Command Post of Future Decision Models

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Topic: C2 Decision Making and Cognitive Analysis

Abstract

DARPA's Command Post of the Future (CPOF) is developing and evaluating advanced Human-Computer Interface (HCI) technologies to improve command post effectiveness. It is advancing the state of the art in advanced visualization, multi-modal input, dialog management, and context tracking technologies, is exploring the contributions of these technologies to new operational concepts, and is discovering and validating general principles for applying these technologies to improve commander situation assessment and decision making.

CPOF experimentation helps investigators identify and validate how these advanced technologies and novel operational concepts can improve command post decision making. The CPOF decision models support CPOF experimentation. They help explain why and under what conditions advanced technologies can make the most difference, provide a theoretical basis for generating hypotheses and metrics, help explain and generalize experiment results, and help investigators discover and validate the general principles of technology application.

This paper introduces the CPOF decision models. It describes their role in CPOF experimentation, summarizes their major elements, details a model of situation-based alternative evaluation, and shows how this model helps explain CPOF experiment results.

ROLE OF MODELS IN CPOF

Development of CPOF technologies and operational concepts are organized around threads and their filaments. Each thread addresses a broad new concept for military operations such as new ways to organize and coordinate military forces. Threads are major elements of CPOF, and continue throughout the duration of the CPOF program. Filaments are parts of threads. Each explores specific technical and operational concepts related to the thread, and lasts from two to six months. Examples of filaments are investigations into methods for depicting events and force capabilities or methods for representing a commander's qualitative reasoning.

Threads and filaments are empirical investigations. Each identifies important issues that it wishes to explore, insights it wishes to acquire, and possible benefits it wishes to validate. It then develops an experimental campaign plan to achieve these goals.

A filament's "experimentation campaign model" (The M_i in Figure 1) is an important part of that filament's experimental campaign plan. This model documents the current state of understanding of the variables and variable relationships important to the concept. It describes elements of the concept that have been established so far and points out elements that are still speculative, and thus are candidates for empirical exploration. The filament participants will select some of these latter elements to be examined through experimentation. Then as the experimentation proceeds, these elements become better understood and other elements become the subject of future experimentation. Thus the filament experimentation campaign model evolves to better capture the increasingly more complete understanding of the concept. The feedback loops for each filament model represents this continual evolution of the filament model.

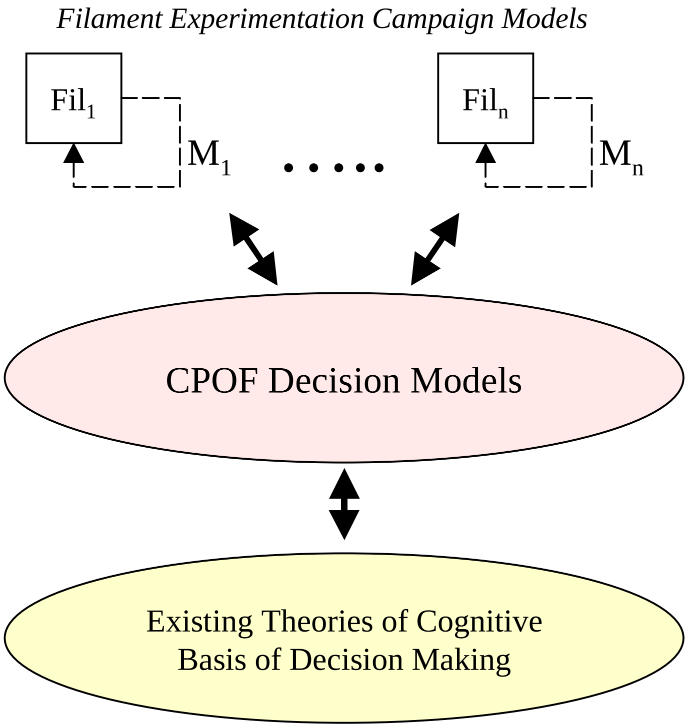

Figure 1. Role of Models in CPOF Experimentation

The filament campaign models are not exclusively focused on decision making, but also address operational and technical issues. The part of the filament model that concerns decision making is supported by an important resource, the “CPOF decision models.” These models are an organized repository of existing cognitive theories of decision making that are of potential relevance to CPOF.

This repository draws on (and can conceivably enrich) diverse existing cognitive models of decision making. As some of these theories become relevant to CPOF, they are incorporated into the repository of “CPOF Decision Models.” Thus, the CPOF Decision Models are not a closed preordained set, but instead dynamically change in accordance with the needs of the CPOF program. Thus, as the CPOF subject matter experts describe how they think about solving an operational problem, any existing cognitive models that bear on that process will be brought into the repository of CPOF Decision Models.

OVERVIEW OF CPOF DECISION MODELS

The CPOF Decision Models reflect a broad spectrum of decision research, with principal focus on naturalistic decision making (Klein, 1993, Adelman, 1998). Because they seek to inform the CPOF experimentation campaign models and because they're intended to explain behaviors observed in CPOF experimentation, these models are descriptive rather than prescriptive.

Decision Processes Addressed by Models

The models presently address seven facets of decision making: goal specification, monitoring, situation diagnosis, opportunities and problem identification, alternative identification and development, alternative evaluation, and alternative selection.

- **Goal specification** is translating possibly vague fundamental goals, principles, and values (in military applications this is usually intent of higher authority) into more concrete "actionable" goals and associated constraints.

- **Monitoring** is continuous. During monitoring people may look for the appearance of pre-specified alerts. They may also check for indicators that the current diagnosis is incorrect, that the current force posture or planned actions are inadequate, and/or that specific problems and opportunities are arising.

- A **diagnosis** is an estimate of the nature of a problem. It comprises all of the elements of situation assessment. A situation diagnosis may consist of 1) an estimate of the ground truth situation that generated the observed situation data, 2) a classification of the kind of situation that this ground truth is, 3) properties expected in this kind of situation, and 4) identification of properties (e.g., centers of gravity) that may be significant for achieving goals.

- **Opportunity and problem identification**. An opportunity is a situation condition that enables an action for achieving our goals, or if there is an adversary, a condition that enables an action that prevents the adversary from achieving his. A problem is a situation condition that can impede achievement of goals. It may be an obstacle to successfully carrying out our planned actions or it may be an adversary opportunity.

- **Alternative identification and development** determines a sequence of actions by which a goal can potentially be achieved. There are five common steps for alternative development: identification and evaluation of general types of actions often useful for achieving a goal, specialization and/or decomposition of these general actions, improvement of component actions, and specification of requirements for support and coordination.

- **Alternative evaluation** estimates the effectiveness and appropriateness of a candidate action being evaluated for future implementation. The model discusses both outcome and situation-based evaluation. The situation-based methods use experience to determine if the situation has the right properties for the action to be effective. Outcome-based methods estimate the outcome and rate it’s desirability.

- **Alternative selection** is the decision. The models describe several different selection processes. These can vary considerably in formality, ranging from the nearly automatic and subconscious selection of the first action considered to an elaborate analytic trade-off among several candidates.

Dealing with Uncertainty

Some of the CPOF decision models discuss methods for planning and decision making under uncertainty. These methods are important when 1) the situation uncertainty is high, 2) the effectiveness of candidate actions are highly uncertain, or 3) there is a low confidence that any of actions considered so far will adequately support goals.

Planning and decision making under uncertainty is a special case of planning and decision making in general. Experienced people can select ways to deal with uncertainty by specializing general methods known to work in various circumstances. Figure 2 organizes these methods in a specialization hierarchy.

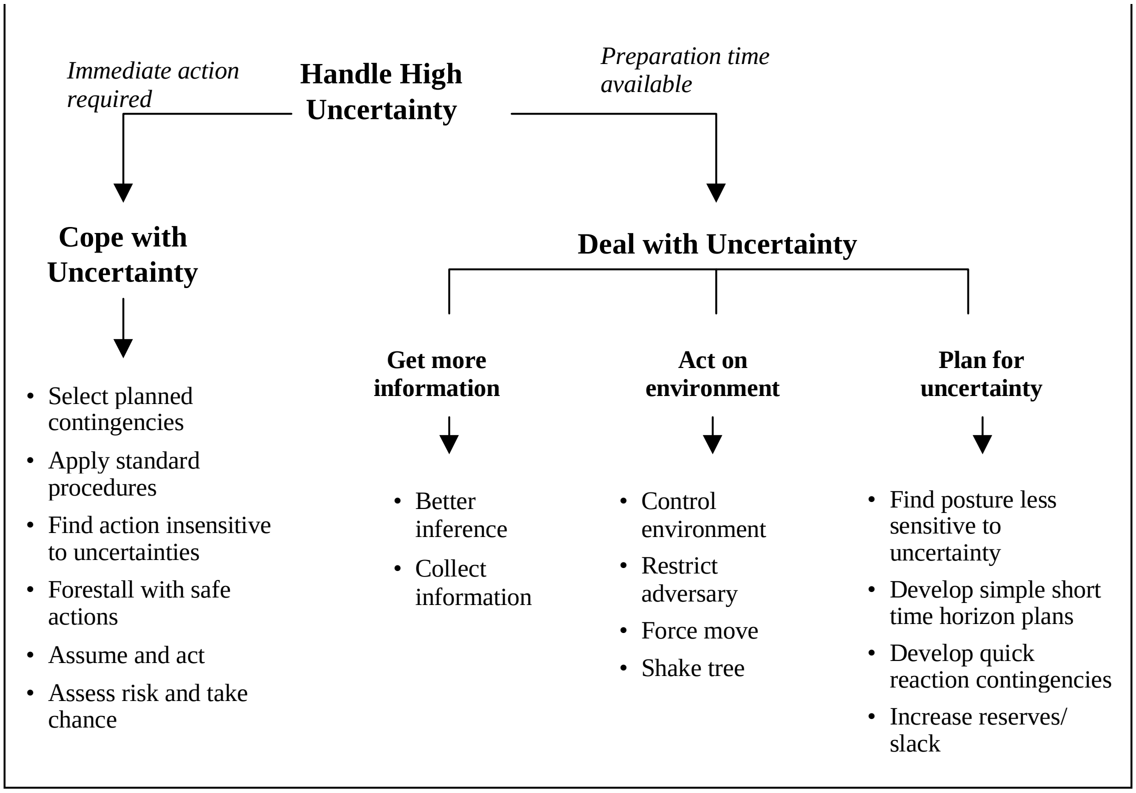

Figure 2. Methods for Handling Uncertainty

These methods are organized into two broad groups: those designed to handle uncertainty immediately, when no time is available to collect additional information about the situation, and those where time is available. The first group, called “cope with uncertainty,” includes six general methods. The second group, called "deal with uncertainty" incorporates three categories of techniques: get more information, act on the environment, and plan for uncertainty.

"Getting more information" deals with uncertainty by building a more complete, precise, and accurate situation picture. "Acting on the environment" reduces uncertainty by controlling or constraining it or by forcing the adversary to reveal his hand. "Planning for uncertainty" hedges for it, principally by finding a posture that is either insensitive to the uncertainties or that can be quickly adjusted when time resolves the uncertainty.

ACTION EVALUATION IN CPOF DECISION MODEL

Situation-based and Outcome-based Alternative Evaluation

The decision model dealing with situation-based alternative evaluation has proved very useful for understanding key results of the initial CPOF experimentation. This paper describes relevant aspects of this model in detail to illustrate how a CPOF decision model can help explain experimentation results.

Figure 3 summarizes the two major ways people use to evaluate the attractiveness of an alternative: situation-based evaluation, and outcome-based evaluation. In the former, people check to determine if the situation has the properties needed for the candidate action under consideration to work well. People need experience and expertise to do this, because they need to know what these needed properties are. People make most of their decisions this way (Klein, 1993). For many decisions, they do it so quickly and easily that they sometimes do not even realize they have made a decision.

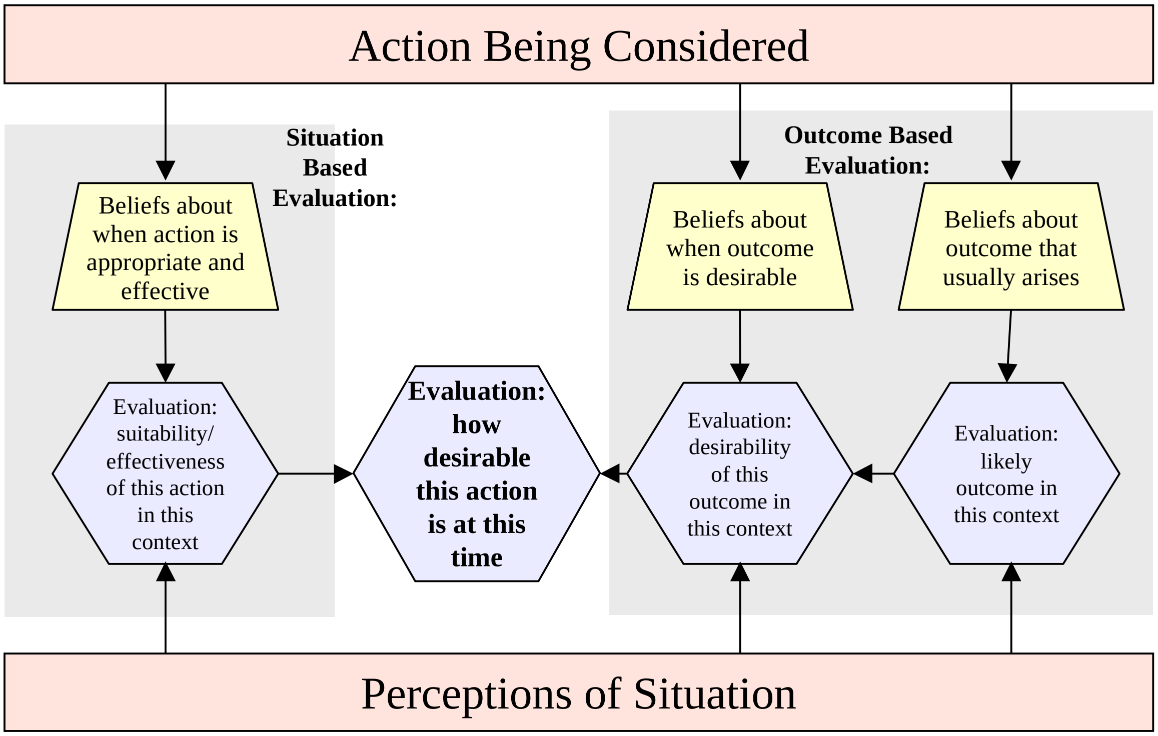

Figure 3. Situation-based and Outcome-based Alternative Evaluation

In outcome-based evaluation, people predict the consequences of the action, and then decide how well they like these consequences. Outcome based evaluation benefits from experience, but unlike situation-based evaluation, does not require it.

These two methods are not mutually exclusive. A person who wants a higher confidence in the effectiveness of a candidate action may choose to use both situation-based and outcome-based evaluation simultaneously.

Situation-based Alternative Evaluation and the Role of Patterns

When people do situation-based alternative evaluation (left hand side of Figure 3), they compare their beliefs about the situation properties under which that alternative will be appropriate and effective with their perception of the situation's actual properties. These comparisons are often indirect and require many inferences.

For example, in ship air defense the properties the situation needs before a track should be shot down is that the track "intends to attack" and "is "capable of causing damage" if it does. Unfortunately, neither "intends to attack" nor "capable of damaging" can be observed directly. Instead, they need to be inferred from situation observables.

Experienced people know what to look for in a situation to make these inferences. They know how a track "intending to attack" behaves and they know the signs of that behavior, so when they see these signs, they can infer the intent. This knowledge of what a track intending to attack looks like is where experience is drawn on. When applied to decision making, such experience can be packaged as a reference pattern in memory. This reference pattern in presumably a set of expected situation elements in some spatial and temporal relationships.

Figure 4 depicts these processes in more generality. The objective of the evaluation, shown in the box at the far right, is to judge the adequacy of a candidate action. The remainder of the Figure is divided into three rows. The top row contains the "desired execution conditions." These are the experienced-based situational reference criteria that the decision maker will apply. The bottom row contains the perceived execution conditions. In CPOF, we assume that these conditions will be the ones presented by the visualization or audio-output technologies. The middle row is the comparison between the desired situation conditions and the perceived ones. These are the immediate basis for the evaluation

As shown in the top row of the figure, people identify the desired execution conditions primarily top down. People start by identifying the general, usually abstract, desired situation conditions (e.g., intends to attack). If they cannot directly observe these conditions, but need to infer them as in the case of "intends to attack," they will then identify the arrangement (pattern) of observables that they can see and which they can use to make the needed inferences. These patterns consist of observables and the relationships among observables. The basic building blocks of the patterns, the entities that need to be observed in order to see the pattern, are on the left most part of the top row.

The bottom row represents the decision maker's perception of the situation. CPOF assumes that this includes the information presented explicitly, either visually or aurally and the immediate inferences that the decision maker can draw from this information. Note that

CPOF can depict information that people cannot see directly. The CPOF visualizations can show the patterns and even the inferences. For example, CPOF visualizations can depict a track icon to designate that it intends to attack.

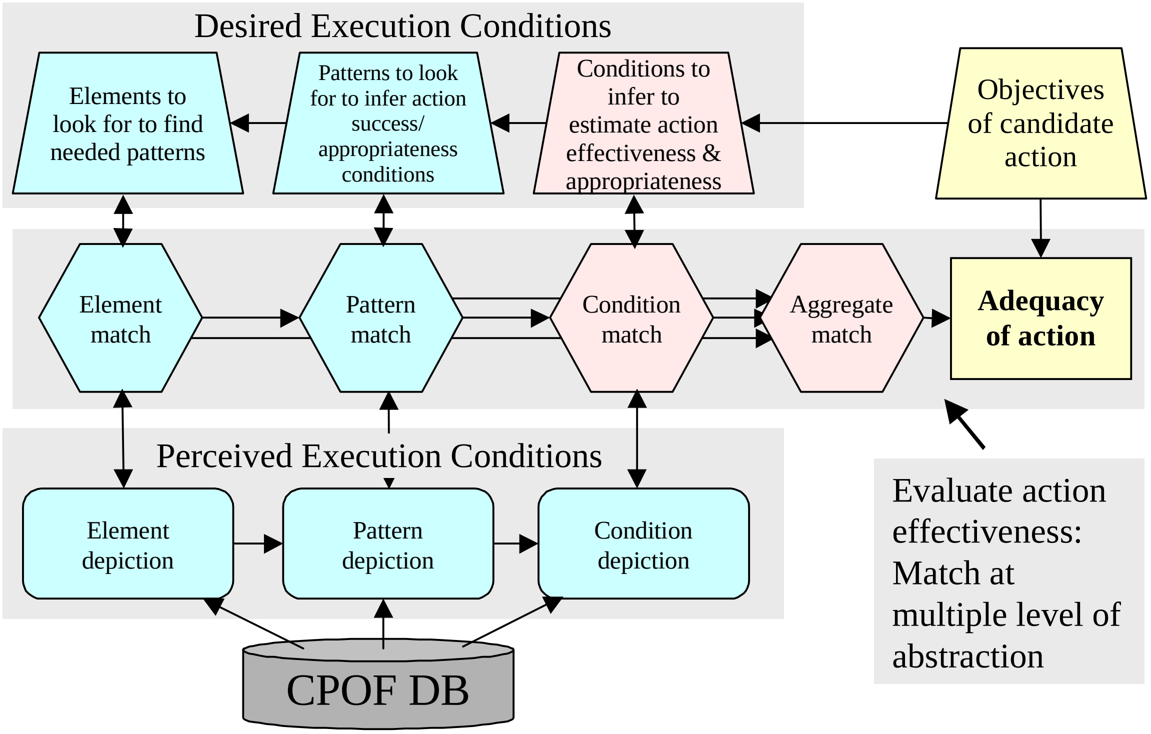

Figure 4. Situation-based Alternative Evaluation

The middle row represents the evaluation of the candidate action. The most immediate evaluation occurs by matching the conditions the decision maker believes are needed for the action to be appropriate and effective with the conditions he's observed or inferred from the situation. If he needed to infer these conditions, then according to this model he did so by matching the patterns expected if the more abstract conditions hold with the patterns he observes. Finally, in order to observe the patterns, the decision maker must match the entities and relationships expected by the pattern with the entities and relationships observed in the situation.

This model suggests how information presentations can support situation-based alternative evaluation and thus improve decision making. According to this decision model, CPOF visualization technologies can improve decision making in three ways. First, if the inference result is in the CPOF database, they can depict that result. Second, if the result is not in the database but the database knows what kinds of patterns support the inference, the visualization can depict the pattern. Finally, if the pattern is not in the database but the CPOF database knows what kinds of entities are usually important to a mission, the technologies can emphasize these entities.

Importance of Patterns to Support Decision Making

Patterns play a key role in situation-based decision making. In summary:

- Patterns are concrete collections of observable entities and relationships
- They enable people to infer abstract situation properties important to action evaluation
- A good display of a pattern should help people infer the abstractions related to that pattern
- Obscuring these patterns will impede people's ability to infer these abstractions

The example in the remainder of this paper uses this understanding of the role of patterns to explain some of the most interesting results to occur in CPOF's first limited objective experiments (LOE 1).

EXAMPLE: USE OF MODEL TO EXPLAIN EXPERIMENTATION RESULTS

Overview of Limited Objective Experiment 1

CPOF's first formal experiment, Limited Objective 1, examined the impact of advanced situation depictions on situation assessment. In this experiment, military officers viewed a baseline and two advanced CPOF situation depictions in four scenarios. The baselines replicated the situation representations available to operational military forces today. The advanced CPOF visualizations augmented these visualizations in various ways to improve situation assessment. Two of the four scenarios were force-on-force operations in the desert, and two were potential insurrections in a third world country.

Overall, the experiment participants performed significantly better with the CPOF advanced visualizations than they did with the baseline visualizations. On close inspection, however, it was observed that various treatments differed considerably in their effectiveness. Several of the advanced visualizations significantly improved situation assessment, some of the techniques failed to yield improvements, and a few of the experimental treatments actually reduced performance.

Figure 5 summarizes some results from the more difficult of the two desert scenarios. In this case, Treatment B, "blobs and allegiance color coding" significantly improved situation assessment. The other treatment, Treatment A, "functional color coding," however, reduced the quality of the assessment. As described in the next sections, the CPOF alternative evaluation model provides an explanation for these results.

Effective and Ineffective Patterns

This explanation follows immediately from 1) the nature of the treatments, 2) the specific answer key for situation assessment, and 3) the importance of patterns and inferences to situation assessment.

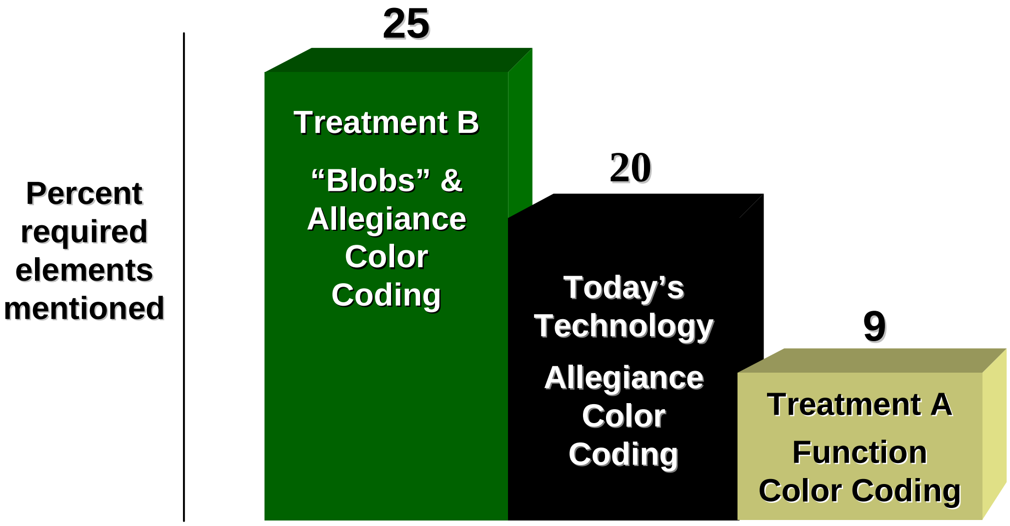

Figure 5. Impact of representation of force allegiance on situation assessment in LOE 1

Figures 6a and 6b above compare the two treatments. Figure 6a shows treatment B. This figure emphasizes the relative strengths of the opposing forces over the geography. Adversary and friendly forces are color coded, using the usual red and blue colors. In addition, aggregate force strength is denoted by color coded contours, with the thickness of the contour representing amount of strength.

In contrast, treatment A (Figure 6b) coded force allegiance by the shape of the icon, with diamonds representing adversary forces and squares representing friendly forces. Color codes for the function of the units. Friendly and adversary forces that have the same function also have the same color. Because blocks of icons with the same shape (area on the same side) are not very easy to see as a group, it is difficult to assess relative force strength over geography. The information is in the display, but it's hard to see.

Table 1 is the answer key for situation assessment for this scenario of LOE 1. This key specifies the inferences that need to be made in order to evaluate various (unstated) actions often important in this kind of situation. Situation assessment performance is scored by the number of these items the experiment participants correctly volunteered. Presumably, participants would mention an aspect of the situation if they recognized the issue as being important and if they were able to draw the right conclusions about the issue.

The yellow highlight designated those elements of the answer key that depend on correctly assessing relative force strength over geography.

According to the theory, visualizations that help people estimate relative force strength will help people draw these inferences. In this case, we think that Treatment A's using color to code for unit function rather than allegiance (and using shape to code for allegiance) obscured the estimate of relative force strength and thus reduced the subject's ability to draw inferences that depended on force strength.

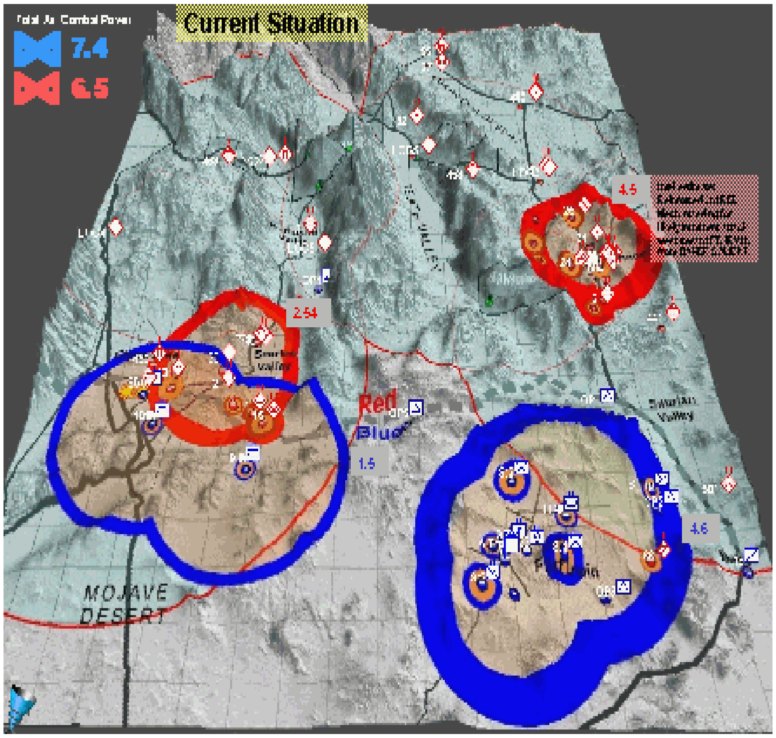

Figure 6a. Treatment B, depicting relative force strength over geography. Color codes for force allegiance. Thickness of contours represents force strength.

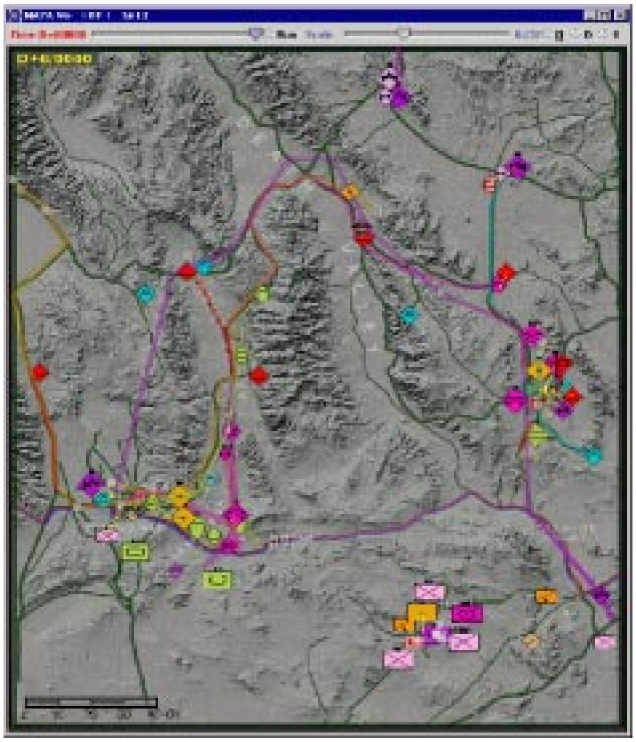

Figure 6b. Treatment A, Color codes for unit function.

Offensive capabilities	Vulnerabilities
• Conduct limited attack in west • Can force blue onto defense in east • Can turn flank at Baker • Inflict causalities with SCUD strikes (Ft. Irwin)	• Northland forces must use a single road to move south from Shosone (can be interdicted) • Weak logistically (Long MSR's, lengthy recent movements) • Lacks force ratios for attack (over extension)
Defensive capabilities	**•Intentions**
• Can hold border area in west • Can occupy and defend in east • Has sufficient air to assist defense	• Northland intends to attack South for Shosone • Pinning attack in the west

Table 1. Answer key for Situation Assessment. Yellow highlight denotes answer that requires assessment of relative force capabilities

In contrast, we think that Treatment B made relative force strength easier to see, and thus facilitated inferences that depend on assessments of relative force strength. We believe that is the reason why Treatment B helped people do better. In summary, the geographic pattern of relative force strength is what people needed to pay attention to in order to identify and volunteer much of the information on the answer key. Function color coding obscured this pattern; blobs highlighted it.

SUMMARY

The CPOF decision models describe natural processes of decision making important to command and control. They address a broad range of decision making activities, including goal formulation, monitoring, situation diagnosis, opportunity and problem identification, and alternative development, evaluation, and selection.

The models document and integrate concepts developed among separate filaments and threads. They help explain how the CPOF technologies impact those aspects of decision making important to each filament. They provide a theoretical underpinning to CPOF experimentation. They suggest hypotheses and metrics, help explain and generalize experimentation results, and help investigators discover and validate the general principles of technology application.

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