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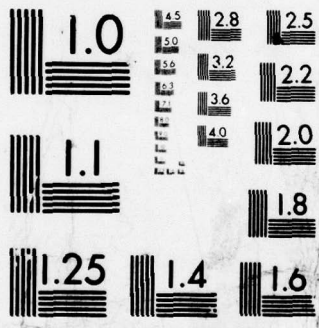
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BY
GEORGE A. PETERS, JR.
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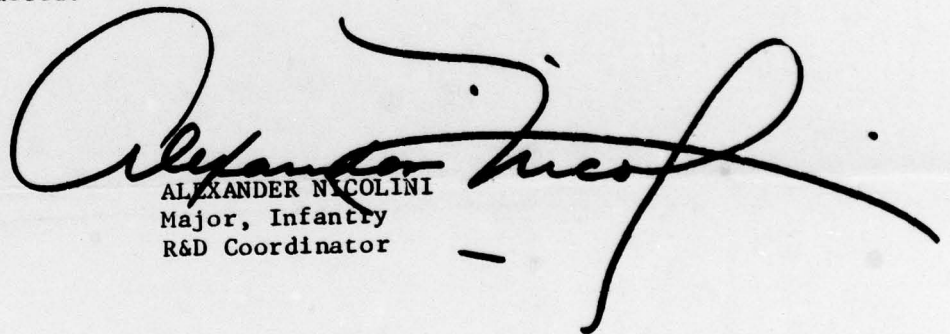
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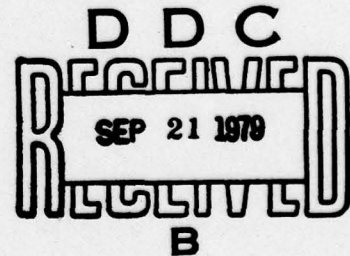
METHODOLOGICAL APPLICATIONS OF HUMAN FACTORS
IN OPERATIONS RESEARCH

George A. Peters
C. Thomas Goldsmith

Human Engineering Technical Memorandum No. 16

Samuel Feltman Ammunition Laboratories
Picatinny Arsenal, Dover, New Jersey

May 1957



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Note: This technical memorandum was prepared for distribution within Picatinny Arsenal and, therefore, reflects only the opinions of the authors. It does not necessarily reflect the opinions or policy of Picatinny Arsenal.

PREFACE

The field of human engineering or human factors engineering has been defined recently (14) as "that activity wherein a special emphasis is placed upon determining the optimum mode of interaction between man and the machine systems of which he is a part". The following are typical examples of the work of the human engineer:

- Recommendations for the design of display and control devices for complex equipment (such as dials, signal and warning lights, knobs, levers, pedals, pushbuttons, switches, etc.)
- Simplification of maintenance procedures (such as color coding parts or components, etc.)
- Optimum illumination for human tasks so that work fatigue and human error is minimized.
- Increasing the reliability of the human operator in controlling or monitoring machines.
- Improvement in machine information links involving the human as an interpreter or decision-maker.
- Layout of work space to improve man-machine unit performance.

Because the field of design engineering has grown so complex, the design engineer may have neither the time nor the specialized knowledge to take into consideration all of the human factors involved in a design problem. Therefore, he may call upon the human engineer in the spirit of the "team approach" for consultation on the human factors involved in

- safety
- training
- maintainability
- reliability
- operator efficiency

However, the human engineer is also concerned with other problems in addition to the specific design details relating to the humans who are to use a piece of military equipment. The larger problem of weapon systems effectiveness often involves human factors problems. Thus, human engineers have an interest in the problems of systems analysis and operational research.

The following paper, which was presented before the Fifth Annual Meeting of the Operations Research Society of America, is one example of the application of human factors research in systems analysis and operations research. It demonstrates the method by which human factors research may be applied to overall evaluative problems requiring management decision.

ABSTRACT

↓ This case study report includes (1) a description of some of the human factors involved in a weapons systems analysis of the effectiveness of anti-personnel mines, (2) an a priori (theoretical) solution for a component of the system, (3) the actual empirical results obtained from field test of the component, and (4) how this relates to the methodological applications of human factors in operations research.

The following points are emphasized: (a) Adequate attention should be given to the human components of man-machine systems in operational analyses. (b) The nature of the decisions resulting from OR evaluations demand acceptable levels of component validity. (c) Common sense and logic when applied to the human variable is quite apt to be erroneous.

↖

This is the text of a report
presented in Philadelphia, Pa.
on May 10, 1957 before the
Operations Research Society
of America

AN ANALYSIS OF THE HUMAN FACTORS COMPONENTS
OF AN ANTI-PERSONNEL MINE SYSTEM

George A. Peters & C. Thomas Goldsmith
Picatinny Arsenal

Those scientific investigations which determine the relative effectiveness or utility of military weapons systems are generally based upon rigorous studies of the appropriate systems components and their interaction. The criterion of such weapons systems effectiveness is usually defined in terms of tactical needs in combat situations. Unfortunately, it is not always possible to check on the validity of the effectiveness estimates for such weapons since there are some very practical limitations imposed upon the setting-up and conduct of real life tests of military weapons. Even if weapons systems could be tested in actual combat against the enemy, this type of practical proving ground does not occur with such regularity or convenience as to be helpful during all design and evaluation phases. Once combat begins, weapons cannot be held back from full production to permit full and ample consideration of the ideal or optimum weapons characteristics.

Under such circumstances, and for other desirable reasons, it is

necessary to formulate analytic solutions to such operational problems. It is apparent that the analytical procedures should carefully simulate reality so as to closely predict what would happen in an actual test. Because of the nature of the problems involved in such simulation, such as the time, effort, and costs involved to measure the typical complex interacting variables, all too often the analytical model of reality leaves much to be desired. Since specific conclusions must be reached as quickly as possible, there is a tendency to rely upon highly simplified and convenient problem-solving techniques. Occasionally, such simplified methods and arbitrary approximations may compound errors which threaten the inherent value of the contributions being made by the systems, operations, and gaming approach.

This is a case report on the validity of just such a simplified approximation of a human factor component in a military weapons systems analysis. The problem was to determine the effectiveness of a tripwired land mine system under certain operational conditions. One important component of the systems analysis included a human factors variable; namely, the probability of visual detection of the tripwire which was to be used in the actuating device of the mine.

Just how could the probability of visual detection be determined?

One solution which had been in use for the systems analysis relied upon the following assumptions. It seemed logical that an enemy soldier would have far greater opportunity to see a long tripwire placed across his path than a comparatively short one. This is because certain portions

of the wire may blend into the heterogenous background usually found in country terrain. A longer tripwire would increase the possibilities of contrasting portions of the wire against the background and, thus, permit more rapid detection of the tripwire by an approaching soldier. Since the eyes of the soldier may focus on one portion of the area to his front rather than another, the greater the area covered by the tripwire, i.e. the longer the tripwire, the greater chance of its detection. As the length of the tripwire approaches the limit of human visual acuity, the opportunities for visual detection would tend to level off. This relationship between length of tripwire and probability of visual detection is shown in Figure 1, wherein the Apriori or Theoretical Function is represented by a curve which has increasing amplitude over the critical range of tripwire length then becoming asymptotic to the maximum value of detection probability. That is, beyond the limits of visual acuity no further advantage in detection is gained. But, the critical range of rapidly increasing detection was within the range of visual acuity given ideal conditions. It is also a critical range in terms of other systems components. The problem, then, would seem to be to check these formulations to be sure that the curve is an accurate description of what would take place in a tactical combat situation.

A preliminary human engineering evaluation of some of the variables at play which might contaminate the securing of valid estimates of visual detection included: the nature of ambient illumination present in the minefield; the color of the tripwire and the terrain against which it is exposed; individual variation in visual acuity and other

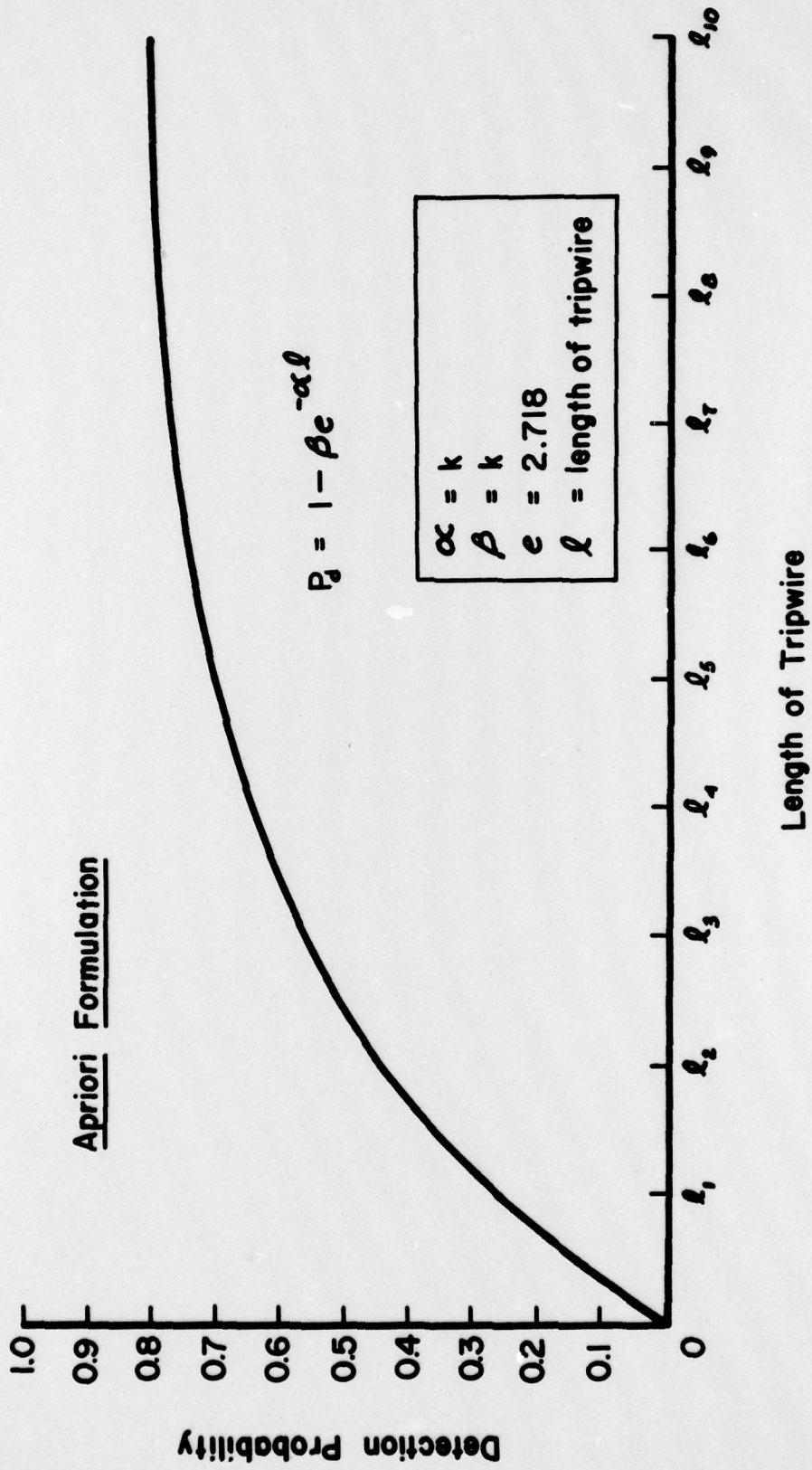


Figure 1 - PROBABILITY OF VISUAL DETECTION

functional visual anomalies such as color blindness, level of motivation of those performing the search; the nature of the visual search, such as the location and percentage of area which is covered during an intensive visual inspection for tripwires; what kind of visual cues might the searcher rely upon; what kind of foliage might be present; what are the effects of the stresses of battle which might be imposed upon the searcher; and some ten or twelve other such variables.

Now to set up an experiment or series of experiments to develop the basic data relating to these variables and their interaction would result in information of fairly general applicability but at a prohibitive cost. Therefore, it was decided to lump all the variables together in a field test which would give overall estimates of the probability of visual detection under simulated tactical or operational conditions.

Therefore, a simulated minefield was constructed in a slightly wooded area of heterogenous background. The tripwires were laid in a manner carefully simulating that which might be expected under combat conditions. Each subject was requested to search for and attempt to detect a series of concealed tripwires while traversing a marked path through the minefield.

In this experiment, 560 tests were conducted with 35 subjects and 16 tripwires of 4 different lengths. Much to our surprise, the resulting empirical findings shown in Figure 2 indicated that the probability of detection does not vary with length but is a constant over the critical ranges tested.

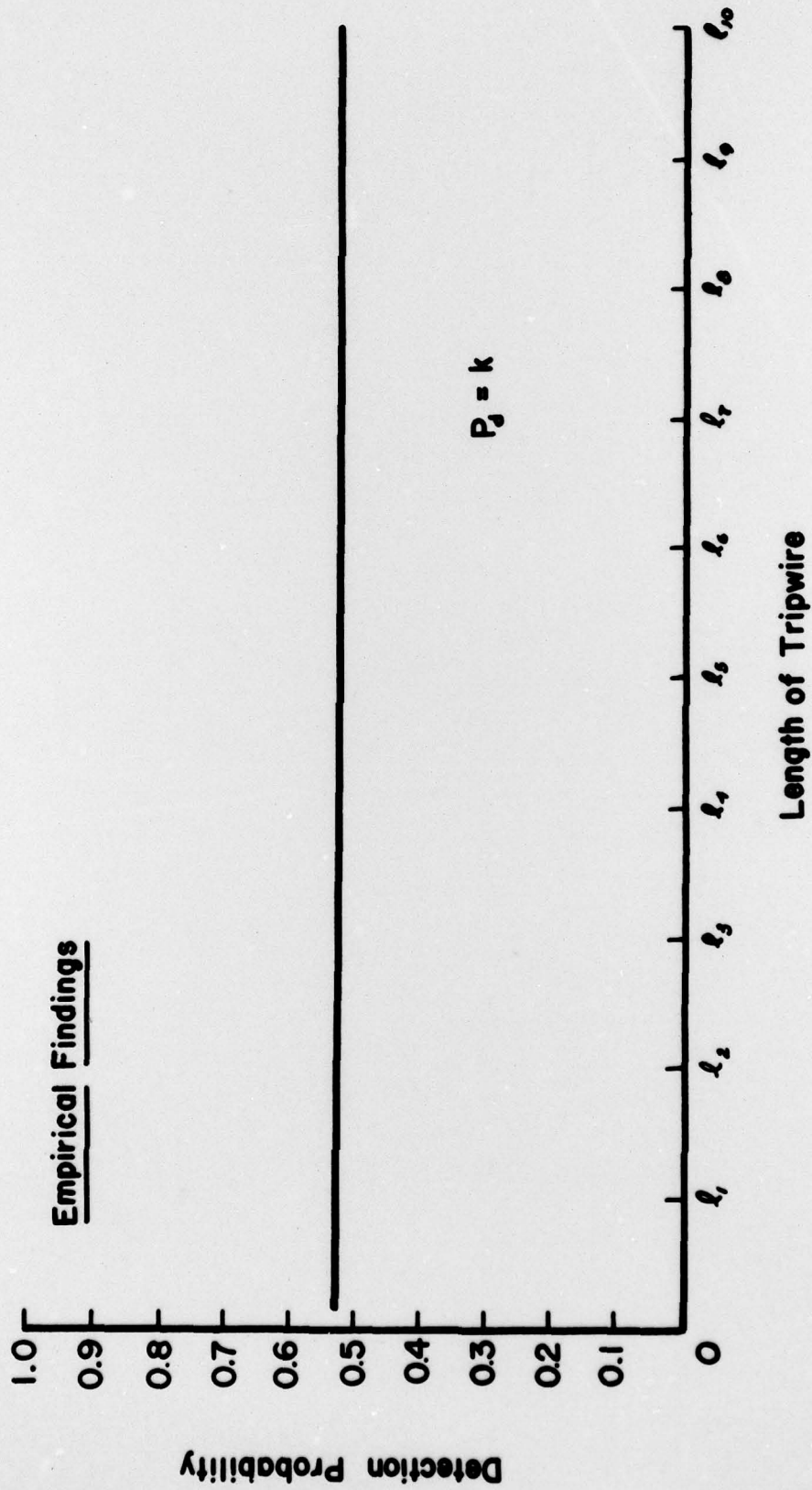


Figure 2 - PROBABILITY OF VISUAL DETECTION

Thus, it can be seen that the original formulations based upon logic and common sense were erroneous. These formulations were corrected because an Operations Research approach was utilized. Specifically, human factors specialists were called in to verify a systems component falling within their field of endeavor, and this altered the recognizable characteristics of the total systems or operation so as to result in a substantial basis for certain management decisions.

Figure 3 indicates the kind of management decisions which could be based upon this study. It is a highly simplified schematic version of the relation of tripwire length to mine system effectiveness. Under the Apriori Formulation, the Current Model (shown by the continuous curve) reaches the minimum level of effectiveness at some point L_x . However, as a result of the field study of visual detection, we find that the curve actually has much higher values (as indicated by the discontinuous curve). Therefore, a Functional Decision may be made which would state that land mines may now be used with longer tripwires, that is to point L_y . This management decision would, of course, effect manufacturing processes, troop training procedures, and current tactical battle doctrine if implemented. There would also be a feedback to countermeasures.

There is, however, opportunity for another management decision. The exponent E of the system equation shown in Figure 3 is a function of probability components P_1 through P_4 which may be considered as constants for this situation. The other two system components, P_5 and $(1-P_d)$, have a significant relationship to each other. P_5 has to

$$\text{System Effectiveness} = P_k = 1 - e^{-E}$$

$$\text{where: } E = P_1 P_2 P_3 P_4 P_5 (1 - P_6)$$

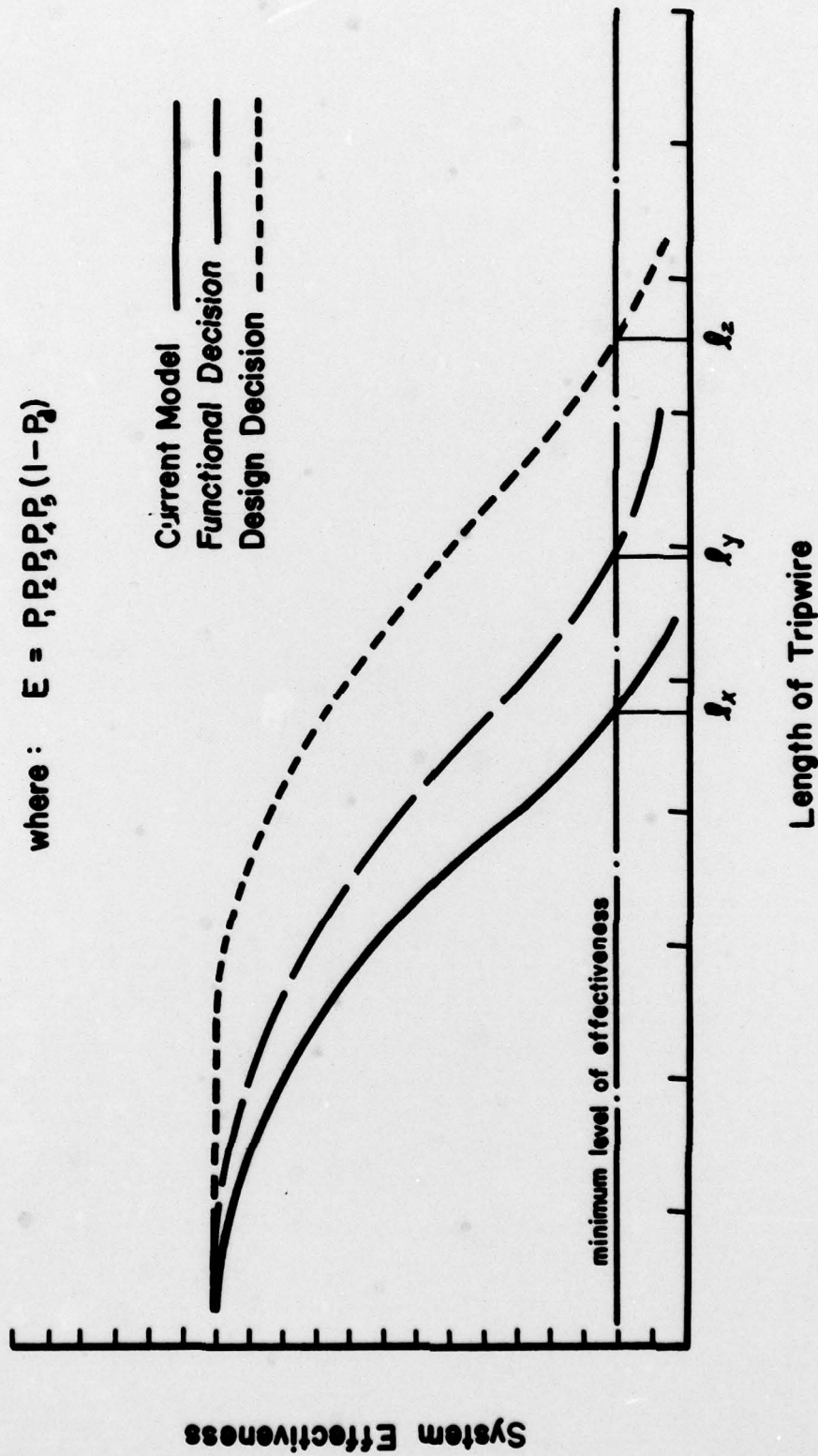


Figure 3 - RESULTANT MANAGEMENT DECISIONS

do with the ordnance design engineering of the mine, that is, the design characteristics of the mine. Under the Apriori Formulation for visual detection, the mine need not be designed for distances beyond L_x because of the high probability of detection with longer tripwire. Enough overdesign was assumed present to justify the previous Functional Decision to extend the tripwire to L_y . But, since component $(1-P_d)$ was found to be a constant, the design of the mine (component P_5) can now be varied to achieve certain revised optimum characteristics. This Design Decision could, then, extend the minimum effectiveness estimate to point L_z . That is, the revised nature of one system component has altered the potential contribution of another system component to the total systems output.

This case study illustrates the utility of the human factors specialist in the OR team. The nature of the executive decisions resulting from OR type methodological evaluations demand acceptable levels of component validity which are obtainable only by full use of each of the several scientific disciplines involved. The application of the operations research approach to the "art" of scientific warfare and the nature of the executive decisions resulting from such methodological evaluations has now greatly emphasized the need for full and proper human factors consideration.

Future studies involving the human component in mine system analyses will attempt to improve the "simulation" by emphasizing the "real life" features of the experimental test situation. For example, in a tactical combat situation, the soldier has many distractions in

passing through a mine field: he has an assigned mission to complete; in addition to searching for tripwires he will have to watch for other types of land mines, the threat of enemy soldiers in ambush, and occasional artillery fire; he may suffer from the stress of battle; or he may be a member of a small group such as the reconnaissance patrol. Operations Research questions include: What is the optimum combination of various land mines and actuation devices for these mines under certain stated terrain and combat conditions to achieve certain objectives in the most efficient manner. These studies should include concurrent operational gaming investigations since tactical combat is, most assuredly, a competitive situation.

In conclusion, several basic principles are implicit in the discussion of this OR case study. First, whenever analytic solutions are based upon what seems to be common sense logic or theoretic approximations, some means should be devised to check on the reality of these suppositions in the tradition of the scientific method. This may seem rather elementary, but we all know that in actual practice it is often neglected. It is particularly germane to the study of variables involving the human factor. Second, this case study illustrated that in the systems approach a specialized investigation of one system component may significantly effect the potential contribution of some other system component thus altering the total systems output. Lastly, certain efficiencies may result in the experimental estimation of human factors variables if this component is treated as a whole under carefully simulated operational conditions. This pertains, primarily,

to OR situations wherein executive decisions will be made on the comparative merits of total systems. However, in the intermediate design and development stages, more detailed or intensive study of the various complex interrelated human variables may be warranted in terms of potential improvement of the total system.

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