	0.573
11	0.771	0.771	0.565
12	0.763	0.644	0.522
13	0.763	0.684	0.676
14	0.743	0.755	0.557
15	0.715	0.644	0.526
16	0.708	0.692	0.755
17	0.692	0.652	0.375
18	0.688	0.478	0.549
19	0.636	0.415	0.372

TABLE 5-2

COMMUNITY OF AGREEMENT IN RANKING

	W	ρ_{av}
Infantry	0.85	0.84
Artillery	0.71	0.69
Infantry-Artillery	0.65	0.63

6
FORT SILL STUDY

6.1 REASON FOR FORT SILL STUDY

In the analysis of the data obtained at Fort Benning, it was observed that the agreement among the officers' judgments on situations involving infantry alone was very good while the agreement on situations involving artillery alone was poor (Fig. 6.1-1 and 6.1-2). Since Fort Benning is an Infantry School, it seemed possible that a bias was reflected in the judgments of its officers. Accordingly, it was decided to run a separate experiment at the Artillery School at Fort Sill and compare the results with those from Fort Benning. The same maps and overlays were used as at Fort Benning and the same procedure was followed.

6.2 SUBJECTS

The judgments of eighteen officers at Fort Sill were secured. The average rank and staff experience of the officers involved at Fort Sill was somewhat higher than that of the officers tested at Fort Benning. There were two colonels, fifteen lieutenant colonels, and one major in the group. The average combat experience was 8.5 months; the average staff experience was 3.5 months; and the average noncombat staff experience was 13 months. Much of the experience was at battalion and regimental levels.

6.3 AGREEMENT AMONG JUDGES

As in the analysis of the data from Fort Benning, the agreement among judges was measured by computing the τ coefficient between the rank order of the simuli for each judge and the average rank order for the other judges. The results for infantry, artillery, and combined infantry-artillery are reported in Table 6-1. Also, the τ coefficient of the officers' agreement among themselves for infantry and the officers' agreement among themselves for artillery was computed. The value obtained was -0.196, indicating that the degree of agreement of an officers' rank order of the infantry stimuli with the average rank order is not related to the degree of his agreement on artillery stimuli. The corresponding τ coefficient between infantry and combined infantry-artillery stimuli was 0.51. The W coefficient for all eighteen judges together is presented in Table 6-2.

6.4 ANALYSIS OF JUDGMENT CRITERIA IN ARTILLERY SITUATIONS

Figure 6.1-1, 6.1-2, and 6.1-3 show that the two groups of officers agreed very well in the infantry situations and on the combined infantry-artillery situations, but on situations containing artillery alone, agreement was not very good. This tendency was also evident within each group. Accordingly, an attempt was made to discover the

TABLE 6-1

AGREEMENT OF EACH JUDGE'S RANK ORDER WITH THE AVERAGE RANK ORDER OF THE REMAINING JUDGES.

Officer	Infantry	Artillery	Combined
1	0.917	0.751	0.743
2	0.874	0.490	0.755
3	0.866	0.470	0.688
4	0.862	0.696	0.743
5	0.842	0.731	0.775
6	0.842	0.723	0.739
7	0.818	0.743	0.791
8	0.806	0.826	0.692
9	0.806	0.383	0.688
10	0.791	0.621	0.751
11	0.787	0.700	0.628
12	0.767	0.688	0.660
13	0.751	0.652	0.688
14	0.743	0.751	0.739
15	0.723	0.771	0.676
16	0.719	0.692	0.680
17	0.644	0.731	0.581
18	0.623	0.735	0.601

TABLE 6-2

COMMUNITY OF AGREEMENT IN RANKING FORT SILL

	W	ρ_{av}
Infantry	0.87	0.86
Artillery	0.73	0.71
Infantry-Artillery	0.71	0.68

TABLE 6-5

CORRELATIONS OF INFANTRY-ONLY WITH INFANTRY-ARTILLERY COMBINED

	F.B. Inf-Arty	F.S. Inf-Arty
F. B. Inf.	0.822	0.794
F. S. Inf.	0.838	0.783

TABLE 6-3

RANKINGS OF SELECTED ARTILLERY SITUATIONS BY SUBGROUPS

t	c	e	s	m	(ec m)	F.B.	F.S.	F.S.	
3	3	0	0	0	1	1	1	1	Over-estimates only
3	3	0	1	0	3.4	2.5	2.4	2.0	
2	2	0	1	0	5.7	4.4	3.6	3.4	
3	3	0	2	0	10.4	6.1	7	4	
1	1	0	1	0	10.5	7.6	8.6	5.1	
2	2	0	2	0	12.5	9.4	9.4	6.1	
3	3	0	3	0	17	11.3	12.2	8.1	
1	1	0	2	0	17.4	16.2	19.6	9.9	
2	2	0	3	0	20.5	15.8	14.8	8.75	
3	2	1	0	0	2.9	4.4	5.2	8.9	Displacements only
2	1	1	0	0	3.4	4.8	5.4	13.4	
3	1	2	0	0	5.3	14.7	14.2	19.9	
3	2	0	0	1	9.1	7.7	5.4	11.9	Misses only
2	1	0	0	1	12.9	14	11.6	14.3	
4	2	0	0	2	17.9	14.9	16	18.1	
3	1	0	0	2	20.7	20.4	20.6	21.3	

TABLE 6-4

AVERAGE EXPERIENCE (Mo.)

Group	Subgroup	G_2, G_3	S_2,S_3,S_4	Reg. C. O. or Exec.	Bn C. O. or Exec.	Company C. O.
F. B.	I	8.3	9.7	0	*	4.0
	II	*	3	*	*	9.6
F. S.	I	*	5	0	*	3.0
	II	*	6	0	9.4	3.25

*Only one man in the subgroup had this experience.

**Two men had this experience.

factors upon which the judgments in artillery situations were based. The factors mentioned most often in the debriefing reports were:

(a) accuracy of reported strength and

(b) accuracy of reported locations.

Some officers stressed the first of these criteria and others stressed the second. By grouping those who seemed to prefer one criterion over the other, both Fort Sill group and the Fort Benning group were divided into subgroups. Subgroup 1 stressed accuracy of strength while Subgroup 2 stressed accuracy of location. Table 6-3 shows how each group ranked typical situations. As may be seen in this table, F. B. $_2$ and F. S. $_1$ agreed very well. However, this close agreement may not be very significant since the attitude of the Fort Benning group might be considered just a displacement of the attitude of the Fort Sill group. Table 6-4 shows the average experience (G_2, G_3, S_2, S_3, etc.) in each subgroup.

6.5 RELATIVE WEIGHTS IMPLICITLY ASSIGNED BY JUDGES

In considering the rankings of the combined infantry-artillery situations, it was noticed that the correlation of the rankings of the infantry-only situations with those of the combined infantry-artillery situations was rather high. Table 6-5 shows the correlations.

A least squares procedure was used to determine the relative weights assigned to the infantry and artillery situation by the judges. If I_α represents the average rank of infantry situation α, and if A_α and IA_α are defined analogously to be the average ranks of artillery situation α and the combined infantry-artillery situation α, respectively, then

$$\hat{IA}_\alpha = a_1 I_\alpha + a_2 A_\alpha \text{ and } \alpha = 1, 2, \ldots, N. \tag{17}$$

The values of a_1 and a_2 were computed by minimizing

$$\sum_\alpha (\hat{IA}_\alpha - IA_\alpha)^2 . \tag{18}$$

If

$$P_j = \frac{a_j}{a_1 + a_2} \text{ and } j = 1, 2, \tag{19}$$

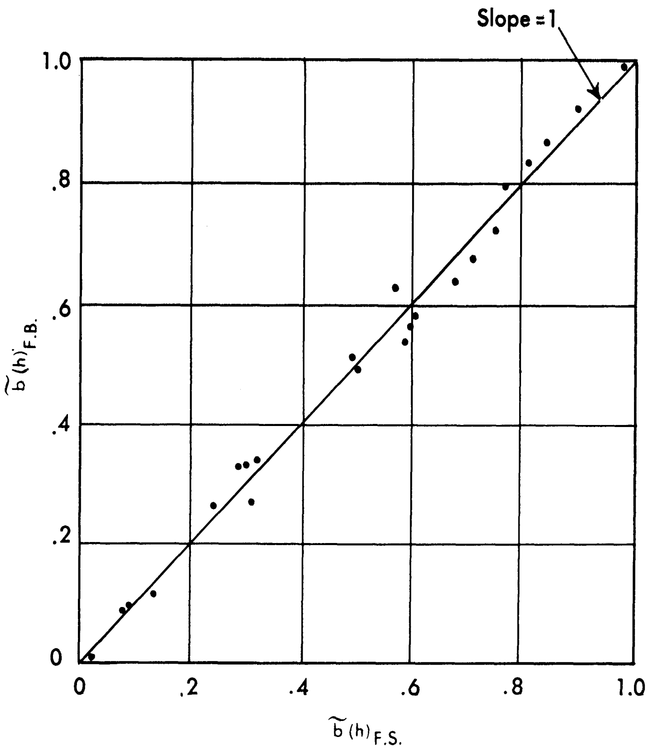
then the values of P_j were found to be

$$P_1 = 0.737 \text{ and} \tag{20}$$

$$P_2 = 0.263,$$

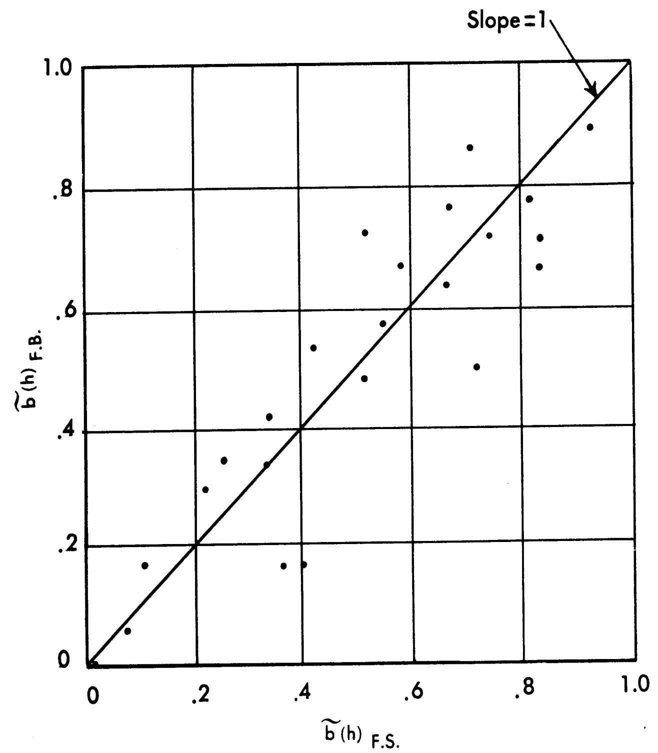
where P_1 is the weight assigned to the average rankings of the infantry situations and P_2 is the weight assigned to the average rankings of the artillery situations. Clearly, the infantry dominates the valuation put upon the estimate in the approximate ratio of three to one.

It seemed possible that the subgroups discussed in Section 6.4 might differ materially in the weights they assigned to infantry and artillery. However, upon investigation this was found not to be the case.



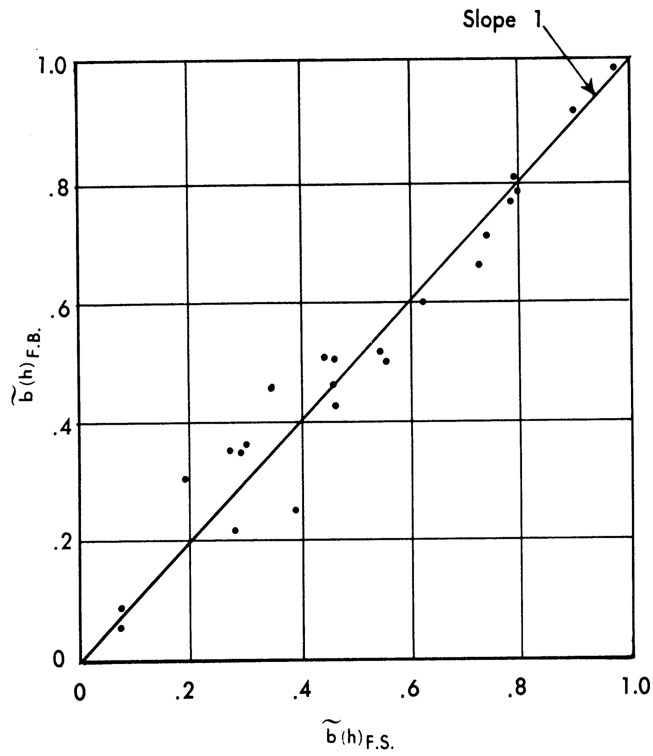
$\tau\left(\tilde{b}(h)_{F.B.}\ \tilde{b}(h)_{F.S.}\right) = 0.95$

FIG 6.1-1 PLOT OF AVERAGE RANK OF INFANTRY SITUATIONS FROM FT. BENNING WITH THOSE FROM FT. SILL



$\tau\left(\tilde{b}(h)_{F.B.}, \tilde{b}(h)_{F.S.}\right) = 0.71$

FIG 6.1-2 PLOT OF AVERAGE RANK OF ARTILLERY SITUATIONS FROM FT. BENNING WITH THOSE FROM FT. SILL



$\tau\left(\tilde{b}(h)_{F.S.}, \tilde{b}(h)_{F.B.}\right) = 0.85$

FIG 6.1-3 PLOT OF AVERAGE RANK OF INFANTRY-ARTILLERY SITUATIONS FROM FT. BENNING WITH THOSE FROM FT. SILL

7

DEVELOPMENT OF THE MODEL

7.1 GENERAL CONSIDERATIONS

The purpose of this study is to devise a linear measure on an absolute scale of the merit of an intelligence estimate of an enemy situation. The idea of using a score of the form

$$d = c - fe - hm, \tag{21}$$

where c, e, and m are, respectively, hits, false alarms, and misses, and f and h are constants, was suggested by some experimental studies in vision research. In that application, values for f and h were assigned by the experimenter, and one purpose of the experiment was to see how changes in f and h would influence the subject in responses near the visual threshold. (In this section subscripts and superscripts are omitted.)

In our problem, c, e, and m are fixed in advance; d is calculated experimentally, and the constants f and h are to be determined by linear regression so as to give a least squares fit.

In early analyses, Formula 21 was used. However, after a more careful examination of the data and after more information was obtained in the debriefing, some modifications were introduced. First, it became clear that the officers almost without exception regarded as a displacement what had been intended as a miss plus a false alarm. To handle this, the concept of displacement was introduced and the following definitions were made:

If the true situation has t units and the estimate shows $\bar{t}$ units, then c is defined to be the number of units whose positions on the two maps coincide.

Next,

$$s = \min (t - c, \bar{t} - c) \tag{22}$$

is defined to be the number of displacements,

$$e = \bar{t} - c - s \tag{23}$$

is defined to be the number of false alarms (errors), and

$$m = t - c - s \tag{24}$$

is defined to be the number of misses.

Also, $\bar{s}$ is defined as the number of near misses (i.e., displacements such that the distances between the true units and the corresponding units on the estimate are less than some fixed amount, e.g., 300 yds for infantry). These quantities are illustrated in Figure 7.1-1 Targets 1, 2, and 3 coincide with Units 6, 7, and 8 of the estimate and Element 10 is a near miss for Target 4.

Next, three methods of using Equation 21 were considered, each of which depends on replacing c, e, and m by combinations of c, e, s, $\bar{s}$, and m as defined above. These methods (exact, judged, and strength) are defined in Table 7-1.

TABLE 7-1
THREE POSSIBLE CRITERIA FOR MEASURING THE VARIABLES

	c	e	m
Exact	c	e + s	m + s
Judged	c + s	e + s - $\bar{s}$	m + s - $\bar{s}$
Strength	c + s	e	m

Table 7-2 shows the values obtained by applying these criteria to the situations in Figure 7.1-1.

TABLE 7-2
MEASURES OBTAINED FROM ONE SITUATION APPLYING THREE DIFFERENT CRITERIA

	c	e	m
Exact	3	3	2
Judged	4	2	1
Strength	5	1	0

Of these criteria some modification of the "judged" gave the best fit, but it was apparent that even better results might be obtained by replacing Equation 21 with

$$d = c - fe + gs - hm, \tag{25}$$

in which s, e, and m are defined by Equations 22, 23, and 24 and f, g, and h are constants to be calculated by linear regression from the observed d values. Perhaps further modifications of Equation 25, which would include $\bar{s}$ as one of the variables, should be considered.

7.2 TRANSFORMATIONS OF EMPIRICAL VALUES TO VALUES OF d

In the foregoing discussion reference has been made several times to "observed" or "experimentally determined" values $\tilde{d}$ of d. These terms are not strictly correct. The experimental results yield directly only each officer's rank order of a set of maps and an average, normalized score $\tilde{b} = \tilde{b}$ (h), Equation 16, which is assumed to be related to $\tilde{d} = \tilde{d}$ (h).

In essence, the officers based the rank of a given estimate of the corresponding true situation upon the effect the errors in the estimate might have on an attack and not on the value of t in the true situation. Thus, two perfect estimates (t = c, s = m = e = 0) would be judged equally good even though one had a much larger value of t. This suggests that $\tilde{b}$ should be matched with $\frac{\tilde{d}}{t}$, i.e., assuming $\frac{\tilde{d}}{t}$ to be a linear function of $\tilde{b}$ and fitting by linear regression. There are some reasons for using $\frac{\tilde{d}}{(t + e)}$ or $\frac{\tilde{d}}{(t+e+s)}$ instead of $\frac{\tilde{d}}{t}$. For example, t + e + s is the total number of objects seen when the estimate is overlaid on the true situation and thus might have some psychological meaning. Inclusion of e, or some multiple of e, in the denominator bounds the range of the fraction.

It is very difficult to decide a priori which of the many possible forms is the best. If $\tilde{b}$ is matched with d/α where α may be t, t + e, or some similar expression, and values of f, g, and h are found by linear regression theory sometimes some possibilities can be eliminated. For example, if, when b is matched with d/α, one of the coefficients in Equation 25 is less than zero, this form is unsatisfactory. Similarly, f>1 or g>1 is, on the face of it, illogical, for g>1 means that a displacement is better than a hit, which is absurd, and f>1 is unlikely, judging from the data from Fort Sill and Fort Benning. If b is matched with d/α,

$$b = \frac{c}{\alpha} - f\frac{e}{\alpha} + g\frac{s}{\alpha} - h\frac{m}{\alpha}. \tag{26}$$

By the procedures described in Appendix A, values of f, g, and h were obtained for $\alpha = t$, $t + e$, and $t + e + s$. Values were also obtained for a special case

$$b = \frac{c}{t} - \frac{fe}{t + \alpha e} + \frac{gs}{t} - \frac{hm}{t} \qquad (27)$$

for a range of values of α. As noted in Appendix A, linear regression theory does not apply to either the latter case or to the case of $\alpha = t$ without some restriction.

Tables 7-3 and 7-4 give the values of f, g, and h obtained from the Fort Sill data using the above cases and present the correlation of the data from Fort Benning with the corresponding b's.

Another approach is to redefine s, the displacement term. The distance between a reported target and the true target can be denoted h. Then the number of stimuli for which

$$s_i = h_{i-i} \leqslant h \leqslant h_i \qquad (28)$$

where $h_0 = 0$ and h_i is chosen arbitrarily for $i \geqslant 1$ can be defined. Then, for i = 1,. 2, and 3

$$s = s_1 + s_2 + s_3 \qquad (29)$$

and the basic equation becomes

$$\hat{b}(h) = \frac{c}{\alpha} - f\frac{e}{\alpha} + g_1 \frac{s_1}{\alpha} + g_2 \frac{s_2}{\alpha} + g_3 \frac{s_3}{\alpha} - h\frac{m}{\alpha}, \qquad (30)$$

where α may be chosen as in the preceding section. In the course of examining this method it was noted that the judges weighted front line misses, displacements, and false alarms differently from corresponding errors in the rear area. Letting x' denote a variable on the front line and x'' denote the same variable in the rear area, a high correlation of $\hat{\hat{b}}(h)$ with $\tilde{b}(h)$ was obtained where

$$\hat{\hat{b}}(h) = \frac{c^*}{t + e^*} + \frac{s^*}{t + e^*} - \frac{m^*}{t + e^*} \qquad (31)$$

and

$$c^* = c,$$

$$s^* = 0.3s_1' - 0.3s_2' - 0.6s_3' - 0.75s_1'' + 0.4(s_2'' + s_3''),$$

$$e^* = 1.25e' + 0.8e'' + s_2' + s_3', \text{ and}$$

$$m^* = m' + 0.4m''.$$

Here

s_1' = the number of displacements $\leqslant$ 300 yds on the front line,

s_2' = the number of displacements between 300 yds and 600 yds on the front line,

s_3' = the number of displacements $>$600 yds on the front line,

m' = the number of front line misses, and

e' = the number of front line false alarms.

Double primes indicate the same quantities in the rear areas. (Note: A front line position with poor trafficability is counted as a rear position.)

Figure 7.2-1 shows the correlation between the values of b(h) obtained in this way and the observed values, $\tilde{b}(h)$. The values of the coefficients of s_1', s_2' and the rest were chosen arbitrarily to yield a good correlation and no attempt has been made to develop a theory for optimal choice of these coefficients.

The results indicate (1) the need for splitting sectors so as to consider front line and rear areas as separate sectors and (2) the possibility of a good fit by simple nonlinear formulas.

TABLE 7-3

THE COEFFICIENTS AND FIT OF EQUATION 26 FOR THREE VALUES OF α

Infantry Case	f	g	h	$\tau(\hat{b}, \tilde{b}_{F.S.})$	$\tau(\hat{b}, \tilde{b}_{F.B.})$
$\alpha = t$	0.149	0.701	0.240	0.735	0.751
$\alpha = t + e$	0.073	0.280	0.474	0.806	0.814
$\alpha = t + e + s$	0.137	0.646	0.742	0.775	0.783

Artillery Case	f	g	h	$\tau(\hat{b}, \tilde{b}_{F.S.})$	$\tau(\hat{b}, \tilde{b}_{F.B.})$
$\alpha = t$	0.274	-0.061	0.298	0.830	0.644
$\alpha = t + e$	0.098	0.145	0.381	0.719	0.830
$\alpha = t + e + s$	0.148	0.297	0.248	0.858	0.640

TABLE 7-4

THE COEFFICIENTS AND FIT OF EQUATION 27 FOR FOUR VALUES OF α

Infantry Case	f	g	h	$\tau(\hat{b}, \tilde{b}_{F.S.})$	$\tau(\hat{b}, \tilde{b}_{F.B.})$
α = 0	0.149	0.701	0.240	0.735	0.751
α = 0.5	0.593	0.617	0.545	0.787	0.779
α = 0.75	0.814	0.631	0.576	0.771	0.751
α = 1.0	0.972	0.620	0.585	0.775	0.743
Artillery	**f**	**g**	**h**	$\tau(\hat{b}, \tilde{b}_{F.S.})$	$\tau(\hat{b}, \tilde{b}_{F.B.})$
α = 0	0.274	-0.061	0.298	0.830	0.644
α = 0.5	0.579	-0.016	0.352	0.838	0.668
α = 0.75	0.717	0.003	0.367	0.862	0.684
α = 1.0	0.820	0.016	0.363	0.802	0.680

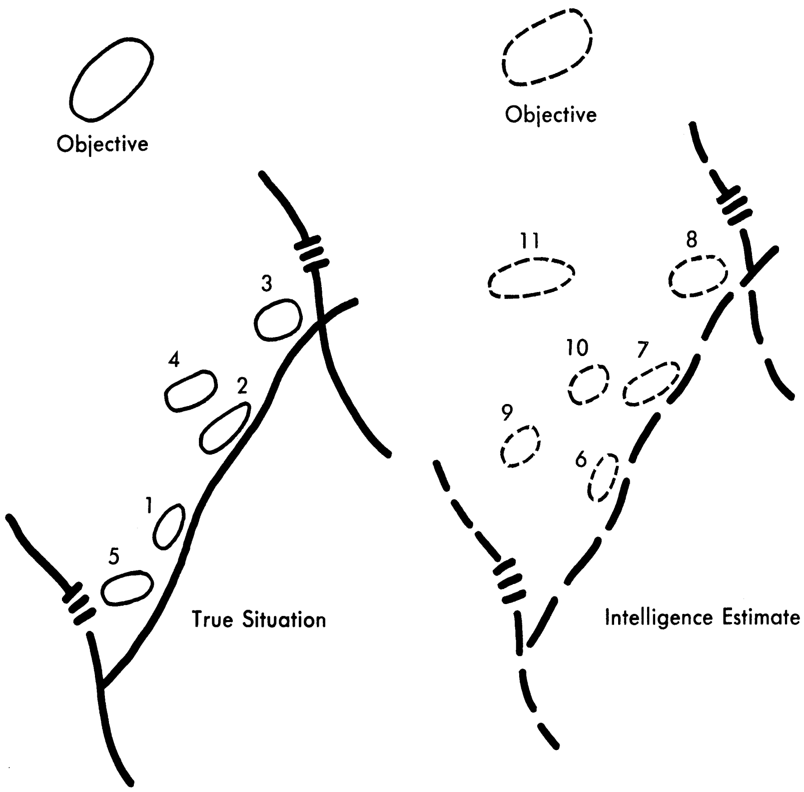


FIG. 7.1-1 ILLUSTRATION OF THE VARIABLES

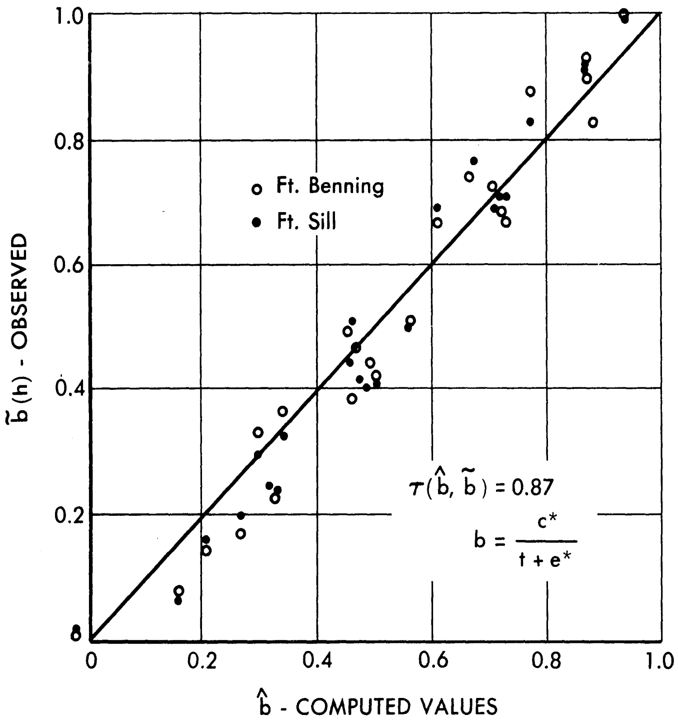


FIG. 7.2-1 COMPARISON OF OBSERVED VALUES WITH PREDICTED VALUES (Infantry Situations Only)

8
CONCLUDING REMARKS

8.1 SUITABLE MODEL

It seems clear that a suitable model can be built although its final form can be developed only after further study. Several of the forms already tested fit the raw data very well. Rank order correlations of 0.8 and higher have been obtained between predicted and observed values of intelligence estimates. These correlations are almost as high as is possible in view of the degree of agreement among the judges.

8.2 SOME UNSOLVED PROBLEMS

(A) The method of collecting data gives individual rank orders of the stimuli (in this case intelligence displays). The average rank order of each stimulus was taken as a numerical measure of its value. The stimuli were selected so as to present a representative sample spread as uniformly as possible from very good to very poor.

One would expect that, if two stimuli are nearly equal in value, some judges would prefer one and some the other and that the amount of overlap could be used to judge the distance between them. Our use of the average rank order as an empirical score represents a primitive utilization of this idea. Further development of a measurement theory seems in order.

(B) The basic scoring equation

$$d = c - fe + gs - hm \qquad (32)$$

gives for d a theoretical range of

$$\min(-hm, -fe) \leqslant d \leqslant t. \qquad (33)$$

It seems reasonable that the upper bound of the importance of a display should be the total number of units present. However, the linearity in e is subject to question for values of e much in excess of t. This suggests the desirability of replacing e in

Formula 32 by some function of e and of t which is bounded in e. For example, one proposal is

$$e\left(\frac{t}{t + e}\right)$$

or, more generally,

$$e\left(\frac{t}{t + ke}\right), \quad 0 < k.$$

A still more general possibility is

$$e \cdot F(t, e), \qquad (34)$$

where F is a non-negative function for which

$$\lim_{t \to \infty} F(t, e) = 1 \qquad (35)$$

and

$$\lim_{e \to \infty} eF(t, e) \text{ exists and is finite for all t.} \qquad (36)$$

The crux here is optimum selection of the function F.

(C) As was noted earlier in this memorandum, the judges do not make their preference choices on the basis of the d values but rather on $b = \frac{d}{\alpha}$ in which α is t or t + s, or t + e + s or some similar quantity. Good fits to the data can be obtained with any of these. Further study, both theoretical and experimental, is necessary to discover the true nature of α.

(D) In the special case $\alpha = t$, a mathematical difficulty is encountered in obtaining a least squares fit to the data. The observed values $\tilde{b}$ are matched against the computed value $\hat{b}$, given by

$$\hat{b} = x\hat{d} + y.$$

As is shown in Appendix A, Equation 45, when $\alpha = t$ the coefficients of the parameters are dependent. Some independent method for computing the mean of the $\hat{b}$ values would eliminate this difficulty. Further analysis of this problem is indicated.

8.3 FUTURE DEVELOPMENTS

In addition to work on the unsolved problems A, B, C, and D the following investigations are planned:

(E) There seem to be two major points of view represented in our artillery data. Officers in one group were interested primarily in pinpoint location of enemy artillery so as to direct counterfire. Officers in another group were interested primarily in accurate knowledge of the number of opposing batteries. Clearly both points of view are important. However, the data are insufficient to give appropriate weights to these two factors. There are two possible approaches to this problem: (a) use higher ranking officers as judges, or (b) redesign the experiment. The purpose in (a) is to obtain judgments from officers who have been in command simultaneously, of infantry troops, and of artillery. The most probable course is to combine (a) and (b).

(F) Analysis of data already on hand should be continued. This involves, in particular, close study of the data on combined infantry and artillery displays.

(G) A new set of displays should be designed to include at least three types of information and a larger front sector. Preparation of this new material will, of course, build on what has already been learned and will require continuing close touch with the military liaison. This material would be intended for judgments by officers of somewhat higher rank than were those in the earlier experiments. The value of the debriefing records from the experiments of last summer indicates the desirability of paying even more attention to this feature.

APPENDIX A

METHODS OF DETERMINING COEFFICIENTS FOR BASIC EQUATION

Indexes referring to sector or category will be omitted in this section. The subscript employed will denote a given display.

Equation 26 of Section 7 may be written in the form

$$\hat{d} = c_i' - fe' + gs_i' - hm_i' \text{ and } i = 1, e, \ldots, N, \tag{38}$$

where

$$X_1' = X_{\frac{i}{\alpha}} \tag{39}$$

α may be taken as 1, t, t+e, t+e+s, or some similar expression, and

$$m_i = (t_i - c_i - s_i). \tag{40}$$

Equation 38 is not in the best form for application of linear regression procedures. In order to adjust the mean and the scale of the predicted values to those of the observed values, Equation 38 is replaced by a linear transformation of it:

$$\hat{b}_i = a_1 c_i' + a_2 e_i' + a_3 s_i' + a_4 m_i' + a_5 \text{ and } i = 1, 2, \ldots, N. \tag{41}$$

Then

$\frac{\hat{b}_d}{a_1}$ is an estimate of $\hat{d}_i$,

$\frac{-a_2}{a_1}$ is an estimate of f,

$\frac{a_3}{a_1}$ is an estimate of g, and

$\frac{-a_4}{a_1}$ is an estimate of h.

The values of c_i', e_i', s_i', and m_i' are known and the N equations represented by Equation 41 are in a form suited to the least squares procedure. Each estimated value $\hat{b}_i$ corresponds with an observed value $\tilde{b}_i$ associated with a particular display. It is desired to minimize the variance of errors of prediction, an error of prediction being

$$\rho_i = \hat{b}_i - \tilde{b}_i. \tag{42}$$

Summing over the displays provides

$$\sum_{i=1}^{N} \rho_i^2 = \sum_{i=1}^{N} \left[a_1 c_i' + a_2 e_i' + a_3 s_i' + a_4 m_i' + a_5 - \tilde{b}_i \right]^2 . \tag{43}$$

The normal equations in a_1, a_2, a_3, a_4, and a_5 which minimize $\sum \rho_i^2$ are obtained by requiring

$$\frac{\partial \sum \rho_i^2}{\partial a_i} = 0 \text{ and } i = 1, 2, 3, 4, 5. \tag{44}$$

This yields five equations which are linear in a_1, a_2, a_3, a_4, and a_5. For $\alpha = t + e$ and $\alpha = t + e + s$, the coefficient matrix of these equations is nonsingular, which allows solving for the unknown. However, for $\alpha = t$ and the special case

$$\hat{b}_i = a_1 \frac{c_1}{t_i} + a_2 \frac{e_i}{t_i + \alpha e_i} + a_3 \frac{s_i}{t_i} + a_4 \frac{m_i}{t_i} + a_5, \tag{45}$$

the coefficient matrix is singular. If we require $a_5 = 0$ and use only the first four equations of the set, the reduced coefficient matrix is now nonsingular and we may solve for a_1, a_2, a_3, and a_4. Setting $a_5 = 0$ has the disadvantage that it forces an artificial mean for values of $\hat{b}_i$ obtained and results in a distortion of the values of f, g, and h. Although this is undesirable, it seemed worthwhile to proceed, since the values of a_5 in the cases $\alpha = t + e$ and $\alpha = t + e + s$ were relatively small. However, this method is not considered adequate and further consideration will be given to developing a more satisfactory method.

APPENDIX B

DEFINITION OF τ, W, and ρ_{av} *

If the degree of agreement between two rankings of N things is to be computed, the Kendall τ is a simple and easily computed measure. τ is computed as follows: Three things x_1, x_2, and x_3 are ranked according to some property by two observers A and B, thus:

Object	A	B
x_1	1	2
x_2	2	1
x_3	3	3 .

If the ranking by A is considered the natural order, then

$$S = \frac{1}{2}N(N-1) - \text{(twice the total number of inversions)}. \quad (46)$$

Here S = 1. Then

$$\tau = \frac{S}{\frac{1}{2}N(N-1)} . \quad (47)$$

Since

$$-\frac{1}{2}N(N-1) \leqslant S \leqslant \frac{1}{2}N(N-1), \quad (48)$$

therefore

$$-1 \leqslant \tau \leqslant 1 \quad (49)$$

and $\tau = 0$ corresponds with a random correlation.

*For a more complete discussion of rank correlation and the quantities τ, W, and ρ_{av}, see Rank Correlation Methods, M. G. Kendall, Charles Griffin and Company, Ltd.; 1943, pp. 26 and 81.

The standard error of τ is of the order of $\sqrt{\frac{2}{N}}$. In the above example, $\tau = 0.333$.

In order to measure the conformity of agreement between M observers in ranking N objects, it is necessary to define

$$S(d^2) = \sum_{h=1}^{N}\left[\frac{1}{2}M(N+1) - \sum_{p=1}^{M} g(h, p)\right]^2 , \quad (50)$$

in which g(h, p) is the rank assigned to the h^{th} object by the p^{th} observer. Then

$$W = \frac{12S}{M^2(N^3 - N)} \text{ and } 0 \leqslant W \leqslant 1 \quad (51)$$

is a measure of the conformity of agreement among the observers and

$$\rho_{av} = \frac{MW - 1}{M - 1} \quad (52)$$

is the mean value of the Spearman coefficient among the $\binom{M}{2}$ possible pairs of observers.

To obtain the values used after the concept of displacements was incorporated, terms were defined thus:

$$s = \min(e_1, t - c),$$

$$e = e_1 - s, \text{ and}$$

$$m = t - c - s ,$$

where e_1 represents the values of e in Appendix C.

APPENDIX C

COMPOSITION OF THE STIMULI

Terrain Instance		true	c	e	t-c	No.	Terrain Instance		true	c	e	t-c	No.
3	a	1	0	5	1	5	1	a	4	4	2	0	6
	b	1	1	3	0	4		b	3	2	2	1	4
1	a	1	1	5	0	6	2	a	5	3	0	2	3
	b	3	2	3	1	5		b	3	1	2	2	3
2	a	1	1	4	0	5	3	a	5	3	2	2	5
	b	3	2	0	1*	2		b	3	3	2	0	5
1	a	2	1	4	1	5	3	a	5	5	1	0	6
	b	3	3	0	0	3		b	2	2	2	0	4
2	a	2	2	4	0	6	1	a	5	3	3	2	6
	b	2	1	3	1	4		b	2	1	2	1	3
1	a	3	2	1	1	3	3	a	6	3	3	3	6
	b	2	2	3	0	5		b	3	2	1	1	3
3	a	3	3	2	0	5	3	a	6	3	0	3	3
	b	3	3	3	0	6		b	3	1	0	2	1
2	a	3	3	3	0	6	2	a	6	4	1	2	5
	b	2	2	0	1	2		b	3	1	3	2	4
2	a	4	2	3	2	5	1	a	6	4	2	2	6
	b	2	2	1	0	3		b	3	1	1	2	2
3	a	4	2	4	2	6	1	a	6	5	0	1	5
	b	2	1	1	1	2		b	1	1	1	0	2
1	a	4	3	2	1	5	2	a	6	5	1	1	6
	b	2	1	0	1	1		b	1	1	2	0	3
2	a	4	3	3	1	6							
	b	3	3	1	0	4							

This table gives the specifications for each of 23 displays of infantry alone, 23 displays of artillery alone, and 23 displays of combined infantry and artillery.

The row headed (a) indicates infantry.

The row headed (b) indicates artillery.

No. Designates total number of units displayed.

*This number is correct for artillery alone but on the combined infantry-artillery there are two misses of artillery positions.

APPENDIX D

RANKINGS OF SITUATIONS BY INDIVIDUAL OFFICERS

TABLE D-1 FORT BENNING INFANTRY RANK ORDERS

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	b_i^j (h)
I-I	1	1	1	3	1	1	2	1	1	1	1	3	3	1	2	1	0	1	8	0.079
I-2	3	3	3	2	5	2	3	2	4	3	2	6	2	3	9	2	4	4	9	0.170
I-3	20	17	20	19	21	20	20	20	20	21	18	19	16	21	19	20	19	19	18	0.878
I-4	10	11	9	12	15	9	11	11	11	15	10	10	14	7	13	12	7	7	11	0.490
I-5	16	16	14	16	13	16	15	17	13	18	19	18	17	16	20	14	10	20	19	0.734
I-6	15	15	16	18	18	17	17	14	15	7	9	16	13	18	15	13	16	16	15	0.677
I-7	21	21	21	20	20	22	19	21	21	20	21	21	19	19	16	17	21	18	20	0.904
I-8	18	19	18	14	17	18	18	15	18	17	17	11	20	17	17	19	11	10	16	0.724
I-9	8	5	5	1	9	5	5	8	7	9	11	1	0	10	11	16	1	3	6	0.289
I-10	2	2	2	4	2	4	1	3	2	2	3	4	4	2	3	3	3	11	1	0.139
I-11	6	7	13	9	7	3	8	13	10	13	7	13	9	6	6	6	12	5	4	0.376
I-12	7	6	12	5	8	12	6	10	14	8	5	7	8	11	1	9	17	2	7	0.371
I-13	5	4	4	6	3	7	4	5	3	4	4	5	5	5	4	4	5	9	5	0.218
I-14	12	9	7	11	10	8	14	6	6	6	13	8	7	8	10	7	8	13	13	0.421
I-15	11	14	10	17	6	10	7	7	8	10	12	9	15	13	14	10	14	14	12	0.510
I-16	22	22	22	22	22	21	22	22	22	22	22	22	22	22	22	22	22	21	22	0.995
I-17	4	12	6	7	4	6	13	4	5	5	14	2	10	15	7	8	6	8	3	0.333
I-18	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0.007
I-19	14	13	15	15	16	13	16	16	12	12	15	14	18	14	18	11	13	17	17	0.667
I-20	9	8	11	8	12	14	10	12	16	14	6	15	6	9	5	18	15	6	2	0.469
I-21	13	10	8	10	11	11	9	9	9	11	8	12	11	4	8	5	9	15	14	0.447
I-22	19	20	19	21	19	19	21	19	19	19	20	20	21	20	21	21	20	22	21	0.911
I-23	17	18	17	13	14	15	12	18	17	16	16	17	12	12	12	15	18	12	10	0.672

TABLE D-2 FORT BENNING ARTILLERY RANK ORDER

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	b_i^j (h)
A-1	9	6	3	12	1	4	7	5	3	5	2	9	7	0	5	9	1	6	4	0.234
A-2	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	1.00
A-3	3	4	2	8	2	9	9	6	2	1	4	7	8	7	12	2	3	14	13	0.278
A-4	4	7	11	3	12	12	13	15	10	14	8	3	11	13	7	5	13	8	11	0.431
A-5	15	16	17	14	10	8	8	7	15	13	14	11	9	6	10	13	17	7	8	0.522
A-6	10	12	12	11	9	5	5	8	9	12	9	6	6	12	4	4	9	5	5	0.366
A-7	6	10	7	2	8	6	2	2	8	11	5	4	5	8	11	8	7	4	6	0.287
A-8	8	5	16	15	15	15	19	16	12	15	20	12	14	14	13	16	16	13	19	0.653
A-9	17	18	15	16	19	2	15	3	16	19	1	14	10	10	2	10	20	2	0	0.500
A-10	2	2	8	1	11	10	12	14	7	6	3	5	12	4	8	12	0	1	3	0.289
A-11	18	17	19	18	17	19	18	17	18	17	19	20	18	20	20	17	15	20	20	0.830
A-12	13	13	10	10	16	3	4	1	14	10	6	13	4	3	1	6	10	3	1	0.337
A-13	7	8	5	4	5	1	3	4	6	4	7	8	3	2	6	3	4	9	7	0.230
A-14	11	15	13	6	13	18	14	18	17	16	13	18	16	16	19	15	12	10	17	0.663
A-15	21	19	21	19	21	21	20	19	19	21	21	21	21	21	21	21	18	21	21	0.919
A-16	5	3	6	5	6	11	6	10	4	9	12	2	1	11	9	1	6	16	14	0.328
A-17	0	0	0	0	4	7	0	9	1	3	0	0	2	1	0	7	8	0	2	0.105
A-18	1	1	1	7	0	0	1	0	0	0	10	1	0	5	3	0	2	15	10	0.136
A-19	14	9	4	9	3	13	10	11	5	2	11	16	13	9	14	11	5	18	16	0.462
A-20	16	14	9	17	14	20	17	13	13	8	16	19	17	15	17	18	14	19	18	0.703
A-21	19	21	20	21	18	16	16	21	20	20	17	15	19	19	18	20	19	12	12	0.821
A-22	12	11	14	13	7	14	11	12	11	7	15	10	15	17	15	14	11	17	15	0.577
A-23	20	20	18	20	20	17	21	20	21	21	18	17	20	18	16	19	21	11	9	0.831

TABLE D-3 FORT BENNING INFANTRY-ARTILLERY RANK ORDERS

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	$b_i^j(h)$
IA-1	1	1	1	2	1	1	1	1	1	1	6	1	1	0	5	2	0	7	1	0.081
IA-2	5	9	4	7	11	12	5	8	6	13	11	18	9	6	11	7	9	12	6	0.404
IA-3	13	16	19	10	14	13	18	19	13	14	13	16	12	17	13	18	4	20	7	0.644
IA-4	4	14	5	9	17	19	11	10	12	18	14	3	14	8	4	10	16	6	11	0.490
IA-5	17	13	13	17	13	14	19	12	9	11	16	19	13	19	15	15	7	15	17	0.656
IA-6	16	17	11	18	12	9	16	15	14	12	15	11	19	5	8	12	18	9	5	0.579
IA-7	22	22	20	20	16	7	17	20	21	16	17	13	21	18	16	17	20	14	9	0.780
IA-8	15	18	10	11	18	22	10	14	19	20	18	7	20	10	12	22	13	13	21	0.701
IA-9	12	8	9	1	6	2	3	7	8	15	1	9	0	4	3	9	10	4	8	0.285
IA-10	7	5	2	6	2	4	2	2	3	4	2	6	4	7	9	1	3	8	14	0.218
IA-11	6	4	18	14	19	17	15	18	16	9	9	10	16	9	7	6	17	3	13	0.541
IA-12	11	2	14	3	15	5	8	6	15	5	3	2	11	2	0	8	21	10	2	0.342
IA-13	2	3	3	5	3	3	4	4	2	2	10	5	3	11	6	3	1	11	4	0.203
IA-14	8	7	7	13	7	11	14	5	5	10	12	12	15	16	18	11	12	16	12	0.505
IA-15	9	15	12	16	8	15	13	9	11	7	20	22	22	15	19	16	6	19	19	0.653
IA-16	21	20	22	22	22	21	22	22	22	22	22	20	17	22	20	21	15	21	22	0.947
IA-17	3	11	6	4	5	8	6	3	4	3	4	4	5	13	2	4	8	2	3	0.234
IA-18	0	0	0	0	0	0	0	0	0	0	00	0	2	1	1	0	2	0	0	0.014
IA-19	10	12	17	12	9	6	12	13	7	6	7	17	8	20	21	13	5	17	18	0.550
IA-20	14	6	15	8	10	10	9	16	17	8	5	8	10	12	17	14	11	5	15	0.502
IA-21	18	10	8	15	4	18	7	11	10	17	8	14	6	3	10	5	19	18	10	0.505
IA-22	20	19	21	21	20	20	21	21	20	19	21	21	18	21	22	20	14	22	20	0.911
IA-23	19	21	16	19	21	16	20	17	18	21	19	15	7	14	14	19	22	1	16	0.754

TABLE D-4 FORT SILL INFANTRY RANK ORDERS

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	$b_i^j(h)$
I-I	1	1	1	1	1	1	1	1	1	1	1	0	1	0	2	3	5	2	0.061
I-2	2	2	5	7	6	3	2	0	2	4	9	2	8	3	6	6	7	4	0.197
I-3	19	19	20	19	21	19	20	21	19	19	19	18	21	21	18	14	18	20	0.871
I-4	11	12	11	11	9	11	12	11	10	13	15	13	13	11	11	0	8	10	0.510
I-5	17	18	15	14	17	15	18	15	13	14	14	17	11	14	19	13	16	15	0.694
I-6	14	16	17	17	10	17	16	17	14	17	17	15	15	16	17	16	15	16	0.712
I-7	20	20	18	20	20	20	21	20	21	21	20	20	19	20	21	21	20	21	0.912
I-8	18	17	21	15	11	14	15	18	17	18	18	19	17	18	13	19	17	18	0.765
I-9	10	5	8	3	5	10	4	8	7	6	2	8	7	5	1	0	1	7	0.245
I-10	4	3	2	9	2	2	3	2	3	2	3	3	3	2	4	2	13	3	0.164
I-11	9	13	6	6	7	5	8	10	12	11	11	12	14	17	9	7	9	11	0.447
I-12	3	9	9	2	8	12	10	12	8	8	5	10	6	9	7	5	2	6	0.331
I-13	5	4	4	10	3	4	6	4	5	3	4	4	2	4	5	9	12	5	0.235
I-14	7	8	10	13	13	8	9	5	9	5	8	9	9	7	8	11	14	8	0.407
I-15	13	11	13	8	16	7	13	9	16	9	7	7	10	12	10	15	10	13	0.503
I-16	22	22	19	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	0.992
I-17	8	6	14	5	4	6	5	6	4	10	6	11	12	8	3	8	3	0	0.301
I-18	0	0	0	0	0	0	0	3	0	0	0	1	0	1	0	1	0	1	0.018
I-19	16	14	16	20	15	18	14	13	15	7	13	16	16	13	15	18	19	14	0.687
I-20	12	10	7	4	12	13	11	14	6	15	12	5	5	10	12	4	4	9	0.417
I-21	6	7	3	16	14	9	7	7	11	12	10	6	4	6	14	12	6	12	0.409
I-22	21	21	22	21	19	21	19	19	20	20	21	21	20	19	20	20	21	19	0.919
I-23	15	15	12	12	18	16	17	16	18	16	16	16	18	15	16	17	11	17	0.705

TABLE D-5 FORT SILL ARTILLERY RANK ORDERS

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	b_i^j (h)
A-1	7	11	8	5	2	9	8	12	5	5	8	9	8	5	10	5	6	10	0.336
A-2	22	22	22	22	22	22	22	22	21	22	22	22	22	22	22	22	22	22	0.997
A-3	14	10	12	15	13	12	15	7	14	4	5	14	14	3	14	7	15	6	0.490
A-4	6	6	16	13	14	11	2	5	11	13	7	12	6	11	4	14	11	18	0.455
A-5	9	12	10	9	9	14	12	18	10	14	6	11	5					14	0.495
A-6	8	9	7	6	7	3	7	11	7	7	9	8	3	9	8	8	7	9	0.336
A-7	1	5	6	3	3	6	1				2	4	4	10	1	2	2	8	0.174
A-8	17	15	17	19	19	10	17	8	17	15	19	18	16	15	19	16	18	20	0.745
A-9	4	8	9	1	1	7	5	20	6	6	4			14	5	4	1		0.293
A-10	2	7	4	4	8	8	4	2	1	9	13	5	10	7	2	9	4	5	0.2
A-11	20	19	20	20	20	20	19	16	22	20	20	19	19	18	20	20	20	21	0.891
A-12	3	4	3	0	0	5	3	17	3	1	1	0	0	12	6	3	0	7	0.172
A-13	5	2	5	8	6	2	6	4	4	0	3	1	7	4	7	0	5	4	0.
A-14	11	16	18	14	15	18	10	15	19	19	14	17	12	17	3		12	15	0.667
A-15	21	21	21	21	21	21	21	19	20	21	21	21		19	21	21	21	16	0.929
A-16	16	3	1	17	11		14			10	15	2	15	2	16	11	14	3	0.422
A-17	0	1	2	2	5	0	0	1	0	8	0	3	1	1	0	1	3	0	0.071
A-18	13	0	0	7	4	4	11	0	12	2	12	7	13	0	13	6	13	2	0.301
A-19	15	13	11	10	16	13	16	10	15	11	17	13	17	6	15	12	17	1	0.576
A-20	19	17	15	18	18	16	20	14	18	16	18	20	20	16	18	15	19	11	0.778
A-21	10	18	19	11	10	19	9	21	9	12	11	10	9	20	9	17	9	17	0.606
A-22	18	14	14	16	17	15	18	9	16	17	16	15	18	8	17	13	16	12	0.679
A-23	12	20	13	12	12	17	13	13	8	18	10	16	11	21	11	18	10	19	0.641

TABLE D-6 FORT SILL INFANTRY-ARTILLERY RANK ORDERS

Situations \ Officers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	b_i^j (h)
IA-1	2	1	1	1	5	2	2	1	1	2	0	1	2	0	5	5	8	1	0.101
IA-2	8	6	6	11	3	8	7	9	6	1	10	17	12	4	17	8	7	7	0.371
IA-3	20	13	10	17	20	13	16	6	18	19	14	16	16	20	19	14	20	14	0.720
IA-4	11	12	12	14	4	7	9	7	14	14	7	12	8	11	9	11	5	11	0.449
IA-5	13	16	14	15	19	19	17	14	11	12	20	19	18	14	13	15	18	13	0.707
IA-6	7	11	4	13	16	9	13	8	12	15	9	13	15	17	8	13	13	15	0.533
IA-7	16	21	16	9	18	14	18	21	16	20	13	11	13	21	7	16	15	19	0.717
IA-8	18	15	22	20	11	17	20	15	19	21	19	15	17	19	20	18	16	17	0.806
IA-9	4	7	18	5	0	1	5	11	4	5	5	9	3	8	1	6	1	6	0.250
IA-10	6	2	2	4	6	6	3	2	2	3	4	4	4	2	11	3	14	4	0.207
IA-11	9	14	9	8	8	10	15	17	15	13	11	8	14	16	15	9	6	16	0.538
IA-12	5	17	7	3	2	5	6	18	7	10	8	3	0	7	2	1	2	5	0.273
IA-13	3	3	5	7	9	3	4	4	3	4	3	2	10	3	3	2	12	3	0.210
IA-14	10	10	15	16	14	11	10	12	8	7	16	7	11	10	12	12	11	12	0.515
IA-15	12	8	17	19	17	16	19	19	17	11	15	18	20	12	18	20	10	20	0.727
IA-16	21	20	21	22	22	22	22	5	22	22	21	20	21	22	21	22	21	22	0.932
IA-17	1	4	11	2	12	4	1	3	5	6	1	10	5	5	0	7	4	2	0.210
IA-18	0	0	0	0	1	0	0	0	0	0	2	0	1	1	4	0	0	0	0.023
IA-19	19	5	19	18	15	20	11	10	13	9	18	22	19	13	16	17	19	9	0.687
IA-20	17	19	13	10	7	15	14	16	9	16	12	14	9	15	14	4	3	10	0.548
IA-21	14	9	3	12	10	18	8	20	10	8	6	6	6	6	6	10	17	8	0.447
IA-22	22	18	20	21	21	21	21	13	21	18	22	21	22	18	22	21	22	21	0.922
IA-23	15	22	8	6	13	12	12	22	20	17	17	6	7	9	10	19	9	18	0.611

APPENDIX E

BRIEFING PROCEDURE

The following is a copy of the instructions given each officer before he began ranking the stimuli:

"The problem with which we are concerned is the evaluation of surveillance systems and of components of a surveillance system.

"The end product of a surveillance system is an intelligence estimate and this estimate is an approximation to a true situation. We are going to develop an equation by means of which we can measure how well one estimate approximates its true situation compared with how well another estimate approximates its true situation.

"However, there are many respects in which an estimate can deviate from a true situation, e. g., identification, strength, and location, and we need to collect data from the judgments of experienced military personnel which we can use to determine the parameters in these equations. Thus the problems which we will present to you for judgment have no "school" solution. You could regard what we're doing as trying to arrive at a school solution by combining the careful judgments made by the officers best qualified, in experience and training, to make them.

"The general procedure is as follows you will be shown a series of estimates paired off with their respective true situations, at first all on the same terrain. You will be asked to rank order from right to left the pairs (an estimate and its true situation) in order of how well the estimate approximates the true situation.

"I will show you an example: (Two true situations were shown, one each on terrain instances I and II, and corresponding estimates were exhibited. Both situations displayed infantry and artillery units. The officers were asked to consider which estimate more closely approximated its respective true situations. One fitted closer to the infantry situation than the artillery situation and the other the reverse. There was no obvious or clear choice and the officers were asked merely to discuss the considerations involved in deciding between them. They were not pushed to make a decision or judgment on these illustrative cases as the objective was merely to bring out explicitly the various considerations that entered into the judgment.)

"There are some things you should know as background.

"Regard yourself as a regimental commander in an attack situation with normal capabilities. You can draw upon higher headquarters for support. The artillery shown is direct support artillery. You are free to choose whether to fight during the day or the night.

"However, even more important for our purposes is the attitude with which you approach these problems. Remember that you are evaluating the surveillance system or component that came up with that estimate of that true situation. Essentially you can imagine that you are ranking the 'systems' as to which one you would prefer to have on your team. Furthermore, you should judge not only as the commanding officer of the regimental combat team but you should also try to keep in mind the welfare of the larger units of which you constitute a part. Thus, for example, a surveillance system may come up with a gross over-estimate of a true situation, so you decide to draw upon higher headquarters for support. This means, of course, that this support is not available elsewhere where it may be needed more, although you yourself will be readily able to accomplish your mission. If such an estimate of a true situation were a good one we wouldn't need surveillance systems, we would just imagine the enemy had maximum capabilities and we would probably lose a lot of campaigns by not fighting them.

"On the other hand, of course, a surveillance system should be penalized if it underestimates a true situation because now you might run up against something for which you are not prepared and suffer serious losses.

"Now, no surveillance system is perfect. Each one will almost certainly give you an inaccurate or incomplete picture of what's out there, and your problem is to decide how important the various kinds of inaccuracies are, relatively by rank ordering, the best approximations on down to the worst approximations from right to left.

"We will first do this for infantry units alone on three different terrain instances and then combine them.

"Then the same thing will be done for a surveillance system which only reports artillery units.

"And finally the same thing will be done for estimates that have both infantry and artillery on them.

"Are there any questions?"

APPENDIX F

DEBRIEFING PROCEDURES

Name ____________________

Date ____________________

QUESTIONNAIRE

1. Find out how much combat command experience. Record in terms of months, echelon, and theater.

2. Same for experience as S-2 or in a G-2 section. Record in terms of months, echelon, and theater.

3. Ask the officer how he would describe his basis for deciding which estimates were best. Information we would like is:
   a) Did he have a formula? If so, what is it?
   b) Did units (infantry and artillery) need to be pin-pointed to be counted as hits? Or did he just look at over-all strength? Or something in between?
   c) How did he weigh information on infantry as compared with artillery?

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1. Surveillance System Model
2. Testing of Model
3. Evaluation of Tests
4. Contract DA-36-039 SC-52654

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