ARI Research Note 96-36

Recognition-Primed Decision Strategies

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Research and Advanced Concepts Office
Michael Drillings, Acting Director

March 1996

United States Army
Research Institute for the Behavioral and Social Sciences

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

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Research accomplished under contract
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REPORT DOCUMENTATION PAGE

1. REPORT DATE 1996, March	2. REPORT TYPE Final	3. DATES COVERED (from. . . to) November 1988-November 1991

4. TITLE AND SUBTITLE Recognition-Primed Decision Strategies	5a. CONTRACT OR GRANT NUMBER MDA903-89-C-0032
	5b. PROGRAM ELEMENT NUMBER 0601102A
6. AUTHOR(S) Gary Klein nd Beth Crandall (Klein Associates Inc.)	5c. PROJECT NUMBER B74F
	5d. TASK NUMBER 1901
	5e. WORK UNIT NUMBER C36
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Klein Associates Inc. 582 E. Dayton-Yellow Springs Road Fairborn, OH 45324-3987	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences ATTN: PERI-BR 5001 Eisenhower Avenue Alexandria, VA 22333-5600	10. MONITOR ACRONYM ARI
	11. MONITOR REPORT NUMBER Research Note 96-36

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

COR: George Lawton

14. ABSTRACT *(Maximum 200 words)*:

We describe activities conducted during a 3-year basic research contract that has its goal extension and examination of a Recognition-Primed Decision (RPD) model of decision making. The RPD model describes a decision strategy commonly employed by proficient personnel called upon to make decisions in operational settings by high risk, time constraints, and ambiguous or incomplete information. Work was organized around three areas of interest: (1) evaluation of the relative strengths and weaknesses of the RPD strategy, (2) examination of the nature of stimulation assessment in C2 environments, and (3) exploration of techniques for supporting decision making in operational environments that are consistent with the RPD framework. The report contains descriptions of nine studies (seven empirical, two analytical) conducted to examine these issues. One important outcome of the research has been to advance understanding of the role of mental simulation indecision making. We have developed a detailed mode of mental simulation, including an account of how mental simulation serves as a source of power for a variety of cognitive functions. Work performed under this contract has helped to establish naturalistic decision making as an important and unique perspective.

15. SUBJECT TERMS

Recognition-primed decisions — Mental modes — Naturalistic decision making
Mental simulation — Problem solving

SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT	20. NUMBER OF PAGES	21. RESPONSIBLE PERSON (Name and Telephone Number)
16. REPORT Unclassified	17. ABSTRACT Unclassified	18. THIS PAGE Unclassified	Unlimited	54	

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RECOGNITION-PRIMED DECISION STRATEGIES

EXECUTIVE SUMMARY

The objective of this three-year research contract was to increase our understanding of naturalistic decision making (NDM). Major goals include an examination of the Recognition-Primed Decision (RPD) model for implications about processes of situation assessment and mental simulation, exploration of limitations of the RPD strategy, and identification of methods for supporting decision makers. Several studies addressed situation assessment in decision making, and we learned about the importance of mental simulation for formulating and evaluating situation assessment; we also identified a set of factors that appear critical for formulating and communicating situation assessment. In reviewing the limitations of a recognitional decision strategy, we identified an inherent problem whereby people can use mental simulation to explain away discrepant data, thereby preserving an inaccurate situation assessment. In developing strategies for supporting recognitional decision making, we tested a technique for using mental simulation to identify weaknesses in a planned course of action, thereby reducing over-confidence.

In accomplishing these objectives, there have been a number of important outcomes that were not tied to specific initial goals. First, we feel that our work has helped to establish naturalistic decision making as an important perspective. The previous traditions of classical decision research, drawing on mathematics, statistics, and game theory, have definite strengths and weaknesses; but there is now emerging an acknowledgement of the importance of NDM for addressing the problems and requirements that are not handled well by the classical research strategies. The 1989 workshop on NDM, supported in part by this research contract, served to crystalize this approach, and the forthcoming book Decision Making in Action: Models and Methods will continue that process. Without these projects, the earlier research findings would likely have remained on the periphery of the decision research community. These projects have implications for the direction of decision research. They have led to an expansion of cognitive accounts of decision making with important applications for decision-centered design of interfaces and displays, training that emphasizes situation assessment, mental simulation and metacognition rather than analytical decision strategies, and more effective approaches to team decision training.

Second, we have demonstrated that the RPD model generates empirical as well as ethnographic research. While the RPD model was primarily developed using ethnographic research methods, there have been as many empirical studies of the

model as ethnographic studies. The field studies have taken place in diverse settings (urban firefighting, forest fire management, design engineering, tank platoon operations, nursing in Intensive Care Units), and the incident accounts from these studies have been vivid and memorable, so it may be easy to forget the empirical studies. Thus far there have been at least a half-dozen empirical studies of the RPD model. We have examined firefighters, using multi-dimensional scaling (Calderwood, 1989); we have used prepared scenarios to collect decision protocols from experienced and inexperienced fireground commanders (Calderwood, Crandall, & Klein, 1987). Mosier (1990) has confirmed the use of recognitional decision making by airline pilots, using analyses of videotapes collected during high fidelity simulations. We have shown that proficient performance can be maintained by skilled chess players, despite severe time constraints (Calderwood, Klein, & Crandall, 1988). We have shown that skilled chess players generate superior options as the first ones they consider, a direct test of the RPD model (Klein, Wolf, Militello, & Zsambok, in preparation). And we have shown that mental simulation exercises can improve decision processes of college students engaged in planning tasks (Kyne, Militello, & Klein, in preparation).

Third, through the mix of ethnographic and empirical research, the RPD model has become more mature and comprehensive than it was three years ago. It has become elaborated to portray several means of achieving situation assessment. It has been shown to generate testable hypotheses, and it has been experimentally supported.

Fourth, the primary expansion of the RPD model has been to achieve a greater understanding of the process of mental simulation. This current research effort has accomplished that important objective. We have derived a model of mental simulation that is far more detailed than any previously available, and we have shown how mental simulation serves as a source of power for a variety of cognitive functions.

INTRODUCTION

In 1985, Klein Associates performed a study for the Army Research Institute to find out how people can make satisfactory decisions under time pressure, when they don't have enough time to generate and evaluate a large set of options. The investigation centered on decision making of fireground commanders. We found that the commanders rarely had to generate more than one option, even for difficult cases. They were using an approach that we called a Recognition-Primed Decision (RPD) strategy for making rapid decisions. The RPD strategy reflects naturalistic constraints on decision making that are not addressed by classical decision strategies.

During the past three years we have conducted a Basic Research project aimed at understanding the role of experience and competence for naturalistic decision making (NDM). We have specifically examined the RPD model which describes a decision strategy that appears well suited for operational settings marked by time pressure, ambiguity, incomplete information, ill-defined, and shifting goals. The revised research plan submitted to our sponsor in March, 1989 listed three goals: Evaluate the relative strengths and weaknesses of the RPD strategy; learn more about the nature of situation assessment in command-and-control environments; and determine whether the RPD strategy has implications for improving decision quality.

The purpose of this Final Report is to document what we have learned in conducting the project and pursuing these goals. Each goal has been accomplished, although there is much more to be learned about decision making in operational settings. We follow with a brief account of the background that shaped our investigations. Then this report will trace the development of the RPD model, from earlier contracts through the present one. Once we have established this framework, we will turn to more specific accounts of the research performed under this contract. The topics will cover mental simulation, situation assessment, option generation, errors and stress, and team decision making, as well as applications of the models and findings of our research. The common theme running through these topics is the attempt to learn how people are able to use experience to make decisions under difficult conditions.

Background

Classical research on decision making (see reviews by Beach & Lipshitz, in press, and by Cohen, in press) has demonstrated the power of a variety of quantitative methods for decomposing and analyzing complex decision tasks. These methods certainly are useful in naturalistic contexts such as trying to decide which type of bullet should be acquired by a police department (Hammond & Adelman, 1976). However, for many decision tasks, the time pressure and limited resources available make it difficult or impossible to conduct such analyses. Accordingly, Beach and Mitchell (1978) and Payne (1976) presented a contingency model of decision making, showing that different types of strategies would be used under different conditions. Svenson (1979) has documented a range of noncontingent decision strategies, which enable a person to select a course of action without going through a full set of analyses.

At the same time, Kahneman and Tversky (1982) had been examining the consequences that can arise when people use heuristics to substitute for a full analysis of probabilities and contingencies. They do not paint a pretty picture. The heuristics result in a number of biases that have been well-documented during the last 20 years. Accordingly, we are left with a discouraging picture of quantitative methods that are rarely used because of the information processing limits of decision makers, and a set of biases that seem inevitable when heuristics are used to substitute for stronger methods. Experts are just as susceptible to the biases as novices.

Orasanu and Connolly (in press) project a different perspective. They point out that just as we have been losing confidence in decision makers because of their reliance on heuristics, the field of problem solving has demonstrated over and over again the power of these heuristics and the clear differences between experts and novices. They define a set of conditions that encompass NDM, including time pressure, ill-defined and shifting goals, and ambiguous and incomplete information. These conditions usually make it impossible to use rigorous quantitative methods, yet, somehow, we are able to function fairly well. One of the key questions arising from the NDM perspective is how people are able to use experience to handle difficult conditions.

The RPD model was derived from interviews with fireground commanders, to learn their strategies and account for their ability to use experience to handle extreme time pressure and other NDM characteristics. The next section describes the RPD model and its development.

DESCRIPTION OF THE RPD MODEL

We originally formulated the RPD model to explain how experienced decision makers could function in time-pressured situations where they were not able to generate and compare large sets of options. The RPD model fuses two processes, situation assessment and mental simulation, to explain such decision making. The model asserts that experience enables decision makers to recognize the essential characteristics of a situation, and thereby to identify feasible goals and plausible courses of action. Courses of action are generated and, if necessary, evaluated one at a time, using mental simulation to see if there are any pitfalls to carrying out the action within the context of the situation. Of course, people sometimes have to wrestle with different options to pick the best one, a task we refer to as concurrent (as opposed to serial) evaluation; concurrent evaluation of options is the subject of other models of naturalistic decision making, and is outside the scope of the RPD model.

There are a few misperceptions about the model that should be addressed. First, the model does not claim that people just retrieve courses of action from memory. In many cases, a decision maker will have to construct a unique course of action. Recognition provides a sense of reasonable goals, and a sense of the typicality of the situation. In some cases, there may be a direct analogue enabling the decision maker to recall a specific course of action that worked before. In other cases, a course of action will be partially constructed and partially based on retrieval of actions from similar incidents. The RPD model simply claims that options are not generated randomly, and that situation assessment lets the decision maker identify promising actions as the first ones considered.

Second, the RPD model includes aspects of problem solving and judgment along with decision making. In the domains we have studied, the three processes are closely related. Furthermore, it appears as if the skill of experienced decision makers enables them to bypass having to perform a concurrent evaluation, so they do not have to select one option from a set of possible courses of action.

Third, the RPD model has evolved over the past few years, but it has not changed. That is, the framework of the model has not been revised. Rather, the model has become more elaborated and sophisticated as it has been applied and tested in different domains.

RPD: Chronology

Our initial research on time-pressured decision making was not driven by any particular theoretical model. We attempted to face the paradox of how people can make good decisions in limited time. Classical models such as MAUA assume lengthy and extensive option generation prior to evaluation and selection, but under time pressure, this seems implausible. Somehow, the option set must be reduced. But how can this be done? If the option set is reduced blindly, there is a chance that the person will have an inferior set from which to choose, and will make a poor decision. If the option set is pre-screened, how might this happen intelligently, except by first generating all options and eliminating the poor ones? But this strategy requires the massive generation of options that it was supposed to avoid. So we saw no way for a person to successfully run a MAUA on a limited set of options.

The hypothesis we used was based on the work of Soelberg (1967; see Montgomery, in press, for a recent version), who claimed that decision makers quickly recognized a favorite option, and a next-best option, and that the decision making consisted of trying to show that the favorite option dominated the next-best option on all evaluation dimensions.

This hypothesis would account for effective rapid decision making, and in our research with fireground commanders (Klein, Calderwood, & Clinton-Cirocco, 1986) we attempted to find evidence for it. We failed. Based on 32 fire or emergency incidents, we probed 156 decision points, and we found that firefighters claimed they were generating only a single option, for most cases.[1]

In its earliest form (Klein, Calderwood, & Clinton-Cirocco, 1985, 1986) the RPD model was simply the synthesis of the claims of the fireground commanders we interviewed. Figure 1 shows the initial version of the RPD model. Note that the essential components of the model are in place: situation assessment to frame the decision (prototype match) and generate a plausible option, and mental simulation (evaluate) to implement, modify, or reject an option. For cases where the initial option is judged unsatisfactory, additional options are generated and tested in a serial fashion. This stands in contrast to classical decision models that emphasize concurrent evaluation of option sets. The RPD model explains how people can use experience to make effective decisions without having to generate and then prune option sets. This, in turn, explains how people can make effective decisions under time pressure. It must be remembered that this was the goal of the RPD model--to explain effective decision making that does not require concurrent evaluation of options.

```
Implement
Prototype Match-------------Action Queue------------Evaluation---- Modify
        Goals                                                      Reject
        Perceptual        --Expectations
        Causal Factors
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Figure 1. Recognition-Primed Decision (RPD) Model: 1985.

Supported by a Basic Research Contract with ARI,[2] we attempted to replicate the findings of the initial research. Calderwood, Crandall, and Klein (1987) studied expert and novice fireground commanders, and concentrated on only nonroutine decision points within nonroutine incidents. The basic findings held up. We also found that we could distinguish among three types of strategies. In the simplest case, the recognitional match allowed the person to generate an option and did not lead to additional effort at situation assessment or mental simulation. We called this the automatic, or simple RPD. The next case, a verified RPD, occurred when the person was unsure about the nature of the situation assessment, devoted some conscious attention to it, and also did some mental simulation to evaluate the option generated. The complex RPD strategy occurred when the person needed to revise situation assessment, or when the person needed to reject an option, based on the mental simulation, and generate additional options. These three variants are shown in Figure 2. It was in this study that we began to appreciate the importance of pre-decision problem solving and framing issues affecting situation assessment. Situation assessment was portrayed as involving goals, cues, expectancies and options; expectancies were shown to lead to

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[1]This research was supported by an SBIR Phase I Contract No. MDA903-85-C-0099 with U.S. Army Research Institute (ARI).

[2]Basic Research Contract No. MDA903-85-0327.

re-examination of the situation in the case of surprises. Also, we described the function of mental simulation in greater detail, to show the possibilities of modification or rejection of an option.

This was where the RPD model stood in 1988, at the end of our Basic Research contract.

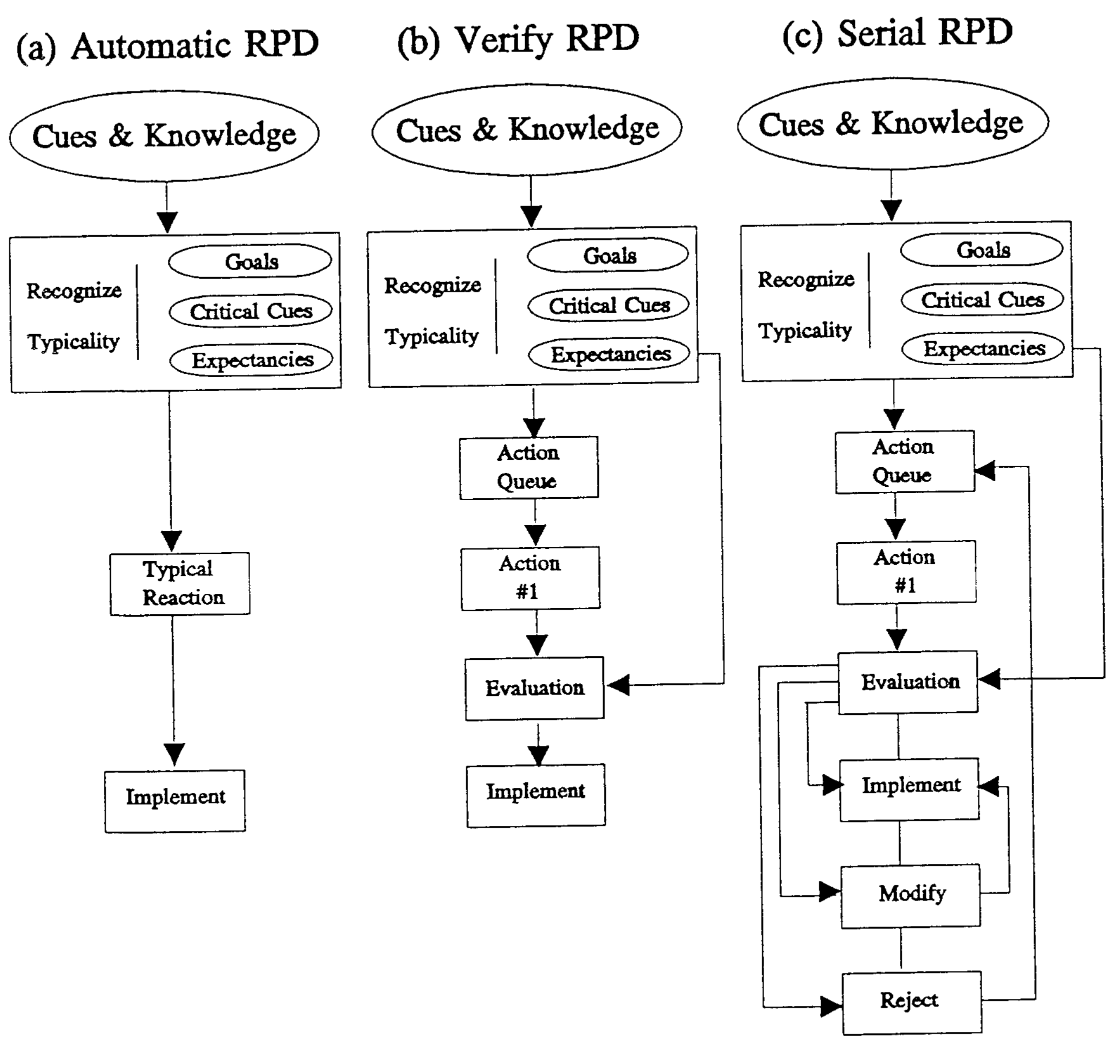

Figure 2. Recognition-Primed Decision model: 1988.

RPD: Boundary Conditions

The RPD model does not cover all of naturalistic decision making. What is not accounted for by the RPD model?

- Cases where the person lacks an experience base to recognize situation assessments, and must rely on decompositional methods. Rasmussen (1985) has referred to these as knowledge-based behaviors.

- Cases where several options are generated and the person uses analytical methods to select the best. Examples here are Elimination-by-Aspects (EBA) (in which the evaluation process is decomposed into single categories, applied one at a time in descending order of importance); Multi-Attribute Utility Analysis (MAUA) (the same as EBA except all categories are applied at the same time, to gain the benefits of compensational trade-offs).

- The Search-for-Dominance Structure strategy. This strategy is described in one of the chapters in the book Decision Making in Action: Models and Methods, (Ablex Publishing Corporation, in press). SDS involves concurrent evaluation of options.

RPD: Extensions and Refinements

The RPD model has been elaborated during the last few years, primarily through projects supported by the Basic Research contract covered by this report. There have been major theoretical elaborations of the RPD model in two areas: mental simulation and situation assessment. These are described next.

Mental Simulation[3]

How is mental simulation different from other forms of reasoning, or from rule-based accounts of behavior? Clearly, the phenomenon overlaps other forms of inference and yet it appears to have its own underlying characteristics. For this reason, it is important to provide a more detailed account of mental simulation so that its unique characteristics can be better appreciated, its role in decision making better understood, and its heuristic power trained and applied.

In our view, an important outcome of this research effort has been the gains in understanding of the phenomenon of mental simulation. We define mental simulation as the process of mentally enacting a sequence of events. People frequently construct and carry out mental simulations in the course of problem solving and decision making. We believe that mental simulation is an important source of power in operational settings characterized by ambiguous or incomplete information, time constraints, and high risk. Within the RPD

[3]The term "mental simulation" was introduced into the decision literature by Einhorn and Hogarth (1981). (See Klein, 1990a; also Klein & Crandall, in preparation, for a more detailed examination).

model, mental simulation serves a variety of essential functions, including evaluating situation assessment, learning about the dynamics of the situation, evaluating courses of action, improving courses of action, and generating expectancies.

We believe that there are additional functions of mental simulation for planning and decision making. This aspect of recognitional decision making may be especially vulnerable to time pressure and other stressors. For example, a critical function of mental simulation may be to examine a course of action for possible flaws. If that search is truncated because of time constraints, the decision maker may proceed with an incompletely evaluated course of action.

Mental simulation is related to a variety of constructs in psychology including mental imagery, progressive deepening, and mental models, but has unique features as well. These include such essential functions as: evaluating situation assessment, learning about the dynamics of a situation, evaluating courses of actions and improving upon them, and generating expectancies.

Prior to the work completed under this contract, the most explicit account of mental simulation that we have been able to locate is that of Jungermann and Thüring (1987). Their four stage model is depicted in Figure 3. Their model, though a good first step, is so general that its explanatory or predictive utility is very limited. The several studies of mental simulation we have conducted have led to a more fully developed descriptive account of mental simulation and its role in decision making.

Like much of decision research, mental simulation has generally been studied under specified conditions, using well-defined tasks. We know little about the kinds of mental simulations people engage in or the purposes they serve in people's day-to-day functioning. Our approach to the study of decision making has consistently emphasized the value of grounding research in the tasks and settings in which the activity occurs. It made sense to us to take a look at how people use mental simulation in their everyday lives, and to work from there to develop a model that describes those activities.

We undertook an ethnographic study of mental simulation, designed to offer an initial, exploratory look at the role of mental simulation in planning, decision making, and problem solving. For the study, we developed a database of 104 mental simulation descriptions--incidents which decision makers report relying on some form of mental simulation for problem solving and decision making.

Within our sample of mental simulation incidents, we identified four primary functions served by the simulations: generate and implement a plan; explain a phenomenon;

discover and explore models of a problem or process; and inspect and evaluate a course of action. Category descriptions follow:[4]

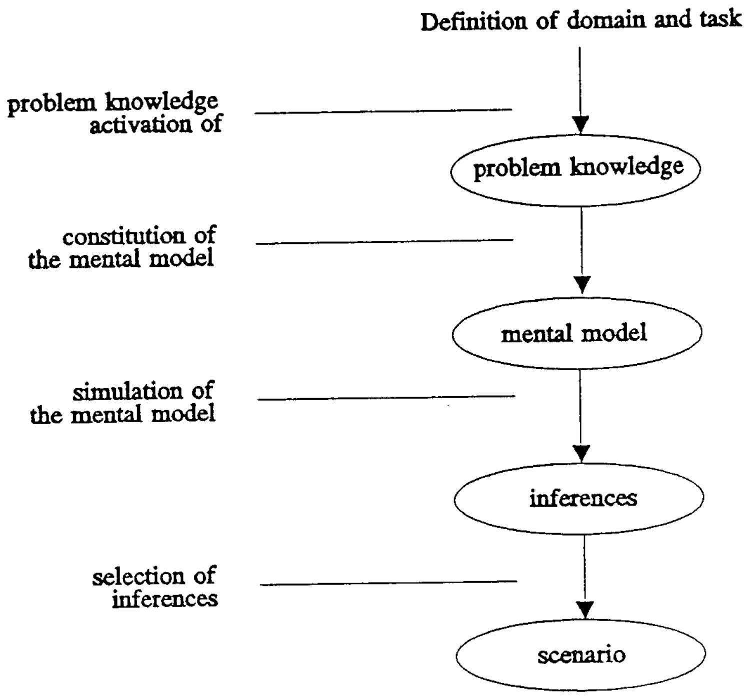

Figure 3. The cognitive process of scenario construction
(From "The use of causal knowledge for inferential reasoning" by H. Jungermann and M. Thüring, 1987, NATO ASI Series, F35, 131-146.)

Generate a Plan

This category includes mental simulations wherein the decision maker attempts to envision a course of action. The mental simulation is used to create a plan, generate information, and develop expectancies about events that are likely to occur in the mentally-simulated situation. The simulations are typically convergent, focused on identifying action sequences, and time-bound. They typically take a current situation or event and project its development over time, from the present into the future. The simulations allow the decision maker to anticipate the "look and feel" of ensuing events, and to adequately prepare for

[4]Two coders independently categorized each item in the database into the four categories. Coding reliability was assessed using kappa, a chance-corrected index of agreement (Fleiss, 1981). Overall kappa across all four categories was .47, where .40 is deemed acceptable and .75 is deemed very good. The informal nature of the incident accounts made it hard to judge category membership in many cases.

them. Once actually in the situation, the decision maker uses these simulation-based expectancies to evaluate his/her assessment of the situation. As the situation unfolds, discrepancies between what the decision maker expected and what s/he observes can serve as a flag that the original situation assessment was off-base, or that critical components have changed and the situation assessment needs to be re-evaluated.

Mental simulations that serve a planning/anticipation function appear to be particularly important where time limits are severe and risks high. An experienced decision maker knows that once in the situation there will not be time to analyze and evaluate, and so uses mental simulation to perform those functions ahead of time.

Explain

This category includes mental simulations conducted to help the decision maker understand how and why an event could have occurred. They involve the search for plausible explanations and are typically focused backward in time. The decision maker attempts to generate a feasible account of how an end state could have arisen, or the factors that could account for an anomaly that has occurred. Inability to generate a plausible explanation can cause the decision maker to abandon the mental simulation altogether and to reexamine other aspects of his or her thinking.

Model/Discover

This type of mental simulation is used to deepen the decision maker's understanding of some process or problem. The simulations often have a musing, expansive quality. The goal of these simulations is to create a hypothetical model or system, and to "observe" it in action. They often involve examination of causal factors and the interactions among them, and they tend to be multifaceted. The simulation typically proceeds iteratively. Knowledge gained from each run of the simulation enhances subsequent simulations of the same problem or process.

Inspect/Evaluate

This category includes mental simulations that allow a decision maker to evoke and assess the impact of a specific action or sequence of events, including the flaws or risks associated with it. The decision maker asks, "Will this work?" or "What could go wrong at this point?"

Evaluation simulations often involve a directed search for specific problems, and an assessment of probable outcomes that includes an affective component (satisfaction vs. disappointment). The affective response evoked by the simulation guides the person's decision whether to actually implement the course of action envisioned. The person uses experience to detect flaws and warning signs as the simulation unfolds. Analogies, rules of thumb, etc. enter into the detection of problems. These flaws fall into other criteria suggested by Robinson and Hawpe (1986): consistency and plausibility. In addition to taking consistency and plausibility into account, the inspection will cover potential flaws in the course of action.

If the simulation satisfies these tests, the person can proceed. If it fails, the person may be able to modify it. In this way, the course of action is improved. In our sample, we found that the decision makers tried to find a workable scenario, and often took the time to evaluate it for flaws. Sometimes they tried to optimize their choice, but there were cases where they just tried to confirm that a course of action would not lead to trouble.

Application of the Four Categories of Mental Simulation

We found 19 cases in which the simulation was used to generate a course of action or to generate predictions and estimates, 36 cases in which the course of action was evaluated and inspected for risk, 11 cases in which a model was derived, and 13 cases in which the simulation was used to explain a situation. There were an additional 25 cases that were judged not to meet the criteria for mental simulation.

For the cases that could be judged, the simulation was primarily visual (56 were judged to be visual and 23 were judged not to be visual). Regarding time stress, 26 were judged to have high stress and 37 to have low stress, with the category not applicable to 16 cases. Risk was generally low, with 16 cases involving high risk and 61 involving low risk, and the category not applicable in 2 cases.

This preliminary study of mental simulation has served as the basis for two additional investigations of planning and risk inspection simulations. These will be described later in this section.

The ethnographic study was also extremely useful as a first step towards developing a conceptual model of simulation that describes the role of simulation in naturalistic decision making and problem solving. A description of the model follows:

We have derived a general account of mental simulation, which is presented in Figure 4. A person uses mental simulation to accomplish some goal, so the first function is to understand the need motivating the activity. For a given need, the next step depicted in Figure 4 is to specify the components of the simulation. The person needs to determine whether the task is to interpolate between a known initial condition and a known terminal condition, to extrapolate forward from a known initial condition (as in predicting the future), or to extrapolate backward from a known terminal state, as in trying to explain a situation. The person needs to identify the casual factors that will be used in the simulation. Our data did not show that this step was done deliberately, e.g., choosing these factors from a larger set, writing them down, etc. Rather, the decision makers used their experience to identify the most relevant factors to work with, and appeared to rely on metacognitive skills to anticipate how many factors to consider. With too few factors, it is hard to formulate an interesting simulation, whereas too many are hard to keep track of. Skill is needed to anticipate what will be a useful level of complexity.

As an example, we asked people to generate a mental simulation of the economic events in Poland, following the shock transformation into a market economy in January, 1990. The data were gathered in February/March 1990. We collected mental simulation data from one person who had a Ph.D. in economics, and had come to the U.S. from Poland at the age of 20. He generated a mental simulation with three factors (inflation rate, exchange rate, and unemployment), and showed how these would fluctuate and interact with each other during the coming year. He knew the current rates, and so could generate specific estimates for all three parameters, quarter by quarter. In contrast, two other people with less experience were unable to construct useful simulations. They each considered unemployment and inflation, forgot about exchange rate, were not able to see how the two factors of unemployment and inflation would affect each other, and did not know the current levels of inflation and unemployment. Needless to say, they were unable to "run" their simulation in order to generate any estimates at all.

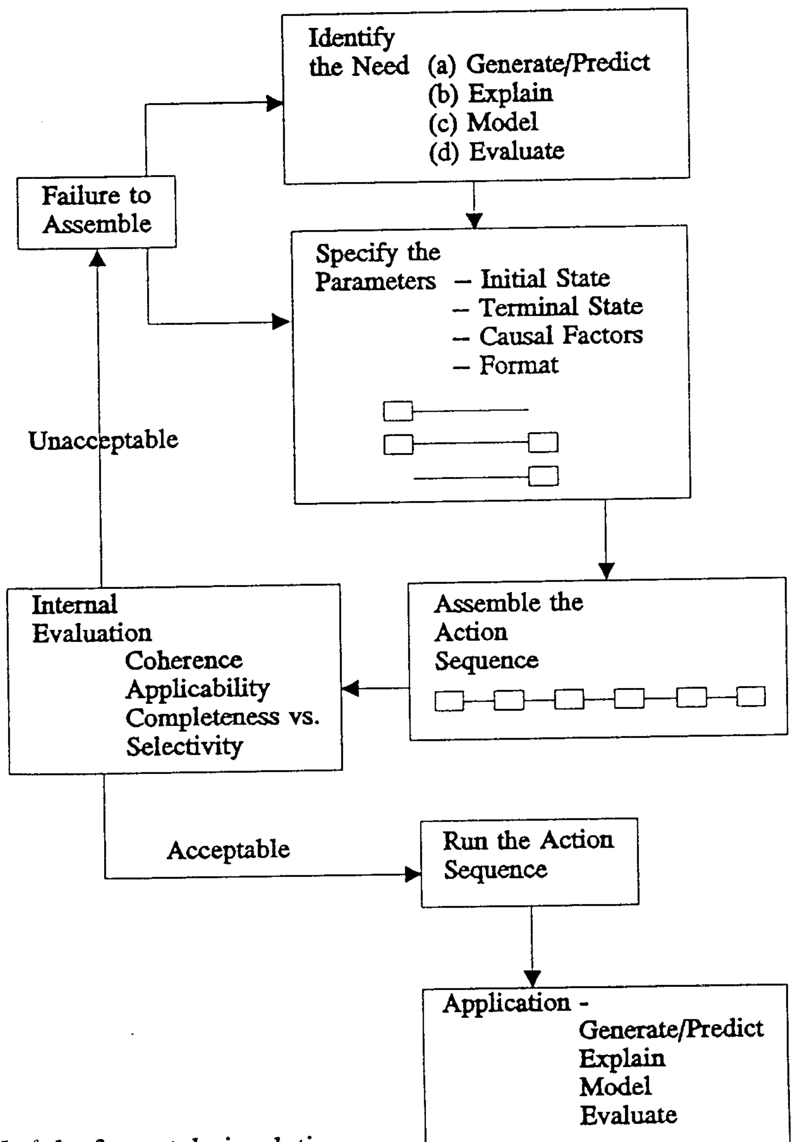

Figure 4. Model of mental simulation.

The third step depicted in Figure 4 is to assemble the simulation. In our database, many simulations consisted of transitions from one state to another. The purpose of the simulation was to examine the nature of these transitions. It appears that people naturally limit the number of factors and transitional states they employ in a simulation. In our study, the median number of transitions was about six, and the median of causal factors that varied was three, with a range of one to six. So we have represented mental simulation as an action sequence with six progressions. We also hypothesize that most mental simulations will center around three operators or causal factors.

Sometimes, the initial state will be given, and the person will have to extrapolate to an end state; at other times both the initial and terminal states will be known, and the task will be to interpolate--to bridge the gap.

We have depicted the transitions from one state to another as discrete, rather than continuous. Therefore, "configuring the simulation" in one's head involves selecting a small number of variables and manipulating these over several transitions--like successive frames in an animated sequence. Not all mental simulations are experienced as a series of discontinuous action states; many appear to run in a continuous action flow. But in these instances as well, the number of factors and the span of the simulating are constrained.

The internal coherence of the simulation is judged using some of the criteria listed by Robinson and Hawpe (1986) for evaluating stories: coherence; applicability; and completeness/selectivity. Pennington and Hastie (in press) have suggested that stories are more acceptable as a function of completeness, consistency, plausibility, and uniqueness. In other words, the simulation has to make sense, it has to address the important features of the situation but not drown in excessive detail, and it has to apply to the goals. If the simulation fails these tests, it will be necessary to try again or to rethink the goals. If it succeeds, then the person runs the simulation and uses the information gained from it.

To illustrate the model, we offer an example. The task is to have one person (working alone) raise a five-ton truck to a height of four feet off the ground, supported in its center by a column of concrete blocks. The available equipment includes a jack, and a large pile of concrete blocks. How might one accomplish the task?

One approach would be to use the jack to lift one tire, placing blocks underneath it, then lift another tire, and so forth until the truck is in the air. Then one could begin to build a column of blocks beneath the truck, raising it gradually and constructing a platform of blocks under the center, releasing the jack so the truck is resting on the center column of blocks, and removing the blocks from each of the tires. In this way, one could mentally play out an action sequence, examine it, and revise it before actually attempting the task.

Let us use the truck example to contrast the different needs that can be served by a mental simulation (see Figure 4).

Generate/predict: The task here is to assemble an action sequence. In the truck example, the challenge is primarily to find a course of action that will do the job. This category includes a sub-category of predicting events and data. The task is to run the action sequence, to determine estimates of different parameters (e.g., time needed to raise the truck). As the action sequence is run, it is possible to generate estimates of the time required for each of the segments.

Explain: The task is to understand how an end state could have arisen. Thus, if you saw a truck resting on a pile of bricks, and you were told that one person, acting alone, had managed the feat, you might try to generate an action sequence to account for how it was done. The process is similar to generating a course of action, except that the failure to assemble a simulation is taken as evidence against the proposed explanation.

Model/discover: The interplay of causal factors is unknown, and the task is to understand it. For example, one might imagine tilting the truck far back, or at extreme angles from side to side, to try to envision its center of gravity and its stability. The goal here is to create a hypothetical model, typically in order to deepen one's understanding of some domain. The simulation is examined iteratively and the knowledge gained is fed back into the simulation.

Evaluate: The task is to judge the adequacy of the expected outcome. In the example of lifting a truck, the evaluation would hinge on the adequacy of the bridge between initial and terminal states. In open-ended tasks, the evaluation would focus on the quality of the terminal state. In our example, the person would look at the process and determine whether it seemed workable or not.

There is another, more specific type of evaluation, in which the person examines the simulation for ways in which it might fail. The person draws on his or her experience to detect warning signs as the imagined action sequence unfolds. Analogies, rules of thumb, etc., enter into the detection of potential problems. If the simulation appears satisfactory, the person can proceed. If it fails, the person may be able to modify it. For instance, the pressure of jacking up one corner of the truck may produce lateral force on the others, causing the truck to topple. The operator may realize that a single column of blocks won't be sufficiently stable--what is needed is a broader platform, along with chocks to keep the tires from shifting. In this way, the course of action gets improved.

In our simulation database, we found that the decision makers tried to find a workable scenario, but were usually careful to evaluate it for flaws. Sometimes they tried to optimize their choice, but there were cases where they just tried to confirm that a course of action would not lead to trouble. We suspect that in many operational environments, use of simulation to inspect a plan for flaws is common <u>if and when</u> time permits.

The inspection of the simulation can also help a person prepare for action. The task here is to find difficult steps and prepare for them. The person uses experience to detect warning signs as the action sequence unfolds. Returning to our truck example, a person might look at the course of action and realize s/he isn't sure when to stop jacking up one of the corners, before the truck becomes unstable. The person may realize it is important to concentrate on visualizing early signs of imbalance.

How might we put this account of mental simulation into practice? Means, Salas, Crandall, and Jacobs (in press) have argued that attempts to train decision skills have largely been ineffective, with the exception of training metacognition. This is consistent with our understanding of naturalistic decision making, since most prescriptive strategies, such as MAUA, are inappropriate for the ill-defined and time-pressured tasks usually encountered. Further, it makes little sense to train people to use naturalistic strategies such as recognitional decision making, since these models describe the way people ordinarily handle decision tasks.

Nevertheless, there is one candidate for training that has interested us, and that is mental simulation. The work of Klein and Crandall (in preparation) suggested a few generic difficulties that people have with mental simulation, including overconfidence and failure to conduct risk assessments. We, therefore, attempted to develop a method for training better mental simulation practices.

Kyne, Militello, and Klein (in preparation) performed two studies on mental simulation strategies. The goal of the first study was to explore the role of mental simulation in evaluating a plan for errors. We have used the term *risk inspection* to describe the process where one mentally walks through a plan before it has been carried out, in order to find flaws or weaknesses in the plan. We are working to develop a mental simulation training procedure which we believe will enhance planning quality through the use of risk inspection. This procedure can be considered a "pre-mortem" in which the possible causes of failure are considered in advance of the event rather than after it. It both motivates a person to perform a risk inspection and inspires a person to be less invested in his/her original plan.

The study focused on changing a person's commitment to his/her original plan. We asked participants to plan a course of action, and to then conduct mental simulations of how the plan might fail. We attempted to change commitment to the course of action in the following way: during the risk inspection phase, we asked participants to take the role of a devil's advocate, with the power to thwart a plan. Their task was to implement Murphy's law by going back over the original plan searching for what could go wrong and describing those weaknesses for us.

The participants were 41 Psychology majors at Wright State University, Dayton, OH. The initial simulation task was to develop a plan for getting to the Dayton airport in time to greet an overseas visitor.

To test whether a person was less committed to his or her original plan, we asked participants to rate their confidence in the plan on a seven-point scale. The mean confidence rating was 4.83. The participants then attempted to find ways in which the plan would fail. Confidence in the plan was again rated, and the mean fell to 3.83. To test whether the decline was significant, we computed difference scores for each subject and compared the mean discrepancy to zero. The t-test revealed a significant change ($t=4.20$; $df=40$, $p<.01$). The data support the use of this approach for alerting decision makers to potential flaws. Moreover, the method appears applicable to many situations, since a person could use it on a plan without knowing in advance where the problematic assumptions were.

The second study was a more systematic attempt to contrast a pre-mortem condition with control groups that either reviewed the plan or just relaxed during the extra time. This time we looked at both changes in confidence and changes in plan quality. The pre-mortem condition in this study was given a slightly different instruction--they were asked to imagine that their plan had been carried out, and that the plan had failed. They were challenged to think of plausible reasons why this failure might have occurred, and to write down as many good reasons as they could.

Participants were 36 first through fifth year graduate students at Wright State University, Ohio State University, and Bowling Green State University, all in Ohio.

Participants were presented a scenario in which their academic advisor had agreed to present the results of a study at a professional conference. Descriptions of certain constraints such as time, money, and other appropriate resources were included in the scenario. Participants were asked to generate a plan to carry out the experiment within the given constraints. Researchers then intervened with one of three instructional sets:

- Pre-mortem - participants were instructed to imagine their plan had failed and to identify reasons for the failure and vulnerabilities to their plan.
- Review - participants were instructed to review their plan.
- Control - participants were instructed to "just relax" and no mention was made of their plan.

Participants were then asked to revise their plans.

We asked participants to rate confidence in their plan and the probability of success three times during the experiment. We asked the participants to complete the following surveys:

-- Rate confidence and probability of success in their original plan immediately after completing it.

-- Rate confidence and probability of success in their original plan after intervention.

-- Rate confidence and probability of success in their revised plan.

Our results replicate our findings from the first risk inspection training study. When tested against zero, there was significant decline in subjective ratings of probability of success ($t=2.32$; $df=11$, $p<.02$) and confidence from survey one to survey two ($t=2.01$; $df=11$, $p<.05$) for the pre-mortem group. The same tests failed to find significant decreases in confidence or probability rating for the Review or the Control group. When considering that the pre-mortem strategy was described in seven minutes, and no practice was provided, these are powerful results.

In addition to examining changes in confidence level, we also investigated changes in plan quality. We evaluated the quality of the plans generated before and after the treatment condition, for each of the three groups. Two raters reviewed all of the plans and provided evaluations, without knowing which of the three conditions the plans fell into. We expected that the pre-mortem condition would show a significant increase in plan quality, and it did; however, plan quality increased significantly in all of the three conditions, $F(343)=32.149$, $p<.001$. Moreover, there was no interaction between treatment condition and plan quality. Therefore, it appears as if the pre-mortem procedure was not significantly more effective in improving plan quality, even though it reduced confidence levels for the original plan.

We then examined the relationship between plan quality and shifts in confidence level ($\underline{r} = -.10$). Specifically, we wanted to know if those subjects whose confidence went down after the treatment condition also showed the most improvement in plan quality, regardless of which condition they were in. The data showed no such relationship. Changes in confidence were not tied to changes in plan quality. These findings suggest that for this task, beliefs and behaviors are not closely related. It should be noted that the two raters showed only moderate levels of agreement with each other on total plan quality ($\underline{r} = .692$ and $.611$) and were therefore measuring somewhat different features of the plans, so it will be necessary to perform additional studies to verify these findings. Nevertheless, the issue is raised of how to use mental simulation and the pre-mortem method to directly improve plan quality.

Before leaving this section, it may be worthwhile to note one additional point. The concept of mental models (e.g., Rouse & Morris, 1986) has often been cited as explaining different phenomena, but suffers from lack of precision. Rouse and Morris caution that too often, "mental models" refers to everything in a person's head, and that this is too inclusive and uninterpretable to have much value. In developing our account of mental simulation, we realized that a mental simulation was a plausible causal chain of events, involving a small set of active variables. In other words, a mental simulation was a story that could be judged for plausibility. There are many different types of models, as discussed above: spatial, statistical, physical, and so forth. Causal models, e.g., explanations of the way a certain type of cancer grows, are basically stories. Perhaps we can consider certain types of mental models in a similar fashion, as stories. A person's mental model of how a piece of software is operating is a story of which files are being created and accessed, and how this is happening. As such, it should be possible to describe the mental model as a story, and to evaluate it using the criteria used to assess the plausibility of stories. This strategy may be helpful in giving more shape to the concept of mental models.

Situation Assessment

In its earlier forms, the RPD model described four variables that were contained in a situation assessment (goals, cues, expectancies, and courses of action), but the model had nothing to say about the way a situation assessment was selected. We now have elaborated this part of the model. We can list several strategies for arriving at a situation assessment. These include nonanalytical recognition, feature matching, story building[5], analogical reasoning, and belief updating (Einhorn & Hogarth, 1987), along with more analytical methods such as Bayesian statistics.

The variations of the RPD model are shown in Figures 5-7. The simplest path (Figure 5) is for the person to directly recognize a situation as typical, e.g., an instance of a prototype or as a direct analogue to a previous experience. This direct recognition can involve a holistic process such as would be involved in holographic memory or neural nets. Alternatively, the recognition can depend on feature matching.

Sometimes the decision maker will evaluate an option by mentally simulating what might happen if the option was implemented, to see if it needs to be modified. This is shown in Figure 6.

The most complex version of the RPD model, as presented in Figure 7, can also apply to cases where a decision maker must select between several alternative situation assessments. When faced with such a decision, as in diagnosing what is wrong with a car engine, or whether a defendant is guilty, then the person must reassess the situation. If the original identification was based on features, then a feature matching process may suffice. More often, the assessment is in terms of a story, or causal account linking different pieces of evidence. Here, the decision makers will evaluate the alternative stories in terms of plausibility, consistency, and so on (see Klein & Crandall, in preparation; Pennington & Hastie, in press).

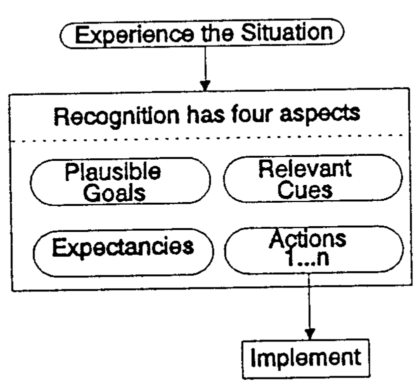

Figure 5. Simple match.

[5]A plausible causal chain that links up the different observations; this is the story model presented by Pennington and Hastie (in press), and it also corresponds to the form of mental simulation described above as explaining an event.

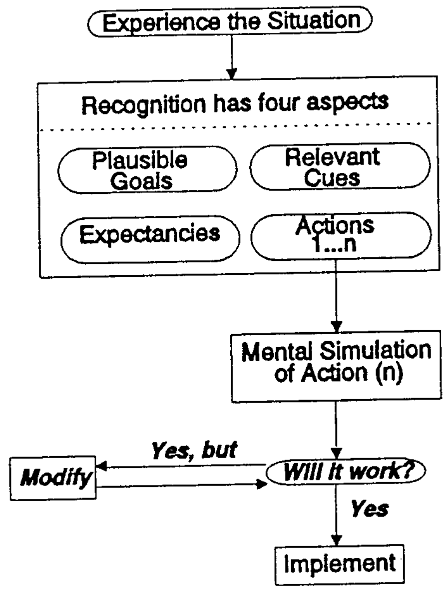

Figure 6. Developing a course of action.

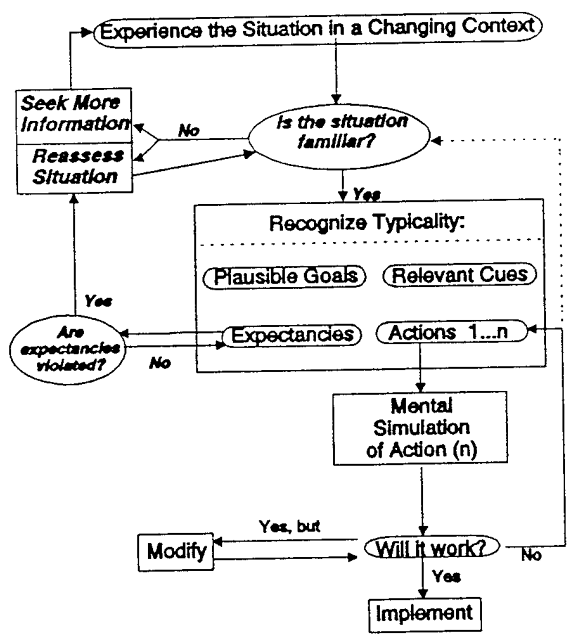

Figure 7. Complex RPD strategy.

One immediate question is whether the processes in Figure 7 appropriately fit within a model of recognitional decision making. The construction and evaluation of stories is hardly a recognitional process, and the deliberate use of feature matching likewise does not count as recognition. Therefore, the elaborated view of situation assessment may be more appropriately considered a companion model to the RPD strategy.

There are also arguments for incorporating these aspects of situation assessment into the RPD model, as we have done in Figure 7. The rationale of the model is to show how experienced decision makers can directly recognize a course of action, once a situation assessment is arrived at, thereby avoiding the need for concurrent evaluation of options. Figure 7 is consistent with this goal. Furthermore, the processes by which multiple situation assessments are generated, e.g., holistic matches and feature matches, are recognitional processes that simply happen to generate more than one match. Finally, the means of selecting a situation assessment, whether feature matching or mental simulation, are already processes contained within the RPD model. Thus, the RPD model already contains the components needed for Figure 7, so it does not seem to be too great a stretch to incorporate these within the model. We must be careful not to expand the model to include every aspect of NDM, or the model will lose its integrity, but in this case it appears that we have remained within the general parameters already set forth by the model.

There are other accounts of how situation assessment is updated that do not appear in Figure 7. These are the use of Bayesian statistics as well as the belief updating model of Einhorn and Hogarth (1987).

Other suggestions have been made to incorporate processes such as analogical reasoning, representativeness, and availability as mechanisms for informing situation assessment. Clearly, these are all important cognitive processes for the RPD model. However, we have chosen not to incorporate them into the model because they are generic cognitive processes; if we incorporate all the relevant cognitive processes (e.g., memory retrieval, inferential activities, pattern matching, motivation, and so on), we would wind up with a model of all the topics included in textbooks on cognitive psychology.

The question then arises: what kind of a model is the RPD model? There are different types of models, including statistical models, spatial models, physical models, and causal models. The RPD is a causal model. It was developed through observations of real-life decision makers; thus, its roots are in a descriptive, not a prescriptive decision-making approach--it is an account of the major processes responsible for carrying out a certain type of strategy. It omits many basic mechanisms (e.g., the mechanisms of drawing inferences, the mechanisms of retrieval), just as any account leaves out processes that do not distinguish it from alternative accounts. The details of the RPD model are intended to draw the distinction between RPD and MAUA as sharply as possible.

RPD: Testing the Model

The RPD model assumes that experienced decision makers can generate feasible options as the first ones considered. This is a strong and critical assumption. In a domain where there are large sets of options, and where most of the options are unsatisfactory, the use of an RPD strategy would be counter-productive.

The assumption of directed rather than random generation of options stands in contrast to classical decision theories. We are not claiming that the classical theories assert that option generation will be random; the idea of a directed option generation is not inconsistent with these theories. Nevertheless, the dilemma normative models are trying to resolve does seem to be tied to random option generation. The dilemma is how decision makers faced with large sets of options can focus down to find a good one to select. Under time pressure, it is impractical to consider a large set of options. We would expect decision making to become ineffective, and yet we know that is not the case. Perhaps people are able to select a small group of promising options from the initial large set, and are thereby able to handle the time pressure. Yet even this hypothesis runs into difficulty since it is not clear how a person would do so without first reviewing the entire large set.

The advantage of using a recognitional strategy is that it provides a reasonable option as the first one considered, and thus avoids the dilemma altogether. There is no need to review a large set of options, or even to whittle this set down, if the first option is workable. Therefore, the RPD model predicts that if subjects are asked to generate options, the first ones they generate will be acceptable and of better quality than the average member of the option set.

Klein, Wolf, Militello, and Zsambok (in preparation) tested this hypothesis using chess as the domain of inquiry. Four chess boards were selected as being representative of challenging move selection requirements. We identified all of the legal moves in each board position, and obtained objective ratings for each of these moves, using previously published evaluations prepared by panels of grandmasters.

The subjects were 16 chess players recruited from the Dayton, Ohio chess club. We tested subjects at two skill levels (as established by their standardized chess ratings). The stronger group corresponded to "A" level strength, and the weaker group corresponded to "C" level strength. For purposes of interpretation, the strongest players are grandmasters, then masters, then experts, then classes A, B, C, and D. So, the stronger players were very good but not outstanding, and the weaker players were still experienced and better than most players in the general population.

The study consisted of four trials with each subject, one for each board position. The subjects were asked to generate a think-aloud protocol as soon as the chess board position was shown to them, in which they articulated each move they identified. Once they arrived at a decision about which move they would play, they were told they could stop generating moves. When all four boards were completed, the subjects were asked to go over each board again and to rate the quality of each of the legal moves. The reason for obtaining these self-ratings was that grandmaster evaluations could be misleading. Suppose there is a subtle and outstanding move according to the grandmasters, but a class C chess player does not see the implications of the move, and thinks it is a blunder. For the purposes of this study the move should count as a blunder, because the subject did not generate what s/he thought was a strong move. The rating scale used ran from 5 = outstanding move, to 1 = blunder.

The results strongly supported the RPD model. Figure 8 shows the contrast between the distribution of all legal moves, and the first moves generated. If subjects were randomly selecting moves from the set of legal moves, their distributions would follow the solid line in Figure 9, and most moves would be poor, with few good moves. The actual distribution of ratings for first moves considered, shown by the dashed line, ran in the opposite direction.

Few first moves were poor. Actually, few were lower than a rating of three, which was assigned to acceptable but not outstanding moves. Most of the moves were rated four or five. The difference between the actual distribution and the one expected from random generation was highly significant, $X^2 = 211.145$, $p < .0001$. The class A players showed a slightly more pronounced difference from random generation, but it was not significantly different from the Class C players.

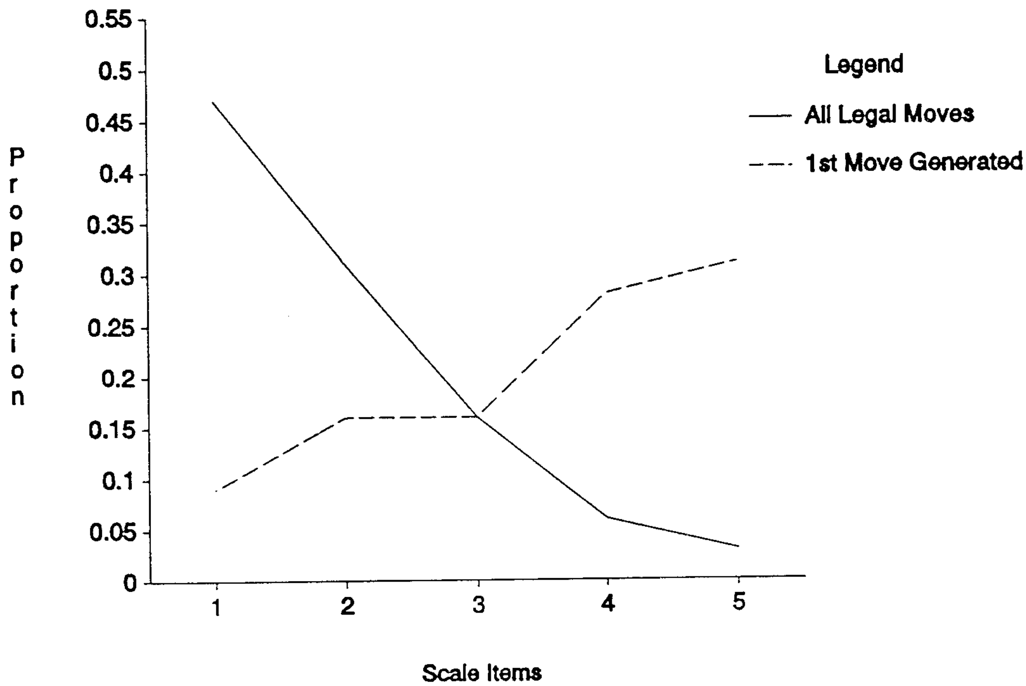

Figure 8. Proportion of ratings.

We also investigated the objective quality of the moves generated, and these data are presented in Table 1. The panel of grandmasters assigned points to each move that they felt was worth considering in a position. Most of the legal moves were given no points at all. We used these data to assign moves into two classes: those worth considering (i.e., those receiving any points at all) and those not worth considering. The ratio was about 5:1, with only 20 of the 124 legal moves on the four boards receiving any points. If subjects were randomly sampling from legal moves, this ratio should have held for the moves they generated. In fact, the ratio of moves worth considering vs. not worth considering was about 1:1, and the difference from random generation was again highly significant, $X^2 = 113.9$, $p < .0001$. So even by objective standards, the subjects were doing a good job of generating acceptable moves as the first one considered.

We also noted that even when subjects generated a poor move early in the sequence, they rapidly assessed it as being of low quality and discarded it, so there was little time penalty for a serial generation/evaluation strategy even when it did not succeed in generating a strong move initially.

Table 1

Frequency of Subject-Generated vs. All Legal Moves by Acceptability Level

	Moves generated by the subjects	All legal moves
Acceptable (Grand Master points were awarded)	41 moves	20 moves
Unacceptable (No Grand Master points were awarded)	23 moves	104 moves

These findings bring into question the value of advising decision makers to generate a large set of options in order to be sure of finding a good one (e.g., Gettys, 1983). There will be some conditions under which this advise holds, but for many other conditions, reasonably experienced decision makers can make more profitable use of their time by relying on their ability to generate acceptable courses of action, and can use their time to conduct more careful mental simulations to evaluate the consequences of these actions.

The data also suggest that we must be careful in interpreting studies such as Payne, Bettman, and Johnson (1988), in which the costs and benefits of different decision strategies were evaluated assuming random generation of options. If option generation is not random, then these costs and benefits would likely be different.

The data also bear on the link between skill level and decision strategy. The RPD model makes sense at skill levels where feasible options can be recognized. It makes less sense, and is less valuable, for people at lower skill levels (although it is not clear that exhaustive generation and selective evaluation will work any better). This study raises the issue of the benefits and costs of recognitional versus analytical decision strategies, as a function of experience level.

In summary, this study represents the first empirical test of the RPD model in which a prediction was generated and rigorously tested. We have encountered two kinds of criticisms in describing the results of this study. The first is that the findings were obvious, since no one really believes in random generation of options. In response to this criticism, we point to the Payne et al. (1988) study as an example of a study predicated on random generation. The second criticism is that the results were not conclusive owing to the shortcomings of protocol studies, so the subjects still could have been generating options randomly, but censoring themselves during the self-report. In response to this criticism, we concur that protocol analysis cannot fully tap cognitive processes of the subjects. We tried to make sure the demand characteristics did not pressure subjects into self-censorship, and we did find a number of instances in which blunders were generated and then noticed. It is interesting that these two criticisms stand in opposition to each other--to say that no one believes in random generation is the opposite of saying that our method has not ruled out random generation so it is still a possibility. Our own assessment is that the prediction based on the RPD model was confirmed, and that the burden of proof has now shifted to proponents of random generation of options.

Option Generation and Recognitional Decision Making

In this section, we present a preliminary description of how decision makers generate options. Despite the importance of option generation for problem solving and decision making, there has been surprisingly little written about the mechanism itself. Random option generation is an approach that is not very enlightening, and, based on the findings just described, not particularly accurate. Analogical option generation is an attractive idea, since analogical reasoning captures some of the experience base needed to move beyond random option generation, but even analogical models are unsatisfactory because it is rare in most domains to find a perfect analogue. There will always be some differences between a prior case and the current one, as well as conflict between different possible analogues. Furthermore, models of analogical reasoning have been more concerned with mapping analogues to different cases, as opposed to describing how analogues might be used to generate courses of action in a new situation. Adelman (personal communication) has recently studied factors that influence which options are generated, but has not addressed the mechanism of option generation. We need to go back to the work of Duncker (1945) and de Groot (1965/1978) to find serious attempts to explain how decision makers generate a course of action. The account we present below is influenced by, and consistent with, the work of Duncker and de Groot.

In the course of conducting the study described in the preceding section, we observed how subjects were sizing up a board and understanding its dynamics in order to even arrive at an option. Klein, Wolf, Militello, and Zsambok (in preparation) have tried to model the factors that determine which option a decision maker will consider.

Klein and Miller (1992) have derived a convergence model of how options are identified. The model consists of three parameters: the zone of orientation, contextual goals, and the detection of leverage points.

(1) Zone of orientation. The zone of orientation (see Tikhomirov & Poznyanskaya, 1966) attracts attention because of its potential information value--it is an area of turbulence, of departures from typicality, of concentration of critical pieces, and so on. This is the area examined first.

(2) Contextual goals. Goals/plans are usually developed in response to large-scale patterns. Usually, there are general plans available even before seeing the board (increase mobility, reduce opponent's range), but these are too general. For a given board position, the player must focus down to a small set of contextually-relevant, specific plans, e.g., a player might notice that the opponent has a Pawn advantage at a certain part of the board and may formulate the goal of holding back these Pawns. This is followed by a search for how to accomplish this goal. De Groot (1965, p. 134) offers several examples: notice a need to do something on the King's wing, realize that the Rook must do something since it is the last piece not engaged, consolidate on the Queen's side, embark on a mating attack, open up the

King's position, maintain pressure. These pattern recognitions are followed by searches for moves to achieve the goals.

(3) Leverage points. Leverage points are departures from typicality that are more tactical than goals/plans. Holding (1985, p. 172) and de Groot (1965) refer to them as experiential linkings. De Groot (p. 297) says that "The extensive and subtly differentiated system of such correspondences (linkings) is, so to speak, the arsenal of the chessmaster...That the chessmaster sees in a few seconds 'what's cooking in a certain position,' i.e., which typical playing methods the situation on the board demands, enables him to begin his investigation in a highly specific direction."

These experiential linkings include patterns or Gestalts such as: a passed Pawn, an isolated Pawn, a hanging Bishop, the possibility of a series of forced moves. These are opportunities as well as threats to be defended against. A chess player might see that s/he has a series of forced attacks against the opponent, and muse "I wonder how I can take advantage of that? If I keep pushing my opponent around, what opportunity might it create for me?"

At the simplest, these experiential linkings are routine patterns such as the fork, the discovered check, the double check, the pin, the tempo move, Zwischenzug, Zugzwang, the sacrifice, and the quasi-sacrifice. De Groot (1965) says that the chessmaster uses several of these patterns, e.g., several tactical weaknesses, to create chains and multi-functional moves. Further, these chains can themselves be typical patterns.

The story is not so simple, since attempts to formulate simple rules run into problems. "Pawn grabbing in the opening is not always fatal; the Rook need not always stand behind the passed Pawn; the pair of Bishops or a Queen side Pawn majority or a protected passed Pawn or a massive Pawn center is not always an advantage" (de Groot, p. 303).

At the most complex level of patterns, are "all sorts of maneuvers, offensive and defensive build ups, ways of regrouping the pieces and getting them to cooperate, etc. The general methods of piece co-operation appear to be particularly difficult to describe in detail, to treat systematically, and therefore to pass on to other students of the game" (de Groot, p. 303).

These leverage points are not easily definable, and according to de Groot, players at different strengths will show different speeds of situation assessment for detecting these critical contextual features. A strong player will immediately notice the threat of a pin, and realize the need to drive the opponent's Queen away and remove the threat. De Groot argues that these are not universals, but just features that are striking in context, as deviations from typicality. In other words, they are defining features of a position, as well as clarion calls for reacting: How to take advantage of that passed Pawn? How to overcome my opponent's space advantage? How to use my pair of Bishops?

So, these leverage points or experiential linkings may be describable at the level of novice, but not at the level of Master. That is a reason to restrict our investigation to novices.

The Convergence model of option generation asserts that option generation occurs as a top-down process of planning, together with a bottom-up process of noticing situational opportunities. Where these correspond, an option arises.

The metaphor is a lightning strike, which is the convergence of two streamers, one positive and one negative. For a lightning strike to occur, first there needs to be a cloud, probably at a suitable temperature (cool) to allow the positive and negative charges inside the cloud to become separated so that the negative charges are at the bottom. When the negative charge is great enough to overcome the air's resistance, a streamer of flowing electrons, called a stepped leader, is discharged towards the ground. At the same time, the negative charge attracts a weak positive charge upward from the earth's surface, a positive streamer. As the stepped leader continues downward, it continues to attract the positive streamer upward. When these meet, the circuit is completed, and the lightning bolt is discharged.

For option generation, the zone of orientation is analogous to the cloud. This is the arena in which the option will become generated. The separation of positive and negative charges in the cloud is akin to the culling out of contextually relevant plans from the general set of possible plans. These specific plans help to focus the option generation process, and help to attract the right option. The specific plans are like stepped leaders, opening up promising channels for investigation. The leverage points, or experiential linkings, are like the positive streamers lifting off of the ground. They take advantage of fortuitous features of geography, such as trees or buildings. In a chess game, atypical features such as a passed Pawn or an undefended Bishop naturally trigger curiosity about how to take advantage of a flaw, or how to defend against a flaw. So the person is simultaneously alert to possibilities for using a feature of the game and for ways to modify the game position in certain directions. As these two lines of investigation grow nearer, e.g., deepening from a leverage point starts to get in contact with a plan, this line of investigation excites more attention and if it is possible to make the contact, the option is generated.

Sometimes, the process will primarily be bottom up, building from a promising leverage point. Other times, the process may be primarily top-down, searching for ways to carry out a plan. A third pattern is a fairly equivalent direction from above and from below.

The Convergence model of option generation seems to be relevant to areas other than chess. Smith et al. (1991) have described how specialists perform blood typing in blood bank centers, using top-down and bottom up processes that correspond fairly well to the processes in the Convergence model. Military planning also calls for option generation. With experience, commanders are able to rapidly focus on a critical part of the battlefield map (the zone of orientation), and are able to both search for ways to carry out plans and to notice leverage points in the battlefield to drive the situation assessment.

Therefore, we suggest that the Convergence model of option generation may have value for understanding and assessing the processes found in operational settings as well as more controlled tasks.

To summarize, there are several aspects of the Convergence model of option generation.

-- It consists of three components, zone of orientation, contextual goals, and leverage points.

-- Each of these components can be further specified for a given board position, and for a given player. That is, players have certain types of plans and certain types of Gestalts, they notice more quickly.

-- The zone of orientation defines where the option will arise.

-- The contextual goals and triggers are the bases for the option. The plan is the top-down portion, and the leverage points are the bottom-up portion. The plan is looking for a way to be realized, and the leverage points are looking for a function to serve.

-- The Convergence model is not a radical departure. It is consistent with the work of Chase and Simon (1973), de Groot (1965), and Holding (1985). Hopefully, it is a little more explicit and therefore, perhaps more useable. Chase and Simon talked about pattern matching to generate moves, whereas the Streamer model relies on pattern matching for experiential linkings (triggers), which helps start the process of option generation but leaves room for the chess player to construct the move sequence, rather than just recognizing it. This was also de Groot's concern, and Holding's--that option generation could not be a simple retrieval process. The Convergence model reflects the importance of low-level patterns (e.g., a passed Pawn), while maintaining the potential for directed search and discovery.

-- The Convergence model is consistent with earlier work on problem solving (Duncker, 1945; Klein & Weitzenfeld, 1978). This work viewed problem solving as consisting of two interrelated processes: identifying the goal and searching for solutions. Ill-defined problems need to do both simultaneously. The Convergence model also views a relationship between specifying the plans and working up from leverage points. The promising triggers are searching for reasonable plans, and the plans are searching for ways to be accomplished, so that plan specification is continuing even as the experiential linkings are being explored. That is why a purely top-down approach doesn't work (i.e., first specify plans, then look for ways to accomplish them), and why a bottom-up approach doesn't work (i.e., mindlessly explore combinations).

Limitations of Recognitional Decision Making

In this section we examine some of the weaknesses of using the RPD strategy. Klein (1989) has noted that classical strategies of concurrent option evaluation are more suitable for tasks where there are abstract data, tasks requiring optimizing rather than satisficing, tasks requiring the choice to be justified, tasks requiring agreement from multiple stakeholders, combinatorial tasks, and tasks where the level of expertise is low. It is therefore apparent that we do not view the RPD strategy as appropriate for all tasks, or for all people. In this section we further explore some of the boundary conditions of the RPD strategy. We begin by reviewing these task characteristics just mentioned. Then, we describe a study of the types of errors found in our naturalistic decision studies. Finally, we examine the impact of stress on recognitional decision making.

Generally, the RPD model will have a greater advantage over classical models when complex stimuli are involved, rather than alphanumeric data. However, the RPD model is still applicable with data such as symbols on a CRT, or even numbers in a table. But as the data and format become more abstract, the advantages of the strategy diminish. Similarly, the recognitional strategy is designed for tasks where people try to satisfice, rather than optimize, but even for an optimizing task such as chess, de Groot has presented protocols showing serial evaluation rather than comparisons between options. With regard to experience level, we have found a lower rate of use of recognitional strategies among novice decision makers, but the rate is still quite high, never less than 35% in any of the studies conducted thus far. The other criteria seem to be firmer: requirement for justification, agreement from multiple stakeholders, and combinatorial tasks all mitigate against the use of the RPD strategy.

What kinds of errors arise from the use of a recognitional strategy? Klein (in preparation) investigated 25 errors, identified from a careful review of a series of studies summarized in Klein (1989) and other sources, and covering more than 450 decision points that had been thoroughly analyzed. The errors fell into three categories. The first class, containing 16 errors, was attributed to a lack of experience, which typically resulted in failure to anticipate certain consequences of actions or in misunderstanding of analogues. The second class, containing five errors, was made up of incidents in which a lack of critical information led to the problem. The third class, containing four errors, was linked to faulty mental simulation, e.g., cases where a critical sign of illness in a patient was explained away by constructing a story that showed how that sign could be the byproduct of some other factor.

It is noteworthy that in these 25 cases, there was not a single example of errors due to miscalculation of probabilities, poor weighing of evaluation dimensions, mistaken assignment of subjective expected utilities, confirmation bias, etc. The implication of these error data is that RPD errors arise from limited experience that renders a person insensitive to factors that should have influenced a situation assessment, and from ineffective use of mental simulation for explaining a situation or for evaluating a course of action. Klein and Crandall (in preparation) have argued that mental simulation can lead to several types of decision errors, including overconfidence in the likelihood that a course of action will be successful, explaining away disconfirming evidence by finding counterexplanations, and failing to perform a thorough mental simulation to investigate the risks of carrying out a course of action.

Another way that the quality of decisions can be degraded is through the effect of stress. Recently, Driskell and Salas (1991) have presented an exhaustive review of the literature on different types of stressors. Klein (1991; Klein & Zsambok, in preparation) has attempted to apply this review to the topic of naturalistic decision making. Klein and Zsambok (1991) have argued that the diverse types of stressors, e.g., cold, noise, sleep deprivation, time constraints, frustration, performance pressure, etc., share a few features in common. First, they affect the speed/accuracy tradeoff, and their effect on decision making can largely be explained in terms of less time being allotted to sub-tasks such as gathering information. Second, each stressor requires attention for adjusting to and managing the stress itself, and this may be seen as constituting a secondary task, so that degraded performance under stress may be also a function of fewer cognitive resources available.

Within the RPD model, the most vulnerable aspect is mental simulation. Recognizing a situation does not require much in the way of cognitive effort, but mental simulation requires careful attention, and is easily disrupted. Therefore, we predict that stress will most easily degrade the mental simulation function and disrupt recognitional decision making through that avenue.

Team Decision Making

Can we apply our ideas about individual decision making to the level of the team? This research project has centered around individual decision making, as captured by the RPD model, but we have also become interested in teams. When we studied urban fireground commanders, we watched how they managed their teams during time pressured events. When we studied Incident Commanders in charge of fighting forest fires, we were interested in the way they managed very large teams and even an entire organization of 4,000 people.

Team as an Entity

Our first attempt to describe team decision making was to export the RPD model wholesale to the team level, and to treat the team as an entity. Thordsen and Klein (1989) hypothesized that the RPD model could be translated to the team level by corresponding the primary components of the RPD model--recognizing the situation, identifying goals, becoming sensitive to critical cues, forming expectancies, identifying a feasible course of action, conducting a mental simulation to evaluate that course of action--to the following correspondences at the team level. Recognizing a situation for a team is linked to making sure that there is a shared understanding (what Orasanu & Salas, in press, have referred to as a shared mental model). Identifying goals corresponds to communicating the leader's intent. Becoming sensitive to critical cues corresponds to effective communication about information signifying changes in the environment. Forming expectancies corresponds to sharing an understanding between team members about expectancies. Identifying a feasible course of action corresponds to sharing an understanding of how to approach the problem. Mental simulation is also found at the team level, as an activity in which the entire team can participate, a phenomenon we observed during an ARTBASS simulation at Ft. Hood (Thordsen, Galushka, Klein, Young, & Brezovic, 1990).

Thordsen (in preparation) has tested this approach by using these categories to generate a taxonomy of team errors. The different taxonomy elements corresponded to different RPD functions, with one additional function for management of the team. He hypothesized that if this taxonomy was reasonable and intuitive, then different rates should reliably generate overlapping ratings.

Thordsen developed as stimulus materials 65 team errors that Klein Associates had observed in four different domains. These included 24 errors from a Department of Energy emergency operations center exercise, 21 errors from tactical military exercises, 14 errors from full flight simulations for commercial airline crews, and six errors from a strategic geopolitical exercise at the National Defense University. Three coders were provided packages containing a set of eight practice errors, descriptions of the 65 team errors, and a detailed outline of the error taxonomy and its relationship to the team decision model.

Inter-coder agreement was assessed using the Kappa coefficient (Fleiss, 1981). Kappa is a chance-related measure of agreement that provides a more meaningful index of inter-rater reliability than do simple percent-of-agreement measures. Kappa values for the overall level of category agreement between pairs of coders were .69, .70, and .74. Kappa values greater than .75 represent excellent agreement, and values between .40 and .75 indicate fair to good agreement.

We were very interested in the issues of what differentiates domains from each other and whether it is possible to gain insight into relationships between a domain's attributes and the categories into which its errors fall. Eight attributes were identified, based on our experiences observing teams in naturalistic settings, along which we believed the domains would vary. These were the level of Uncertainty, the amount of Time Pressure, the level of Responsibility and Risk of and to the team members, the average level of individual Expertise, the amount of team Cohesion, the Dynamics of the environment they were working within, the Complexity of the tasks they must perform, and the degree of Distribution of the team members. While no list would be exhaustive, we believe this one captures many of the critical factors.

The data revealed some indications of relationships between domain attributes and error type. For example, there were no Cues errors from the domain with the lowest Dynamic rating. In a non-dynamic environment, the Cues that are present often remain constant and few new Cues are introduced. The vast majority of Goal errors were attributed to the domain which possessed high Uncertainty and a high Dynamic environment. Both of these characteristics might make it difficult to develop adequate goals, especially under high time pressure, which this domain also possessed. This same domain also had the largest number of Evaluation errors. Once again, the high uncertainty, dynamics, and time pressure could easily account for this trend since it would be difficult to quickly evaluate unclear, changing situations. Implementation errors were largely dominated by the only domain in which the team members were directly responsible for the actual implementation of courses of action. The other domains operated more in planning and managing capacities. One team dominated the Management errors. This particular team was comprised of individuals who seldom worked together and whose areas of expertise did not match the work that their team was expected to accomplish, that is, they had the least team Cohesion and the lowest individual Expertise.

The study of team errors demonstrated that it is possible to consider a team as an intelligent entity, and to apply the perspective of an individual decision maker to a team. We originally conceived the study as a test of the RPD model, and developed it using the RPD model as the conceptual frame. But over the course of this study and other ongoing work devoted to team decision making, we have come to believe that the RPD model is too narrowly focused on particular aspects of decision making and does not adequately reflect the breadth or variety of team decision processes. Rather than trying to force our analyses of teams into the RPD model, our more recent work has used a more general cognitive process model of team decision making. The Team Error study was a valuable first step in development of a cognitive perspective on team functioning.

Cognitive Model of Team Development

In this section we describe a cognitive developmental model of team decision making. The model treats teams as intelligent entities, and uses our knowledge of cognitive psychology and developmental psychology as a source of hypotheses and guidance. The use of metaphors in science (e.g., Hesse, 1966) has been established as a means of generating new hypotheses. Thus, a cognitive metaphor alerts us to the needs a team has to direct attention, to store information, to retrieve information from a distributed memory, to develop metacognitive skills, and so forth. In this way, cognitive psychology provides a perspective for understanding teams, and for identifying processes in which teams must engage. Similarly, developmental models serve as a metaphor for understanding a maturing organism. Functions such as the formulation of identity and the achievement of cognitive sophistication, as well as the development of metacognitive skills, all draw on the research literature on the cognitive development of children.

There is another way of viewing a cognitive development metaphor, and that is to use teams to understand individuals[6]. Max Black (1962) has asserted that metaphors are interactive. To say that man is a wolf changes the way we perceive men, and also the way we perceive wolves. To treat a team as an intelligent entity requiring cognitive development can aid us in understanding teams, but it can also inform us about cognitive development. Specifically, in our research on teams we have seen how important and difficult the task of forming and communicating intent is, and this raises questions about the function of intent in directing individual cognition. In our work with teams, we have observed how difficult it is to draw on the different team members to formulate ideas. No one in the team knows what the final ideas will be during a planning session. Different members contribute different components, and each member may have an idiosyncratic interpretation of the final product. This chaotic process may map onto individual cognition, where different experiences somehow converge into an idea, a product that was not previously known. Therefore, the study of thinking in teams may help provide hypotheses about the process of individual cognition.

The cognitive model of team development was first articulated by Thordsen and Klein (1989), who specifically used cognitive processes such as perception, metacognition,

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[6]This suggestion was made by Gavern Lintern, personal communication, April, 1991.

intention, and limited attention to describe the cognitive behavior of teams.[7] The cognitive model was then applied in a study of teamwork among commercial aviation cockpit crew members (Klein & Thordsen, 1989).[8] The cognitive model was further elaborated to include the process of cognitive development as a way of describing the growth in teamwork skills; this was accomplished during a study of battalion teams functioning in field conditions (Thordsen, Klein, & Wolf, 1991).[9] Finally, under the auspices of the present basic research contract, we have extended the developmental model even further, as described below. Thus, we have come full cycle during this three-year contract, from the initial formulation of a model of teamwork, to a much more detailed account based on several field studies.

The Advanced Team Decision Making Model (Zsambok, Klein, Kyne, & Klinger, 1992) describes how teams become a collective body that is capable of high performance and advanced decision making. The model is stated in developmental terms. It includes two key characteristics of decision making teams--*team identity* and *conceptual level*--and one master regulating process--*self monitoring*. As teams develop from a state of weak to strong team identity, from a low to high conceptual level, and from lax to vigilant self monitoring, they become advanced decision-making teams.

The model also describes processes by which teams may improve in each of the key components of team decision making. Figure 9 depicts the critical processes that are related to each of the components. As teams sharpen their ability to use these processes, they strengthen their team identity, raise their conceptual level, and improve in their overall ability to self monitor. The processes are ones that observers can learn to see in teams--with practice, team members can learn to see them too. Through observation, feedback, and practice with these processes that groups of individuals can develop to advanced, high performance decision-making teams.

The three components of teams are parallel to dimensions frequently used to observe an individual who is trying to develop a skill. Inexperienced teams go through all the awkwardness and confusion of novices. For example, novices have difficulty with their own identity, so they often can't judge which tasks they will be able to successfully perform. Novices have difficulty in pursuing long range goals without getting distracted. Novices can be comical--watch someone step onto a racquetball court for the first time with no idea which way the ball will ricochet. Novices also get confused when they have to view a problem from more than one perspective, and they are unable to think about their own thinking--to gauge what strategy to use in performing a task.

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[7]This article followed the work of Thordsen in formulating his study design, but it was completed earlier since the Thordsen project involved running subjects and analyzing data.

[8]This project was supported by a contract from NASA/Ames.

[9]This study was sponsored by the ARI field unit at Monterey, through SBIR Contract No. MDA903-90-C-0119.

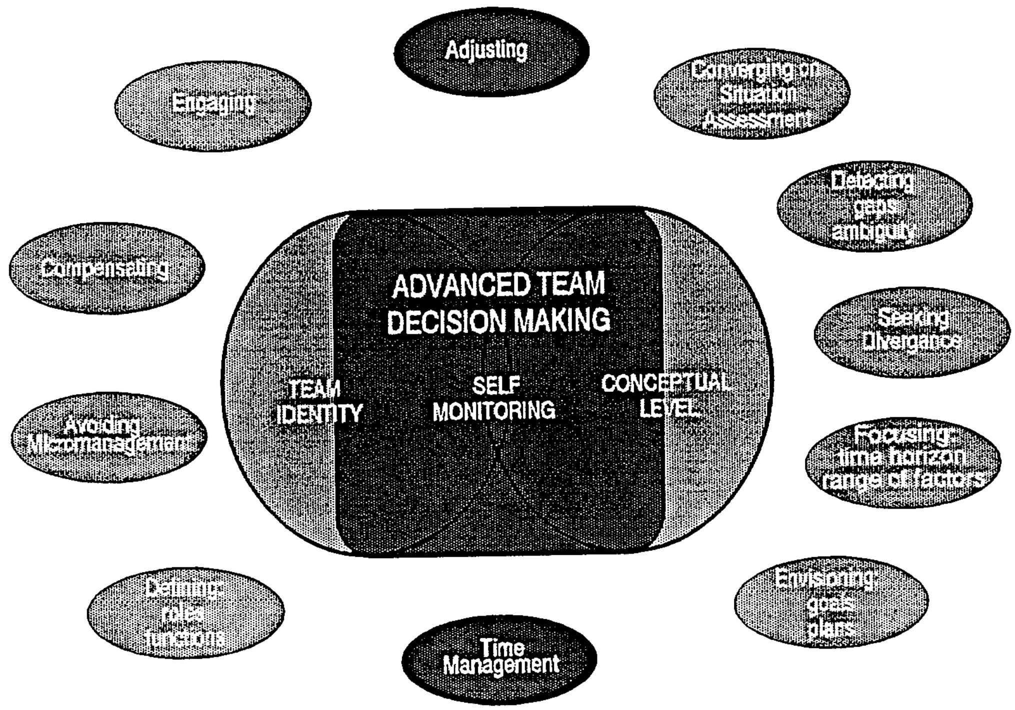

Figure 9. Key behaviors for advanced team decision making.

This model was developed to help teams learn to identify specific processes they can use to improve their performance--to help them develop into an advanced decision-making team. A brief description of each of the processes follows:

Self Monitoring

An advanced team monitors itself while acting within the task, and balances the need for time to monitor with that required to perform the task. By definition, self monitoring is the process of team members observing and assessing their own team performance. But the term also implies that they try to *adjust* various aspects of performance that have been found wanting. In advanced teams, adjusting occurs interactively--watching, adjusting, watching again, and so forth. One critical aspect of self monitoring concerns *time management*--being able to meet goals at the desired level of quality before deadlines overtake the team.

Self monitoring is a regulatory process that encompasses all other, more specific processes related to team identity and cognitive level. Each of these is discussed below. Just as teams can develop and improve in their use of these specific processes, they can also improve in their ability to engage in the process of monitoring itself.

Team Identity

Team identity reflects the extent to which members conceive of themselves as an interdependent unit, and operate from that perspective while engaged in their tasks. One key outcome of strong team identity is that members can anticipate the needs and actions of one another, thereby facilitating coordination of thoughts and actions across the team. Teams can advance in the strength of their identity by developing the way they use certain critical processes:

Defining roles and functions. Team members cannot monitor whether the functions assigned to particular roles are being properly carried out if they don't know what those roles and functions are. Advanced teams recognize that they must understand the pattern of working relationships among their members in order for them to coordinate activities across the team.

Engaging. The extent to which members are fully absorbed in the roles and functions that need to be performed to achieve team goals is an index of team engagement. More experienced teams are careful to get the full use of each member, so they monitor themselves to see if any members have become disengaged from the task at hand.

Compensating. Compensating describes the process of stepping out of an assigned role or function and taking on a different one to help the team reach its goals. Advanced teams encourage members to flexibly step outside their roles as the need arises in order to remedy difficulties that other members are having in fulfilling their functions.

Avoiding micromanagement. Micromanagement occurs when a team member becomes involved in managing information, tasks, or people at a greater level of detail than is necessary. Advanced teams realize that micromanagement drains the team of resources in two ways: 1) the team member engaged in micromanaging is distracted from other, higher level tasks; and 2) the micromanager often duplicates what others are doing, or otherwise interferes with another member's work. As teams develop in their ability to avoid micromanagement, they recognize the need to monitor for this problem, and to resolve it quickly when it does occur.

Conceptual Level

Advanced teams are able to achieve a more complex and sophisticated understanding of tasks, events, and situations. They are able to employ hypothetical reasoning, carry out contingency planning, and manage divergent ideas. In contrast, less advanced teams crystalize their thinking around a few concrete courses of action even when the situation requires more flexibility. A key outcome of developing a high conceptual level is that team members are able to improvise quickly and effectively in the face of unexpected events. Processes critical to a teams' conceptual level include:

Envisioning goals and plans. The process of envisioning involves bringing to life in realistic and graphic terms the mission (goals) of the team, and the process (plan) the team will use to meet its goals.

Focus: Time horizon. The Time Horizon is the focal distance at which a team is perceiving the world. Whether a team is using an appropriate Time Horizon is a direct function of the task in which they are engaged. For example, for a helicopter crew, the Time Horizon may be the map cue that is just beyond the next visible navigation marker. For a Division planning team, the appropriate Time Horizon might be 24-72 hours in the future. For high level planning teams, the appropriate Time Horizon might be 5-10 years into the future.

Focus: Range of factors considered. Another aspect of perception that changes as a team develops is the range of factors monitored. The team becomes sensitive to a wider set of causal factors, and learns to apportion its attentional resources so that different members can capture different types of information.

Detecting gaps and ambiguity. Advanced teams actively attempt to detect gaps in information by scrutinizing what they've been given, and by clarifying their assumptions about the information base. Advanced teams are also not perplexed by ambiguous information. They make note of the ambiguity, rather than ignoring it or becoming confused by it.

Converging on situation assessment. Advanced teams work towards developing a shared understanding across team members of a commonly held situation assessment. Under rapidly changing conditions, advanced teams recognize the need to re-assess the situation and to ensure that shifts in SA are understood by all members.

Seeking divergence. Advanced teams explicitly seek divergent views from their members to sharpen and deepen their situation assessments and plans of action. They encourage diversity rather than suppressing it as an unwanted complication.

The Importance of Teamwork and Intent

We have conducted a study of one of these components, that aspect of a team's identity by which it learns how to communicate about its own goals. This study (Kaempf, Klein, & Kyne, in preparation) examined goal communication under field conditions. We tried to understand the elements that contribute to the effectiveness of commander's intent statements. There were several objectives for this analysis. The first was to identify the characteristics of effective commander's intent statements. The second objective was to determine if these characteristics depend on the type of mission. The final objective was to examine if the commander learns to convey better intent statements across missions within the training rotation.

The intent statements were obtained from mission orders created during force on force exercises at the National Training Center (NTC). Individual commanders participate in a series of missions called a rotation. Each rotation is made up of one mission per day for approximately two weeks. Because of the nature of battle, the commander executes different types of missions. For example, his mission might be to attack, to initiate a movement to contact, or to build a defense in a sector. The type of mission executed, of course, depends on the play of the battlefield.

We received mission orders from 11 rotations in successive order, just as they had been played out at NTC. Each rotation contained approximately seven intent statements (range: five to nine). The analysis of this data is a non-intrusive means of studying the way intent statements are framed, and how they change with command experience. The commander's intent statements were extracted from actual mission orders.

Questionnaires were distributed to 17 volunteers from three operational settings. Of those, seven completed questionnaires were returned. These questionnaires solicited opinions about the quality and content of 35 statements of commander's intent extracted from mission orders created during force on force exercises at the National Training Center. Those settings include:

Army War College. Questionnaires were distributed to ten volunteers enrolled in courses at the Army War College (AWC), Carlisle Barracks, PA. One volunteer returned a completed questionnaire.

Former National Training Center commanders. We distributed questionnaires to two Army personnel who have had extensive experience as commanders at the NTC. One served as a commander for the Red Forces, the other, who is now a brigadier general, conducted field exercises and rotated forces through NTC. Both people returned a completed questionnaire.

Instructors from the Tactical Commander Development Course at Fort Leavenworth, Kansas. Questionnaires were distributed to five retired Army personnel and instructors at Fort Leavenworth. Four returned completed questionnaires.

The questionnaire consisted of three parts. The first part contained questions that represent the participants' level of experience. The second part listed the elements we have identified as contributing to effectiveness of commander's intent statements. The evaluator was asked to rank those elements in terms of their importance for conveying intent effectively. The evaluator was also asked to include any elements that were missing from our list. They were then asked to reorder them in terms of importance to include their elements. The third part of the questionnaire was the 35 intent statements extracted from the 77 mission orders created at the National Training Center.

Evaluator expertise. The level of experience and rank reported by the evaluators indicated a highly experienced group. The average length of active duty was 24 years, the minimum being 21 years, and the maximum 29 years. One of the evaluators was a Brigadier General, two were Colonels, and four were Lieutenant Colonels. Having battalion and/or brigade level command experience was an important basis for selecting these evaluators. All evaluators reported having battalion level command experience, the average being 2.4 years with a range of 1.5 to 4 years. One evaluator also reported having 23 months of Brigade command experience.

Experience as an operations officer was not a criterion used to select our evaluators for this study, however we hoped that some would enjoy such experience. As it turns out, five of the seven evaluators reported having over one year of battalion and/or brigade level experience as an operations officer.

From these reports of experience level and from the fact that we selected our evaluators from areas in the Armed Services where proficiency with operation orders is high, we are confident that our data were collected from evaluators who are highly qualified to rate the effectiveness of intent statements.

Taxonomy of functional quality. Through interviews and review of relevant literature, we identified several elements that contribute to the effectiveness of commander's intent statements. We asked evaluators to rank those elements in terms of their relative importance to them. Using the median to measure the central tendency of rank for each element we obtained the following hierarchy:

1. Presents a clear image of the desired outcome.
2. Provides a basis for determining mission priorities.
3. Presents a clear image of how the brigade mission fits into the division's effort.
4. Uses clear and concise language.
5. Does not present conflicting messages.
6. Does not provide detailed instructions about how to conduct the mission.

We also asked evaluators to identify elements of an intent statement that should be included in our list. They reported the following:

- Intent of future operations if operation is successful.
- How the commander envisions using the force as a whole.
- Integrates anticipated enemy disposition and action.
- Identifies intent for each subordinate element/commander.
- Includes use of deception (tied to above).
- Presents clear statement of responsibilities for execution.
- Addresses significant risks and how they are to be dealt with.
- Identifies and describes main effort and conditions under which it would be changed.
- Content and contributions of any deception efforts.
- Should include a concise statement of intent of division and corps commanders, i.e., two levels up.

General Findings

Several important findings have emerged from this study. First, there is not strong agreement between the raters on the coding categories. Although there is sufficient agreement to permit further analyses, it is noteworthy that the raters do not share a clear, common understanding of what is involved in formulating an effective commander's intent statement. Furthermore, the raters we identified as the most experienced agreed with each other. Thus, there is a central cluster that differs from the others.

Second, there are clear differences among the different commanders. Some were seen as having better intent statements than others. More interesting, some commanders show improvement from the beginning to the final exercises at NTC; others do not show much improvement. Moreover, we can see patterns regarding the ways that units do improve--how their intent statements change.

Third, the aspect of commander's intent that is identified as most important pertains to the visualization of the battlefield. Some of the NTC units failed to convey an adequate visualization, while others were successful.

Fourth, we expected that excessively detailed intent statements would be rated as poor, since the detailed account of how to accomplish a mission is inconsistent with the need to portray a visualization of the outcome. However, the intent statements rated as more detailed were not rated as less effective. The only problem with detailed intent statements was that they appeared to engender more conflicts and internal inconsistencies, and even this may have been useful for surfacing areas of confusion that might otherwise have been masked.

We have identified eight functions of a commander's intent statement. Such statements should enable personnel to:

-- Understand how a mission objective fits in with the plans and objectives of the higher--level organization

-- Prepare to continue the effort after the objective is accomplished

-- Establish priorities, to know how to invest resources

-- Determine non-goals at points of ambiguity, to help clarify the goals

-- Direct their actions without needing constant guidance

-- Improvise as necessary, if the pre-conditions change drastically

-- Recognize when pre-conditions have changed

-- Recognize unexpected opportunities and judge whether to pursue them.

We have reviewed the commander's intent statement as a frame, containing several slots. Such slots might include:

-- the mission objective (which is the title of the frame), the purpose of the objective (e.g., the higher-level goal),

-- non-objectives (to clarify ambiguous aspects of the objective),

-- plan features, which constitute their own frame, with slots for the actions, the rationale for each action, contingencies, and additional considerations to be taken into account such as terrain

-- criteria and priorities, which indicate what counts as a successful outcome (e.g., enemy casualties) and targeted resources for achieving the outcome, such as time of expected completion and casualty rate for friendly troops

-- the adversary's intent.

We have found that virtually all of the intent statements describe the plan of action, and 29 of the 35 intent statements include a rationale for plan elements. However, only seven statements indicate the higher--level purpose for the plan. Furthermore, the criteria for achieving the plan are not clearly presented. We found that 11 statements indicated success in terms of enemy casualties, but only one referred to guidance on friendly casualties. None of the statements indicated the time when the overall objective was to be accomplished. In most organizations, if a task is given, there is the expectation that one will be told when it must be finished, and the level of effort to expend. However, for these statements that did not hold. The time of completion and level of resources (e.g., personnel casualties) were missing. It is possible that time of completion was stated elsewhere in the operations order, but there seems to be reluctance to estimate acceptable casualty levels, due to the effect this might have on morale.

These findings suggest that intent statements can be characterized as frames with slots, and that commanders can be given guidance on how to instruct statements that are more clear. In addition, soldiers can be taught to expect certain types of guidance from an intent statement, in order to seek clarification if necessary information is missing.

APPLICATIONS OF RPD MODEL AND RESEARCH ON DECISION MAKING

In this section we review a series of projects intended to apply our research in decision making.

Studies conducted under this contract have extended our understanding of how decisions are made in operational settings. Our findings are resulting in practical implications for the development of training programs and decision support systems. During the past several years, we have been testing applications of the RPD model and the knowledge elicitation methods we developed in parallel with it. The applications have been carried out for a variety of government and commercial sponsors and in a number of different tasks and domains.

One primary focus of our applied work is designing human-computer interfaces (HCIs). The use of decision strategies to identify system requirements provides a different perspective for designers, to enable them to be better able to identify cognitive requirements. We are using a Decision-Centered Design approach that is a form of Cognitive Systems Engineering, in which the cognitive task analysis centers around the key decision points, and attempts to describe the types of strategies used to make these decisions. This approach has been used in a project for the Armstrong Laboratory, in designing the interface for the Self-Defense Suite of the JSTARS aircraft (Thordsen, Wolf, & Crandall, 1990), a joint Army-Air Force surveillance aircraft. We used the RPD model to understand the decision strategies. Another application is for the Navy, concerning the HCI of the AEGIS Combat Information Center to develop a set of design principles for use in development decision support systems. Specifically, the project on Tactical Decision Making Under Stress (TADMUS) is aimed at understanding how crew members in a CIC are able to make complex decisions when faced with time pressure and other stressors. TADMUS applies the RPD model and similar approaches to naturalistic decision making.

Another application of our decision research is to understand consumer decision making. We have conducted in-depth market research studies for Johnson and Johnson, and for Procter and Gamble.

A third area of application is for team training. We have conducted a number of studies to develop methods for observing and providing feedback to teams. These have included echelons above corps, at the Army War College, the Industrial College of the Armed Forces, and the Air Force Institute of Technology (Klein, Zsambok, Kyne, & Klinger, 1991), battalions (Thordsen, Klein, & Wolf, 1991), and helicopter crews (Thordsen & Klein, 1991). Other applications have been for emergency operations teams in manufacturing facilities (Klein, Thordsen, & Calderwood, 1989) and a current effort sponsored by the FAA to apply our decision research to Advanced Qualification Program (AQP).

SUMMARY

There are a number of major accomplishments emerging from this Basic Research contract. These have been identified in the earlier sections of this Final Report, and we will simply review them here.

First, the research performed and projects accomplished have established Naturalistic Decision Making as an important and unique perspective. The previous traditions of classical decision research, drawing on mathematics, statistics, and game theory, have definite strengths and weaknesses, and there is now emerging an acknowledgement of the importance of Naturalistic Decision Making for addressing the problems and requirements that are not handled well by the classical research strategies. The 1989 workshop on NDM was extremely significant for solidifying this approach, and the forthcoming book <u>Decision Making in Action: Models and Methods</u> will continue that process. Without these projects, the earlier research findings would likely have remained on the periphery of the decision research community. Because of these projects, the direction of decision research may have been permanently changed. We believe that there has been a breakthrough in cognitive accounts of decision making, and because of this research project we have been able to solidify that breakthrough and make it accessible to other cognitive researchers. We also believe that this breakthrough will have important applications for decision-centered design of interfaces and displays, training that emphasizes situation assessment, mental simulation and metacognition rather than analytical decision strategies, and more effective approaches to team decision training.

Second, we have demonstrated that the RPD model generates empirical as well as ethnographic research. While the RPD model was developed through ethnographic research methods, currently there have been as many empirical studies of the model as ethnographic studies. The field studies have taken place in diverse settings (urban firefighting, forest fire management, design engineering, tank platoon operations, nursing in Intensive Care Units), and the incident accounts from these studies have been vivid and memorable, so it may be easy to forget the empirical studies. Thus far there have been at least a half-dozen studies of the RPD model. We have examined firefighters, using multi-dimensional scaling; we have used prepared scenarios to collect decision protocols from experienced and inexperienced fireground commanders. Mosier (1990) has confirmed the use of recognitional decision making in airline pilots, using analyses of videotapes collected during high fidelity simulations. We have shown that proficient performance can be maintained by skilled chess players, despite severe time constraints. In the next few months we also expect to show that skilled chess players generate superior options as the first ones they consider, a direct test of the RPD model. We have also shown that mental simulation exercises can improve decision processes of college students engaged in planning tasks.

Third, through the mix of ethnographic and empirical research, the Recognition-Primed Decision model has become more mature and comprehensive than it was three years ago, at the beginning of this contract. It has become elaborated to portray several means of achieving situation assessment. It has been shown to generate testable hypotheses, and it has been experimentally supported.

Fourth, the primary expansion of the RPD model has been to achieve a greater understanding of the process of mental simulation. The current research effort has accomplished that important objective. We have derived models that are far more detailed than the ones previously available, and we have shown how mental simulation serves as a source of power for a variety of cognitive functions.

The naturalistic decision making (NDM) perspective has shown a great deal of progress in the short time that it has guided field researchers. As expected, linkages with other cognitive processes such as planning and decision making have been facilitated by the shift from a classical decision perspective. Models have begun to proliferate, but in contact with others to permit synthesis as we learn more about boundary conditions. The RPD model itself has undergone a steady elaboration, maintaining its overall structure while increasing the detail with which it describes sub-processes such as situation assessment and mental simulation. Each new perspective brings with it a period of rapid expansion of knowledge, followed by a slowing of accomplishments as the field reaches an asymptote and the questions addressed become less productive. It appears as if the NDM perspective is still within the initial phase of rapid exploration and application.

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APPENDIX A

"Recognition-Primed Decision Making"
Contract No. MDA903-89-C-0032
Supporting Documentation

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