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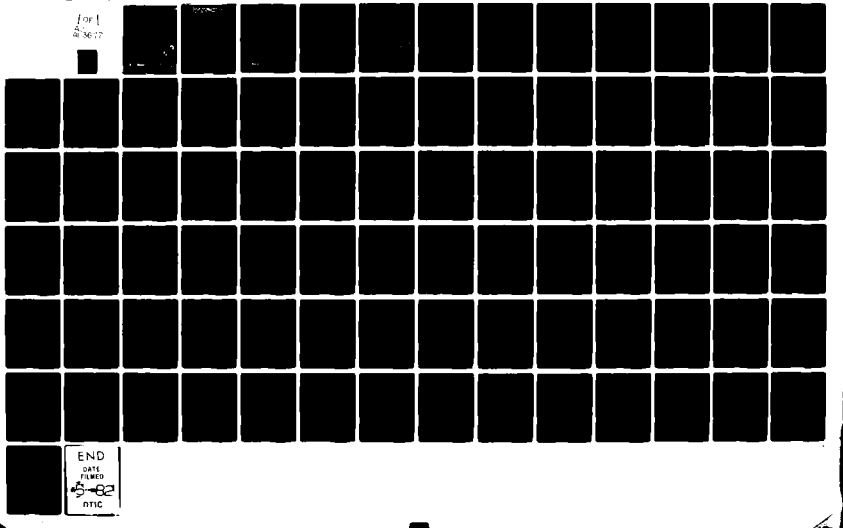

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DEMONSTRATION OF THE SUBJECTIVE TRANSFER FUNCTION APPROACH APPLIED TO AIR-FORCE-WIDE MISSION AREA ANALYSIS

Clairice T. Veit, Monti Callero,
Barbara J. Rose

February 1982

N-1831-AF

Prepared For

The United States Air Force

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DEMONSTRATION OF THE SUBJECTIVE TRANSFER FUNCTION APPROACH APPLIED TO AIR-FORCE-WIDE MISSION AREA ANALYSIS

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This Note describes an application of the subjective transfer function (STF) approach to complex system analysis to an Air-Force-Wide Mission Area Analysis (AFWMAA) problem domain. Following a short description of the background that led up to the research and an overview of the STF approach, the authors discuss how the STF approach was applied to the AFWMAA problem domain of immediate targeting for battlefield air interdiction in the tactical command and control mission area. That section includes: the hypothesized structure of the problem domain; how the judgment data were gathered; the judgment models entertained as STFs to explain how the components comprising the structure affect judged outcomes; how the data were analyzed to provide information about the appropriateness of the hypothesized structure and the appropriate STFs for functionally linking the components of the structure; and how resulting STFs would be used to assess the capabilities of alternative command and control systems. Finally, the significant features of the STF approach are described and a brief summary is presented. 74 pp. (Author)

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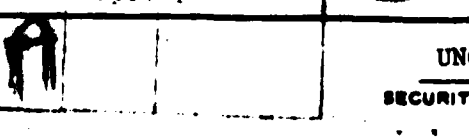

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PREFACE

In this briefing note, the authors present the results of an investigation of the applicability of the subjective transfer function approach to complex system analysis--as developed by Rand[1]--to Air-Force-Wide Mission Area Analysis. The work was requested by the Capability Assessment Division, Directorate of Plans, Office, DCS/Plans and Operations, Headquarters, United States Air Force. It was conducted as part of the Concept Development and Project Formulation project of the Project AIR FORCE Resource Management Program.

[1] See C. Veit and M. Callero, Subjective Transfer Function Approach to Complex System Analysis, The Rand Corporation, R-2719-AF, February 1981.

SUMMARY

This Note describes an application of the subjective transfer function (STF) approach to complex system analysis (Veit and Callero, 1981) to an Air-Force-Wide Mission Area Analysis (AFWMAA) problem domain. The application demonstrates that the STF approach can be readily used by AFWMAA to establish a basis for evaluating Program Decision Packages and for generating subjective inputs to utility models supporting major mission areas. Furthermore, the STF approach has the advantages of (1) clearly and efficiently representing the problem domain, (2) empirically testing the representation and the relationships among its factors that explain how they produce outcomes of interest, (3) illuminating and accounting for synergistic effects among factors, and (4) directly showing tradeoffs among the factors for guiding decisionmaking.

The selected AFWMAA problem domain was immediate targeting for battlefield air interdiction (BAI) in the tactical command and control mission area. The initial representation of the problem domain consisted of five sets of factors hypothesized to either directly, or indirectly through outcomes internal to the structure, affect the ability to do BAI immediate targeting. Respondents answering questionnaires fielded for study were Air Force officers assigned to the Pacific Air Forces (PACAF) and Headquarters, Pacific Command.

Results of data analyses indicated that the initial representation should be altered to consist of four (instead of the originally hypothesized five) factor sets, with a separate STF to link each set of

factors to its outcome. Three STFs were selected to account for interactions observed in the data among many of the factors. Two kinds of interactions were observed. For two sets, when capability was poor for one factor, another factor affected judgments less; e.g., the ability of the tactical air control facilities to support the immediate-targeting function made less difference when the ability to communicate tasking orders to the tactical air forces was poor than when it was good. For another set, when capability was poor for one factor, another factor had a greater effect on judgments; e.g., the capability of gathering enemy emitter data made a greater difference to respondents when capability for gathering enemy vehicle data was poor than when it was good. A fourth STF best explained the primarily additive (noninteractive) data found in the fourth set.

The resulting structure and STFs provide the basis for evaluating command and control and intelligence collection system configurations in terms of how well the BAI immediate targeting function could be performed. Examples are provided using notional configurations to demonstrate how Program Decision Packages would be evaluated and inputs provided to theater models.

CONTENTS

DEMONSTRATION OF SUBJECTIVE TRANSFER FUNCTION APPROACH APPLIED TO AFWMAA

Slide 1

This briefing note reports on the application of the subjective transfer function (STF) approach to an Air-Force-Wide Mission Area Analysis (AFWMAA) problem domain.

OUTLINE

- **Background**
- **STF approach overview**
- **Application**
- **Significant features**

Slide 2

Above is an outline of the note. Following a short description of the background that led up to the research and an overview of the STF approach, we will discuss how the STF approach was applied to a selected AFWMAA problem. That section includes:

- o the hypothesized structure of the AFWMAA problem domain;
- o how the judgment data were gathered;
- o the judgment models entertained as STFs to explain how the components comprising the structure affect judged outcomes, and
- o how the data were analyzed to provide information about the appropriateness of the hypothesized structure and the appropriate STFs for functionally linking the components of the structure;
- o how resulting STFs would be used to assess the capabilities of alternate command and control systems.

Finally, we describe the significant features of the STF approach and briefly summarize the paper.

BACKGROUND

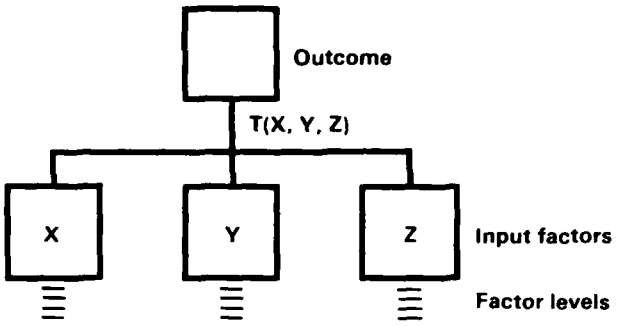
- **Initiated by XOXIM**
- **Investigate improved techniques**
- **Demonstration effort**
- **Tactical C2/BAI/immediate targeting**
  - **PDP assessment**
  - **Theater model support**

Slide 3

The study was initiated by the Capability Assessment Division (XOXIM), *Directorate of Plans, Office, DCS/Plans and Operations*, Headquarters, United States Air Force, in order to investigate improved methods for conducting AFWMAA.

It was decided that Rand's effort would be to demonstrate the STF approach to a representative MAA problem domain. The domain selected was in the tactical command and control portion of the orientation mission area. Specifically, it was the immediate targeting function within the battlefield air interdiction (BAI) mission area. We were particularly interested in demonstrating how program decision packages (PDPs) would be assessed and how inputs to the MAA theater model would be generated using the STF approach.

STF APPROACH



Slide 4

This slide is a generic representation of a small problem domain--one set of input factors linked by a STF (T(X,Y,Z)) to a single outcome. Three aspects of the STF approach will be pointed out using this generic representation.

1. The problem domain is causally structured; it is comprised of sets of proposed causally linked factors (one set of causally linked factors is shown in this slide). This set depicts the hypothesis that input factors, x, y, and z, impact on the outcome factor. Each input factor is described in terms of its factor levels. For example, if the outcome of interest pertained to making immediate targeting decisions, factor x might be the currency of enemy information coming into the command and control system. The currency factor levels might be one hour, 30 minutes, 15 minutes, and five minutes. Factor y might be the percentage of the BAI area that is covered, with factor levels ranging from 90% to 10%. Factor z would be another hypothesized input factor.

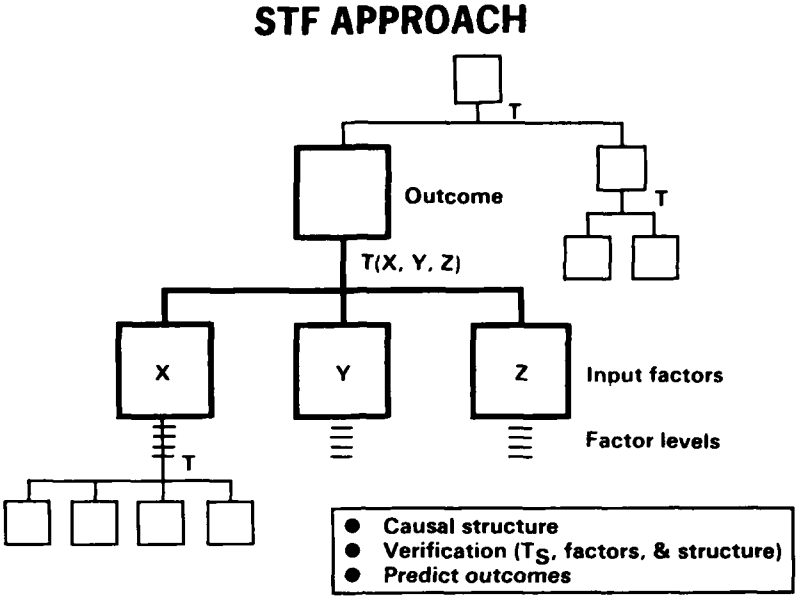
The idea in the STF approach is to determine, from experts' judgments of the outcomes, the subjective transfer function (T(x,y,z)) that links the input factors (described by their factor levels) and the outcome they affect. The T is the algebraic model that specifies how the experts' subjective values of the input factor levels affect their subjective outcome values.

2. In the STF approach, transfer functions (Ts) and the proposed causal structure are simultaneously verified. To do this, questionnaires are generated from factorial combinations of the input factor levels and given to informed respondents. Each item on the questionnaire is comprised of a different combination of factor levels and thus represents a different set of command and control capabilities. To each item, the respondent judges what the outcome (along the specified judgment dimension) would be in that situation. When statistical analyses of respondents' data indicate that one or more of the proposed input factors does <u>not</u> affect their judged outcomes, these factors are eliminated from the structure. If respondents find the task difficult because important information is missing or if much of their data is internally inconsistent, other factors are sought (usually through interaction with the respondents) to describe the structure. The design that generated the questionnaire makes it possible to test different algebraic formulations of T. Only after appropriate Ts are found to explain all the judgment data, does the final causal structure emerge.

3. Once an appropriate T is found, it is possible to use it to predict what the outcome would be for each possible combination of the

input factor levels and hence each different set of command and control capabilities.[1]

[1]When input factor levels are measured using physical values (e.g., minutes, meters, percent), the function relating those physical values to their subjective counterparts (referred to as the psychophysical function or utility curve) is derived from the transfer function, T. Thus for those factors, the appropriate subjective value can be interpolated from the function for any physical value.



Slide 5

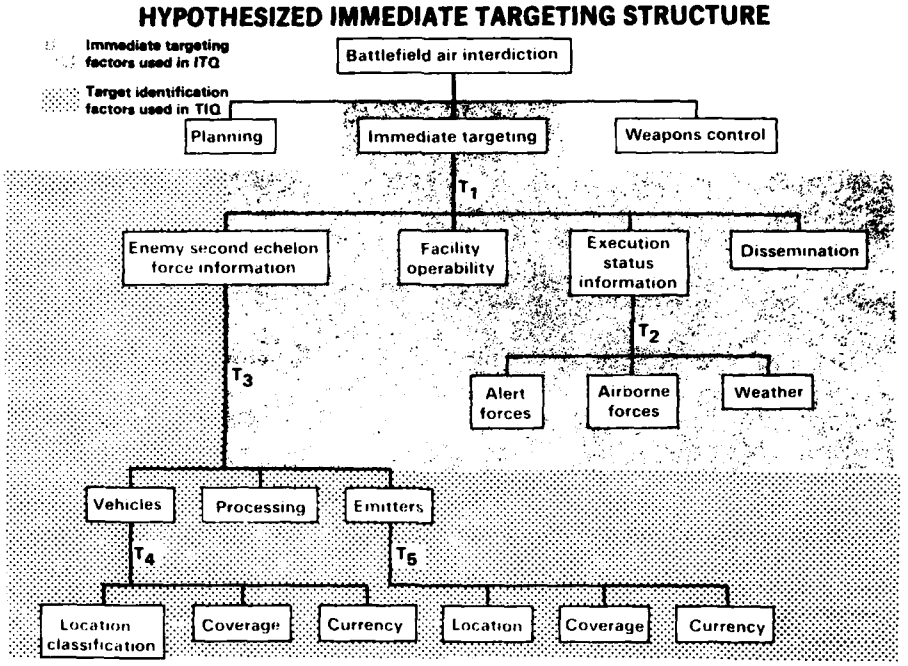
This slide depicts a complex problem domain consisting of four causal sets and four subjective transfer functions (Ts). Verification of the Ts serve to validate the structure (the factors and their hierarchical arrangement) and functionally interlink the sets. When the STFs are known, it is possible to assess how changes in input factor levels at the bottom of the structure affect outcomes throughout the structure and at the top.

STF APPLICATION

- **Structure**
- **Data-gathering methods**
- **Tests of proposed transfer functions**
- **Transfer functions**
- **Outcomes**

Slide 6

The topics to be covered in describing the application of the STF approach to a MAA problem domain are outlined above. We will describe the hypothesized factors and their causally linked sets that make up the structure; data-gathering methods; tests of transfer functions to explain the judgment data; the actual transfer functions that were supported by the respondents' data; and some outcomes implied by those functions.



Slide 7

The problem domain structure used in our demonstration study was that of immediate targeting in the battlefield air interdiction (BAI) area. This slide outlines the factors and factor structure initially hypothesized to depict that problem domain. The domain is hierarchically structured. At the top, three factors are hypothesized to impact on BAI operations. These are the ability to plan those operations (Planning), the ability to do immediate targeting (Immediate Targeting), and the status of weapons control (Weapons Control). Because this study focused on immediate targeting, the remaining structure only depicts the factors hypothesized to affect that component.

Factors hypothesized to directly impact on immediate targeting are: information about the enemy (Enemy Second Echelon Force Information);

information about the relevant friendly forces and the weather (Execution Status Information); the adequacy of the facilities within which the immediate-targeting function takes place (Facility Operability); and the ability to disseminate immediate-targeting decisions to the forces (Dissemination).

Three factors--information about alert forces (Alert Forces), information about airborne forces (Airborne Forces), and information about the weather (Weather)--are hypothesized to impact on immediate targeting through Execution Status Information (T(2)).

Three factors are hypothesized to impact on enemy second echelon force information (T(3)). These are: enemy vehicle information (Vehicles); enemy radio/electronic emitter information (Emitters); and the means by which that information is processed (Processing).

Three factors are hypothesized to impact on enemy vehicle information (T(4)): how well the enemy vehicles can be located and classified (Location/ Classification); how many of them can be observed (Coverage), and how long it takes to report vehicle observations to the command and control system for processing (Currency). Three similar factors, Location, Coverage, and Currency, are hypothesized to impact on enemy emitter information (T(5)). As can be seen, all of the factors at the bottom of the hierarchy impact on immediate targeting at the top through their subjective transfer function links.

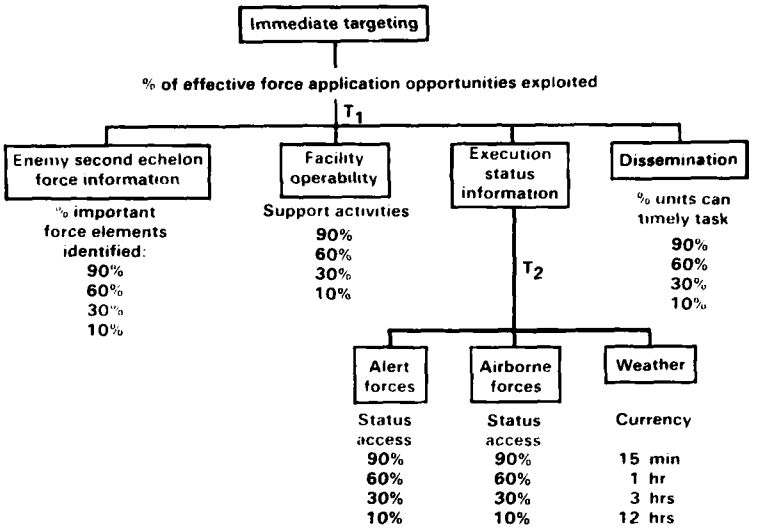
The factors comprising the immediate-targeting structure were separated into two sections that correspond to the two questionnaires fielded for study. Factors used to generate the Immediate Targeting Questionnaire (ITQ) are those in the top (speckled) portion of the

slide. Factors used to generate the Target Identification Questionnaire (TIQ) are those in the lower (dotted) portion of the slide. For both questionnaires, the scenario used as a background was the Korean scenario described in Volume III of the Air Force Planning Guide. Before being given the questionnaires, respondents were given a copy of the scenario and were briefed on the factors comprising the immediate targeting structure.

Respondents for both questionnaires were Air Force officers assigned to the Pacific Air Forces (PACAF) and Headquarters, Pacific Command. They participated on an as-available basis through informal cooperation with the PACAF Assistant DCS for Intelligence and the Special Assistant for Operations Analysis, DCS/Operations and Intelligence.

The next two slides describe the factors and factor levels separately for the two questionnaires.

IMMEDIATE TARGETING QUESTIONNAIRE FACTOR LEVELS



Slide 8

The factors and factor levels used in the ITQ are shown here. Questionnaire items were comprised of different combinations of the factor levels. Thus, each item described a different set of system capabilities. For each item, respondents judged the percent of the effective force application opportunities that could be exploited by the immediate-targeting function, given a command and control system that had the described capabilities. Effective force application opportunities were defined as resulting from the true battle situation and the true availability of forces, whether or not they could be perceived by the immediate-targeting decisionmakers. An effective force application would be the matching of a proper tactical air weapon system with an important enemy target at an appropriate time. The practical advantages of this outcome measure are that it can be used to indicate relative values, in an operational context, of different configurations

of systems that support the immediate-targeting function, as well as provide a valid subjective input value to force effectiveness utility models in the MAA theater engagement mission area.

The input factor, Enemy Second Echelon Force Information, reflects the percentage of the second echelon force elements important to the course of battle that are identified in time for use in performing the immediate-targeting function. The factor levels range from 10% to 90%--a range considered sufficient to span all feasible system configurations.

The input factor, Facility Operability, reflects the ability of the tactical air control facilities to support the immediate-targeting function. It includes condiderations of survivability, capacity, and endurance. It is described in terms of the percentage of all the immediate-targeting activities that would be necessary for the facility to perform if all effective force application opportunities were to be exploited. Again, the factor levels range from 10% to 90%.

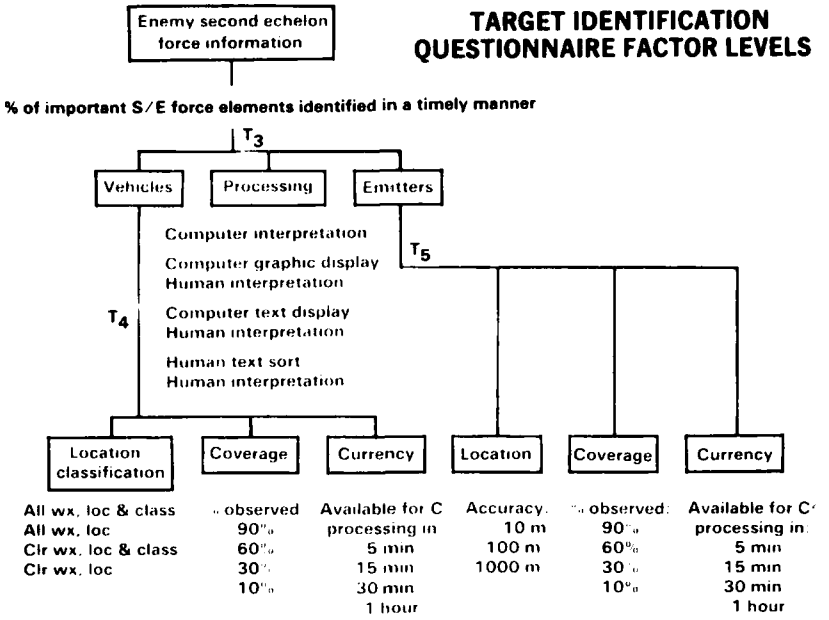
Dissemination reflects the ability to communicate tasking orders to the tactical air forces. It is described in terms of the percentage of forces to which tasking orders can correctly be communicated in time for those forces to accomplish the tasking. Forces of interest to the immediate-targeting function are those on the ground and in the air that can be scrambled or diverted, respectively, to second echelon interdiction missions. Factor levels range from 10% to 90% of the available forces.

Execution Status Information reflects the status of our friendly forces. It is proposed that three factors affect Execution Status

Information. The input factor, Alert Forces, reflects the ability to access information about the status of the designated alert forces. Similarly, the input factor, Airborne Forces, reflects the ability to access information about the status of tactical air forces that are airborne. Both factors are described in terms of the percentage of the forces about which status information can be accessed in time to perform the immediate-targeting function. The factor levels range from 10% to 90%.

The input factor, Weather, reflects the currency of reliable weather data about the enemy second echelon area and the tactical air bases. The factor levels range from 12 hours to 15 minutes.

The factors and factor levels used in the ITQ are described in more detail in Appendix A.



Slide 9

This slide depicts the factors and factor levels used in the TIQ. The outcome measure for this questionnaire (relating to enemy second echelon force information) is defined along the same continuum as when this component was used as an input factor in the ITQ (see Slide 8). That is, respondents judged the percent of the important second echelon force elements that could be identified in a timely manner.[2]

This outcome measure is like the outcome measure for the ITQ in that it can be used to indicate relative values, in an operational context, of different configurations of systems that support the tactical fusion portion of the immediate-targeting function. It also

[2] In the STF approach, this feature of using a factor as both an independent and dependent variable serves to functionally link major sections of hierarchical structures (see Veit and Callero, 1981, for more detail). The Enemy Second Echelon Force Information transfer function (T(3)) serves to link the two major sections--immediate targeting and target identification--of our immediate-targeting structure. This will be illustrated in the results section.

can be used as input to force effectiveness utility models in the MAA theater engagement mission area.

The input factors at the top of this portion of the immediate-targeting structure are data about enemy vehicles (Vehicles); data about enemy emitters (Emitters); and the process by which these data are analyzed (Processing).

The factor levels associated with the three factors hypothesized to affect enemy vehicle information, T(4), are as follows. The location/classification input factor that reflects the ability of our sensor systems to locate and classify enemy vehicles has four factor levels:

1. Locate and classify vehicles in all weather conditions.
2. Locate (but not classify) vehicles in all weather conditions.
3. Locate and classify vehicles in clear weather only.
4. Locate (but not classify) vehicles in clear weather only.

The coverage input factor reflects the percentage of enemy vehicles in the second echelon area that have been observed. The factor levels range from 10% to 90%. The currency input factor reflects the time interval between observing vehicles in the second echelon area and the availability of the data for processing in the command and control system. The factor levels range from 1 hour to 5 minutes. Times beyond 1 hour were considered not relevant to the immediate-targeting function.

The factor levels associated with the three factors hypothesized to impact on the capability to pick up enemy emitter information (T(5)) are as follows. The input factor levels for Location refer to accuracy with which enemy emitters can be located; they vary from within 10m to within

1000m. The input factors Coverage and Currency have the same interpretation and factor levels as for vehicles.

Processing reflects the means by which enemy vehicle and emitter data are interpreted. The factor levels vary by extent of computerized support. At one level there is no automation; humans interpret the data by sorting through hard-copy textual materials (e.g., formatted reports). The other three levels include automation and computer output devices. At one level the human uses the computer to organize, select, search and display textual data to facilitate interpretation. At another level, the human also uses automated graphic displays to present pictures made up of symbols and line drawings, for example, a map with military units, towns, roads, and terrain features. At the fully computerized level, the computer alone organizes and interprets the data.

The factors and factor levels used in the TIQ are described in more detail in Appendix B.

QUESTIONS ADDRESSED IN STF APPROACH

- **Are all factors included relevant?**
- **Is the structure appropriate?**
- **What are the appropriate transfer functions?**

Slide 10

Once an initial structure of the problem domain has been hypothesized, the STF approach is designed to answer the following questions:

(1) Do each of the hypothesized factors empirically affect the Air Force professionals' judgments; that is, have irrelevant factors been included in the structure?

(2) Is the structure appropriately depicted by five causal sets and hence five transfer functions: two for the immediate-targeting portion of the structure and three for the target identification portion?

(3) What are the appropriate transfer functions that best explain the judgment data; that is, what are the functional rules that Air Force professionals use in making their immediate targeting and important target identification judgments?

The questionnaires fielded for study were designed to answer these

questions. In the STF approach, these three questions are addressed simultaneously with tests of the hypothesized STFs.

Once answers to the questions are found, it is possible to use the STFs to assess the capabilities of different command and control systems described by the structure.

POSSIBLE STFs

NONINTERACTIVE (ADDITIVE) MODELS

	Model Formulation	Model Type
1.	$R = \sum_{i=1}^{f} w_i s_i$	Additive
2.	$R = \dfrac{\sum_{i=1}^{f} w_i s_i}{\sum_{i=1}^{f} w_i}$	Relative-Weight Averaging
3.	$R = \dfrac{w_0 s_0 + \sum_{i=1}^{f} w_i s_i}{w_0 + \sum_{i=1}^{f} w_i}$	Relative-Weight Averaging with Initial Impression

INTERACTIVE MODELS

(Formulations are for 3 factors -- A, B, and C)

4. Multiplicative Combinations of Factors

	Model Formulations	Model Type
5.	$R = \dfrac{w_0 s_0 + w_A s_i + w_B s_j + w_C s_k}{w_0 + w_A + w_B + w_C} + \omega(s_{max} - s_{min})$	Range
6.	$R = \dfrac{w_0 s_0 + w_i s_i + w_j s_j + w_k s_k}{w_0 + w_i + w_j + w_k}$	Differential Weight

R = Observed Response
f = Number of factors
s = Subjective scale value associated with factor level
w = Subjective weight
$w_0 s_0$ = Initial impression of the scale value (s) and weight (w) -- what the judgment would be in the absence of specific information
ω = the range coefficient that indicates the size of the range effect in Equation 2.

This slide describes a number of different algebraic models that might serve as STFs. Each model makes different predictions (described in more detail in the results section) with respect to a set of judgment data. It was necessary to consider this wide variety of models because judgment research had never been performed on the factors and factor levels entertained in our immediate-targeting structure (Slides 8 and 9).

Research designs selected to generate the questionnaires allowed tests among the additive and interactive models outlined on this slide. A major questionnaire design feature used to test among the predictions of these models is the factorial combination of the hypothesized factor levels.

For both questionnaires, items were generated from factorial combinations of the input factor levels. Each item represented a different set of command and control capabilities to which the Air Force professional was asked to respond in a particular manner (described next). Details of the designs used to generate the ITQ and TIQ are presented in Appendixes A and B, respectively.

JUDGMENTS OF IMMEDIATE TARGETING EFFECTIVENESS

192 questions; 13 respondents; 40-60 minutes

Response scale: % of the effective force application opportunities that *could be exploited* by the Immediate Targeting Function

Sample Items:

Weather data are 15 min old
Facilities can support 60% of the necessary I/T activities
Timely access to the status of 90% of the designated Alert forces
Timely access to the status of 30% of the Airborne forces

Weather data are 12 hrs old
Timely access to the status of 90% of the Airborne forces
Tasking can be correctly communicated to 60% of the forces in time
Timely access to the status of 10% of the designated Alert forces

Slide 12

For the ITQ, 13 respondents completed 192 items. Respondents were instructed to treat each item as a different situation; that is, each item represented a different description of the command and control capabilities. For each item, respondents judged the percent of effective force application opportunites that could be exploited. Respondents took from 40 to 60 minutes to complete the questionnaire.

JUDGMENTS OF IMPORTANT TARGET IDENTIFICATION

203 questions; 13 respondents; 40-60 minutes

Response scale: % of important second echelon force elements that could be identified in a timely manner

Sample items:

Emitters are located within a 10m accuracy
Emitter info is available for processing 5 min after observation
Human sorts hard copy, textual info; Human interpretation
10% of the second echelon Emitters are observed

Emitter info is available for processing 5 min after observation
Human uses computer to sort textual info; Human interpretation
90% of the second echelon Emitters are observed
Emitters are located within a 100m accuracy

Slide 13

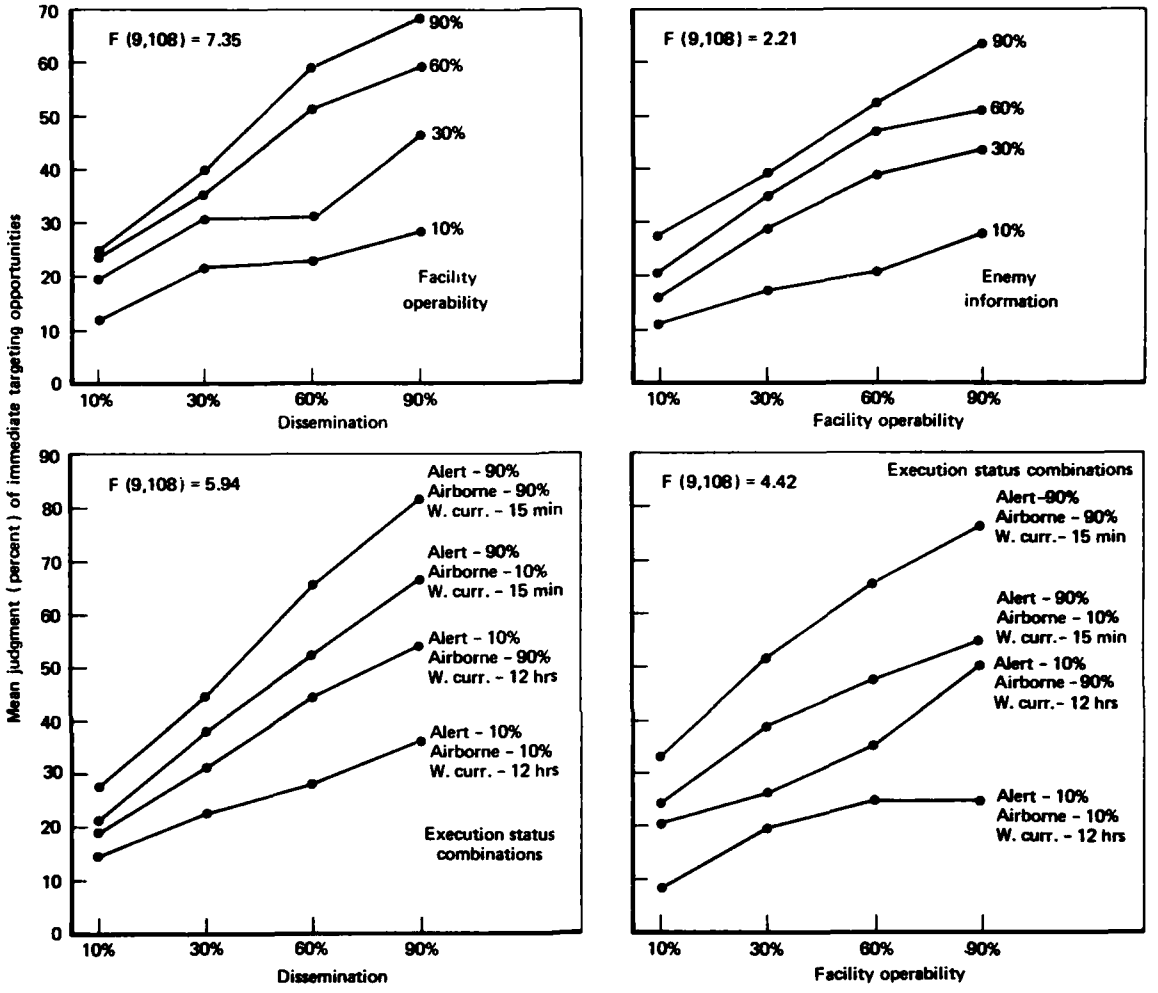
Instructions and procedures were similar for respondents answering the TIQ. For each item, respondents judged the percent of important second echelon force elements that could be identified in the given situation. Thirteen respondents took between 40 to 60 minutes to complete the 203 items.

RESULTS

The goal in data analyses was to find the set of transfer functions (algebraic models) that best explained the judgment data and thus the immediate-targeting structure.

Below, we discuss the results for the two questionnaires (slides 14-21). For both sets of analyses, judgments were averaged over all 13 respondents. Model predictions were tested against mean judgments.

Data from ITQ



Slide 14

ANALYSES AND RESULTS FOR THE IMMEDIATE-TARGETING QUESTIONNAIRE DATA

This slide presents representative graphic and statistical analyses of the ITQ data.

In each panel, mean judgments (percents) of immediate-targeting opportunities that could be exploited are plotted on the y-axis as a function of one of the immediate-targeting factors on the x-axis. A

separate curve is plotted for each level of one of the other immediate targeting factors. The slopes of the curves in each panel indicate the main effect of the factor plotted on the x-axis; vertical separations between the curves depict the main effect of the other factor. Every factor included in the ITQ had a significant effect on judged outcomes. This finding argues for their inclusion in the immediate targeting structure.

Both graphic and statistical (analysis of variance) analyses of the ITQ data revealed interactions among a number of the factors. That is, judgments tended to exhibit synergistic effects. These particular interaction effects are divergent in nature and can be seen by examining the data points in the separate panels above. As capability associated with one factor (e.g., Facility Operability in the upper right-hand panel) improved, the capability level of the other factor (e.g., Enemy Information) made more of a difference (i.e., had a greater effect). (This can be seen by comparing the difference in the vertical distance between the top and bottom curves at 10% and at 90% Facility Operability in the upper right-hand panel. The same effect can be seen in the other panels.) These interactions ruled out additive and averaging models as an appropriate transfer function at the top of the structure. Further, the observed divergence was not of the form that would be expected if values placed on factor levels were being subjectively multiplied.[1] Thus, all models that specified multiplicative interactions among factors were also rejected as appropriate transfer functions.

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[1] Multiplicative models predict bilinear interactions among factors hypothesized to combine multiplicatively (an example is shown in Veit and Callero, 1981).

A range model (shown on slide 11) captured the particular synergistic effects observed in the judgments. A range model predicts that the extremity of the information contained in the questionnaire items has a unique effect on the judged outcomes. For these divergent interactions, the range model had a negative range coefficient (omega in Slide 11), indicating the increased effect of one factor with the improvement in capability of another factor.

Further, the range model that best explained the Immediate Targeting judgments was a six-factor model that included the three execution status information factors--Alert Forces, Airborne Forces, and Weather--as separate factors in the model. That is, the best explanation of the data was one that eliminated execution status information as a separate causal set in the hierarchical structure. These results argue for collapsing the top two tiers of the immediate-targeting structure and depicting this portion of the structure as a single causal set of six factors--Enemy Second Echelon Force Information, Facility Operability, Alert Forces, Airborne Forces, Weather, and Dissemination--impacting on Immediate Targeting. The average data/model discrepancy over all 192 data points was less than 4 percent for this single six-factor range model.

The single six-factor range model was tested against alternative possible explanations of the data. (Competing sets of models were tested using a computer program (written at Rand) that used the STEPIT subroutine[2] to find a simultaneous least-squares solution to all 192 data points.) Because a divergent interaction of the form shown in the

[2] J. P. Chandler, "STEPIT--Finds Local Minima of a Smooth Function of Several Parameters," Behavioral Science, Vol. 14, 1969, pp. 81-82.

above panels was found between the factors Airborne Forces and Weather, the immediate-targeting portion of the structure was also treated as a two-transfer function (two causal set) structure with a range model as the transfer function for execution status information and a range model for immediate targeting.[3] The two range models, however, did more poorly than the single six-factor range model in predicting the data.[4]

Interactions among the other pairs of execution status information factors and the three-way interaction were not significant. Thus, the relative-weight averaging model with an initial impression shown in Slide 11 was also entertained as a transfer function. Again, the fit for a two-transfer function structure with a range model for immediate targeting and a relative-weight averaging model with an initial impression for execution status information was poorer than the single six-factor range model.[5]

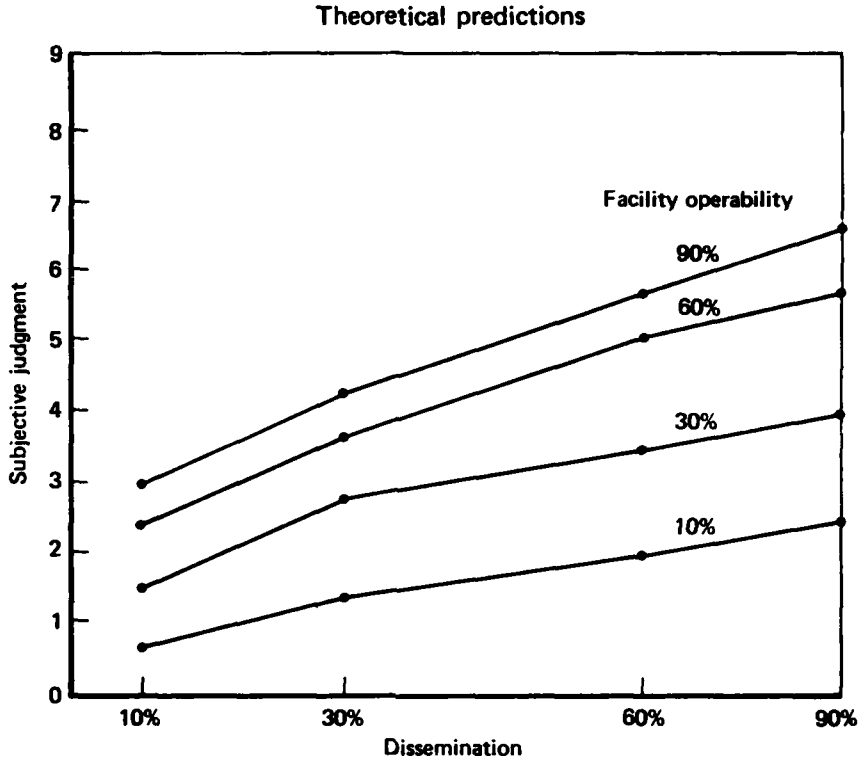
For both two-transfer function representations, the number of parameters estimated was greater and the models' fits were poorer.

---

[3] This two-transfer function structure was tested by fitting a range model to the data obtained from the designs (see Appendix A) that included just the execution status information factors, and embedding the outputs obtained from that function in a range model fitted to data from designs that included all the factors.

[4] The sum of squared data/model discrepancies was 44.6 for the two range models (with 35 estimated parameters) and 28.8 (with 33 estimated parameters) for the single six-factor range model.

[5] The sum of squared data/model deviations for the two-transfer function structure (a range model for immediate targeting and a relative-weight averaging model with an initial impression for execution status information) was 48.5 with 34 estimated parameters).

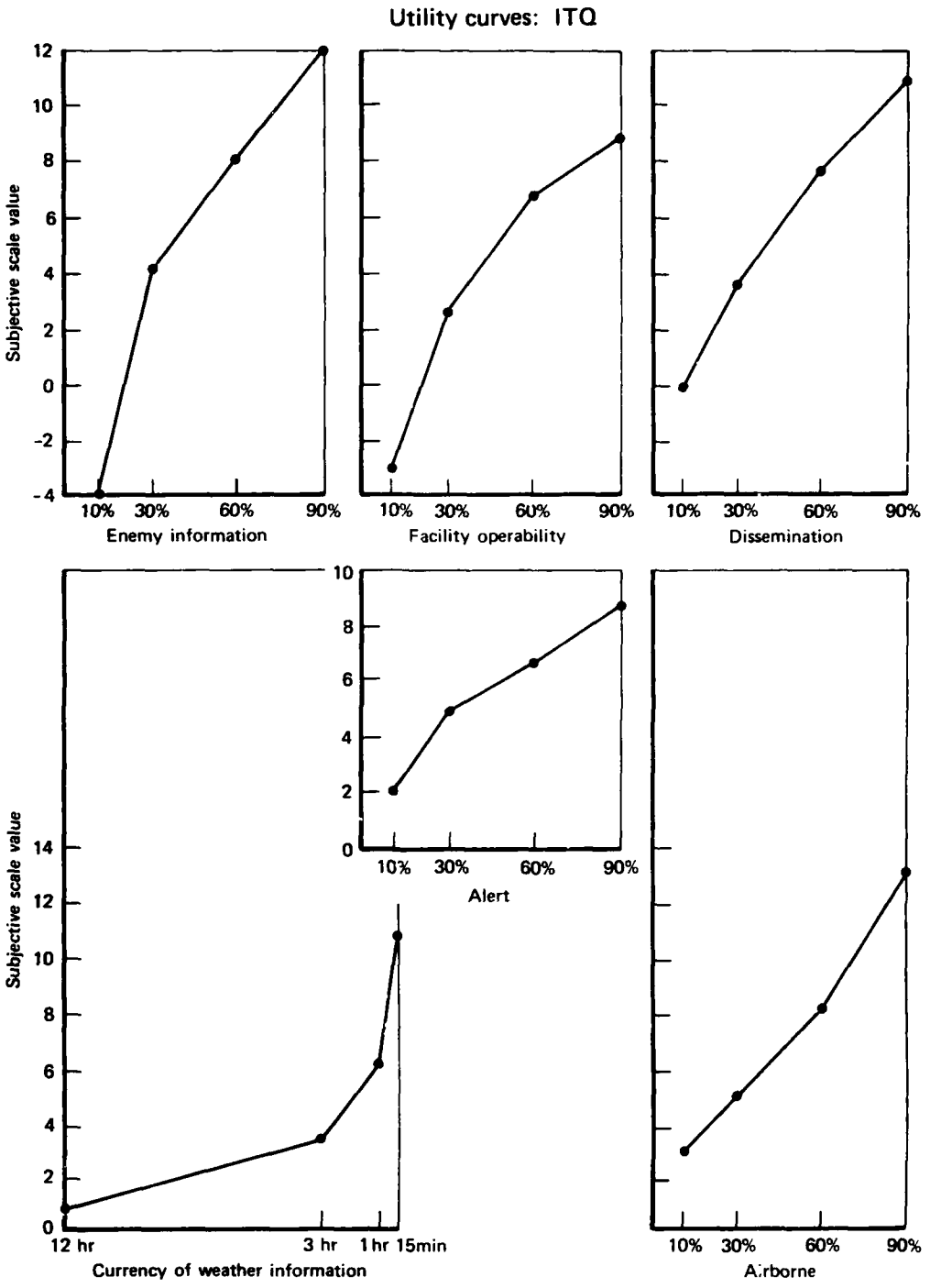


Slide 15

The judgment theory provides the basis for making predictions.[6] This slide illustrates how subjective tradeoffs in factor levels can be assessed once the STFs have been determined. Points on these curves are the theoretical predictions (subjective values derived from the six-factor range model) for the immediate-targeting data shown in the upper left-hand panel of Slide 14. Theoretical values (subjective response values derived from the range model) are plotted on the y-axis as a function of the dissemination factor. (The spacing on the x-axis

[6] The best predictor of data points will be the causal theory that explains their behavior. For example, in astronomy, movements of the planets are predicted better from the theory that explains their orbital movements than from empirical tables of previous data points.

reflects the subjective spacing between the dissemination factor levels; their corresponding physical values are noted on the graph.) A separate curve is plotted for each level of Facility Operability. The theoretical predictions can be used to assess the subjective tradeoffs between these two factors by drawing horizontal lines through the curves. For example, the subjective value of the percent of immediate-targeting opportunities that could be exploited seems to be about the same for a Dissemination capability of 90% and a Facility Operability capability of 30%, and a Dissemination capability of 30% and a Facility Operability capability of 60%. Another way of looking at this is the following. Suppose your present capability lies at the 30% Facility Operability and 30% Dissemination point. You could do about equally well in increasing your overall capability either by increasing your Facility Operability to 60% or by increasing your Dissemination capability to 90%.


Utility curves: ITQ
Subjective scale value
12
10
8
6
4
2
0
-2
-4
10% 30% 60% 90%
Enemy information
Facility operability
Dissemination
Alert
14
12 hr
3 hr
1 hr 15min
Currency of weather information
Airborne

Slide 16

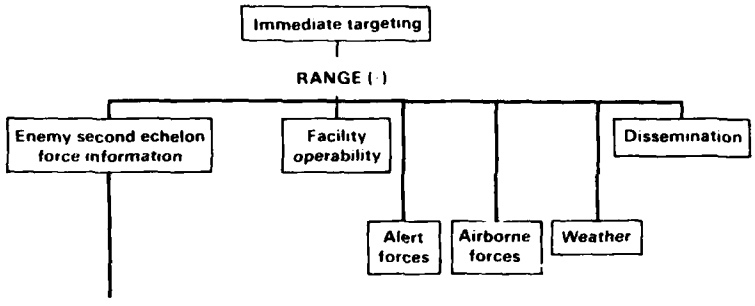
In the STF approach, once an appropriate STF has been found, subjective scale values (utilities) associated with the factor levels can be derived from the STF. When the factor levels are physical values (such as the percents used in this study), the function relating the subjective values to the physical values can be determined.

This slide demonstrates the functional relationship between subjective scale values associated with the factor levels and their physical descriptors. In each panel, subjective scale values derived from the range model are plotted on the y-axis. The physical values associated with the factor levels are plotted on the x-axis. Each panel is for a different factor used in the ITQ that had numerical factor-level descriptions. These functions (referred to as psychophysical functions or utility curves) are all nonlinear.

Estimates of the subjective scale values associated with each level of the six immediate-targeting factors, subjective weights associated with each of the six factors, and the range coefficient are presented in Appendix C.

SUMMARY OF ITQ RESULTS

- **All hypothesized factors are relevant**
- **Altered immediate targeting structure**



- **Transfer function: 6-factor range model**

Slide 17

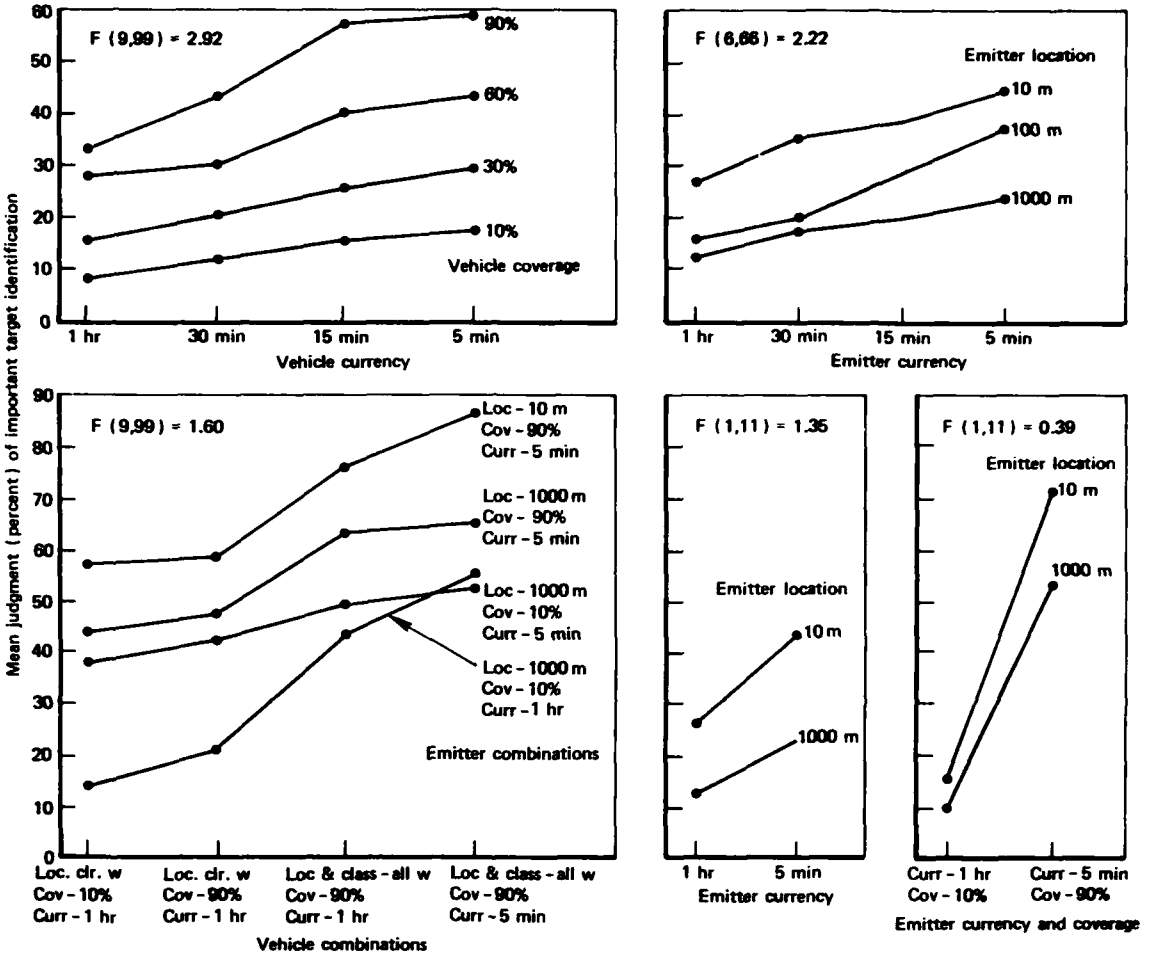
In summary, the major conclusions for the data obtained from the ITQ are:

(1) All manipulated factors should be included in the structure.

(2) A better fit to the data was achieved by describing Execution Status Information as three separate factors rather than a single composite factor, which argues for excluding this causal set from the immediate-targeting structure; the altered structure is shown on this slide.

(3) A six-factor range model with a negative range coefficient provided the best fit to the data, which argues for this model as the transfer function for immediate targeting.

Data fromTIQ



Slide 18

ANALYSES AND RESULTS FOR IMPORTANT TARGET IDENTIFICATION QUESTIONNAIRE DATA

The four panels shown in this slide depict data obtained from the TIQ. In each panel, mean judgment (percent) of important second echelon force elements that could be identified is plotted as a function of one factor, with a separate curve for each level of another factor. Again, the slopes of the curves in each panel of this slide depict the main

effect of the factor on the x-axis; vertical separations between the curves represent the main effect of the other factor.

As with factors included in the ITQ, each factor included in the TIQ had a significant main effect on the judgments, which argues for inclusion of all initially hypothesized factors in the immediate-targeting structure.

The trends found in the TIQ data were markedly different for each of the three causal sets hypothesized to comprise the target identification portion of the immediate-targeting structure. These trends are graphically depicted in the lower left-hand corner for enemy second echelon force information data; the upper left-hand corner for vehicle data; and the two right-hand panels for emitter data. These different judgment trends were best accounted for by a separate transfer function for each of the three hypothesized causal sets, thus supporting the idea that all three sets should be included in the final immediate-targeting structure.

We will describe the trends in the data separately for each causal set as well as the transfer function that was supported by the data. Then we will discuss the alternative transfer functions and structures that were considered.

Enemy Second Echelon Force Information Data

Questionnaire items that corresponded to this causal set in the immediate-targeting structure contained information about the three factors--Vehicles, Processing, and Emitters--hypothesized to directly impact on enemy second echelon force information capabilities. That is,

the items contained information on enemy vehicle data, processing capabilities, and enemy emitter data.

In the lower left-hand panel of this slide, vehicle capability is plotted on the x-axis (each point on the x-axis represents a different combination of vehicle Location, Coverage, and Currency levels). Four separate curves are plotted for four different combinations of emitter capability (different combinations of Location, Coverage, and Currency levels). It can be seen from this graph that both convergent and divergent interaction trends are occurring in the data. If only the top three curves are considered, the curves diverge from the second vehicle combination (second value on the x-axis) to the last vehicle combination. However, when the bottom curve is considered, a marked convergence occurs between that curve and the other three curves from the lowest to the highest value on the x-axis. That is, when the capability of picking up information on enemy vehicles is very poor (lowest point on the x-axis), it makes a big difference as to how well enemy emitter data can be picked up. As the capability of picking up vehicle data improves (moving to the right on the x-axis), this difference is less. Overall, the interaction between these two factors was not statistically significant but it was systematic.

The same divergent/convergent interaction patterns were found for the other enemy second echelon force information data. The interaction between Processing and Emitters was slightly divergent (of borderline significance), while the three-way interaction between Vehicles, Processing and Emitters was convergent. Even though the interactions were either nonsignificant or of borderline significance, a range model

with a positive range coefficient best explained these data (described in more detail below).

Vehicle Data

The graph shown in the upper left-hand corner of the slide depicts a significant divergent interaction between the percent of enemy vehicles observed (Coverage) and the currency of this vehicle information (how quickly it gets into the command and control system). Note that it makes more of a difference to respondents how much information comes into the command and control system when the data are current than when they are not current (compare the magnitude of the vertical separations between the curves at the lowest and highest value on the x-axis). This divergent interaction was typical of the relationship observed among all of the vehicle factors. These prevalent divergent interactions ruled out additive models to explain the data. Multiplicative models were also ruled out because the interactions did not have the bilinear form predicted by multiplicative models. A range model with a negative range coefficient best accounted for these data (discussed below).

Emitter Data

In the upper right-hand panel of the slide, the Currency of enemy emitter information is plotted on the x-axis; a separate curve is plotted for each level of emitter Location capability (the accuracy with which enemy emitters could be located.) Note that the top and bottom curves are quite parallel (the class of additive models predicts

parallelism among factors). However, the middle curve representing an emitter location accuracy of 100m tends to interact with both the top and bottom curves but in different ways. This curve converges with the top and diverges with the bottom curve. This interaction was not significant. The other two-way interaction (between emitter location and coverage) and the three-way interaction were also nonsignificant. The single significant interaction was a divergent interaction between the emitter coverage and currency factors. However, the model that best explained all these data was the relative-weight averaging model with an initial impression (shown in Slide 11).

The data shown in the lower right hand panel of this slide are presented to demonstrate why a simple additive model (the first model shown on Slide 11) was ruled out for the emitter data. The additive model predicts that the effect of a factor (e.g., Emitter Location Accuracy) should be <u>independent</u> of the number of other pieces of information describing the situation to be judged. Compare the magnitudes of the separations between the two curves in the two subpanels. Note that the effect of emitter location accuracy is less when three pieces of information (information about emitter location accuracy, percent of emitters observed (Emitter Coverage), and currency of emitter information) describe the situation to be judged (right-hand subpanel) than when only two pieces of information describe the situation to be judged. That is, the additional information <u>decreased</u> the effect of a particular piece of information--Emitter Location Accuracy. This diminished effect infirms an additive model but is predicted by an averaging model.

Tests of TIQ Transfer Functions and Structures

As noted in the last three sections, a three-transfer function structure was supported by the data; the three functions considered appropriate were: (1) a range model with a positive range coefficient (to pick up the convergent trend shown in the lower left-hand panel of this slide), which was the best transfer function among those entertained for enemy second echelon force information data; (2) a range model with a negative range coefficient (to pick up the divergent interaction trends illustrated in the upper left-hand panel), which was the best transfer function for the vehicle data; and (3) a relative-weight averaging model (to account for the primarily additive emitter data), which was the best transfer function for the emitter data.[7] The average data/model discrepancy over all 203 data points for this combination was about 4 percent.[8]

We tested the notion that this portion of the immediate-targeting structure should be represented by only one causal set, by assessing how well a single seven-factor model accounted for the data. Three seven-factor models for a single-transfer function structure were entertained. These were: (1) a range model, (2) a relative-weight averaging model, and (3) a relative-weight averaging model with an initial impression (Eqs. 5, 2, and 3, respectively, on Slide 11). All of these possibilities provided a poorer fit to the data than the three-transfer function structure described above.[9]

[7] This combination of models was tested by embedding the output of the vehicle range model and the output of the emitter relative-weight averaging model in the enemy second echelon force information range model.

[8] The sum of squared data/model errors for this set of models was 34.8 with 40 paramters estimated.

[9] The sum of squared data/model deviations for the range model, relative-weight averaging model, and relative-weight averaging model

We also assessed two different three-transfer function (three causal set) hypotheses based on the patterns observed in the data.[10] First, we tested the hypothesis that a range model was appropriate for the emitter data (to pick up the emitter Location and Currency interaction trends shown in the upper right-hand panel); a range model was appropriate for the vehicle data (to pick up the divergent interactions); and a relative-weight averaging model with an initial impression was appropriate for the enemy second echelon force information data (interactions among factors here were borderline or nonsignificant). This three-function hypothesis did poorer than the accepted three-function hypothesis.[11] Our second three-function hypothesis was like the first in that a range model was tested for the emitter and vehicle data, but different in that a relative-weight averaging model without an initial impression (see Eq. 2, Slide 11) was tested for the enemy second echelon force information data. When the initial impression was excluded from the averaging model for enemy second echelon force information data, the sum of squared data/model deviations got substantially worse.[12]

A table of subjective scale values, weights, and range coefficients derived from the three-transfer function combination described in the first paragraph of this section is presented in Appendix D.

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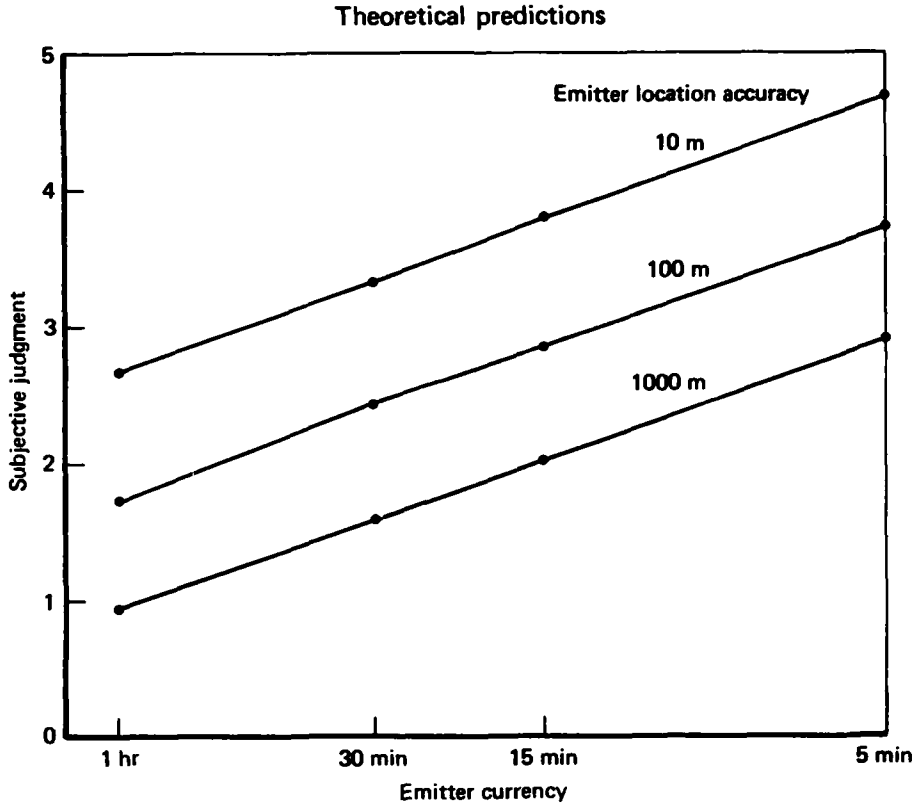
with an initial impression were 51.3, 127.5, and 41.2, respectively, with 37, 34, and 36 estimated parameters, respectively.

[10] These three-transfer function hypotheses were tested by embedding the outputs from the emitter and vehicle functions in the enemy second echelon force information model.

[11] This competing combination had a sum of squared errors of 59.2 with 40 estimated parameters.

[12] The sum of squared deviations increased to 126.3. It is interesting to note that the averaging model without an initial impression is the model that is often accepted as appropriate for all functions in complex systems analyses without empirical tests (of factors, structure, or the function). When this model was tested for all three causal sets in this portion of the structure, the sum of squared data/model deviations was 126.3 with 36 estimated parameters.



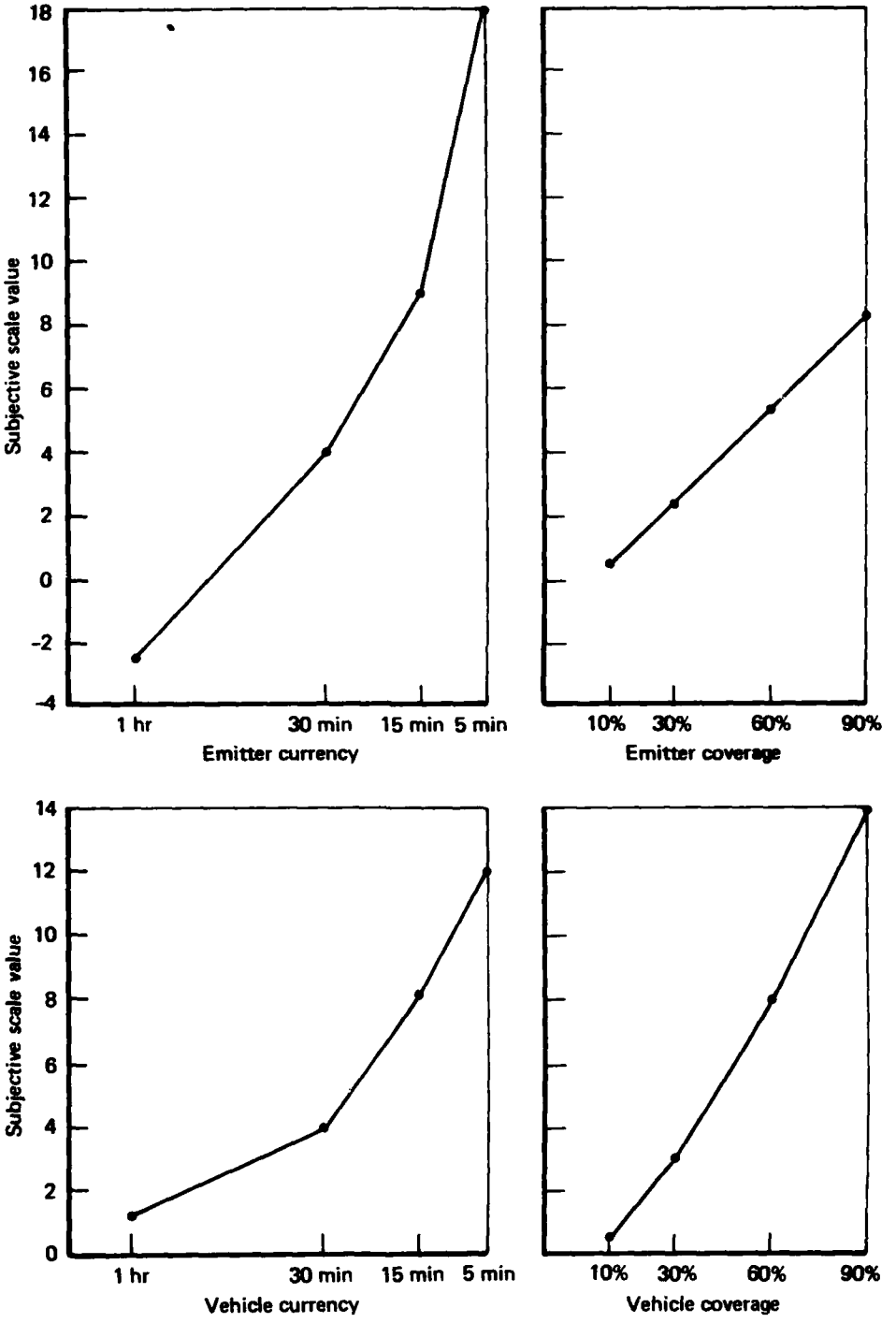
Slide 19

This slide illustrates how subjective tradeoffs in factor levels can be assessed once the STFs have been determined. In this graph, subjective values associated with enemy emitter information (derived from the accepted three-transfer function combination) are plotted on the y-axis. The four levels of emitter currency, spaced according to their subjective values, are on the x-axis. There is a separate curve for each level of the emitter location factor.

This graph tells us, for example, that an emitter location accuracy capability of 1000m combined with an emitter currency capability of 5 minutes is subjectively equivalent to a location accuracy capability of

100m combined with a currency capability of 15 minutes. Also, a location accuracy capability of 100m combined with a currency capability of 5 minutes is about equal to a location/currency combination of 10m and about 20 minutes (interpolated from the graph). Other subjective tradeoffs can be assessed by drawing horizontal lines through the curves.

Utility curves: TIQ



Slide 20

This slide depicts the form of the psychophysical functions (utility curves) obtained for those factors comprising the TIQ that had factor levels measured on a physical scale. Once these functions are known, subjective scale values for factor levels not used in the study can be determined from the functions.

SUMMARY OF TIQ RESULTS

- **All hypothesized factors are relevant**
- **Hypothesized structure is accepted as appropriate**
- **Transfer functions:**
  - **Range model for enemy second echelon force information data**
  - **Range model for vehicle data**
  - **Relative-weight averaging model with initial impression for emitter data**

Slide 21

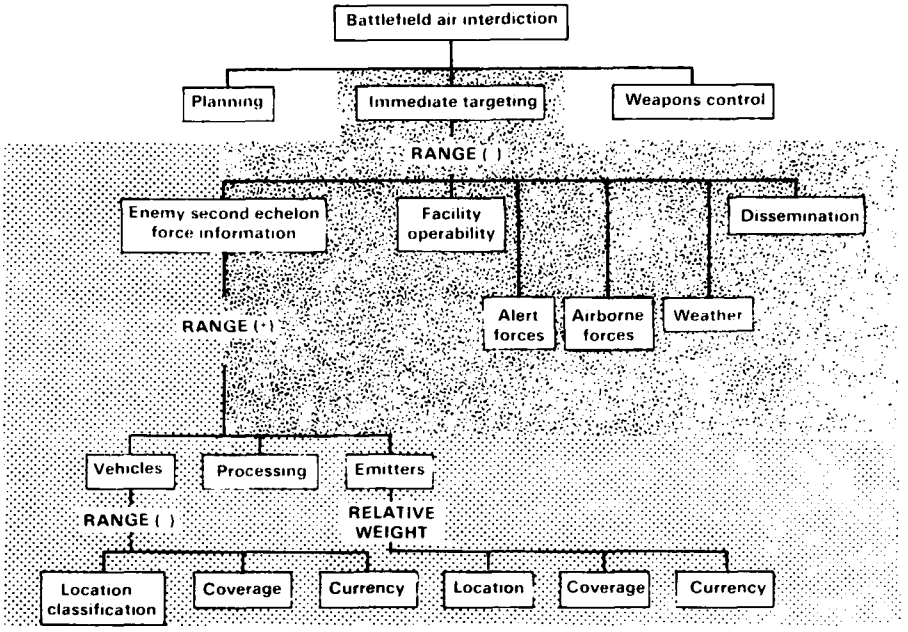
In summary, analyses of the TIQ data indicate that:

(1) the hypothesized factors all affect target identification judgments and therefore should be retained in the structure;

(2) this portion of the immediate-targeting structure should consist of the three originally hypothesized causal sets; and

(3) the three transfer functions are a range model with a positive range coefficient for Enemy Second Echelon Force Information, a range model with a negative range coefficient for Vehicles, and a relative-weight averaging model with an initial impression for Emitters. The algebraic formulations of these models was presented in Slide 11.

FINAL STRUCTURE AND STFs



Slide 22

This slide depicts the final immediate-targeting structure with the name of the appropriate transfer function for each causal set.

Once the STFs have been determined, immediate-targeting outcomes can be predicted for any specific configuration of systems that support the immediate-targeting function. This would be done in the following manner. The capabilities of the support systems (such as communications, intelligence, information processing, the work facility and its equipment, reporting systems, etc.) of a configuration of interest would first be described in terms of the factors from the final representation. For example, the intelligence system, which collects and processes raw data on enemy emitters and communicates it to the command and control system, would be described by its accuracy in locating emitters, how much of the BAI area it observes (Coverage), and

how long it takes to process the data and report it to the command and control system (Currency). These descriptions would reflect technological capabilities and operational concepts and procedures.

If the description is a physical measure, then the physical measure would be entered into the appropriate utility curve (Slides 16 and 20) to determine the appropriate subjective value needed for its STF. If the factor is described verbally (such as the processing and emitter location factors), then psychophysical functions (utility curves) do not exist and the description must be one of those used in the development of the STF, so that its scale value is known (see Appendixes C and D).[13]

Once the subjective scale values are determined, all outcomes are determined by computing the STFs from the bottom to the top of the hierarchical structure. A description of such a computation is presented in Appendix E. (In practice, the STFs would be incorporated into a computer program for prediction purposes.)

The next seven slides illustrate how outcomes from different "notional" system configurations can be determined once the structure and the STFs are known. These outcomes could be used both to indicate relative value of different system configurations and to provide input to utility models used in the theater engagement mission area.

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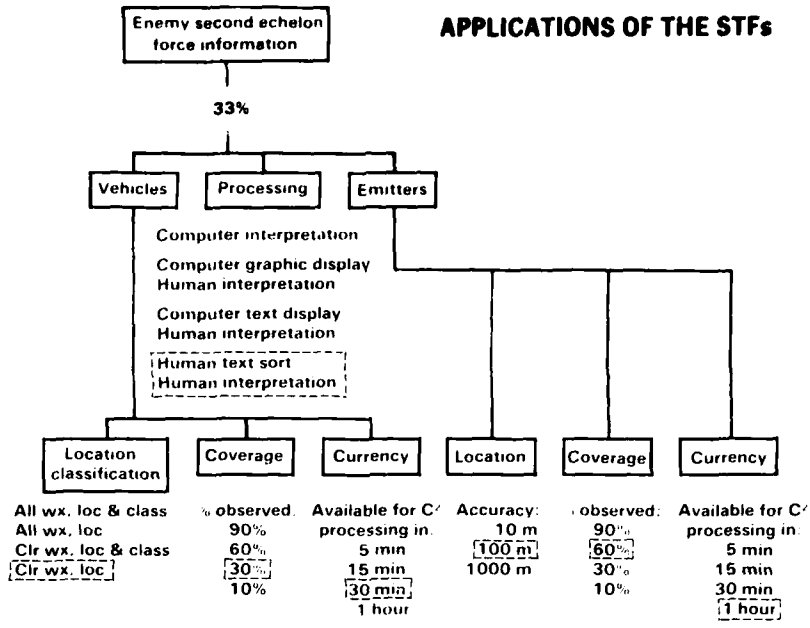
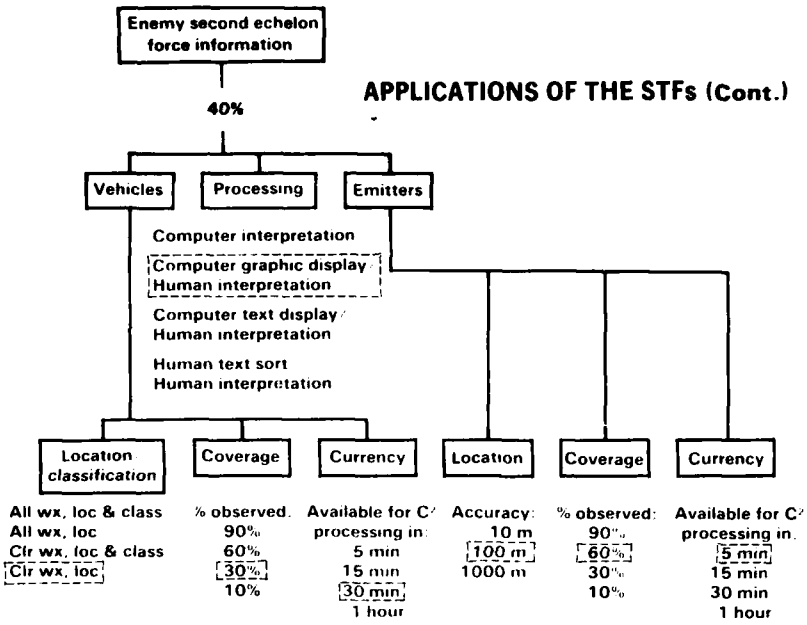
[13] If the description is new, a small pilot study that manipulates only the factors in its related set could be performed. The purpose of the study would be to scale the new descriptor, but it would also serve as a validation study for the existing STF.



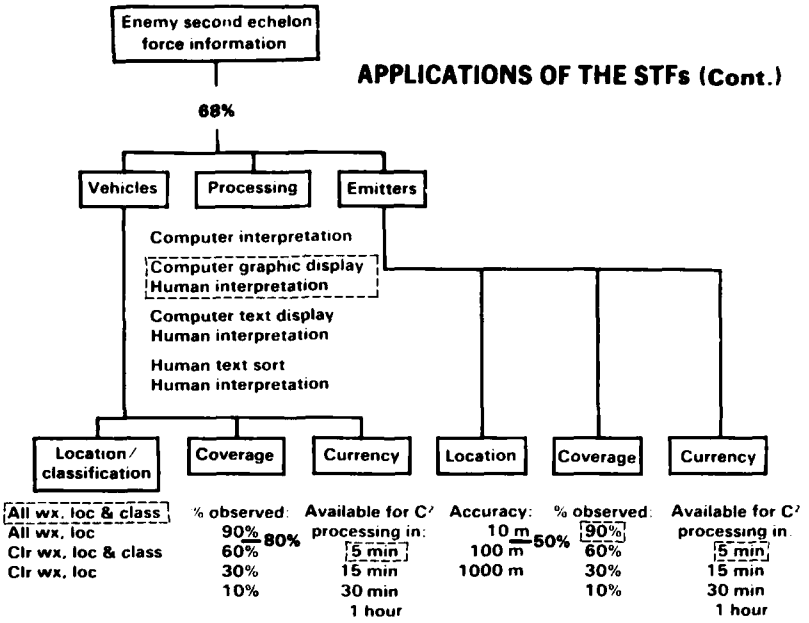
Slide 23

This slide depicts a notional baseline configuraton wherein supporting systems are capable of achieving the factor levels circled. With this configuration, the percent of the important targets in the enemy second echelon area that could be identified in a timely manner is predicted to be 33%. (It is emphasized that the respondents in this demonstration, though having area knowledge, were selected primarily by availability rather than as Air Force representatives. Therefore, the results of their judgments depicted on this and the following slides are exemplary for purposes of this demonstration only and do not represent official or unofficial Air Force judgments. Furthermore, the example configurations and the factor levels used to represent them are "notional" rather than accurate reflections of actual systems; hence, the outcomes are also notional--intended only to illustrate how the STF approach is used to evaluate systems and system options).



Slide 24

To assess a PDP for upgrading sensor data processing (such as a BETA system, for example), factor levels achieved by the improved system configuration would be determined and the outcome predicted. On this slide, a notional set of factor levels resulting from such an upgrade is shown. With this configuration, the percent of important targets in the enemy second echelon area that could be identified in a timely manner is predicted to be 40%--an improvement of 7% over the baseline configuration.

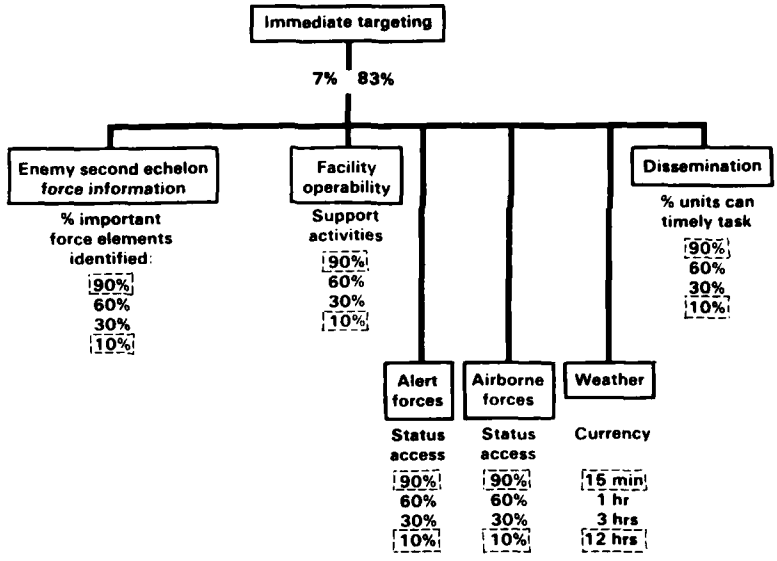


Slide 25

Now, if improvements in reconnaissance and surveillance systems are also added, they may bring the factor levels to the levels shown here. The levels of 80% for vehicle coverage and 50 meters for emitter accuracy were selected to demonstrate that any values (not just the values contained in the questionnaires) can be used for factor levels having physical measures. For this configuration the predicted outcome is 68%--a 28% increase over the notional "BETA-like"-only configuration and a 35% increase over the baseline.

We next consider the effect these configurations would have on the overall measure of immediate-targeting effectiveness.

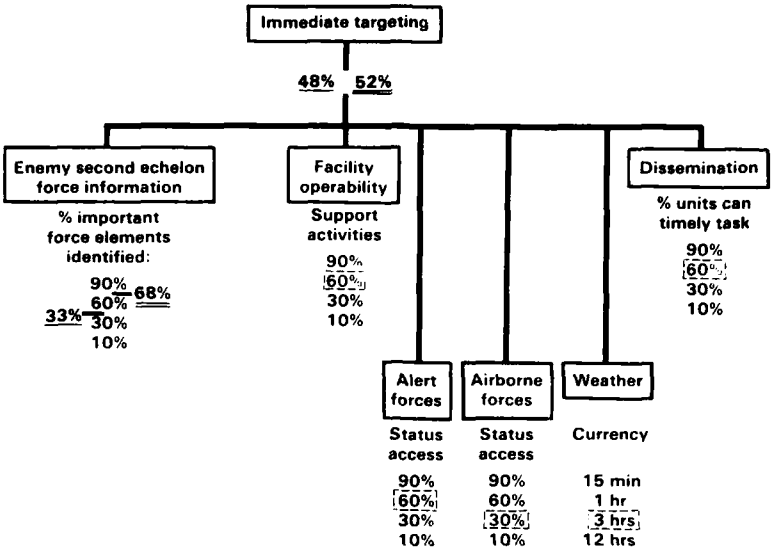
APPLICATIONS OF THE STFs (Cont.)



Slide 26

This slide shows the range of *immediate-targeting outcomes*, given the highest factor levels and the lowest factor levels. Recall that the outcomes are in terms of the percent of effective force application opportunities that could be exploited.

APPLICATIONS OF THE STFs (Cont.)

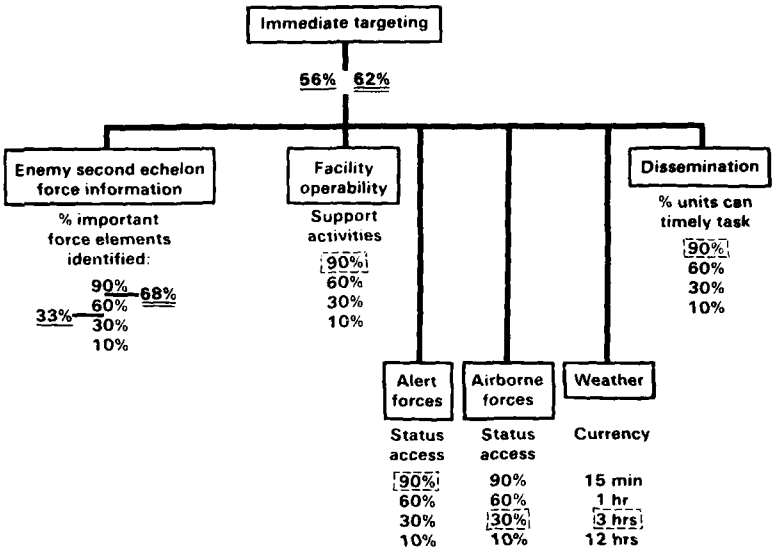


Slide 27

In this example, we have depicted a notional baseline configuration supporting the immediate-targeting function and determined outcomes for both the baseline and enhanced configuration examples previously used for enemy second echelon force information. The outcome on the left, 48%, corresponds to 33% of the important enemy force elements being identified; and the outcome on the right, 52%, corresponds to 68% of the important enemy force elements being identified.

Hence, in this configuration, an increase of over 100% (33% to 68%) in the percentage of important enemy force elements identified is judged to produce only a 4% increase in the immediate-targeting outcome measure. This may indicate the perception of a target-rich (in relation to friendly resources) environment in the conflict scenario. It could also indicate that other factors are constraining the utilization of the additional information. Other factors can be easily investigated with this structure.

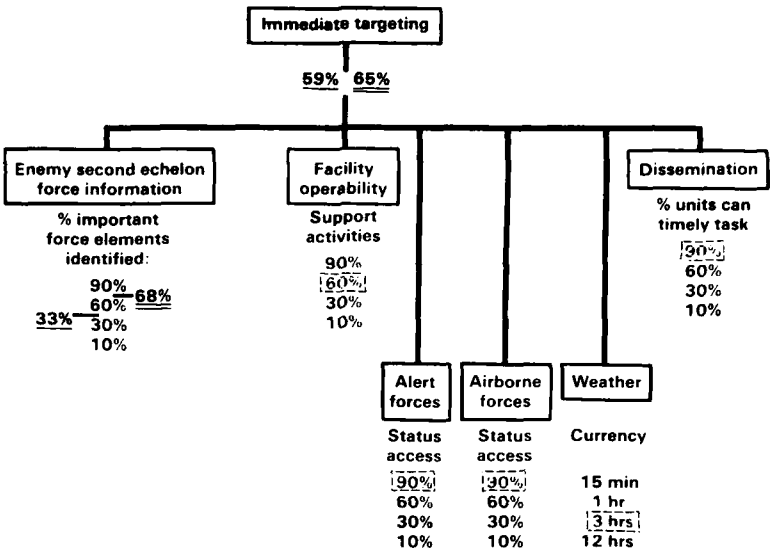
APPLICATIONS OF THE STFs (Cont.)



Slide 28

If we consider an upgrade to the facilities, including better communications capability, which would achieve the notional factor levels shown on this slide, we see an improvement from this upgrade that exceeds the improvement attained by the enhanced enemy information system configuration within the immediate-targeting baseline shown on the previous slide. In the baseline (Slide 27), the enhanced enemy information configuration yielding 68% of the important force elements identified achieved an immediate-targeting outcome of 52% opportunities exploited. On the other hand, using the enemy information configuration yielding 33% of the important force elements identified, the facility upgrade alone achieved a 56% immediate-targeting outcome. Whether this difference (52% versus 56%) is considered significant is up to the decisionmakers, but it exemplifies the type of tradeoff that can be disclosed by the STFs and structure.

APPLICATIONS OF THE STFs (Cont.)



Slide 29

A final example considers only a notional addition to airborne radar and communication capability. If the factor levels achieved with such an upgrade were as shown, the immediate-targeting outcomes would be 59% and 65%. Hence, the notional outcomes from upgrading facilties (previous example) or adding airborne capabilities are judged here to be about the same in terms of the percent of effective force application opportunities exploited by the immediate-targeting function.

In summary, the subjective transfer function approach provides the framework to investigate the outcomes of individual or multiple effects of program decision packages (PDPs) throughout the structure, and hence permits the comparison of any system configurations that can be described by the factors.

STF FEATURES

- **Contextual causality**
  - **Input factors**
  - **Input factor levels**
  - **Outcomes**
- **Empirical tests of STFs, factors, and structure**

Slide 30

The major features of the STF approach to complex system analysis are summarized on this slide.

1. The structure depicts a context of sets of causal hypotheses. The sets are composed of factor inputs that are hypotheszied to impact on outcomes. Input factors are defined along dimensions of interest (e.g., those that correspond to PDP descriptions). Outcomes are also operationally defined along dimensions of interest (e.g., those that PDPs are supposed to affect).

2. The structure and the transfer functions that specify the links among the sets of causal hypotheses are empirically verified. Appropriate transfer functions are used to predict outcomes throughout the structure and at the top of the structure.

SUMMARY

The STF approach develops hypotheses about

- **Complex system factors**
- **Complex system structure**
- **Functional links among causal sets**

The STF approach validates

- **Hypothesized factors**
- **Hypothesized structures**
- **Functional links (STFs)**

The STF approach is useful for

- **Assessing PDPs**
- **Providing valid input measures to other models**

Slide 31

The STF approach provides a framework for capturing the experts' judgment process and validating the experts' measures of the outcomes and input factors. This demonstration study has illustrated that the STF approach is an advantageous procedure for evaluating complex systems--hypothesized factors, structures, and functional links. Specifically, we have demonstrated the usefulness of the approach for evaluating perceived effects of PDPs, and for providing AFWMAA with valid and useful subjective measures needed for computational utility models.

Appendix A

METHODS AND PROCEDURES FOR THE IMMEDIATE TARGETING QUESTIONNAIRE

Respondents judged questionnaire items that described factors that affect the immediate-targeting function performed within the tactical air control system. Judgments were percentage of the effective force application opportunities that could be exploited by the immediate-targeting function, given the information described in the item.

Independent Variables

The definitions and selected levels of the factors affecting immediate targeting are described below.

Enemy Information. This variable reflects the amount of the second echelon force elements which are important to the course of battle that are identified in time for use in performing the immediate-targeting function. Four levels were considered as follows:

10% of the important 2nd echelon force elements are timely identified.

30% of the important 2nd echelon force elements are timely identified.

60% of the important 2nd echelon force elements are timely identified.

90% of the important 2nd echelon force elements are timely identified.

Facility Operability. This factor reflects the ability of the tactical air control facility(ies) to support the immediate-targeting function. It would include consideration of survivability, capacity,

and endurance. It is described in terms of the percentage of all the necessary immediate-targeting activities that the facilities could perform if all effective force application opportunities were to be exploited. Four levels were considered:

Facilities can support 10% of the necessary immediate-targeting activities.

Facilities can support 30% of the necessary immediate-targeting activities.

Facilities can support 60% of the necessary immediate-targeting activities.

Facilities can support 90% of the necessary immediate-targeting activities.

Dissemination of Tasking Orders. This factor reflects the ability to correctly communicate tasking orders to the tactical air forces, on the ground and in the air, that are designated and/or available for second echelon interdiction missions. Four levels were considered:

Tasking can be communicated correctly to 10% of the forces in time.

Tasking can be communicated correctly to 30% of the forces in time.

Tasking can be communicated correctly to 60% of the forces in time.

Tasking can be communicated correctly to 90% of the forces in time.

Execution Status Information. This is a composite factor composed of information about the designated alert forces, the tactical air forces that are airborne, and the weather. Each of these variables is described separately.

Alert Force Status Information: This factor reflects the ability to access information about the status of the designated alert forces in time to be used by the immediate-targeting function. Four levels were considered:

Timely access to the status of 10% of the designated alert forces.

Timely access to the status of 30% of the designated alert forces.

Timely access to the status of 60% of the designated alert forces.

Timely access to the status of 90% of the designated alert forces.

Airborne Force Status Information: This factor reflects the ability to access information about the status of tactical air forces that are airborne in time to be used by the immediate-targeting function. Four levels were considered:

Timely access to the status of 10% of the airborne forces.

Timely access to the status of 30% of the airborne forces.

Timely access to the status of 60% of the airborne forces.

Timely access to the status of 90% of the airborne forces.

Weather Data: This factor reflects the currency of reliable weather data in the second echelon area and at the tactical air bases. Four levels were considered:

Weather data are 12 hrs. old.

Weather data are 3 hrs. old.

Weather data are 1 hr. old.

Weather data are 15 min. old.

Stimuli and Design

There were 192 items presented for judgment in the ITQ. These were constructed from single factors or factor combinations. To include all possible combinations of four levels of each of the 6 variables and all possible subsets would require 15,624 items ($6 \times 4 + 15 \times 4^2 + 20 \times 4^3 + 15 \times 4^4 + 6 \times 4^5 + 4^6$). Therefore, a subset of possible designs were chosen that met the following criteria: collectively they would (a) include the complete range of set-size (from 1 to 6 factors), (b) allow assessment of all interactions of interest, (c) constrain parameter estimates, and (d) permit tests among the models under investigation. The 192 items were generated from the designs described below.

1. Single factor designs. For 24 items, respondents based their judgments on only one of the six variables; each of the six variables had four levels.

2. Execution status information designs. Fifty-six items contained combinations of the factors reflecting execution status information. Forty-eight items, in which two pieces of execution status information were available, were constructed from three 4x4 designs--Alert Force Status x Airborne Force Status, Alert Force Status x Weather

Data, and Airborne Force Status x Weather Data. Eight three-factor items were generated from a 2x2x2, Alert x Airborne x Weather, design; the top (best) and bottom (worst) levels of each of the three execution status information variables were used in this design.

3. Execution status information in combination with the other three factors made up another 80 items. Sixteen items were generated from a 4x4, Execution Status Information x Dissemination of Tasking Orders, design, where the four levels of Dissemination were crossed with four sets of Execution Status Information--the combined top levels from each of three execution status variables, the combined bottom levels from each of the three execution status variables, and two other combinations made up of the top levels of Alert and Weather with the bottom level of Airborne, and the top level of Airborne with the bottom levels of Alert and Weather. Sixteen items were generated from a 4x4, Execution Status Information x Facility Operability, design, where the four levels of Facility Operability were crossed with the same four sets of Execution Status Information used in the Execution Status Information x Dissemination design. Thirty-two items were generated from an 8x4, Execution Status Information x Enemy Information, design, where the eight Execution Status Information sets were constructed from a 2x2x2, Alert x Airborne x Weather, design; the top and bottom levels of each of the three execution status information variables were used. Sixteen items were generated from a 2x2x2x2, Execution Status Information x Dissemination of Tasking Orders x Facility Operability x Enemy Information, design; the two sets of Execution Status Information consisted of one set of top levels and one set of bottom levels of the

three execution status variables; the two levels of Dissemination, Facility, and Enemy Information were the top and bottom levels for each.

4. Dissemination of Tasking Orders by Facility Operability. Sixteen items were constructed from a 4x4, Dissemination x Facility Operability, design.

5. Facility Operability by Enemy Information. Sixteen items were constructed from a 4x4, Facility x Enemy Information, design.

Item Examples

The following are examples of items consisting of different numbers of pieces of information. An example of an item containing only one piece of information that describes Dissemination capability would be:

Tasking can be correctly communicated to 90% of the forces in time.

An example of an item containing three pieces of information would be:

Timely access to the status of 90% of the designated alert forces.
Timely access to the status of 90% of the airborne forces.
Weather data are 15 min. old.

An example of an items containing information about all factors would be:

ENEMY INFO: 90% of important 2nd echelon force elements are timely identified.
EXECUTION STATUS INFO: Have timely access to the status of 10% of the designated alert forces and 10% of the airborne forces; weather data are 15 min old.
DISSEM: Tasking can be correctly communicated to 10% of the forces in time.
FACILITIES can support 90% of the necessary immediate-targeting activities.

Procedure and Task

The 192 items were printed in random order on 21 pages forming a questionnaire booklet. Page orders were randomized for each respondent. Each booklet also contained a set of instructions and 18 representative warm-up items.

Before beginning the questionnaire, respondents were given an informational briefing on the background and goals of the research, and a descriptive briefing on the conflict situation to be used as a backdrop in formulating their judgments.

The respondent's task was to judge the percentage of the effective force application opportunities that could be exploited by the immediate-targeting function, given only the information described in an item. Respondents worked at their own pace.

Appendix B

METHODS AND PROCEDURES FOR THE TARGET IDENTIFICATION QUESTIONNAIRE

Respondents judged questionnaire items that described characteristics of enemy second echelon force information available to the tactical air control system for making immediate-targeting decisions. They estimated percent of important second echelon force elements that could be identified in a timely manner, given the described characteristics.

Independent Variables

The characteristics of enemy second echelon force information relate to the quality of information on enemy vehicles and emitters, and the process used to interpret this information. Enemy vehicle information was characterized by location and classification capabilities, coverage capabilities, and the currency of the information. Information on enemy emitters was characterized by its location accuracy, coverage, and currency. The definitions and selected levels of these characteristics are described below.

Enemy Vehicle Location and Classification. This characteristic reflects the ability of sensor systems to locate and classify enemy vehicles. Four levels of this characteristic were considered:

Can locate and classify vehicles in all weather.

Can locate (but not classify) vehicles in all weather.

Can locate and classify vehicles in clear weather only.

Can locate (but not classify) vehicles in clear weather only.

Enemy Vehicle Coverage. This characteristic reflects how many of the enemy vehicles in the second echelon area have been observed. Four levels of this characteristic were considered:

10% of the second echelon vehicles are observed.

30% of the second echelon vehicles are observed.

60% of the second echelon vehicles are observed.

90% of the second echelon vehicles are observed.

Enemy Vehicle Currency. This characteristic reflects the time interval between the observation of vehicles in the second echelon area and the data's availability for processing in the command and control system. Four levels of this characteristic were considered:

Vehicle information is available for processing 1 hr. after observation.

Vehicle information is available for processing 30 min. after observation.

Vehicle information is available for processing 15 min. after observation.

Vehicle information is available for processing 5 min. after observation.

Enemy Emitter Location Accuracy. This characteristic reflects the accuracy with which enemy emitters are located in the enemy second echelon area. Three levels of the characteristic were considered:

Emitters are located within a 1000m accuracy.

Emitters are located within a 100m accuracy.

Emitters are located within a 10m accuracy.

Enemy Emitter Coverage. This characteristic reflects how many of the enemy emitters in the second echelon area have been observed. Four levels of this characteristic were considered:

10% of the second echelon emitters are observed.

30% of the second echelon emitters are observed.

60% of the second echelon emitters are observed.

90% of the second echelon emitters are observed.

Enemy Emitter Currency. This characteristic reflects the time interval between the observation of emitters in the second echelon area and the data's availability for processing in the command and control system. Four levels of this ccharacteristic were considered:

Emitter information is available for processing 1 hr. after observation.

Emitter information is available for processing 30 min. after observation.

Emitter information is available for processing 15 min. after observation.

Emitter information is available for processing 5 min. after observation.

Processing. This characteristic is the means by which enemy vehicle and emitter information is interpreted. We considered four

levels, which varied by extent of computerized support. One had no automation: humans interpret the information by sorting through hard copy, textual materials (e.g., formatted reports). The other three levels included automation and computer output devices. The human uses the computer to organize, select, search, and display the information to facilitate interpretation. Graphic displays present pictures made up of symbols and line drawings, e.g., a map with military units, towns, roads, and terrain features. In the fully computerized case, the computer organizes and interprets the information. The four levels were identified in the questionnaire as follows:

Human sorts hard copy, textual information; human interpretation.

Human uses computer to sort textual information; human interpretation.

Human uses computer to graphically display information; human interpretation.

Fully computerized interpretation.

Stimuli and Design

There were 203 items presented for judgment in the TIQ. These were constructed from single characteristics or combinations of characteristics. To include all possible combinations of the levels of each of the seven variables described above would require 62,499 items $(6 \times 4) + (1 \times 3) = 27$ single-characteristic items; $15 \times 4^2 + 6 \times 4 \times 3 = 312$ two-characteristic items; $20 \times 4^3 + 15 \times 4^2 \times 3 = 2{,}000$ three-characteristic items; $15 \times 4^4 + 20 \times 4^3 \times 3 = 7{,}680$ four-characteristic items; 6×4^5

$+ 15 \times 4^4 \times 3 = 17{,}664$ five-characteristic items; $1 \times 4^6 + 6 \times 4^5 \times 3 = 22{,}528$ six-characteristic items; $4^6 \times 3 = 12{,}288$ seven-characteristic items)

Therefore, we chose a subset of possible designs that would include the complete range of set-size (from 1 to 7 characteristics), would allow assessment of all interactions of interest, would constrain parameter estimates, and would permit tests among the models under investigation. The designs that generated the 203 items are described below.

1. Enemy vehicle information designs. Sixty-eight items contained one or more pieces of enemy vehicle information. For 12 items, respondents based their judgments on only one characteristic of enemy vehicle information; each of the three variables had four levels. Forty-eight items, in which two pieces of enemy vehicle information were available, were constructed from three 4x4 designs--Location x Coverage, Coverage x Currency, and Location x Currency. Eight three-characteristic items were generated from a 2x2x2, Location x Coverage x Currency design; the top (best) and bottom (worst) levels of each of the three vehicle information variables were used in this design.

2. Enemy emitter information designs. Fifty-nine items contained one or more pieces of enemy emitter information. For 11 items, respondents based their judgments on only one characteristic of enemy emitter information; Coverage and Currency each had four levels and Location Accuracy had three levels. Forty items, in which two pieces of enemy vehicle information were available, were constructed from two 4x3 designs--Location x Coverage and Location x Currency--and one 4x4

design--Coverage x Currency. Eight three-characteristic items were generated from a 2x2x2, Location x Coverage x Currency design; the top and bottom levels of each of the three emitter information variables were used in this design.

3. Vehicle by emitter design. Sixteen items were constructed from a 4x4, Vehicle x Emitter, design. The four levels of Vehicle information were made up of the combined top levels from each of the three vehicle variables, the combined bottom levels from each of the three vehicle variables, and two other combinations--the top levels of Coverage and Currency with the bottom level of Location and the top level of Currency with the bottom levels of Location and Coverage. The four levels of Emitter information were made up of the combined top levels from each of the three emitter variables, the combined bottom levels from each of the three emitter variables, and two other combinations--the top levels of Location and Coverage with the bottom level of Currency and the top level of Coverage with the bottom levels of Location and Currency.

4. Processing. This factor, alone and in combination with vehicle or emitter information, made up another 52 items. For four items, respondents based their judgments on only the Processing variable, which had four levels. Twenty-four items were constructed from an 8x3, Emitter x Processing, design, where the eight Emitter Information sets were constructed from a 2x2x2, Location x Coverage x Currency, factorial design, using the top and bottom levels of each of these three emitter information variables and three levels of the processing variable--human sorts hard copy ..., human uses computer to sort textual information

..., and fully computerized interpretation (these are completely stated in the section titled "Independent Variables"). Twenty-four items were constructed from a 2x12, Processing x Vehicle, design, where the 12 Vehicle Information sets were constructed from a 2x2x3, Location x Coverage x Currency, factorial design, using the top and bottom levels of Location and Coverage and three levels of Currency--the two top levels and the bottom level (5 min., 15 min., and 1 hr.); the two levels of Processing used were the top and bottom levels.

5. Vehicle by processing by emitter design. Eight items were generated from a 2x2x2, Vehicle x Processing x Emitter, design. The top and bottom levels of Processing were used. The two sets of Vehicle Information consisted of one set of top levels and one set of bottom levels of the three Vehicle Information variables. The two sets of Emitter Information were constructed in the same manner.

Item Examples

The following are examples of items consisting of different numbers of characteristics. An example of an item containing only one characteristic would be:

90% of the second echelon Emitters are observed.

An example of an item containing three characteristics would be:

Vehicle info is available for processing 5 min. after observation.
Can locate and classify vehicles in all weather.
90% of the second echelon Vehicles are observed.

An example of an item consisting of all seven characteristics would be:

Locate and classify, in all weather, 90% of the second echelon vehicles;
vehicle info is available for processing 5 min after observation.
Locate (within a 10m accuracy) 90% of the second echelon emitters;
emitter info is available for processing 5 min after observation.

Human sorts hard copy, textual info; human interpretation.

Procedure and Task

The 203 items were printed in random order on 22 pages forming a questionnaire booklet. Page orders were randomized for each respondent. Each booklet also contained a set of instructions and 18 representative warm-up trials.

As in the ITQ, before beginning the questionnaire, respondents were given an informational briefing on the background and goals of the research, and a descriptive briefing on the conflict situation to be used as a backdrop in formulating their judgments.

The respondent's task was to judge the percentage of the important second echelon force elements that could be identified in a timely manner, considering the context of immediate targeting in the second echelon area and given only the characteristic(s) described in an item. Respondents worked at their own pace.

Appendix C

WEIGHTS AND SCALE VALUES FOR THE IMMEDIATE TARGETING QUESTIONNAIRE

SCALE VALUES (s)

Factor	Level 1	2	3	4
Enemy Information	-1.092	4.309	8.715	14.255
Facility Operability	-0.634	3.009	7.145	9.519
Alert Force Status Information	1.824	5.123	7.093	9.192
Airborne Tactical Force Status	2.412	5.357	9.755	16.528
Weather Currency	0.532	3.124	6.141	10.935
Dissemination of Tasking Orders	-0.464	3.496	7.973	10.806

Initial Impression (s_o) = 2.303

WEIGHTS (w)

Factors for Immediate Targeting Node

Enemy Information	0.654
Facility Operability	0.865
Alert Force Status Information	0.614
Airborne Tactical Force Status	0.503
Weather Currency	0.328
Dissemination of Tasking Orders	1.000

Range coeffficient (ω) = -0.079

Initial Impression (w_o) = 1.554

Appendix D

WEIGHTS AND SCALE VALUES FOR THE TARGET IDENTIFICATION QUESTIONNAIRE

Factor	Level 1	2	3	4
Enemy Vehicle Location	3.54	7.03	10.12	17.44
Enemy Vehicle Coverage	0.28	2.97	8.04	14.32
Enemy Vehicle Currency	1.43	3.94	8.04	11.99
Enemy Emitter Location	2.24	6.88	12.16	
Enemy Emitter Coverage	0.58	2.37	5.08	8.33
Enemy Emitter Currency	-3.56	3.95	8.97	18.74
Processing	4.02	3.80	4.51	3.75

Initial Impression (s_o) = 1.096

WEIGHTS (w)

Factors for Vehicle and Emitter Nodes

Vehicle Factors		Emitter Factors	
Enemy Vehicle Location	0.176	Enemy Emitter Location	0.235
Enemy Vehicle Coverage	0.434	Enemy Emitter Coverage	1.187
Enemy Vehicle Currency	0.240	Enemy Emitter Currency	0.115

Range coefficient - Vehicles (ω) = -0.048

Factors for Enemy Second Echelon Force Information Node

Vehicles	25.950
Emitters	24.552
Processing	1.000

Range coefficient - Enemy second echelon force information (ω) = 0.320

Initial Impression (w_o) = 0.972

Appendix E

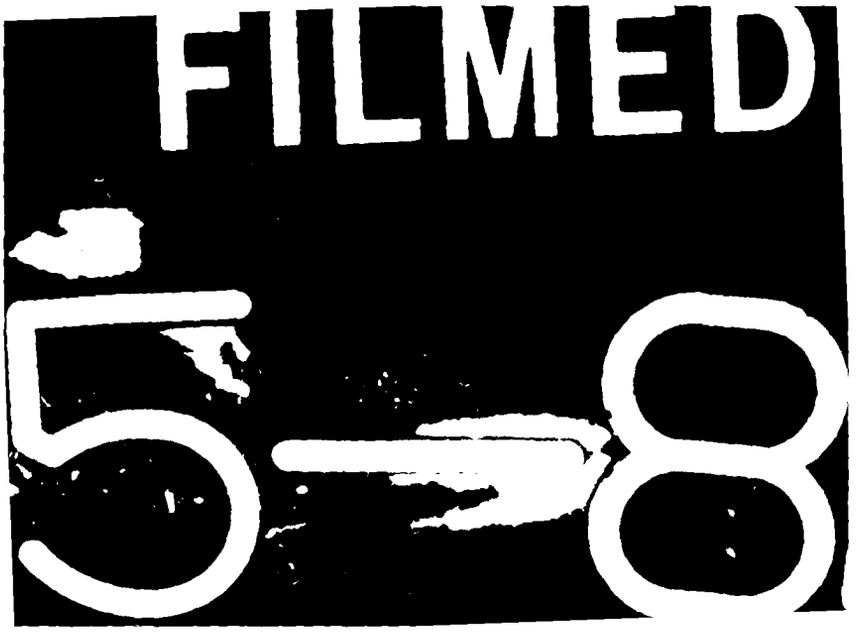
DESCRIPTION OF HOW TO USE STFs

The predictions are arrived at by substituting the appropriate numerical values from Appendix D (weights and scale values for TIQ) into the appropriate model formulas given on Slide 11. For example, the prediction of 33% is arrived at by the following procedure:

1. The weights derived for the vehicle factors and the scale values derived for the selected set of vehicle factor levels are given in Appendix D, together with the other parameter estimates for the range model. These numerical values are substituted into the range model (Eq. 2 on the right-hand panel of Slide 11). The output value of 2.11 is obtained for the selected vehicle combination.

2. The relative weight model (Eq. 3 on the left-hand panel of Slide 11) parameters needed for the emitter factors are given in Appendix D. Substituting these values into the model produces an output value of 3.31 for the selected emitter combination.

3. The output values for the vehicle node and the emitter node become the scale values (s) for those factors in the range model at the enemy second echelon force information node. The remaining parameters needed (weights for Vehicles, Processing, and Emitters; scale value for the given level of Processing; initial impression weight and scale value; and the range coefficient) are given in Appendix D. The range model with these values produces a predicted response of 3.3 (on a 1 to 9 response scale) which corresponds to a percent response of 33%.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