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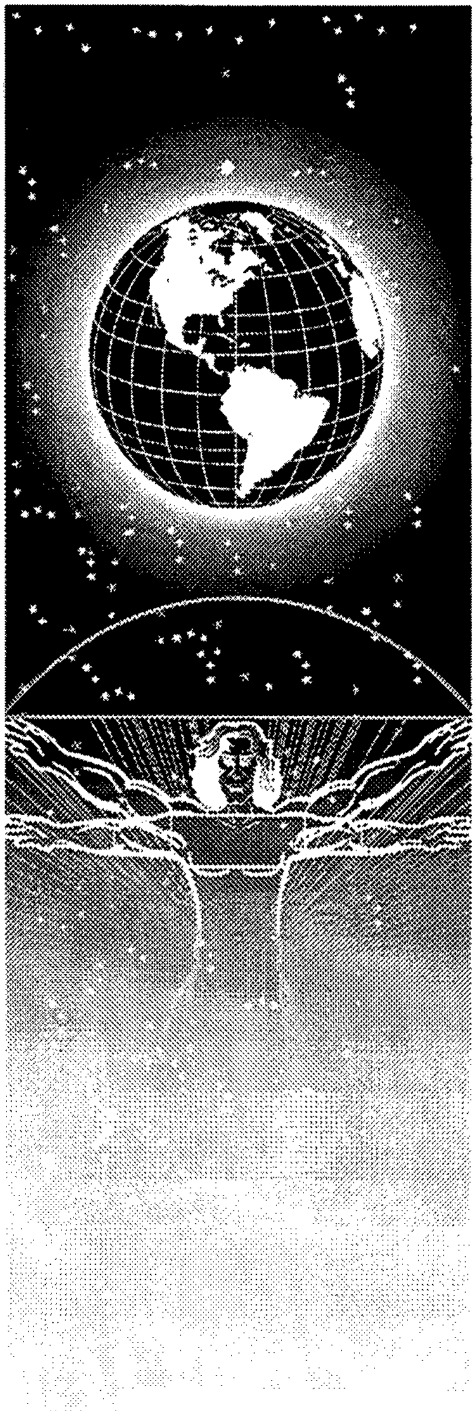

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

IMPLICATIONS OF THE NATURALISTIC DECISION MAKING FRAMEWORK FOR INFORMATION DOMINANCE

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FOR THE COMMANDER

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This report explores the implications of the Naturalistic Decision Making (NDM) framework for the domain of Information Dominance, defined as an operational advantage obtained through superior effectiveness of informational activity. NDM is the study of how people use their experience to make decisions in field settings. Expertise was considered at both the individual and the team level of decision making. The report defines the components of expertise and identifies obstacles to the acquisition of Information Dominance. These obstacles include: 1) excessive data, 2) pre-processed data, 3) excessive procedures, 4) performing formal analyses, 5) passive data handling and limited ability for information seeking, and 6) interfaces that obscure the big picture.

The danger exists that these obstacles will severely limit the use of expertise at the individual and the team level, and that information technology will result in reduced rather than increased performance. The application of the NDM perspective demonstrates how information technologies can interfere with expertise, and provides assistance in the development of procedures which ensure that information technologies support Information Dominance functions. Directions for future research into the nature of the obstacles are identified.

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PREFACE

This project was accomplished under Collaborative Systems Technology Branch Work Unit Number 71841046, "Crew Systems for Information Warfare." It was completed for Armstrong Laboratory, Collaborative Systems Technology Branch (AL/CFHI), under contract F41624-94-0-6000 for prime contractor, Logicon Technical Services, Inc. (LTSI). Donald Monk was the Contract Monitor.

The effort was initiated by Gilbert Kuperman, of AL/CFHI, who wanted to determine what the Naturalistic Decision Making framework had to offer the field of Information Dominance. I am grateful for his encouragement and support. I also want to thank LTSI staff members Robert Stewart, project manager, and Elisabeth Fitzhugh, technical editor, for their help in completing this project.

I also want to express my gratitude to my colleagues at Klein Associates. Rebecca Pliske did an outstanding job in using her professional background in decision research to help me edit this document. It is much improved by her efforts. Rob Hutton, Tom Miller and Dave Klinger also provided valuable advice for clarifying arguments and strengthening the document. And Barb Law and Teresa Heller provided useful assistance in making necessary arrangements and in production.

SUMMARY

This report explores the implications of the Naturalistic Decision Making framework for the domain of Information Dominance, which has been defined as an operational advantage obtained through superior effectiveness of informational activity. Naturalistic Decision Making (NDM) is the study of how people use their experience to make decisions in field settings. The expertise Klein Associates considered was at both the individual and the team level of decision making. We defined what expertise consists of and we identified some important barriers that might be particularly troublesome in an era of Information Dominance. These barriers include the following:

excessive data
pre-processed data
excessive procedures
performing formal analyses
passive data handling, limited ability for information seeking
interfaces that obscure the big picture

The danger exists that these barriers will severely limit the use of expertise at the individual and the team level, and that information technology will result in reduced rather than increased performance.

The challenge is to understand how information technologies can interfere with expertise, and to develop procedures for ensuring that these technologies support proficiency in carrying out Information Dominance functions.

The NDM perspective can offer some ideas about using information technology to support skilled decision making. We have identified several possible directions for future research into learning more about the barriers themselves: predicting the extent to which new designs will increase or decrease performance levels, developing new system designs that will support the key requirements of decision makers, and defining the affordances of Information Dominance for expanding situation awareness and for decreasing the adversary's situation awareness.

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I. INTRODUCTION

The rapid developments of information technology are generating a wide range of implications for the way military leaders conceptualize future warfare. One of the emerging themes in future operations is Information Dominance. Information Dominance covers a number of different fields, including hardware and software engineering, communications technology, sensor technology, artificial intelligence, encryption techniques, C4I, and has been defined in many different ways. Whitaker and Kuperman (1996) have recently examined many of the cognitive engineering and human factors aspects of Information Dominance and for the purpose of this report we will use their definition of Information Dominance which is as follows:

> ***Information Dominance is an operational advantage obtained through superior effectiveness of informational activity (acquisition and processing of data, information, and/or knowledge), to the extent that this advantage is demonstrable through superior effectiveness of instrumental activity.***

The purpose of this report is to explore the implications of the Naturalistic Decision Making framework for the domain of Information Dominance. Inasmuch as Information Dominance can be conceptualized as a way of making better and faster decisions, while degrading and slowing down the decision cycle of an adversary, new insights can be gained by viewing Information Dominance from a decision making point of view.

The organization of the report is as follows. Section II describes the Naturalistic Decision Making framework, and Section III presents a recognitional model of Naturalistic Decision Making. Section IV discusses the aspects of expertise found in decision making. Section V is a critical discussion of the barriers that information technology poses to proficient decision making, and a set of hypotheses about the ways that Information Dominance programs can make these barriers more severe, resulting in worse performance rather than increased performance. Then in Section VI we shift to an examination of team decision making, particularly the concept of the "team mind." Section VII discusses the nature of expertise in team decision making. Section VIII examines the barriers to proficient team decision making. Section IX offers recommendations for shaping information technologies to support proficient individual and team decision making and an agenda for future research. Appendix A presents a review of the literature on the cognitive aspects of team decision making.

II. WHAT IS NATURALISTIC DECISION MAKING?

Naturalistic Decision Making (NDM) can be defined as the study of how people use their experience to make decisions in field settings. The NDM framework (Flin, 1996; Flin, Martin, Strub, & Salas, in press; Klein, Orasanu, Calderwood, and Zsambok, 1993; Zsambok and Klein, 1997) is designed to investigate the strategies people use in performing complex, ill-structured, high-stakes tasks, under time pressure and uncertainty, with changing conditions, and in the context of team and organizational constraints.

The NDM framework arose independently of the normative decision research tradition. The normative research tradition assumes the decision maker is a rational/economic person (Simon, 1956) or vigilant decision maker (Janis & Mann, 1977) who systematically searches for relevant information in an unbiased manner and then carefully weighs the utility of each alternative before making a choice. This tradition is also referred to as the Rational Choice Model of decision making. This approach evaluates the quality of decision-making behavior by comparing the decision-maker's performance to a normative statistical model, such as Bayes Theorem, to determine whether the optimal choice was made.

In the period 1985-1989, a number of researchers studied the way people made judgments and decisions in realistic settings such as urban fire suppression, identification of hostile units in military engagements, and nuclear power plant operation. Many of these efforts had been funded by the U.S. Army Research Institute for the Behavioral and Social Sciences, in an attempt to design training and decision support systems that could be put into use. And most of the researchers were grounded in other domains (e.g., engineering, training, human factors) with little or no background in the normative decision research tradition. The research methods were primarily descriptive, aimed at gaining an initial understanding of the way that experienced personnel handled the difficulties of time pressure, uncertainty, and the other factors listed above. The Army Research Institute sponsored a conference on NDM in 1989, and this may be considered the beginning of the NDM movement. At this conference (Klein, Orasanu, Calderwood, & Zsambok 1993), the investigators learned that they were observing the same processes even though they were studying different domains.

What are these common processes? Researchers working in the NDM framework have observed that for most high-stakes tasks, people with experience are making the decisions, rather than novices. Furthermore, experience enables decision makers to identify reasonable courses of action as the first ones considered (Klein, Wolf, Militello, & Zsambok, 1995), so that the burden of difficulty is on assessing the nature of the situation rather than on comparing alternative courses of action. In addition, in most settings it is less important to arrive at the optimal choice than it is to arrive at a workable choice in a short period of time — a tactic Simon (1956) has called "satisficing." Uncertainty is a common difficulty in naturalistic settings. However, people do not appear to try to estimate the level of uncertainty for different outcomes, or to quantify the uncertainty for different hypotheses. Instead, experienced decision makers have developed strategies for managing uncertainty (Schmitt & Klein, 1996), which can involve knowing when to accept it, when to try to seek more information, and how to structure a situation in order to reduce the uncertainty. Cohen, Freeman, and Wolf (1996) have discussed the importance of metacognitive strategies in managing uncertainty.

Lipshitz (1993) reviewed nine different NDM models, and identified a set of common themes. These included the importance of situation awareness, the use of mental imagery in many of the models, the importance of context in trying to understand real-world decisions, the shifts between intuitive and analytical strategies, and the emphasis on helping people by supporting the decision strategies they use rather than by trying to have them adopt different decision strategies.

Zsambok (1997) has identified several themes that characterize NDM research. First, in the period from 1989 to 1994 she found activity in developing and testing models. Second, the focus of NDM is expanding to include a greater interest in related lines of work, such as studies of expertise, problem solving, situation awareness, and process control. Third, is the growing emphasis on situation awareness as a key aspect of decision making. Fourth, is the effort that goes into improving the methodologies for carrying out field research. Fifth, is the interest in finding applications for NDM findings.

Klein (1997a) has discussed some trends in the applications growing out of the NDM framework. On the surface, it would appear that NDM research should have less application than normative decision research, because NDM seeks to describe what people do, whereas normative studies often try to discover deviations from optimal strategies in order to prescribe better strategies. However, as was discussed above, the normative strategies cannot be used in many field settings because the boundary conditions in terms of data quality and time available to perform the analyses are not met.

The NDM framework cannot rely on normative standards for evaluating performance, but it can use the strategies of skilled decision makers to serve as criteria for evaluating novices. Furthermore, a naturalistic approach will attempt to build on the strategies people already use, rather than seeking to replace these strategies. As a result, the likelihood of acceptance is greater, because resistance is reduced.

One final advantage of the NDM framework is that it tends to ground the applications within a context. Whereas the normative, analytical approach had the strength of being generic, it had the weakness of not being grounded within the context of a specific domain. Thus, a strategy for comparing the strengths and weaknesses of options can be used in selecting automobiles, buying homes, choosing a school for a child, but it does not have the depth of a strategy used by baggage screeners in airports to identify threatening items to inspect more closely, or a strategy used by air traffic controllers to spot early warning signs that airplanes may soon be violating separation criteria. These latter strategies are domain specific, and context-restricted. In supporting a new baggage screener or a new air traffic controller, it may be more useful to consider the context-specific strategies used by the experienced decision makers. Teaching multi-attribute utility analysis methods or Bayesian statistics to air traffic controllers does not appear to have great value.

III. THE RECOGNITION-PRIMED DECISION MODEL

The Recognition-Primed Decision (RPD) model is one of the examples of how NDM research can bring a new perspective to understanding how people use their experience to make decisions in field settings. The RPD model was originally developed to explain how fireground commanders were able to use their experience to select a course of action without having to compare different options. Fireground commanders are the leaders of teams that are called out whenever there is a fire or related emergency, primarily in urban settings. The model was based on interviews and observations of fireground commanders working with difficult and challenging incidents. Klein, Calderwood, and Clinton-Cirocco (1986) examined more than 30 incidents. The commanders were working against severe time pressure, since more than 80% of the decisions were made in less than a minute. The stakes were high; poor decisions could result in loss of lives and property. Information quality was uneven, goals shifted, and conditions changed. The situational dynamics changed an average of five times in each incident studied. Klein et al. expected that the commanders would have to resort to a limited comparison between options, and were surprised to discover that the commanders reported they were not making any comparisons at all.

These findings raised two key questions: First, how could the commanders be sure of carrying out effective courses of action without generating a set of options from which to choose? Second, how could the commanders evaluate a course of action without comparing it to others? Klein et al. (1986) carefully examined the interview data and the 156 decision points probed, and developed the RPD model based on the fireground commanders' own accounts.

The answer to the first question (how the commanders did not have to generate a set of options) was that the commanders could use their experience to size up a situation and thereby recognize the typical action to take. They could generate a reasonable option as the first one considered. They were not trying to find the optimal solution, but rather to quickly arrive at a workable solution that could be enacted in time to arrest the spread of a fire that might be growing exponentially.

The answer to the second question (how the commanders could evaluate an option without comparing it to others) was that once the commanders identified a typical course of action, they would evaluate it by imagining it, mentally simulating it to see if it would work in the context of the situation they were facing. If the course of action was found satisfactory, it would be initiated without any further delay. If they found any flaws, they would switch to a problem-solving mode to repair the flaws. If they could not repair the flaws, they would reject the course of action and consider the next most typical reaction, repeating the process until they found a workable option.

In short, the firefighters were able to use their experience to identify a workable course of action as the first one they considered. If they needed to evaluate a course of action, they conducted a mental simulation to see if it would work.

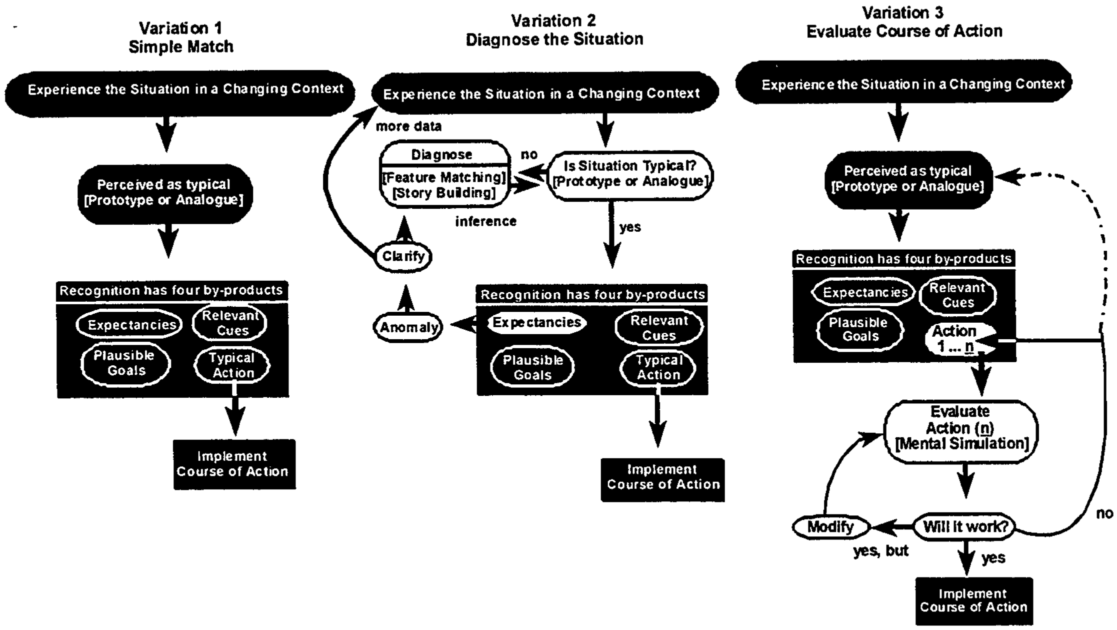


Figure 1: Recognition-Primed Decision model.

The RPD model is shown in Figure 1. The simplest case is where a decision maker sizes up a situation, forms expectancies about what is going to happen next, determines the cues that are most relevant, recognizes the reasonable goals to pursue in the situation, recognizes a typical reaction, and carries it out. This is probably also the most common case. We consider this a decision because reasonable alternative courses of action could have been taken. Other decision makers, perhaps with less experience, might have selected these alternatives. Therefore, a decision point hypothetically existed even though the decision maker did not treat it as such.

The second panel of Figure 1 shows a more difficult case, where the decision maker is not certain about the nature of the situation. Perhaps some anomaly arises that violates expectancies and forces the decision maker to question whether the situation is perhaps different than it seems. Another possibility is that the uncertainty might be present from the beginning. Here, decision makers must deliberate about what is happening. Studying the Commanding Officers and Tactical Action Officers of AEGIS cruisers, Kaempf, Wolf, Thordsen, and Klein (1996) found that one strategy they use is to build a story that explains the various pieces of information. If there are competing interpretations of the situation, the decision maker may try to build a story for each, and appraise which story is the most consistent and plausible. Diagnosis is the attempt to link the observed events to causal factors; by establishing such a linkage the decision maker would obtain an explanation for the events. Diagnosis is important for the RPD model because the nature of the situation can largely determine the course of action adopted. Often, decision makers will spend more time and energy trying to determine what is happening, and distinguishing between different explanations, than comparing different courses of actions.

Diagnostic activity is initiated in response to uncertainty about the nature of the situation. The purpose of the diagnosis is either to evaluate an uncertain assessment of the situation or to compare alternative explanations of events. Two common diagnostic strategies are feature matching and story building. In their study of Navy anti-air warfare incidents, Kaempf et al. (1996) examined 103 instances of diagnosis. Of these, the most common strategy was to use feature matching to assign a diagnosis. Feature matching consists of identifying the relevant features of a situation in order to categorize it. This occurred in 87% of the cases. In 12% of the cases the decision maker engaged in story building to accomplish the diagnosis (e.g., showing that the erratic course of an unidentified aircraft could be explained as a lost helicopter trying to locate the carrier from which it was launched). Despite this small proportion, the episodes of story building were, in several incidents, the key part of the decision-making activity.

Story building often involves a type of mental simulation in which a person attempts to synthesize the features of a situation into a causal explanation which can be evaluated and used in a number of ways. Pennington and Hastie (1993) have also examined the various functions of stories, one of which is to build causal explanations. Mental simulation can be used to project a course of action forward in time (Variation 3 in Figure 1), and it also can be used to look backwards in time as a way of making sense of events and observations. Here, the decision maker is trying to find the most plausible story, or sequence of events in order to understand what is going on, a process of diagnosis that is intended to result in situation awareness.

The third panel of Figure 1 shows that once decision makers arrive at an understanding of a situation, they will recognize a typical course of action and then evaluate it by mentally simulating what will happen when they carry out the action. In this way, if they spot weaknesses in their plan, they can repair the weaknesses and improve the plan. This is a better strategy than generating a large set of options and comparing these to find the best one. The evaluation that uses mental simulation can produce a better course of action instead of settling for picking one from a set.

The three panels are presented for purposes of explanation. The model can be synthesized into one diagram, shown in Figure 2.

The RPD model claims that with experienced decision makers:

- The first option they consider is usually workable so they do not have to generate a large set of courses of action to make sure of getting a good one.
- Comparing options is not a goal. They generate and evaluate options one at a time instead of comparing their advantages and disadvantages.
- Finding a workable course of action is a goal. They are trying to find the first option that works, not the best one.
- Evaluating an option occurs by imagining how it will be carried out, not through formal analyses and comparisons.

- Options can be strengthened by imagining the option being carried out, spotting weaknesses, and finding ways to avoid them.
- The focus is on the way they assess the situation and judge it as familiar, not on choosing between options.
- The emphasis is on being poised to act quickly, rather than being paralyzed until all the evaluations have been completed.

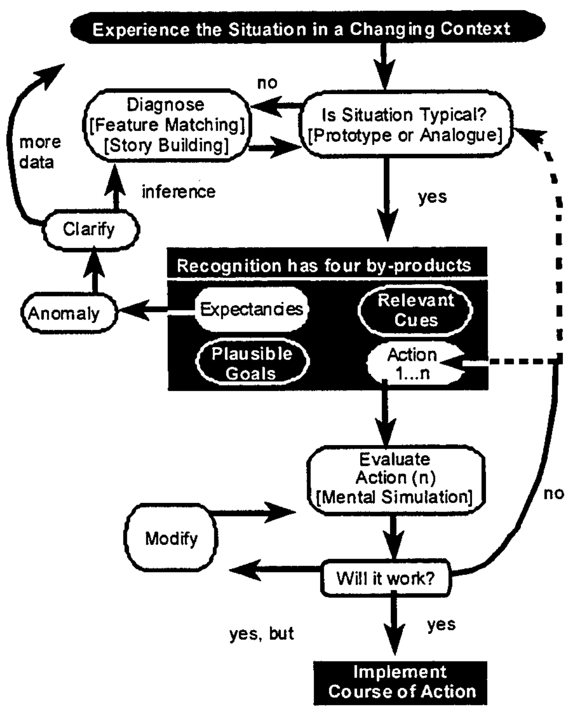


Figure 2: Synthesized version of the RPD model.

The RPD model asserts that people can use experience to generate a reasonable course of action as the first one considered. Is this a valid claim? Klein, Wolf, Militello, and Zsambok (1995) tested this hypothesis in a study that used 16 skilled chess players. With the assistance of a chess master, we selected four reasonably challenging chess positions and presented each of these to players whose official ratings were at a "C" level (mediocre) or an "A" level (very strong). Each player was tested individually, and we asked each one to think aloud while trying to generate a move to play. The data consisted of the first option articulated by the player. When the player had repeated this process for all four boards, we asked them to rate the quality of all the legal moves on each of the boards.

The most critical assertion of the RPD model is that people can use experience to generate a plausible option as the first one they consider. If this assertion is invalid, the rationale for the RPD model disappears.

Figure 3 shows the percentage of first moves and all possible moves receiving each of five move quality ratings. Figure 3 shows that across the full set of legal moves most were rated as poor ones. However, the very first move that the chess players considered was rated very high, using the players' own assessments. This means that, according to their own standards, the first moves were good ones.

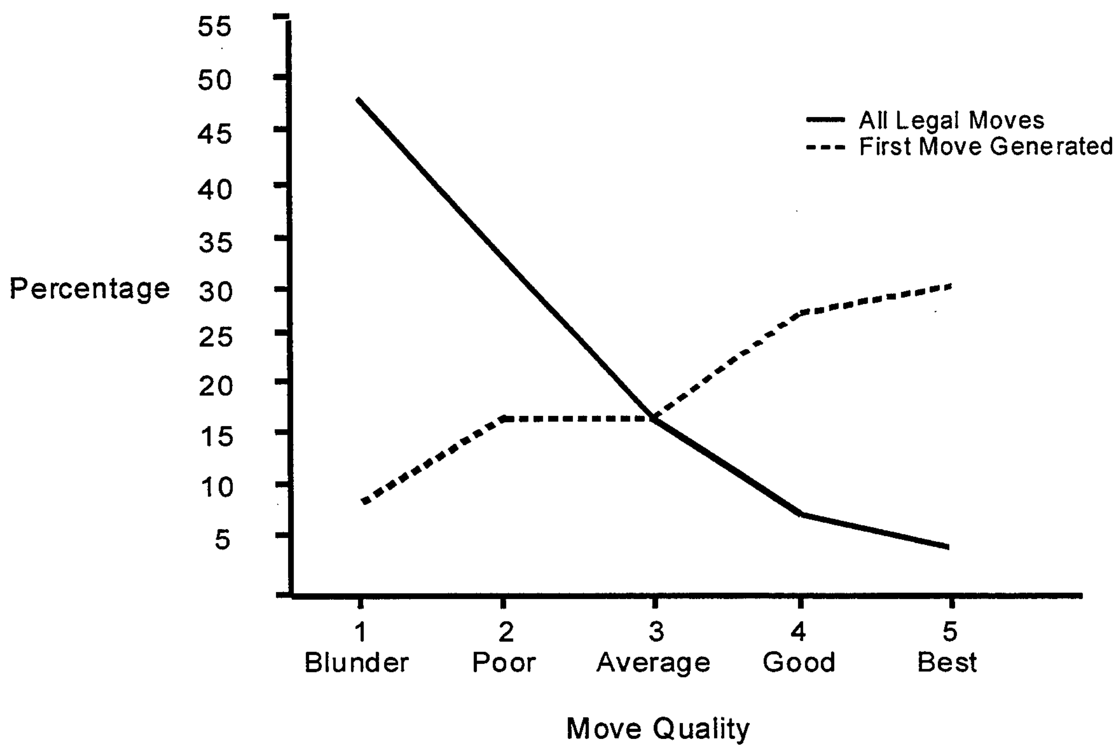
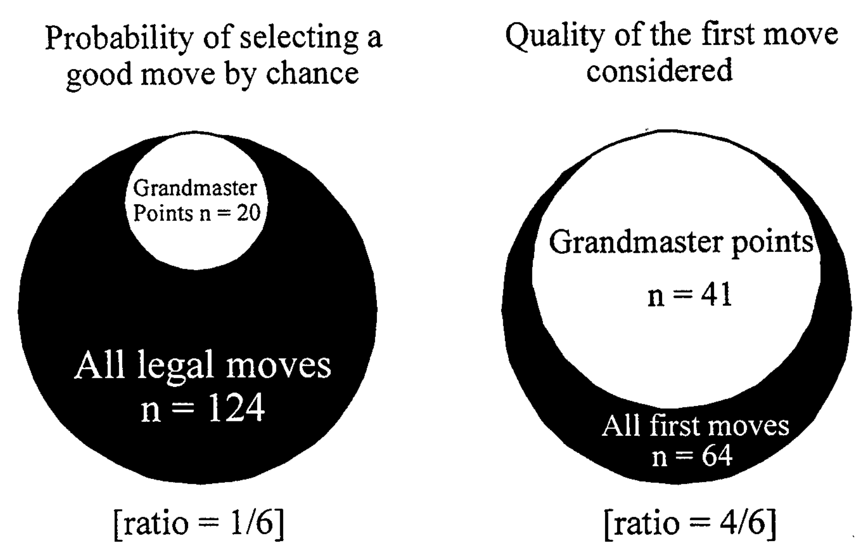


Figure 3: Quality ratings of first moves and all legal moves.

Still, we might wonder how good these first moves were, by objective standards. To investigate this issue, we had used board positions that were taken from games analyzed by chess grandmasters. The grandmasters awarded points to those options they deemed playable. Figure 4 shows that the grandmaster awarded points to only 20 out of 124 legal moves. If the participants in the study had been selecting randomly from legal moves, they would have shown the same pattern. However, they showed the opposite pattern. Of the 64 first moves (16 participants and four board positions each), 41 were moves that had received grandmaster points. Therefore, using objective criteria, we find that skilled decision makers can generate good options as the first ones they consider. These findings confirm the claim made by the RPD model that people can use experience to recognize typical actions that are usually satisfactory.

A second assertion of the RPD model is that time pressure need not cripple the performance of decision makers who have considerable expertise, since they use feature matching. Traditional Rational Choice models would predict that time pressure would be likely to interfere with the analytical processes needed, and could result in degraded performance at all levels. An earlier study of chess playing provides support for this prediction from the model. Calderwood, Klein, and Crandall (1988) studied the quality of chess moves generated under tournament conditions, using either regulation time (approximately 2.6 minutes per move) or blitz conditions (approximately 6 seconds per move). We found that even under the extreme time pressure of blitz chess, move quality remained at a very high level. The rate of blunders shown by class "B" players did increase, from 11% to 25% under time pressure, but the rate of blunders remained unchanged for chess experts, 8% vs. 7%.



Note: A move was rated acceptable if it received points from a panel of grand masters and unacceptable if it did not. The sixteen subjects each used four boards, for a total of 64 first moves. There were approximately 30 legal first moves in each of the four board positions, for a total of 124 legal moves.

Figure 4: Objective evaluation of the first chess move generated.

A third assertion of the model is that experienced decision makers can adopt a course of action without comparing and contrasting possible courses of action. Kaempf et al. (1996) probed 78 instances of decision making in operational Navy anti-air warfare incidents involving AEGIS cruisers. These were, for the most part, actual encounters with potentially hostile forces in which several courses of action theoretically existed. The 78 instances were probed retrospectively, during interviews, to determine the rationale for the decision. Kaempf et al. estimated that in 78% of the cases the decision maker adopted the course of action without any deliberate evaluation, and in 18% of the cases the evaluation was accomplished using mental simulation. In only 4% of the cases was there any introspective evidence for comparisons of the strengths and weaknesses of different options.

Since it was first proposed in 1985, the RPD model has received a great deal of support from researchers. Klein (1989) has summarized the data from studies with tank platoon leaders, design engineers, urban and wildland firefighters, and brigade level military planners, showing that the RPD model accounts for most of the decision points (between 50% and 95% of the decisions made by experienced personnel), whereas Rational Choice (i.e., comparisons between options) rarely occurs. In a variety of domains, involving high time pressure (urban firefighters) and low time pressure (design engineers), individuals (design engineers) and teams (wildland firefighters, commercial aviation crews), military (Army, Navy) and paramilitary (firefighters), and nonmilitary (commercial pilots, design engineers), decision makers rarely use Rational Choice methods. Similarly, Randel, Pugh, Reed, Schuler, and Wyman (1994) probed electronic warfare technicians while they were performing a simulated task, and found that 93% of the decisions involved serial (i.e., non-comparative) deliberations, in accord with the RPD model. Only two of the 38 decisions studied were classified as showing comparisons between options. Mosier (1991) has obtained similar findings in a study of pilots who were videotaped during a simulated mission. Pascual and Henderson (1997) have also obtained data supporting the prevalence of recognitional decision making, in a study of Army command-and-control personnel. Driskell, Salas, and Hall (1994) found that training experienced Navy officers to follow vigilant procedures (e.g., systematically scanning all relevant items of evidence and reviewing the information prior to making a decision) resulted in worse performance than if the Navy officers were allowed to use "hyper-vigilant" procedures that were compatible with recognitional decision making (e.g., scanning only the information items needed to make a decision, in any sequence, and only reviewing items if necessary).

Taken together, these studies show a growing body of empirical support for the Recognition-Primed Decision model as a descriptive account of the way experienced people make decisions.

Boundary Conditions

Klein (1989) has also speculated about the boundary conditions for using recognitional decision making and those for using Rational Choice. These are shown in Figure 5. When time is short, the decision makers are experienced, the conditions keep changing, and the goals are ill-defined, a recognitional strategy is appropriate. On the other hand, if the decision makers are novices, have ample time, have to justify their choice to others, need to resolve conflicts among team members with different priorities, have to find the best option, and/or are working with a task requiring a great deal of computational complexity, then a Rational Choice strategy makes sense. A Rational Choice strategy would be useful in many operational settings, such as selecting a weapons system during a competitive procurement, and prioritizing research areas in order to allocate funds.

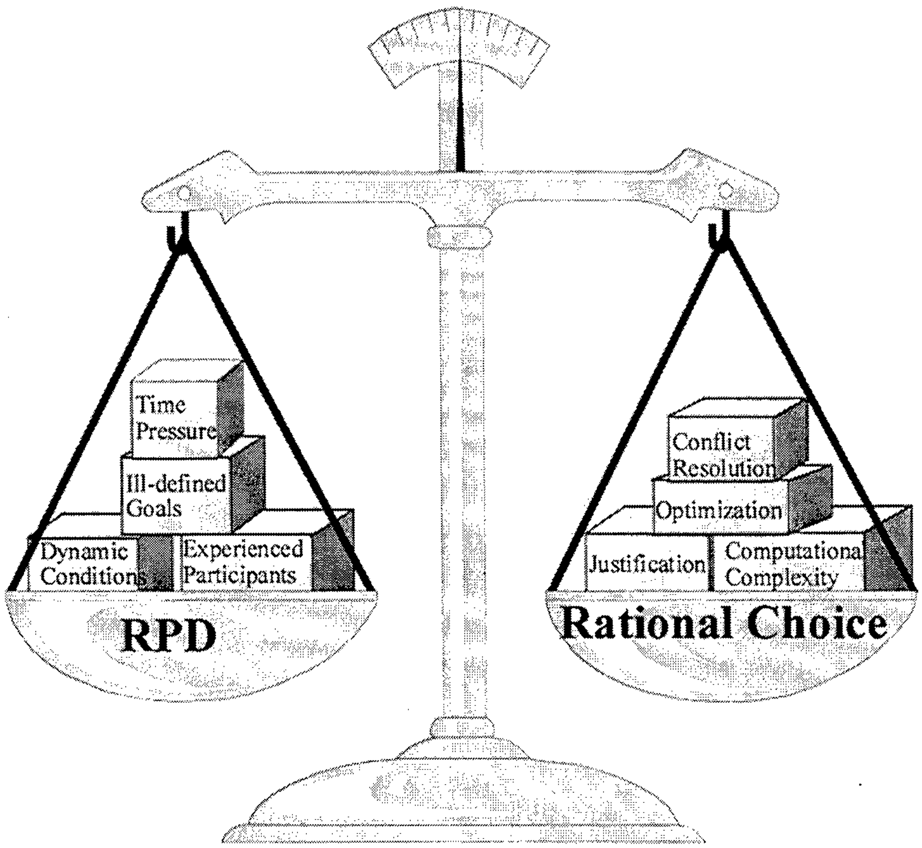


Figure 5: Boundary conditions for different decision strategies.

It is clear the NDM movement is not in conflict with traditional decision research. Rather, the two approaches are addressing different questions. The traditional research is studying how analytical methods can be used to make optimal choices, whereas NDM is focused on how people use experiential strategies to make reasonable choices. There will obviously be times in operational settings when people should rely on analytical procedures. There are times when people are faced with the choice between options, and attempt to select the best one. NDM researchers do not dispute these cases. Instead, the NDM research shows that these cases are relatively infrequent, and not necessarily as critical as decisions about the nature of the situation. The field of NDM needs to understand how people use experiential strategies as well as analytical strategies, and how they blend the two.

There are other models of naturalistic decision making, such as Image Theory (Beach, 1990), Story Building (Pennington & Hastie, 1993), Search for Dominance Structure (Montgomery, 1993), and the decision ladder (Rasmussen, 1993). These are entirely consistent with the RPD model; the differences pertain to emphases. Image Theory is concerned with explaining how decision makers incorporate individual values and expectancies into the decision-making process. Story building is essentially a form of mental simulation; Pennington and Hastie have studied story-building strategies in the context of juror decision making, which is directed at explaining previous events rather than projecting forward to anticipate new events. Search for Dominance Structure is an attempt to build on observations by Soelberg (1967) that decision makers do not rationally contrast all options. Soelberg's research was also a key impetus for the RPD model, and so both models explain the same thing: the tendency of a decision maker to select an option without comparing it to others. Montgomery's approach is to envision a comparison between a favorite option and a comparison option, aimed at demonstrating that the favorite option is better. The RPD model goes further, and asserts that in most cases people do not bother even going through the motions of a comparison; they identify a favorite and use mental simulation to satisfy themselves that this favorite will work. Rasmussen's decision ladder showing the linkage between skill-based, rule-based, and knowledge-based behavior is undoubtedly the most well-known of NDM models. Rasmussen describes a level of skill-based behavior that has no analogue in the RPD model. Rasmussen's level of rule-based behavior does overlap with the RPD model, particularly in its simplest form. And Rasmussen's level of knowledge-based behavior also overlaps with the RPD model in terms of the use of mental simulation to explain and diagnose events, and to evaluate courses of action. The two approaches clearly are compatible, and are both attempts to explain how people using their experience actually make decisions.

We should also identify further some of the limitations of the RPD model. The RPD model does not address all the concerns of naturalistic decision making (e.g., the influence of team and organizational constraints). Additionally, the RPD model does not reflect memory or attentional processes. It is important to understand the boundary conditions of a model. Cohen, Freeman, and Wolf (1996) have expanded the RPD model in order to account for metacognition (the management of thinking) along with decision making.

IV. THE ROLE OF EXPERTISE IN NATURALISTIC DECISION MAKING

One way to understand the role of expertise in NDM is to consider a set of core beliefs about expertise and decision making (Ball & Jones, 1996; Blasiol, 1996; Jones, 1996; Baron & Brown, 1991; Russo & Shoemaker, 1989; Wickelgren, 1938). These are listed in Table 1.

Table 1. Core Beliefs About Expertise and Decision Making

- Intuition is something you're born with. Either you have it or you don't.
- The way to make decisions is by rationally comparing options.
- The way to solve problems is to first define the goal, then find ways to reduce the difference between your current and your desired state.
- Information technology will eventually clear up the fog of war, largely eliminating uncertainty.

- Planning should be done by figuring out how to allocate resources to objectives, then building a synchronization matrix.
- Situation awareness is achieved by starting with data, converting them into information, then into knowledge, and converting knowledge into understanding.

From the perspective of NDM, one of the striking features of these beliefs is that all of them are mistaken. Some are only partially erroneous, whereas others are completely wrong. By examining these beliefs, we can gain a better appreciation of expertise.

The first belief asserts that intuition is something you are born with. A surprisingly high proportion of people hold this belief. When an account such as the RPD model is described, one common reaction is that it might work for the 10% of the decision makers who have intuition, but the rest of the population better not depend on it. However, there are no data suggesting individual differences in intuition. There may be some personality tests that distinguish intuitive from analytical styles, but this merely refers to the preferences in handling evidence, not to the presence or absence of intuition itself. Within the framework of NDM, intuition is seen as a function of experience. It is linked to perceptual skills, which are often difficult to articulate. Therefore, decision makers may have the experience of "intuiting" a reaction because they cannot explain the basis for that reaction. The difficulty is one of articulation regarding tacit knowledge.

Bechara, Damasio, Tranel, and Damasio (1997) has shown a physiological basis for intuition — the physiological reactions that precede conscious awareness of correct strategies. The European tradition (e.g., deGroot, 1986) has had little difficulty with the concept of intuition, whereas in the United States, we find a much greater level of suspicion. If we recast the term "intuition" in terms of expertise, the problems and concerns should diminish. The pattern matching and perceptual and recognitional skills are what alert us to the existence of a problem, or an opportunity.

Klein and Hoffman (1993) have provided a perceptual account of expertise that helps illustrate the links to intuition. According to this account, experienced decision makers see the world differently than novices. They can make fine discriminations that are invisible to novices. They can use mental simulation to recognize the precursors to a situation, and can anticipate the next developments, whereas novices just see what is in front of them. Experts can recognize typicality, which is only possible after a sufficient number of experiences to allow a decision maker to learn the characteristics and variability of situations. And by recognizing typicality, experts can quickly detect anomalies. Because they are seeing a different world, experts may not realize that others cannot make out what is obvious to them. And because of the perceptual basis of their ability, experts cannot describe it to others.

The second belief asserts that the way to make decisions is by rationally comparing options. We have already discussed the difficulties with this belief in the previous sections. Sometimes it makes sense to contrast options. But in many operational settings, it is impractical to follow this strategy.

The third belief asserts that the way to solve problems is to follow the standard stage model of defining the goal, then generating courses of action for achieving the goal. The flaw here is that in most cases, we are dealing with ill-defined goals. Therefore, if we must first wait to define the goal, we can never begin. Klein and Weitzenfeld (1978) have argued that with ill-defined goals, problem solvers must simultaneously be seeking solutions and redefining the goal. As the solution attempts fail, the evaluations will explain the reason for the failure, and usually this will help clarify what goal properties are necessary. Klein (in press) has argued that Artificial Intelligence (AI) approaches to problem solving are misleading if we take them as models of human cognitive processes. AI systems typically proceed by defining a large problem space, composed of all the pathways between the current and desired state (thereby assuming well-defined goals). The system then conducts a search through this problem space, either using an algorithm or a heuristic. This account reduces problem solving to searching through a problem space. However, for most problems people do not establish a problem space. They are redefining goals, recognizing likely solution strategies based on the way they represent the problem.

Klein and Wolf (in press) have argued that problem solving is a constructive activity, rather than a search through a problem space. People appear to be able to use expertise to recognize leverage points, which are potential building blocks for assembling a solution. The job of the problem solver is to pursue these leverage points to try to construct a solution strategy.

Another limitation of the classical account of problem solving is that it does not provide sufficient emphasis on the process of problem detection. Klein and Crandall (1997) have analyzed more than 50 cases of problem detection, and found that a considerable amount of expertise is necessary to detect and interpret the initial subtle cues that are the early warning signs that a problem is developing.

The fourth belief asserts that information technology will clear up the fog of war. Even if this was true, it would likely be irrelevant because the pressure to expedite decision cycles would merely result in a situation where commanders were making faster decisions, at the same level of uncertainty as they were used to. With the advent of radars on ships, many expected that safety would increase. In fact, ship captains had reached a risk homeostasis, and used the new technology to increase their speed, keeping accident levels constant. So, too, with information technology. If a decision was formerly made in an hour, at a level of 70% confidence, and the technology provided the 70% confidence level in 30 minutes, we suspect that the decision would be made at that point, rather than waiting the full hour to achieve 80% confidence, or waiting four hours to achieve 100% confidence.

However, information technology is not likely to clear up the fog of war. Schmitt and Klein (1996) have distinguished different sources of uncertainty (missing information, unreliable information, ambiguous/conflicting information, and highly complex information) and different levels of uncertainty (data, inferences about the data, and projections into the future). Thus, one type of uncertainty in war is about the location of friendly troops (missing data). Global Positioning System can be helpful here. But another type of uncertainty is about the intent of the enemy commander (ambiguous projection into the future). Global Positioning System will not help with that. An historical mapping of enemy units might offer some clues. Another type of uncertainty is the enemy's capability to mass forces on a given target, within a given timeframe (complex inference). And another type of uncertainty has to do with inconsistencies in messages (unreliable data). No one technology will address all of these problems. And the increased pace of communications will increase some types of uncertainties even as it diminishes others. Skilled commanders have been able to press on regardless of uncertainty (e.g., Eisenhower selecting a date to cross the English channel for D-Day, despite uncertain weather forecasts), and to structure the battlefield in order to reduce uncertainty. Skilled commanders also know when to seek more information, whereas less-talented commanders seem to be using data collection as a tactic to avoid making hard choices, looking for data that are not particularly diagnostic and take too long to collect. Expertise is therefore in the form of when to seek more information, which information to seek, and how to make better use of the available information.

The fifth belief is that we should try to achieve systematic planning. Neal Schmitt (1997) has described the folly of aiming for complex synchronization schedules in an environment as chaotic as combat. Mintzberg (1994) has presented a severe critique of the entire concept of strategic planning. The arguments are essentially that the rigor is not a substitute for imagination. Expertise allows decision makers to size up situations accurately and to recognize leverage points as a basis for constructing effective strategies. Planning can be done once the strategies have been outlined, but strategic planning is not an effective means of formulating strategy.

The sixth belief is that situation awareness is built up from the level of data, to the level of information, to the level of knowledge, and finally, to the level of understanding. This is an extremely common belief (e.g., Endsley & Robertson, 1996). It is wrong because it ignores the way experienced decision makers work. They do not want to rely on the analyses of less skilled subordinates. They do not want to be at the mercy of ill-trained clerical staff members who aggregate the data to begin with. They do not want their role to be reduced to a passive one of receiving information summaries and twice-a-day briefings. Rather, they want to have an active, information-seeking role. Their hypotheses about the nature of the situation will determine the types of data that are diagnostic and easily obtained.

Moreover, there is no basic level of data, as if data elements were primitives. The relevant data are a function of the way the situation is understood. In a study of weather forecasters, Pliske, Klinger, Hutton, Crandall, Knight, & Klein (1997) found that the most highly skilled forecasters would sometimes hand-plot the data, rather than rely on computer-generated plots, because the grain of the computer system was too coarse at a given locale to capture some subtle features. The skilled forecasters did not want to begin their workshift with a briefing about the situation, or with a computer-generated report. They wanted to look back over the data for the past several hours and generate their own mental model.

Because experienced decision makers can identify trends and subtleties in the data that their subordinates cannot see, they often direct their subordinates not to filter any data, but to pass along everything. This, of course, results in the information explosion. Skilled decision makers do not need to see all the data or all the information. They need to be able to drill down for the diagnostic data in a situation, based on their understanding. Thus, the nature of the understanding defines the data — the granularity and features of the data that are useful.

Taken together, this critique of the beliefs presented in Table 1 provides a picture of the importance of expertise in NDM. The point is not just that expertise is important. The point is to describe how it is important, how it affects decision making, planning, situation awareness, and problem solving.

V. BARRIERS TO EXPERTISE

Just as we have learned a great deal about different aspects of expertise and how they are involved in NDM, we have also learned a great deal about ways to interfere with expertise. In this section, we describe some of the primary barriers that will prevent decision makers from using their intuition. The barriers selected are directly linked to information technology. That is, stressors such as time pressure and uncertainty are not included because they are not necessary aspects of information technology.

In addition, the section describes how these barriers are likely to affect military operations related to Information Dominance. The claim here is simple: attempts at Information Dominance run a strong risk of reducing, rather than improving performance, because the technologies are often at odds with human expertise. Only by gaining a clear picture of expertise can we take the necessary steps to avoid or reduce these barriers.

Table 2 lists six primary barriers to expertise that are posed by information technology. The six barriers listed in Table 2 will be discussed in order, and each subsection will indicate the ways that Information Dominance can exacerbate the difficulty.[1]

Table 2. Barriers to Expertise That Are Posed by Information Technology

- Excessive data
- Pre-processed data
- Excessive procedures
- Performing formal analyses
- Passive data handling (reactive mindset), limited ability for information seeking

[1] This discussion of barriers to expertise does not include all of the potential barriers to expertise within the domain of Information Dominance. For purposes of this discussion I identified barriers that result from our own information systems. I did not discuss barriers to expertise that result from actions that an enemy could potentially take to reduce the effectiveness of our information systems, such as introducing a disinformation. Nor did I address barriers to the expertise involved in detecting opportunities for disrupting the enemy's information systems awareness.

- Interfaces that obscure the big picture

- <u>Excessive Data</u>. Decision makers would ideally select and use only relevant information when presented with a large amount of information. However, a review of the relevant research, in both laboratory and applied settings, found that decision makers frequently select irrelevant data and that use of these irrelevant data adversely affects their decision making performance (Gaeth & Shanteau, 1984). More recent studies have continued to uphold these conclusions. For example, Stewart, Moninger, Heideman, & Reagan-Cirincione (1992) studied expert meteorologists and found that as the amount and quality of the information increased, there was a substantial decrease in agreement among the forecasters regarding their predictions of microbursts. Similarly, Lusk and Hammond (1991) demonstrated that forecast accuracy did not increase with increasing information.

  In the past, when it was observed that a decision maker only utilized a subset of the available data, it has been seen as a shortcoming of humans, an inability to process large amounts of data. We can change this perspective, and appreciate the importance of expertise for enabling skilled decision makers to select the small set of relevant data with which to work.

Information technologies are exciting because they can present enormous amounts of data to decision makers, at very high rates. This sounds wonderful, until we realize that these data rates will likely be excessive, and may result in a degraded use of intuition and experience. In some ways, the very premise of information technology runs counter to the effective use of experience. We must develop ways to facilitate decision makers so that they can take advantage of the enormous amounts of data that they now have access to, without causing them to be overwhelmed by the sheer volume of information available.

- <u>Pre-processed Data</u>. Experts prefer to build their own mental models rather than rely on the aggregation and analyses of subordinates who are less skilled. The activity of building a mental model itself provides a feel for the situation. In one project (Klinger, Andriole, Militello, Adelman, Klein, & Gomes, 1993), we heard from old-time AWACS weapons directors that in previous positions, as ground controllers, they had to watch radar screens and mark targets with grease pencils. And they felt they had a better feel for the situation than they did as AWACS weapons directors, with computers to automatically enter and tag the aircraft. The manual engagement with the screen helped them to own their big picture.

  Information technologies handle the data explosion by relying on various types of fusion algorithms, artificial intelligence, and related procedures. Skilled decision makers are often forced to rely on pre-processed data. A critical issue that must be addressed when designing future information systems is who needs access to which raw data? Should the general's staff always pre-process the data before it is passed to him? Research from the NDM perspective suggests that limiting high-level decision makers to pre-processed data can be a barrier to expertise. Information technologies must be exploited to allow high level decision makers to have access to relevant subsets of raw data when necessary.

- Excessive Procedures. Experienced decision makers are flexible in how they perform tasks and adapt to situations. This provides high levels of efficiency. It also allows them to work in context, rather than mindlessly performing routinized actions that do not always make sense, because no routines can anticipate the different challenges of chaotic battlefields. If we require experts to follow routines, we are eliminating one of their important strengths. Pliske et al. (1997) found that expert weather forecasters are extremely flexible in their information search strategies depending on the nature of the weather situation at hand (e.g., potential for high winds, potential for hail, etc.). Unfortunately, the automated information system that Air Weather Service forecasters are required to use to produce their forecasts is not flexible; it had been designed to support a highly proceduralized forecasting process. Although this highly proceduralized system helped novice forecasters produce mediocre forecasts, this system actually served as a barrier to the true experts.

Information technologies will likely require highly routinized actions in order to avoid system errors, and in order to adapt to the needs of the knowledge bases regarding the type of data needed and the format that is necessary. However, these technologies can also be used to develop flexible human-computer interfaces that will support decision makers of various skill levels. Highly skilled human decision makers must be allowed to override routinized functions in information systems that interfere with their ability to utilize their expertise.

- Performing Formal Analyses. The act of making factors explicit, which is central to decision analysis, may itself interfere with subtle judgments. A number of studies have reported this fairly surprising finding (e.g., Schooler & Wilson, 1991; Erev, Bornstein, & Wallsten, 1993; Reber, 1993), that if you ask decision makers to produce a judgment for a complex task, the judgments are reasonably good. But if you first require the decision makers to perform formal analyses of the elements of the situation, and then ask them to make an overall judgment, the quality of those judgments is significantly reduced. Therefore, we can interfere with intuition by first having the decision makers perform analysis.

  The fascination with hard data (i.e., quantitative data) is in part because of its objectivity, in part because of the ease of performing sophisticated analyses. However, when hard data are uncoupled with the soft data that are needed to interpret them and put them in context, the results can be very misleading.

Information technologies will often require very formalized inputs in order to run the decision support systems, and these inputs are non-intuitive. They rely on formal analyses and decompositions, all of which will lead decision makers away from their intuitions. Information technologies need to be exploited to support intuitive judgments as well as analytic judgments.

- Passive Data Handling (Reactive Mindset), Limited Ability for Information Seeking. As discussed above, skilled decision makers rely on an active engagement with the situation. They rely on a powerful repertoire of information-seeking strategies. They need to build their own mental models. If you prevent them from taking an active role, if you put commanders into a passive role of receiving data, if you put C2 staff into a passive role of scrolling through emails, you reduce their ability to use their expertise.

  The neuropsychologist Oliver Sachs (1995) wrote about a case in which a 50-year old man who had lost his vision in early childhood, due to thick cataracts, had recently regained his vision through a simple cataract removal operation. After studying this man, Sachs realized that there was still a major disability. The man now had fairly good acuity. He could see shapes and colors. However, during the decades of blindness he had lost the ability to **see**. That is, he was content to passively receive a succession of images. But he did not naturally look at things, or look for things. Upon being introduced to people, he did not really look at their faces. "Virgil would look, would attend visually, only if one asked him to or pointed something out — not spontaneously. His sight might be restored, but using his eyes, looking, it was clear, was far from natural to him; he still had many of the habits, the behaviors, of a blind man." (p. 117). Sachs concluded that the patient was mentally blind.

  If we make this distinction between passive receipt of images and active looking, then we can see how much is lost when we reduce decision makers to a passive mode.

Information technologies have a very strong tendency to reduce users to passive recipients of data, particularly users who are not intimately familiar with the way the hardware and software is designed, and so are reluctant to try to work around problems or strike out on their own. We may be creating a new breed of commanders who become mentally blind in that they will have lost their ability to look, to search. Moreover, the Information Dominance architectures will be designed by technophiles who may have little appreciation for the demands of combat. Technophiles often try to design technically impressive systems, to impress their colleagues, and view the users as the potential weak link in the cycle. Technophiles sometimes see the operator as a way to feed the system, and strive to design a system that offers minimal opportunities for the operators to stray from the intended strategies. System designers need to keep in mind that the human expert needs to be actively engaged in the information-seeking functions of the information system.

- Interfaces That Obscure the Big Picture. It is easy to reduce functional expertise by denying decision makers a chance to see the big picture. This can be done in many ways, by overloading a display with data, by formatting the data inconveniently, by letting variables change without calling attention to themselves, by requiring an annoying number of secondary tasks to update a screen, by using confusing symbols, and so forth. The field of human-computer interface has been discovering new methods for hiding the big picture for several decades.

In addition, simplistic slogans often masquerade as approaches. The term "user-friendly" quickly wore out its welcome. Soon, the term "user-centered design" will do the same. The facile suggestion to rely more on graphics and less on alphanumerics, ignores findings that for some tasks, such as inducing patterns in data, numerical data are more useful than graphical representations; the issue of graphical versus alphanumeric depends on the nature of the task. In short, slogans are not going to substitute for careful studies of the cognitive requirements for the tasks.

Information technologies could easily distort the big picture because the information battlefields they will portray are even more complex than the geographical battlefields with which we are familiar. Since we never learned how to do a good job of presenting the big picture for the geographical battlefields, we face a tremendous challenge in this area. If system designers take into consideration the cognitive requirements of the intended user of the information system, then information technologies could be utilized to support the development of the big picture rather than obscure it.

The arguments presented in this section can be synthesized into a single claim: *the quest for Information Dominance runs a real risk of reducing rather than improving the performance of decision makers.* The reason for this is because information technologies can interfere in a major way with the expression of expertise on the part of skilled commanders and staff members. Section VIII will explore some suggestions for avoiding these barriers. But we can only avoid them if we understand what they are.

Up to this point, the report has concentrated on the individual decision maker. The next sections change this focus, and examine the team decision-making process.

VI. REVIEW OF THE LITERATURE ON TEAM MIND AND TEAM DECISION MAKING

For Information Dominance, much of the decision making will take place in the context of teams. The nature of expertise is different at the team level than it is at the individual level. In this section of the report, we examine expertise at the team level. More specifically, we are interested in the concept of a "team mind," an emergent phenomenon in which the team understands and thinks and decides in ways that transcend the individuals. For example, an air campaign planning process depends on a team mind. One element updates the target nomination list. A second element updates the available airfields and aircraft. A third element prioritizes the target list. A fourth element assigns resources to targets. A fifth element prepares the Air Tasking Order. With specific instructions, each of these elements may be able to work at the procedural level, and few of the tasks require much decision making. Yet the team as a whole is engaging in a complex planning and problem-solving activity. No individual member of the team may understand the deep strategic implications of the eventual Air Tasking Order.

Our challenge is to apply NDM at the level of teams for purposes of understanding Information Dominance. We need to clarify the cognitive processes involved, the nature of expertise, and the likely barriers to expertise. In order to explore the implications of the NDM framework for Information Dominance in the context of teams, it will be useful to consider NDM models of team performance. Many different models of team performance have been proposed and we review relevant models in Appendix A. In this section, we briefly describe some of our own work on team decision making that has relevance to the domain of Information Dominance.

Advanced Team Decision Making

Thordsen, Klein and Kyne (1994) developed a model of Advanced Team Performance, based on the Advanced Team Decision Making work by Zsambok, Klein, Kyne, & Klinger (1993). Thordsen et al. relied on a **cognitive** metaphor, viewing teams as cognitive entities with an identity and the ability to think and monitor itself. The goal of this work was to develop a theory-based framework which would enable observers to assess the skills and deficiencies of teams as they conducted business in either simulated or actual environments.

Based on observation of strategic decision-making teams, Thordsen et al. (1994) identified 13 key behaviors that are essential to high performance teams. These are organized into the ATDM model. The four components of the ATDM model are Team Competancies, Team Identity, Team Cognition, and Team Metacognition. Each of these components is composed of directly observable behaviors. The components and behaviors are depicted in Figure 6.

Team Competencies refer to the skills of the individual team members, and the degree to which the team has mastered common routines for action. *Team Identity* describes the extent to which team members conceive of the team as an interdependent unit, and then operate from that perspective while engaged in their tasks. In other words, are the team members able to decenter from their individual roles to consider the team as a whole? *Team Cognition* captures the notion of a team as an intelligent entity, a "team mind" that thinks, solves problems, makes decisions, and takes actions collectively on a level of complexity and sophistication that matches the demands of the task. *Team Metacognition* is a regulatory process for all other processes described in the model. Self monitoring is a metacognitive process which helps teams promote advanced team decision making, moving from weak to strong identity and from a low to high conceptual level by determining how successfully the team is using key behaviors and making necessary adjustments. Team Metacognition by definition is the ability of a team to observe itself while acting to accomplish its tasks.

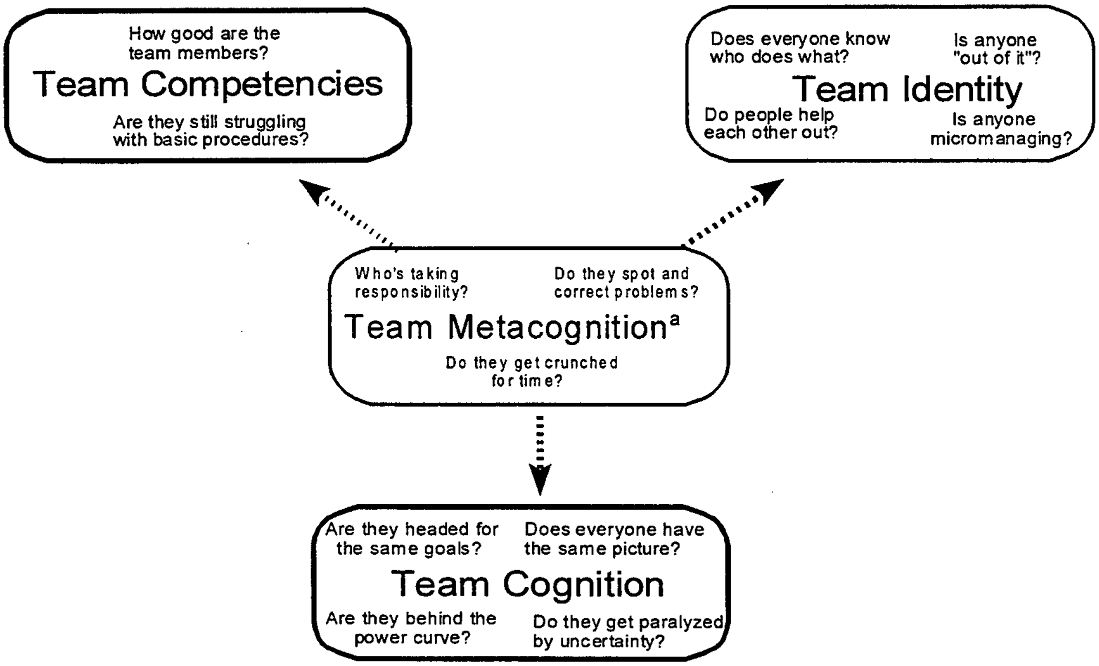


Figure 6: Advanced Team Decision-Making model.

For the component of *Team Competencies*, there are two behavioral markers, the skills of the team members and the mastery of routines by the entire team. For the component of *Team Identity* there are four dimensions or behavioral markers. Defining roles and functions ("Does everyone know who does what?") concerns the extent to which teams ensure that all their members know what they are expected to do to attain the team goals. Engaging ("Is anyone 'out of it?'") concerns the extent to which team members are involved in the team task and their own functions. It also concerns encouraging other members to engage in the team task. Compensating concerns the ability of team members to step outside their assigned roles or functions and perform different ones in order to help the team reach its goals. This dimension includes compensating when problems arise as well as trying to learn what caused the problem. Avoiding micro management is seen as key to advanced team performance. Team members take steps to manage information, tasks, or people at an appropriate level of detail.

The component of *Team Cognition* also contains four behavioral markers. Envisioning goals and plans concerns the ability of teams to use specific, concrete language that is put into a context relevant to the team members, both through examples that relate to their experience and through outcomes that contrast success and failure. The time horizon ("Are they behind the power curve?" refers to where attention is directed. Managing uncertainty concerns the ability of a team to discover and fill holes in the team's information base and to recognize and handle inconsistencies or contradictions that might be present. Achieving shared situation awareness involves actively seeking a variety of views from team members about plausible situation assessments, and then ensuring that all members share a common understanding of the assessment that the team eventually accepts.

The component of *Team Metacognition* concerns three key behaviors. Self-monitoring ("Do they spot and correct problems?") is the team's ability to modify the way it is performing when problems are discovered through the monitoring function. Time management refers to the ability of a team to meet goals before deadlines overtake them, to sequence subtasks effectively so that output from one task connects where and when it should as input to the next task, and to maintain a strategic allocation of time to subtasks in terms of their priority for reaching the overall goal. Leadership ("Who's taking responsibility?") refers to the ability of the team to perform leadership functions, either using the designated leader or through workarounds where necessary.

Klein and Thordsen (1989) have introduced the term "team mind" to refer to the emergent cognition at the team level in settings such as cockpits. We described different levels of awareness for information items. If all the individuals in an airplane cockpit know something, it is at the level of the collective consciousness. If only one member knows it, and does not share it with others, we can say that the knowledge is at the pre-conscious level. We went on to describe cognitive processes that can be adapted to teams: the concept of reaction time, of working memory (a team can only discuss one thing at a time), of long-term memory, situation awareness, and inferences. One of the difficulties teams will have is to derive inferences when the elements are held at the pre-conscious level — that is, if individual (a) knows one thing, and individual (b) knows another, the fusion of those aspects of knowledge into a higher level inference can become difficult. Wegner (1987) has amplified the concept of a team's long-term memory.

Klein and Miller (1997) have studied distributed planning teams in a variety of domains (Joint Force Air Component Commander [JFACC] planning, U.S. Marine Corps regimental command post planning, Patriot missile battery planning, air campaign planning) and have developed a model, shown in Figure 7, that includes the planning functions themselves (e.g., detecting problems, generating courses of action, evaluating the plans), the types of plans required (e.g., modular versus integrated plans, conceptual versus detailed plans), and the forcing functions in the environment that determine the process and product (e.g., time pressure, resource limitations). Using this model, we were able to note that in JFACC planning, the intent for striking targets, that was part of the target nomination cell's deliberations, was not adequately captured when the planning package was sent to the combat operations cell, with the result that targets were sometimes hit with inappropriate munitions. In addition, the modular types of plans (air tasking orders) that were produced were not suitable for overall evaluation, and as a result, did not get evaluated. These functions were simply not relevant for the JFACC plans, whereas they were extremely relevant for Patriot missile batteries, where the intent about which targets needed the most protection was clear, and the evaluation of the plans (how the orientation of the batteries provided double or triple coverage) was carefully accomplished.

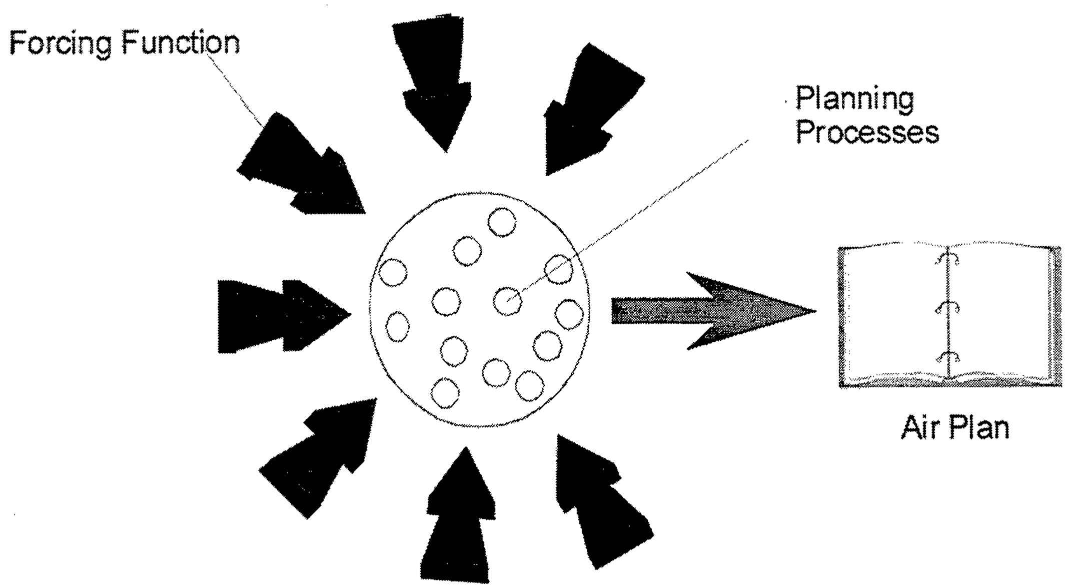


Figure 7: Distributed planning teams.

Thordsen, McCloskey, Heaton, and Serfaty (1996) have studied power projection in naval air planning involving FA-18, EA6B, and E2C aircraft. Typically, there are few opportunities for these pilots to prepare and rehearse their missions together. As a result, critical aspects of coordination may not be anticipated, resulting in inefficiencies and occasionally inadequate performance. For example, the crew aboard the EA6B may not be directly involved in certain aspects of the strike mission, but they are still listening in on their radios to gauge how the mission is going. If critical messages are passed while the EA6B is in a jamming mode, the EA6B team will not hear the radio traffic, and will suffer a degraded situation awareness.

Klein, Wolf and Serfaty (1997) have developed a model of information management which decomposes the primary functions of information management (collecting data, assigning meaning to the data, and either applying the inferences, transmitting the information, or seeking additional information. Each of these functions is associated with typical errors which result in degradation or breakdown of the information management function.

This brief review of the research we have conducted on team decision making indicates that the nature of expertise is different at the team level as compared to the individual level. In the next section, we discuss the role of expertise in team decision making in more detail.

VII. THE ROLE OF EXPERTISE IN TEAM DECISION MAKING

The interaction between naturalistic decision making work and teams is fairly subtle, and is best understood by looking at what is **not** happening, rather than at what is being addressed. Traditional decision research emphasizes a Rational Choice model for individuals, and therefore would direct attention to the use of a Rational Choice model (i.e., multi-attribute utility analysis) for teams. Under a traditional framework, we should be trying to help teams by finding ways for them to work together to generate more options to be considered, by helping them identify more dimensions for evaluating these options, by assisting them to properly weight the evaluation dimensions, and by supporting them in rating the options and synthesizing the ratings across team members. Traditional decision researchers have studied ways of providing all of these types of aid, including brainstorming (to increase the set of options and evaluation dimensions), and other techniques for combining the judgments and ratings of individual team members. In contrast, NDM models do not look at any of these types of methods.

The NDM view of team decision making directly parallels the view of individual decision making found in accounts such as the Recognition-Primed Decision model (Klein, 1997b). **Situation awareness** is a critical function for teams, and the models of teamwork emphasize ways to use the inputs of team members to build a better situation awareness, and ways to encourage shared situation awareness among the team members (e.g., Stout, Cannon-Bowers, & Salas, 1996). The use of situation awareness to focus attention on critical cues is important for team members, and one of the challenges is to find ways to selectively share information so that information overload is avoided. Expectancies are important for coordinating team activities, and for enabling all team members to notice discrepancies and anomalies and thereby to notify the team that the shared situation awareness may be inaccurate. Situation awareness includes the description of goals, and one of the important functions within team decision making is for the leader to communicate intent so that the other members can make their own decisions about how to carry out directions and how to improvise. Situation awareness should provide a sense of appropriate actions, and NDM researchers are finding that in many settings it does not make sense to generate alternative courses of action, despite doctrinal recommendations. Finally, mental simulation is an important strategy for evaluating courses of action in teams as well as in individuals. The collective experience base of the team can be effectively utilized by having the members review how the course of action is intended to be carried out, so that pitfalls can be spotted along with opportunities for improvement. Viewed in this way, the NDM approach to team decision making is radically different than traditional approaches.

The NDM framework emphasizes situation awareness. Therefore, one approach we can take is to define Information Dominance as the struggle over situation awareness. Several observers have converged on a three-part categorization of information warfare: attack the enemy's information system (by physical destruction, deceit, etc.), defend our own information system, and enhance the use of our information system (U.S. Air Force Scientific Advisory Board, 1995; Widnall & Fogelman, 1995; Arana-Barradas, 1995; Ely, 1995; Whitaker & Kuperman, 1996). *Recasting this, we can view Information Dominance as the attempt to disrupt the enemy's situation awareness, protect our own situation awareness from attack, and enhance* *our own situation awareness.*

From this perspective, it is critical to learn how teams, particularly distributed teams, acquire a shared situation awareness. These mechanisms may offer important opportunities for attack, defense, and enhancement. Following Klein and Thordsen (1989), if a team mind is analogous to an individual mind, then, borrowing from the RPD model, we would suggest that a team's situation awareness should hinge around the critical cues within the context of the mission, the expectancies, the goals being pursued, and the typical courses of action, or the most promising leverage points and most threatening choke points.

Because information seeking is so central to building situation awareness, we may want to pay particular attention to the way teams go about their information seeking. One common strategy is to announce critical information requirements. We have observed many exercises where this was done. In almost all cases, these critical information requirements were ignored throughout the entirety of the exercise. There is a great deal of work that needs to be done here.

VIII. BARRIERS TO EXPERTISE: THE IMPACT OF INFORMATION DOMINANCE ON TEAM DECISION MAKING

In Section V we covered a set of barriers to proficiency at the individual level of NDM. We identified a set of conditions we could impose that would diminish expertise, and we showed how each of these was likely to occur with the use of information technologies for Information Dominance. In this section, we will do the same at the team level. We will describe how each of these barriers affects team decision making, using the Advanced Team Decision Making (ATDM) model (shown again here as Figure 8) as our frame of reference.

The list of barriers to expertise is the same one that was used in Section V:

- excessive data
- pre-processed data
- excessive procedures
- performing formal analyses
- passive data handling (reactive mindset), limited ability for information seeking
- interfaces that obscure the big picture

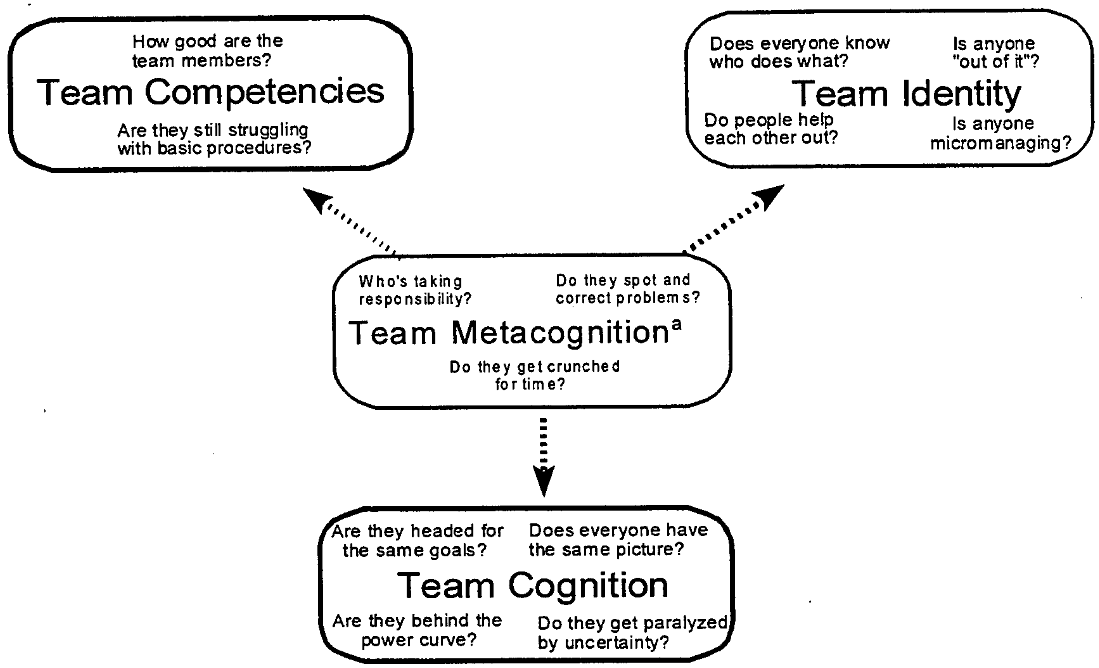


Figure 8: ATDM model.

- Excessive Data. This will disturb a team's decision making in several ways. With regard to *Team Identity*, it will blur roles and functions because as information floods a team the boundaries between individual roles and functions become unclear. If there are any weaknesses in the clarity of roles and functions, then with information overload the team members consider the additional information to be an added burden, and not part of their jobs. No one may feel that a particular piece of information is his/her responsibility. So data will be lost, and the team members receiving the data will be confused about what their responsibilities are.

  With regard to *Team Cognition*, excessive data will shrink the time horizon. Consider the analogy to driving. On a highway it is very easy to look far up the road to search for obstacles and indications regarding a route. In a city, a driver has more difficulty — there is too much information, too many different signs to be scanned. As a result, the car has to be driven more slowly, because the look ahead is reduced. Similarly, the range of factors considered by the team becomes compromised. Teams have more difficulty considering a wide range of factors, in knowing which factors are important, and in understanding how any one factor impacts another.

Information Dominance is designed to increase the data stream. So we may find breakdowns in Team Identity and Team Cognition.

- Pre-processed Data. If we provide a team with information and knowledge and analyses that have already been performed, perhaps electronically, it can enhance their operations. But it can also lead to confusions about where the data came from, and how accurate they are. In the ATDM model, this relates to the function of *Team Competencies*, in which one of the difficulties of teams is gauging the competence of other members. This is particularly true in distributed teams, where the identities and competence of the other members are unknown. In battle command exercises, much of the gain of using pre-processed data is lost in the frantic search to verify data quality and source.

  Team Cognition is also compromised in using pre-processed data, particularly the shared situation awareness. Uncertainties about data source and quality will typically result in differing levels of confidence with the picture that is painted, thereby interfering with the goal of building a shared picture.

Information Dominance will require an increased level of pre-processed data, which may create confusions about data source and quality, and interfere with the development of a shared situation awareness.

- Excessive Procedures. By requiring teams to follow rigid procedures, we reduce the ability of the teams to be flexible and to adapt to conditions. We reduce their efficiency. The impact is seen most clearly in the area of *Team Metacognition* — the leadership ability of seeing what is working and what isn't, and making corrections.

  This is particularly visible in contexts such as the JFACC planning/execution cycle. The 72-hour cycle is rigidly laid out. With the deliberateness of a production line, the Air Tasking Order marches through the various stations, from the target nomination board to the combat operations cells, and out to the aviators. One of the striking aspects of this process, as we observed it, is the minimal input of the commander. In conventional, ground-based combat, we understood that the focus of activity was not against the enemy strengths, not to take advantage of the enemy weaknesses, not against the enemy troops, but against the mind of the enemy commander. By striking at the enemy commander's mind, he could be persuaded to draw back rather than strike boldly, to become reactive rather than proactive. In some cases, commanders have surrendered despite having superior troop strength and resources compared to their opponents. And the will of one's own commander was critical for providing a vision of what was to be accomplished.

  But in the JFACC planning cycle, we were hard pressed to find evidence of the impact of the Joint Force Air Campaign Commander. The Air Tasking Order was assembled by procedures. The rationale was not bundled with the targets. In fact, for exercises we have observed, the only activity of the commander was to indicate what percentage of sorties were to be allocated for interdiction, close air support, and so forth, as the battle changed. We recognize that in combat the role and influence of the commander varies greatly. This role, issuing percentages, seems fairly trivial; in most cases, the percentages are obvious, and this is a far cry from generating a vision of what is to be accomplished.

It also struck us that no one had a particularly clear understanding of the big picture, because there was no grand plan, but rather a collection of micro-plans for conducting strikes against a variety of targets. The expertise of the team was in carrying out procedures, not in gauging the effectiveness of their approach, or reconfiguring their approach.

Information Dominance may result in a fundamental change in the nature of combat. It may eliminate the attempt to attack the mind of the enemy commander, and it may render obsolete the leadership of one's own commander. It may move us to a proceduralized planning and implementation cycle that is difficult to adjust on the fly because no one has the big picture, no one understands how the process is working, and no one has the confidence to make changes because of a fear of unintended consequences.

- Performing Formal Analyses. Mintzberg (1994) has documented in great detail the ways that strategic planning has been ineffective and has resulted in worse performance, rather than better performance. He discusses the dangers of formal analyses performed by planning teams that are disconnected from operational realities, attempting to decompose situations into elements, and relying on quantitative data rather than on subjective impressions. The team decision making function most severely compromised by formal analysis is *Team Cognition*, because the quality of the plans, solutions, and decisions is degraded. But *Team Identity* is also affected because the formal analyses are usually performed in a way that disengages the operational staff from the planning staff.

Information Dominance will call for an increase in formal analyses because the complexity of the problems and the needs to rely on intelligent decision support systems will require quantitative data for decomposed elements. The result may be less flexible and imaginative decision making.

- Passive Data Handling (Reactive Mindset), Limited Ability for Information Seeking. One of the challenges at a team level is to know how to exchange information, to produce an effective shared situation awareness. If too many data items are exchanged, the result is an overload. And if too few are exchanged, critical items will not be acted upon.

  A passive mentality allows both to happen. It is easy to simply reroute emails to everyone, or to generic user groups, knowing that there are no consequences for sending irrelevant messages. Thus, in Desert Storm, General Boomer received 1.3 million emails in the first 30 hours of the ground war. (This did not bother him because he spent almost no time in his command post during this period.)

It is also easy to exchange too few data items. If there is an important item of information, the holder needs to understand its implications in order to deal with it appropriately. But what happens if the critical pattern is dispersed among several individuals? Each one may discount the data item he or she is holding, because by itself it may have no significance. The significance is only in concert with the other data elements. An active mindset is needed to put these pieces together. What will happen in combat when we must depend on the individual team members to actively wonder about the deeper implications of certain data elements, and actively seek out others to check on what is happening? A passive mindset will make such behavior less likely.

In another example, during a recent exercise one of the officers noted that the command post had not received any pilot reports for a while. He wondered about this (it is very hard to detect negative cues — the absence of events), checked with others, and found that there were no pilot reports for the previous 24 hours. Further investigation showed that someone in the command post had changed the makeup of newsgroups (which had been set up to reduce the confusion over all the email), and as a result, the pilot reports had been dropped! And no one had noticed, not any of the analysts sitting in front of their screens reading their emails, except one officer who had maintained his active mindset.

The real challenge to a team is to provide a partially shared situation awareness, in which people learn what they need to, and are not bombarded with excessive messages. This is difficult to work out, possibly impossible. The solution is **not** to work this out, but to maintain active mindsets so that the team members are engaged in information seeking, rather than information receipt.

Information technologies have a strong tendency to produce a passive mindset in the team members, and the development of Information Dominance is likely to make this worse by increasing message flow and increasing the fear of missing something.

- Interfaces That Obscure the Big Picture. We know much less about how to interfere with the expertise of teams, than we do about interfering with the expertise of individual decision makers. Nevertheless, it should be possible to speculate about some easy ways to disrupt teams, using the ATDM model as a starting point. We would diminish the sense of *Team Competencies* by masking the identity of the other team members, working at separate stations, and keeping the inputs of all team members stylized so that there is little opportunity to gauge competence. We would diminish the sense of *Team Identity* by making it difficult to track who the others are, what parts of the task they are doing, what their progress is, where they might need help, and so forth. We would diminish the sense of *Team Cognition* by preventing a common, shared picture of the current situation, by allowing different perspectives on the nature of progress, by allowing different understanding of the goals of the mission. And we would diminish the sense of *Team Metacognition* by making it difficult to gauge how each of the team members was proceeding (rate of progress).

> An example of an interface that was effective in obscuring the big picture for teams was recently observed in a military exercise that was, ironically, trying to show how information technology could be valuable in presenting the same big picture to all the staff members in the command post. What happened was that the large screen display showed clusters of red symbology, indicating the presence of enemy units, but upon closer inspection these were not credible. They included elements such as reported sightings of enemy tank units that were 24 hours old (and therefore obsolete), but had not yet been removed from the screen. The display also showed areas that were clear, suggesting that these were safe zones for inserting troops, but upon closer inspection these were not credible either. They included areas where there were no sensors, so it was entirely possible that large enemy units might be there. Because of confoundings such as this, the large screen display generated too much confusion, and on occasion led the officers in charge to erroneous interpretations of the situation.

As we pursue the goal of Information Dominance, the interface will become an even more critical aspect of effective team decision making. The present state of the art is inadequate for supporting team decision making. Possibly, there are technological solutions just beyond the current state of the art, that will solve these problems. More likely, they will be only partial solutions, and will create additional problems. The inadequacy of interfaces may continue to disrupt team decision making.

Just as we observed that the quest for Information Dominance reduced the expertise of individual decision makers, so we must also prepare for this quest to reduce the expertise of decision-making teams.

IX. NATURALISTIC DECISION MAKING AND INFORMATION DOMINANCE: RECOMMENDATIONS AND RESEARCH AGENDA

In this report, I have explored the implications of the NDM framework for the domain of Information Dominance. I have argued that we must work to shape the technologies going into Information Dominance, so that they can support individual and team decision-making expertise, otherwise the technologies may actually hinder expert performance. The objective of developing system requirements in service of individual and team expertise is challenging; it has many facets and many complexities.

Although this report has raised a number of cautionary notes about information technology, the intent has not been to criticize this technology or discourage its use. The benefits of information technology are clear enough, and have been described in countless briefings and articles. The argument presented in this report is that there are few unmixed blessings, and if we do not try to anticipate some of the undesirable consequences of information technology, we will be doing ourselves a disservice. Our challenge is to learn how to manage information technology so that it does not compromise the expertise of individuals and teams. We need to learn how to shape information technologies to support different aspects of expertise, such as making fine discriminations, anticipating events, seeking diagnostic data, detecting early signs of problems, seeing the big picture, and so forth.

The NDM perspective appears to offer a number of important directions for future study, in order to support highly skilled individual and team decision making in the Information Dominance arena. In this section we list six areas. The NDM approach emphasizes the importance of studying the decision maker within his or her natural work environment. For the following recommendations we focus on the intelligence analyst's work environment for the sake of clarity, and are not suggesting that this is the only decision maker relevant to the domain of Information Dominance.

First, it would be highly instructive to conduct a Cognitive Task Analysis to **document** the cognitive aspects of the job of an intelligence analyst. A Cognitive Task Analysis would document the critical cognitive demands that are central to the analysts' job. It would also document the extent to which current information systems support these demands, and the ways that they degrade and interfere with them. Based on the results of the Cognitive Task Analysis, we could develop a tangible database of lessons learned that would be used to guide future system design efforts and the other research areas described below.

Second, the barriers analyses presented in this report for individual and team decision making should be developed into a **model** of the critical factors needed to sustain expertise for intelligence analysts. This model would generate predictions of how well specific information systems will support (or degrade) intelligence analysts' performance. These predictions could then be empirically validated using performance data from analysts using existing systems, as well as analysts using new systems as they are implemented. The outcomes of the empirical tests could then be used to revise the model in order to improve its accuracy for use in the development of future information systems.

Third, research needs to be conducted to **identify** how intelligence analysts spot leverage points that could be used to degrade an adversary's information systems. Research could also identify the strategies that analysts use to spot vulnerabilities in our own systems. Expertise in Information Dominance will center around the ability to see and respond to these leverage points, and so it would be valuable to study how skilled information warriors notice them in the first place. This research would build on the results of the Cognitive Task Analysis and focus specifically on how intelligence analysts understand the types of opportunities that allow us to degrade an adversary's situation awareness.

Fourth, research needs be conducted to **discover** new human-computer interface features that support key requirements for individual analysts. The emphasis here is on generating new practices, new ideas for system and interface design. The strategy would be to identify common requirements for expertise, to document failures in supporting these requirements, along with some of the reasons for these failures, and to explore strategies for providing effective support.

This research would again build on the results of the Cognitive Task Analysis, but would extend that research to address human-computer interface design issues for individual analysts.

Fifth, research needs to be conducted to **clarify** the indicators of team competence in Information Dominance by conducting a Cognitive Task Analysis of distributed teams that include individual intelligence analysts. In order to complete this research objective, new methods of Team Cognitive Task Analysis will need to be developed. By developing appropriate methods, we will be able to collect data that will allow us to compare different information system and interface designs. This research would improve the performance of individual intelligence analysts by supporting the cognitive demands faced by the distributed team.

Sixth, additional research is needed to **characterize** the interactions in distributed Information Dominance teams in order to study ways to re-engineer them. As information technology continues to be delivered, there will be ongoing pressure to change the composition and configuration of Information Dominance teams. Platforms need to be developed for representing and comparing different approaches to organizing and staffing these teams. This research would extend the Team Cognitive Task Analysis methods to explore the utility of various representation platforms.

In conclusion, NDM is the study of how people use their experience to make decisions in field settings. This report examined the domain of Information Dominance. The expertise we considered was at the individual and team level of decision making. We defined what expertise consists of, and we identified some important barriers that might be particularly troublesome in an era of Information Dominance. We have also seen that the NDM perspective can offer some ideas about using information technology to support skilled decision making. We have identified several possible directions for future research into the barriers themselves, the possibilities for support of decision making, the implementation of Information Dominance to expand situation awareness and decrease the adversary's situation awareness, and for enabling a battle staff to re-engineer its own functionality.

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GLOSSARY

AI	Artificial Intelligence
ATDM	Advanced Team Decision Making
JFACC	Joint Force Air Component Commander
NDM	Naturalistic Decision Making
RPD	Recognition-Primed Decision

APPENDIX A - MODELS OF TEAM PERFORMANCE[2]

In this Appendix, several models of teamwork are reviewed. These models describe team processes. Specifically, we focus our attention on five different models of team performance that have been used to formulate assessment tools to evaluate teams (Fleishman & Zaccaro, 1993; McIntyre & Dickinson, 1992; Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986; Olmstead, 1992; Helmreich & Foushee, 1993). A sixth model (Zsambok, Klein, Kyne, & Klinger, 1993) was described in the body of this report. Although these models use different terms, there is really a great deal of similarity in the concepts. Some of the models do not address the decision making function per se, but all of them are relevant to NDM because they consider factors that would have a direct bearing on a team's ability to make effective decisions.

We conclude the section with a brief discussion of other accounts of team mind.

Fleishman and Zaccaro (1993): Team Performance Model

Fleishman and Zaccaro prepared an extensive **taxonomy** of team functions, and derived a model by synthesizing the behaviors they catalogued. Their model has been applied to military domains, primarily Navy teams.

The earliest step in the evolution of the Team Performance Model was the work of Nieva, Fleishman, and Rieck (1978), who developed a model of team performance based upon an extensive review of the group performance literature. They concluded that team performance has two primary components: individual task behaviors, or those behaviors requiring no coordination among team members; and coordinated task-related processes/functions/behaviors, including all behaviors that promote coordination among individuals, members, and subtasks. Both of these components combine to determine the level and nature of group performance. The weight of each component's contribution to overall team performance varies according to the nature of the particular task characteristics.

Four antecedent classes of variables that influence team performance were identified during the literature review (Nieva et al., 1978). These include: external conditions imposed on the team, member resources, team characteristics, and task characteristics and demands. *External Conditions* imposed on the team refers to both the larger organizational system in which the team is embedded, and the team's physical environment. These external conditions often determine the amount of time available to complete the task, job operating procedures, intergroup communication patterns, and power and authority distribution. The team must either adapt to, model, or be influenced by these changing elements. The changing environmental conditions

[2] Adapted from Militello, Kyne, Klein, Getchell-Reiter, & Thordsen (1994). Comparing models of team performance. Fairborn, OH: Klein Associates Inc. Prepared under Contract MDA903-92-C-0098 for the U.S. Army Research Institute, Alexandria, Virginia.

thus influence member resources, team characteristics, and task characteristics and demands.

Member resources include the knowledge, skills, abilities, and experiences that members bring to the team's task. In addition, the members' motives, attitudes, personality characteristics, and traits are considered performance-related resources. These resources can combine to form relationships that enhance or degrade team performance. *Team characteristics* are defined as those that apply to the group as a whole rather than to specific individuals. Examples of team characteristics include group cohesion, size, structure, and authority structure. The Team Performance Model specifies that team variables are affected by both member resources and task characteristics. *Task characteristics and demands* include the aspects of the task that determine process and performance requirements. These aspects of the task determine the critical requirements for successful performance and affect the interactions that team members have with each other.

Nieva et al. (1978) suggest that these antecedents can alter the nature of team processes. In order to fully understand how these variables relate to team performance and its underlying processes, the authors proposed a taxonomy of team functions which clearly specify particular team performance functions. The taxonomy in its most recent form is shown in Table 3. It contains seven major categories of team performance functions. Each category of functions is intended to reflect a focus on task accomplishment with a concern for member interconnectedness. They are considered molar functions, cutting across specific member activities; and the categories are relative, meaning that they can be ordered with respect to each other.

Orientation functions refer to the processes used by team members in the acquisition and distribution of information necessary for task accomplishment. This includes most of the activities in the planning stage of team performance. *Resource distribution functions* refer to processes to assigning members and their resources to particular responsibilities. This includes resource assignment across subtasks. *Timing functions (activity pacing)* are directed toward the organization of team resources and activities to ensure that performance tasks are completed within established temporal boundaries.

Response coordination functions refer to the coordination and integration of independent and synchronized member activities. *Motivational functions* refer to the definition of team objectives and processes for motivating members to adhere to these objectives. This includes the establishment and acceptance of performance norms and reward systems. *Systems monitoring* refers to the detection of errors in the nature and timing of ongoing activities of both the team as a whole and individual members. *Procedure maintenance* refers to the monitoring of both synchronized and individual actions to ensure compliance with established performance standards.

Table 3. Taxonomy of Team Functions: Current version. (Fleishmann & Zaccaro, 1993) [Reprinted with permission]

Orientation Functions

a. Information Exchange Regarding Member Resources and Constraints
b. Information Exchange Regarding Team Task and Goals/Mission
c. Information Exchange Regarding Environmental Characteristics and Constraints
d. Priority Assignment Among Tasks

Resource Distribution Functions

a. Matching Member Resources to Task Requirements
b. Load Balancing

Timing Functions (Activity Pacing)

a. General Activity Pacing
b. Individually-Oriented Activity Pacing

Response Coordination Functions

a. Response Sequencing
b. Time and Position Coordination of Responses

Motivational Functions

a. Development of Team Performance Norms
b. Generating Acceptance of Team Performance Norms
c. Establishing Team-Level Performance-Rewards Linkages
d. Reinforcement of Task Orientation
e. Balancing Team Orientation with Individual Competition
f. Resolution of Performance-Relevant Conflicts

Systems Monitoring Functions

a. General Activity Monitoring
b. Individual Activity Monitoring
c. Adjustment of Team and Member Activities in Response to Errors and Omissions

Procedure Maintenance

a. Monitoring of General Procedural-Based Activities
b. Monitoring of Individual Procedural-Based Activities
c. Adjustments of Nonstandard Activities

McIntyre and Dickinson (1992): Teamwork Model

The Teamwork Model, developed by McIntyre and Dickinson, was also sponsored by NTSC and is based upon the results of the TEAM studies, and a review of the teamwork literature. The Teamwork Model incorporates the findings of the TEAM studies that directly address teamwork (as opposed to taskwork) and those of other researchers investigating teamwork. This work was carried out in the context of a Navy ship's combat information center, where information from a number of sources must be processed and acted upon by many individuals before a final decision can be made to deal with a threat.

McIntyre and Dickinson use a **control theory** metaphor, in that a team is considered to be a communication network with formal, prescribed communication, and informal, closed-loop communication. Teamwork is considered to consist of those behaviors that engender a sharing of information and a coordination of activities: behaviors that are crucial to the workings of the Combat Information Center and many other domains and tasks. This process of sharing information and coordinating activities through teamwork is the focus of this line of research.

Based upon several literature reviews, McIntyre and Dickinson identified seven core components of teamwork. *Team orientation* refers to the attitudes that team members have toward one another and the team task. It reflects acceptance of team norms, level of group cohesiveness, and importance of team membership. *Team leadership* involves providing direction, structure, and support for other team members. It does not necessarily refer to a single individual with formal authority over others. Team leadership can be shown by several team members. *Communication* involves the exchange of information between two or more team members in the prescribed manner and by using proper terminology. Often the purpose of communication is to clarify or acknowledge the receipt of information. *Feedback* involves the giving, seeking, and receiving of information among team members. Giving feedback refers to providing information regarding other members' performance. Seeking feedback refers to requesting input or guidance regarding performance. Receiving feedback refers to accepting positive and negative information regarding performance. *Backup behavior* involves assisting the performance of other team members. This implies that members have an understanding of other members' tasks. It also implies that team members are willing and able to provide and seek assistance when needed. *Monitoring* refers to observing the activities and performance of other team members. It implies that team members are individually competent and that they may subsequently provide feedback and backup behavior. *Coordination* refers to team members executing their activities in a timely and integrated manner. It implies that the performance of some team members influences the performance of other team members. This may involve an exchange of information that subsequently influences another member's performance.

The emphasis here is on closed-loop communication. The system is thus comprised of input, throughput, and output variables through which communication is a common thread. Team coordination is the result of members who are dedicated to the team task providing, seeking, and receiving feedback to support each other's efforts; lending backup to help others perform their tasks; and continually monitoring the team's performance. These throughput variables of monitoring, feedback, and backup are influenced both by members' orientation or commitment to their team and task, and the structure and the mission of the team as dictated by the leader. Finally, all team processes are linked through sharing information or communication.

Morgan, Glickman, Woodard, Blaiwes, and Salas (1986): TEAM Model

The Team Evolution and Maturation (TEAM) model was developed as part of a project sponsored by the Naval Training Systems Center (NTSC) to examine the factors that influence the development of teamwork during training. The model is based on the results of an extensive literature review and has its origins in an open systems framework of organizational effectiveness.

Morgan et al. (1986) adopted a **developmental** view of teams. The TEAM model combines the constructs developed by Tuckman (1965) and the findings of Gersick (1988) to form a model of team performance that predicts the stages that teams go through before, during, and after performance of a task (i.e., preforming, forming, storming, norming, performing-I, reforming, performing-II, conforming, and de-forming). Morgan and his colleagues posit that teams evolve through this series of stages. Teams may begin at different stages of development and spend different amounts of time in the various stages. Teams do not necessarily progress through all the stages.

All teams must, however, resolve along two tracks in order to be successful. The track of "operational team skills training" represents the skills needed for individual team members to perform their respective tasks. The track of "generic team skills training" includes those activities that are devoted to enhancing the quality of interactions, relationships, cooperation, communication, and coordination of team members. Specific behaviors included in this teamwork track include: *communication, cooperation, team spirit and morale, giving suggestions or criticism, acceptance of suggestions or criticism, coordination, and adaptability.* These two tracks must converge either before or at the point of task performance in order for the team to be effective. At some point after the task performance these two tracks again diverge, representing the fact that all teams disperse eventually.

Olmstead (1992): Model of Organizational Competence

Olmstead's work has been aimed specifically at understanding the dynamics of large military organizations. This research has focused on issues of organizational performance and ways of improving the effectiveness of organizations. His work investigating the functioning of the battle staff and factors leading to its functional integration has led to the development of the Model of Organizational Competence.

The Model of Organizational Competence describes an organization as a **homeostatic** system that is able to cope, adapt, and become better integrated. This model has been applied to the Army battle command, where the battle staff receives information from above, works on the information within the staff, and sends information out to effect change. Olmstead defines organizational competence as the functions, or processes, required by organizational systems for effective accomplishment of missions or objectives.

According to Olmstead, Organizational Competence is concerned with the quality of performance by the command-and-control system of a combat unit. The command-and-control network serves as the brain and nervous system of a combat unit, acquiring information from various sources, collating all information, making decisions concerning actions to be taken, and sending appropriate instructions and directives to personnel who are in contact with opposing forces. The extent to which this system functions flexibly, efficiently, and effectively determines, in large part, the ability of the unit to accomplish its tactical objectives.

Competence depends upon skills of battle staff personnel in acquiring and interpreting information; making choices concerning to whom acquired information is to be communicated, as well as communicating accurately and completely; making decisions concerning ways to cope with unusual or unanticipated situations; and executing actions deriving from such decisions — all performed at high levels of proficiency and coordination. Some technological assists may be available, such as data-processing equipment, electronic surveillance equipment, and highly sophisticated communications devices; however, the payoff in competence ultimately reduces to the judgments and actions of key personnel. Of equal importance, *performance of the processes is a team product and much of the quality of process performance depends upon teamwork and the coordination of separate responsibilities and activities.*

Olmstead contends that equal to the skills of individuals is what he terms "the integration of structure and function." This means that the positions, roles, and functions that make up an organizational system must fit together and support each other in their respective activities. In short, integration of a battle staff, with the resulting teamwork, is essential. If integration of structure and function does not occur, missed signals, aborted decisions, overlooked intelligence, and activities at cross-purposes may be the result. In the extreme, loss of integration may produce a collapse of essential functions, which can threaten survival of the unit.

The Model of Organizational Competence presents three aspects of organizational competence. *Reality testing* is concerned with determining the real properties of an environment. How well is the team able to assess the operational situation? *Adaptability* is concerned with learning through experience. This refers to the team's ability to react flexibly to changing requirements. *Integration* is concerned with unifying the actions of team members, or the team's ability to maintain itself under times of stress. Olmstead claims that it is critical that a team maintains adequate performance in each of these components. This speaks against trying to maintain a rigid top-down control of organizations in a dynamic environment that demands responsiveness. An effective team must be able to assess its own environment, adapt quickly to changing requirements, and maintain cohesiveness of all members and sub-units.

In addition to these three aspects, seven processes of organizational competence are proposed. These seven processes are summarized in Table 4. *Sensing* refers to the process by which the team acquires and interprets information concerning the state of, or events occurring in, the environment. *Communicating information* is about getting the right information to the right people. This process involves the initial transmittal of information by those who have sensed it, to dissemination of the information throughout the organization. *Feedback* is the process of assessing and evaluating the effects of prior action. This involves further sensing of the external and internal environments. *Decision making* includes those activities leading to the conclusion that some action should be taken. *Communicating implementation* refers to the process whereby decisions and resulting requirements are communicated to those individuals who must implement them. This includes achieving clarification of orders through discussion and interpretation. *Coping actions* are those activities involving direct action against external and internal environments. This is the ultimate determinant of effectiveness: the effect of the organization upon the target environment. *Stabilizing* is the process of taking action to adjust internal operations to maintain stability in the face of potential disruption.

Table 4. Criteria for assessing quality of process performance. (Olmstead, 1992)

Sensing

a. Accurate detection of all available information
b. Correct interpretation (attachment of correct meaning) of all detected information, to include appropriate weighing of its importance
c. Accurate discrimination between relevant and irrelevant information
d. Attempts to obtain information are relevant to mission, task, or problem
e. Sensing activities are timely in relation to information requirements and the tactical situation of the moment
f. Internal processing and recording of information provides ready availability to users

Communicating Information

a. Accuracy of transmission of available information
b. Sufficiently complete to transmit full and accurate understanding to receivers of communications
c. Timeliness appropriate to unit requirements
d. Correct choice of recipients; everyone who needs information receives it
e. Whether message should have been communicated

Decision Making

a. Adequacy – Was the decision adequately correct in view of circumstances and information available to the decision maker?
b. Appropriateness – Was the decision timely in view of the information available to the decision maker?
c. Completeness – Did the decision take into account all or most contingencies, alternatives, and possibilities?

Stabilizing

a. Adequacy – Action is correct in view of the operational situation and conditions which the action is intended to change or overcome
b. Appropriateness – Timing is appropriate in view of the situation, conditions, and intended effects. Choice of target of the action is appropriate
c. Completeness – Action fully meets the requirements of the situation

Communicating Implementation

a. Accuracy of transmission of instructions
b. Sufficient completeness to transmit adequate and full understanding of actions required
c. Timely transmission in view of both available information and the action requirements of the participants
d. Transmission to appropriate recipients
e. "Discussion or interpretation" is efficient, relevant, and achieves its purpose
f. Whether message should have been communicated

Coping Actions

a. Correctness of actions in view of both the current operational circumstances and the decision or order from which the action derives
b. Timeliness of the action in view of both operational circumstances and the decision or order from which the action derives
c. Correctness of choice of target of the action
d. Adequacy of execution of action

Feedback

a. Correctness of the decision and action to obtain feedback in view of operational circumstances the preceding actions whose results are being evaluated, and current information requirements
b. Timeliness of the feedback decision and action
c. Correctness of choice of target(s) of the action
d. Appropriate use of feedback information in new actions, decisions, and plans

Helmreich and Foushee (1993): Crew Resource Management

Helmreich and Foushee's (1993) work utilizes an **interpersonal** view of teams. Crew Resource Management (CRM) grew out of concerns for aviation safety during the 1970's. Experimental evidence collected by Ruffel Smith (1979) first led to the identification of resource management behavior as an important variable in aviation safety and to the need for related behavioral skills training. In a full mission simulation, Ruffell Smith found that a crew's effectiveness in identifying and utilizing the human material resources available influenced how safely and effectively the crew handled problem situations.

Robert Helmreich and his colleagues at the University of Texas and NASA Ames Research Center initiated a program of research to investigate the foundations of flight crew behavior, to develop measures of crew performance, and to develop training designed to enhance aviation safety by enhancing pilots' abilities to work as effective teams. Wiener, Kanki, and Helmreich (1993) provide the most recent comprehensive review of the CRM field.

Helmreich and Foushee (1993) developed CRM concepts within the boundaries of a three-factor model of the determinants of group performance. This model defines three major components of group behavior: input factors, crew performance or group process factors, and outcome factors. Input factors include characteristics of individuals, groups, organizations, and the operational environment. Group process factors include the nature and quality of interactions among group members. Outcome factors include primary outcomes such as safety and efficiency of operations as well as secondary outcomes such as member satisfaction, motivation, and attitudes. The underlying assumption of the model is that input factors provide the framework and determine the nature of group processes that lead to the various outcomes. A central feature of the model is the presence of feedback loops between the components. Outcomes may change the components of input factors, and these changes may alter subsequent group processes and outcomes. In addition, outcomes may alter group processes directly without affecting input factors.

Helmreich uses this three-factor model as a framework for studying the CRM functions of team performance. He describes CRM performance with a three-layer hierarchical model. At the highest level are three clusters of observable CRM behaviors: Communications and Decision Making Tasks, Team Formation and Management Tasks, and Situation Awareness and Workload Management Tasks.

Communications Process and Decision Tasks concern how the team members communicate with each other and the decision processes that they employ. These are both prime determinants of crew performance. This cluster of tasks comprises the observable behaviors: Briefings, Inquiry/Assertion, Self Critique, Communications, and Decisions.

Team Formation and Management Tasks concern the formation of the crew as a team. Early in the formation process, teams establish communication and interaction patterns that persist throughout the team activity. These patterns can lead to either effective or ineffective team performance. This cluster of tasks comprises the behaviors: Leadership, Task Concern, and Group Climate.

The third cluster, *Situational Awareness and Workload Management Tasks*, addresses concerns about the crew's awareness of operational conditions and contingencies and how the crew distributes tasks to avoid overloading any crew member. The observable behaviors include: Preparation, Planning, Vigilance, Workload Distribution, Task Prioritization, and Distraction Avoidance.

The lowest level of the model of CRM comprises specific behavioral markers. Helmreich and his colleagues (1993) have identified behavioral markers for each of the behaviors described above. Trained evaluators employ expert rating scales to assess performance on each of these markers, and use these ratings to assess performance on each of the behaviors. Such assessments are then used to focus debriefings following training sessions.

Additional Accounts of Team Mind

There are other accounts of the team mind that have not been developed as fully as these mentioned above. We list these here because they offer different perspectives that may have some value in studying Information Dominance.

The concept of shared mental models, developed and applied by Orasanu and Salas (1993), Cannon-Bowers, Salas, and Converse (1992) and others, is being used in the Navy to train teams. Prince, Chidester, Cannon-Bowers, and Bowers (1993) have developed several well-accepted team training programs for the Navy. Helmreich (1986) has expanded his initial Crew Resource Management program from use in commercial aviation to a wide array of domains.

Salas, Cannon-Bowers, and Johnston (1997) have concluded that expert teams can be developed by:

- fostering shared or compatible mental models of the task and of the roles of each team member,
- training the team members on teamwork skills such as situation awareness, leadership, and compensatory behavior,
- providing experience for teams to function under the types of stressful conditions they will encounter, by cross-training (letting the team members practice on the roles and tasks of others),
- showing leaders how to maintain shared situation awareness.

Hinsz, Tindale & Vollrath (1997) have reviewed a variety of approaches that treat groups as information processors, a central tenet of the "team mind" framework. They have examined research on attention, encoding, storage, retrieval, processing, response, feedback, and learning in small interacting groups. These research efforts are also relevant to our understanding of team mind phenomena. Along these lines, Endsley and Robertson (1996) have examined team situation awareness in aviation maintenance settings.