TAKING RISKS AND TAKING ADVICE:
THE ROLE OF EXPERIENCE IN AIRLINE PILOT DIVERSION DECISIONS

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ABSTRACT

This research involves an experimental investigation of how commercial airline pilots make decisions about diversion in the face of anticipated bad weather. 50 active-duty pilots (United Airlines) served as subjects. Half of the pilots had more than 20 years of commercial airline flying experience, while half had less than 20 years. In the experiment, each pilot was captain of a flight that receives unexpected information enroute about a zero-visibility, zero-ceiling fog bank moving toward the destination and alternate. The pilot has a now-or-never choice of diverting to a third airport, which is unaffected by the weather problem, or continuing. Information about the weather situation was graphically presented and consisted of a worst-case, expected-case, and best-case prediction for the weather at the time the flight was expected to arrive.

There were significant differences among the pilots in how they responded to dispatch advice, in their willingness to take risks in the face of uncertainty, and in the processing strategies they employed: (1) Dispatch advice had no effect on the diversion decisions of pilots with less than 20 years commercial flying experience, but had a significant effect on the decisions of more experienced pilots. (2) A similar number of experienced and inexperienced pilots can be classified as "risk-taking," i.e., willing to continue into a situation in which there was some chance (if only worst-case) of both the alternate and destination being below minimums. (3) Qualitatively different processing strategies may have been used by different pilots: (a) Risk-taking pilots appear to use a *tradeoff* strategy, in which the advantages of continuing are weighed against the disadvantages. (b) Less experienced non-risk-takers tended to use either worst-case strategies (in which a worst-case forecast of no place to land was both necessary and sufficient for diversion) or cautious strategies (in which it was sufficient but not necessary). (c) Experienced non-risk-taking pilots used the worst-case strategy when dispatch recommended continuing and the cautious strategy when dispatch recommended diverting. They appear to have taken the dispatch recommendation as a starting point and looked for problems; if and only if no problems were found, the dispatch advice was implemented. Such a "meta-strategy" efficiently allocated their attention to relevant issues, and allowed them to take advantage of dispatch advice without following it blindly. The results support the hypothesis that domain-specific processing methods are an important component of expertise.

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SUMMARY

This research investigates how commercial airline pilots make decisions about diversion in the face of anticipated bad weather. The study examines differences in handling uncertainty about outcomes and in responding to dispatch recommendations as a function of experience.

50 active-duty pilots (United Airlines) served as subjects. Half of the pilots had more than 20 years of commercial airline flying experience, while half had less than 20 years. In the experiment, each pilot was captain of a flight that receives unexpected information enroute about a zero-visibility, zero-ceiling fog bank moving toward the destination and alternate. The pilot has a now-or-never choice of diverting to a third airport, which is unaffected by the weather problem, or continuing. Information about the weather situation was graphically presented and consisted of a worst-case, expected-case, and best-case prediction for the weather at the time the flight was expected to arrive. Ten different predictions were compared: They comprised three possible fog-bank locations (neither destination nor alternate affected, destination only affected, destination and alternate affected) crossed with best-case/expected-case/worst-case (with the constraint that in any given scenario the expected case prediction is the same or better than the worst-case prediction and the best-case prediction is the same or better than the expected-case prediction). For half the pilots, the company dispatcher recommended diverting to the third airport (providing a variety of reasons for this recommendation); for the other half, the dispatcher recommended continuing on the original flight plan.

There were significant differences among the pilots in how they responded to dispatch advice, in their willingness to take risks, and in the processing strategies they employed:

(1) The more experienced pilots were more likely to divert when dispatch recommended diversion and more likely to continue when dispatch recommended continuing. Ironically, diversion decisions by the less experienced pilots were completely unaffected by dispatch recommendations.

(2) A similar number of pilots in both the experienced and inexperienced group can be classified as "risk-taking": These pilots were willing to continue into a situation in which there was some chance (if only worst-case) of both the alternate and destination being below minimums.

(3) Qualitatively different processing strategies appear to have been used by the risk-taking pilots, the less experienced non-risk-taking pilots, and the more experienced non-risk-taking pilots:

(a) Risk-taking pilots appear to use a *tradeoff* strategy, in which the advantages of continuing are weighed against the disadvantages.

(b) Less experienced non-risk-takers tended to use either worst-case or cautious strategies. In the worst-case strategy, a worst-case possibility of no place to land is both sufficient and necessary for diversion. In the cautious strategy, the no-options possibility is sufficient for diversion, but not necessary. These pilots may divert simply because the expected case or best case do not look very good. Combined with the tendency to disregard dispatch advice, the cautious strategy can lead to unnecessary diversions.

(c) Experienced non-risk-taking pilots consulted different information depending on dispatch advice. These pilots took the dispatch recommendation as a starting point, and examined it for potential problems. If no problems were found, the dispatch advice was implemented. If problems were found, they considered another option, also examining it for potential problems. Thus, when dispatch recommended continuing, experienced pilots focussed on the worst-case forecast, to verify that continuing would not lead to a no-options situation. When dispatch recommended diversion, on the other hand, these pilots looked at expected-case or best-case information, to see what the advantages of continuing were, as well as worst-case information to see if continuing was possible.

The experienced pilots thus adopted a "meta-strategy" that allowed them to take advantage of dispatch advice without following it slavishly, and which efficiently allocated their attention where it could have the most effect.

In another experimental condition, pilots were given only information about the expected case. For half the subjects, this condition was presented prior to the best/expected/worst-case condition; for the other half, it was presented after. This display did not support the kinds of problem-solving strategies observed with the richer display. In this condition differences among pilots based on experience and risk-taking disappeared. Virtually all pilots were willing to accept some implicit risk, i.e., a choice that might lead to a no-options situation. Experienced pilots were slightly less likely to take risks when they had been exposed to the best/expected/worst-case condition first.

These results support the hypothesis that an important component of expertise is the development of domain-specific methods for handling novel or unusual situations. Display concepts are outlined which are consistent with pilots' cognitive capacities and preferences, but guard against pitfalls in their preferred processing strategies.

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1.0 INTRODUCTION: DECISIONS TO DIVERT

A commercial airliner was enroute from Chicago to Spokane when bad weather forced the Spokane airport to close. The Captain contacted the company dispatcher by radio, who advised him to continue to Spokane, hold there, and then (if the weather did not clear) to proceed to Seattle. Landing at Seattle would provide better connections for the passengers than landing at Portland. The Captain, however, made an instant decision to go to neither Spokane nor Seattle, but to divert to Portland.

Had a less experienced Captain followed the dispatcher's recommendation, or delayed even for a short while in deciding to reject it, a dangerous situation might easily have developed. The Seattle airport was itself falling under bad weather and was closed shortly afterward. If the pilot had entered a holding pattern at Spokane or diverted to Seattle, fuel limitations would have made it impossible for him subsequently to divert to Portland or anywhere else.[1]

The present research asks how pilots make decisions of this kind, what factors determine whether they are made well or poorly, and how they may be improved. Such decisions are representative of a small but important class of situations in which goals conflict, there is uncertainty, and time is of the essence. These decisions are often hard to evaluate: (1) Because they involve competing goals, a given decision is likely to be good in some respects and bad in others. In diversion decisions, for example, efficient use of air space, along with fuel economy and passenger convenience, conflict with an improvement in safety. The former suggest (at least at first glance) that the present course be continued, while the latter suggests that change is necessary. (2) In diversion decisions, the degree of danger may itself be unclear, involving an uncertain judgment about evolving weather. Because these decisions involve uncertainty, a good outcome does not mean that the decision was good (a foolhardy choice can work out all right by sheer luck); and a bad outcome does not mean that the decision was wrong. Many real-life problems are too unique even to permit confident estimation of probabilities. (3) Finally, since such decisions must be made under time pressure, even if an "ideal" decision making method were known, there might not be enough time to use it. What makes some diversion decisions especially hard is that the decision to change must be made immediately if it is made at all.

Despite the high stakes and difficulty of these decisions, they have suffered relative neglect from the research community. Cockpit automation and aviation human factors have focused largely on more basic tasks, such as controlling and navigating the airplane, and on more dramatic problems, such as avoiding mid-air collisions. Research on decision making by experimental psychologists has typically dealt with inexperienced subjects performing artificial tasks (e.g.,

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[1] Based on an interview with an active-duty pilot.

Kahenman, Slovic, and Tversky, 1982). Specific concepts for improving diversion decisions during the cruise phase of flight have received attention only during the past few years (viz., Layton, Smith, McCoy, and Bihari, undated; Cohen, Leddo, and Tolcott, 1989; Rudolph, Homoki, and Sexton, 1990; Boeing Aircraft Corporation, internal research). And these concepts are not yet based on a solid empirical understanding of how diversion decisions are made and how they may go wrong.

Two quite different approaches to human decision making have emerged in recent research and might be applied to pilot diversion decisions. According to the analytical or normative approach, a decision is "rational" if it represents a logically consistent set of judgments about probabilities and values. Consistency is defined with respect to formal constraints dictated by "self-evident" axioms. There is ample evidence that unaided human decisions do not satisfy such constraints. Indeed, systematic errors, or "biases," have been identified at virutally every stage of a decision making process (Cohen, in press; Kahenman, Slovic, and Tversky, 1982). From this point of view, pilot diversion decisions might be improved by training pilots in systematic methods for assessing probabilities and values, and/or by automating the calculations required to generate a choice.

According to the second approach, decision evaluation must start with understanding how experienced, effective decision makers actually do make decisions in real-world tasks (e.g., Klein, Orisanu, and Calderwood, in press). This perspective puts more emphasis on knowledge, the ability to recognize situations and quickly retrieve appropriate responses, than on formal consistency. A large body of research has uncovered interesting differences in the way novices and experts solve realistic problems. From this point of view, decisions might be improved by accelerating the accumulation of experience, e.g., by using realistic simulators to expose pilots to a large and varied sample of diversion situations together with outcome feedback.

The recognition-based approach emphasizes large quantities of specific knowledge rather than a few general-purpose methods. A third approach, however, is possible. It emphasizes the importance of *specialized methods* - i.e., strategies for making decisions in specific types of situations. Pilots might develop such strategies (in addition to a stock of recognitional templates) over the course of their experience in a domain. Such strategies would be based on experience rather than on axiomatic derivation. But they would help decision makers handle novel situations, which do not directly match their store of past experiences.

This report has three parts. First, we discuss the three points of view on how decisions ought to be made: analytical, recognition-based, and recognition-plus-specialized expert strategies. Next, we describe an experimental study involving 50 active-duty pilots of a major commercial airline. They were asked to make a series of diversion decisions like the one with which this section began. We found clear and consistent differences between highly experienced pilots (20 or more years of commercial flying experience) and relatively inexperienced pilots in how they made diversion decisions, and, in particular, in how they responded to dispatcher recommendations. These findings provide support for the importance of domain-specific strategies. The decision processes of highly experienced pilots match neither the normative model of the "ideal decision maker" nor a simple process of recognition.

In the final section, we draw some tentative conclusions for improving diversion decision making. We argue that improvements in performance will come from displays and training methods that encourage more expert-like strategies. Such improvements will be consistent with natural ways of making decisions and will target specific weaknesses in the way some pilots make these decisions, rather than forcing them to adopt radically different analytical techniques.

2.0 THREE APPROACHES TO DECISION MAKING

2.1 Decision Tree Analysis

Normative models of decision making require a highly structured model of the problem, a large number of precise numerical inputs, and a set of mathematical formulae for deriving solutions (Raiffa, 1968; Keeney and Raiffa, 1976). How would this approach apply to the diversion decision?

The pilot would first have to structure the problem. The structure would include identifying all the options, the possible outcomes for each option, and a set of evaluative dimensions for the outcomes. The result is a decision tree of the sort shown in Figure 1. In our example, the pilot's initial options include (1) proceeding to the destination, Spokane, and holding there; (2) diverting immediately to Seattle; or (3) diverting to Portland. Each of these involves a set of possible outcomes, subsequent options, further outcomes, and so on.[2]

The pilot would also have to identify what matters to him (or to the airline) about the possible outcomes. Such evaluative criteria might include: (a) total fuel usage, (b) the expense of providing connections or accommodations for diverted passengers, and (c) the cost of a crash (including loss of life, loss of aircraft, bad publicity, etc.).

After the problem has been structured, precise numerical inputs must be assessed for all the components: Probabilities of all outcomes in the tree (e.g., the probability that, at the time the critical fuel level is reached while holding at Spokane and given that the Spokane weather did not clear, Seattle weather will be expected to be clear when the aircraft reaches Seattle); and importance weights to make the different evaluative dimensions comparable to one another (e.g., how many dollars of fuel savings would justify a given increase in the chance of a crash?). Utility functions might also be assessed to translate between objective measures like dollars or lives lost and subjective preferences.

Finally, each path through the decision tree must be scored on each evaluative dimension: what is the expected fuel usage, passenger connection/accommodation expense, and cost of a crash if ... e.g., the pilot decides to hold at Spokane, the weather does not clear at Spokane but is

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[2] The first option involves holding at Spokane until either the weather clears (and then landing at Spokane) or until the remaining fuel falls below a critical level. (The critical level must be calculated to be enough fuel to get to Seattle and land there plus an FAA-required safety margin.) The possible outcomes of the first option are thus affected by uncertainty regarding both the weather at Spokane and the weather at Seattle. If the weather in Spokane has not cleared by the time fuel reaches the critical level, and the weather in Seattle is not expected to be acceptable, the pilot has a truly difficult new choice: emergency landing in Spokane versus diversion to Seattle, with the likelihood of an emergency landing there.

expected to remain clear at Seattle, the pilot then decides to divert to Seattle, is required to make an emergency landing there, and lands safely?

According to this model, rational decisions are made by (1) an exhaustive enumeration of options, outcomes, and goals, and (2) taking weighted averages across different outcomes and goals. The utility of an outcome is a weighted average of its scores on the different evaluative criteria (assuming the criteria are independent). The subjectively expected utility (SEU) of an option is a weighted average of the utilities of its possible outcomes, weighting them by their probabilities. The ideal decision maker then chooses the option with the highest SEU.

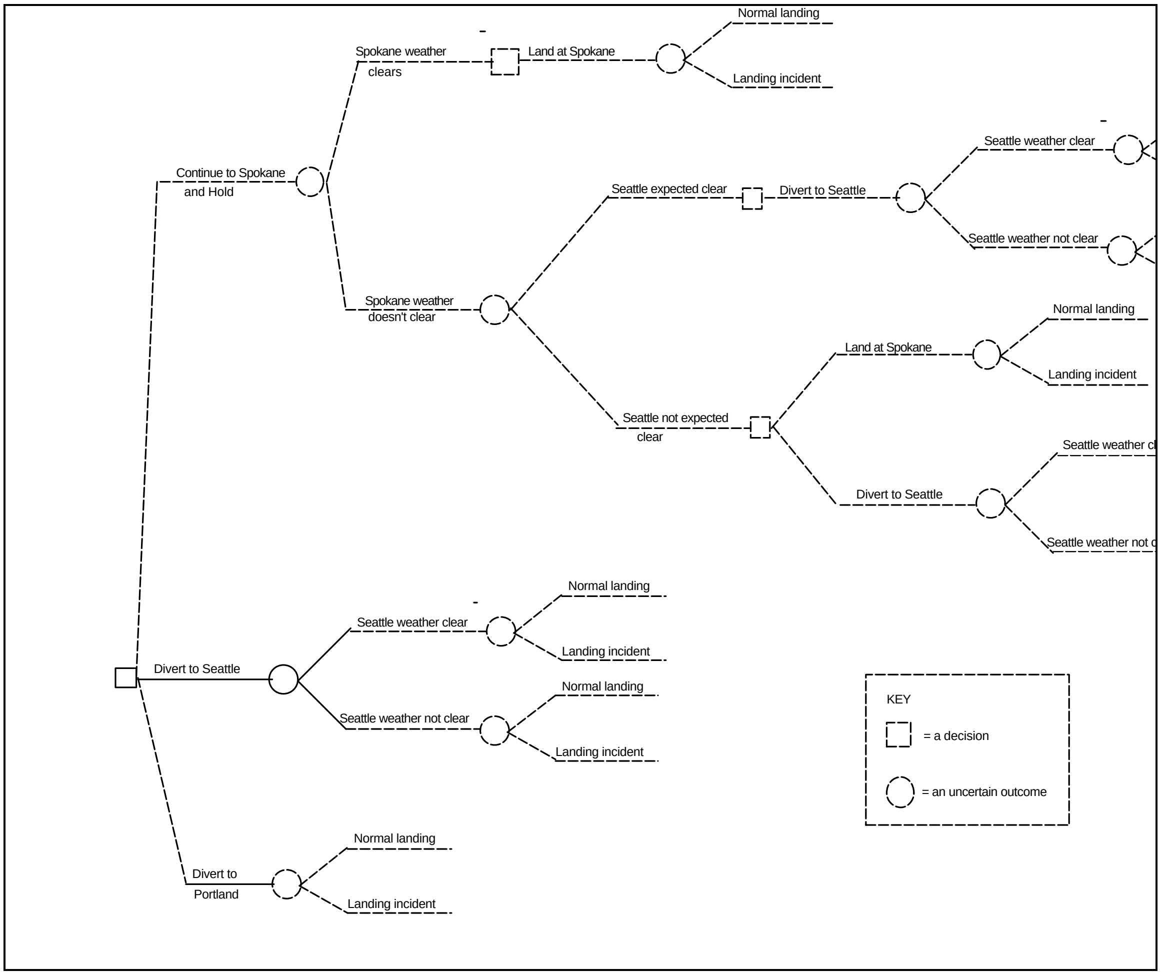


Figure 1. Decision Tree for Illustrative Diversion Decision

2.2 Recognition-based Decision Making

There is increasing evidence in a variety of domains that successful decision makers need not engage in the exhaustive weighing of outomes and dimensions involved in normative choice models. Seasoned decision makers appear to draw upon a storehouse of remembered situations that match the current problem in key respects and provide candidate solutions. Empirical studies comparing novices and experts in a variety of fields, have supported a view of expertise as the accumulation of relatively automatic responses to familiar situations, in contrast to the more analytical, means-ends strategies of sophisticated novices (e.g., Chase and Simon, 1973; Larkin, 1980). According to Anderson (1982), the development of expertise consists in (a) the replacement of explicit, declarative knowledge by unverbalized procedural knowledge and (b) the development of ever more refined procedural discriminations through experience. Expertise, on this view, is the increasingly detailed and "intuitive" skill of expecting that the future will resemble the past.

Some of the research on expert problem solving has emphasized the representational structure of expert knowledge rather than simply its quantity and automaticity. Experiments suggest that recognition by experts occurs in terms of fundamental domain concepts (e.g., underlying causal processes) rather than superficial features of a problem (Chi et al., 1981; Shoenfeld and Herrman, 1982; Weiser and Shertz, 1983; Adelson, 1984; Larkin, 1981; Noble et al., 1989). Chi, Glaser, and Rees (1982) argue that novices structure their knowledge in a way that is "more incomplete, incoherent, and at a level hierarchically lower than experts."

Klein (1989) and his associates have proposed a model of decision making based on recognitional processes that closely parallels the above work in problem solving. According to the Rocognition-Primed Decision Making (RPD) model, real-world decisions almost never involve comparison of options, as required by the normative approach. The key to "choosing" the right action is understanding the situation. Recognition of a situation as familiar involves activation of a stored memory representing either a previously experienced event or a typical event. This representation includes information about goals, critical cues, expectancies, and typical actions that are associated with the recognized situation. The decision maker automatically knows what to do when he knows what "kind of situation" he or she is in.

The RPD model appears to be highly efficient. Klein and his associates have found that proficient decision makers typically generate a workable option as the first they consider. Attempting to generate and systematically evaluate a large set of options might lead to no decision at all in the time available for many real problems.

2.3 Strategic Choices in Expert Decision Making

If problem solving were based entirely on recognition, experts would be stymied by novel or unusual situations. While experts may be said to "recognize" problems, the process of recognition itself is by no means simple or invariant. It is subject to a variety of choices based on the degree of familiary of the situation and intermediate results of the process. For example, experts change their representation of the problem until it makes contact with their knowledge, i.e., until it becomes "familiar." According to Larkin (1980), physics experts often creaste a sketch of the superficial objects and relations in a physics problem and examine it in order to determine the next step: If the depicted system is familiar, the expert may directly retrieve the equations required for solution. If the system is unfamiliar, the expert constructs an idealized representation (i.e., a free-body diagram), which is then used to stimulate retrieval of solution equations. In extremely difficult problems, experts appear to shift to a more novice-like strategy of means-ends analysis (Larkin, 1977): explicitly asking what they are trying to derive and looking for ways to derive it. Chi, Glaser, and Rees (1982) found that physics experts were better than novices at estimating the difficulty of a problem. Moreover, according to Chi, Glaser, and Rees (1982), the process of qualitative analysis of a problem is not a discrete phase that is concluded prior to the generation of quantitative equations. They found that experts returned to, and refined, the initial gross representation throughout the course of the problem.

A useful concept in accounting for choices of this kind is *metacognition*. Metacogniton has been defined, somewhat vaguely, as "individuals' knowledge of the states and processes of their own mind and/or their ability to control or modify these states and processes" (Gavelek and Raphael, 1985). This definition of metacognition stresses its "self-referential" character: it involves monitoring and regulating other cognitive processes and states. Metacognition thus includes such concepts as task familiarity or difficulty, which rely on self-assessments of the decision maker's own knowledge and abilities; it includes sensitivity to flaws (such as implausibility or inconsistency) in one's current situation picture or goals; it also includes the value of allocating attention to one task or process versus another, in terms of the expected benefits versus the costs of time and effort. Within what I have called a Recognition/Metacognition framework (Cohen, in press), metacognitive processes monitor and regulate the application of domain-specific knowledge.

Optional processes play a key role not only in facilitating recognition, but in verifying the results of recognition once it occurs. Physics experts were found to utilize the abstract physical representation of a problem to verify the correctness of their method and result, e.g., by checking whether all forces are balanced, whether all entities in the diagram are related to givens in the problem, etc. (Larkin, 1980). Metacognitive processes play a role in the decision of how much and what kind of checking is required. Similarly, in chess, Simon (1972) observes that some search in the space of future moves and countermoves may take place in order to verify members of the initial "recognized" subset of good moves. It is, therefore, of interest that more recent research has found that differences in search skill (i.e., depth, breadth, and speed) are in fact correlated with chess expertise (Charness, 1981; Holding and Reynolds, 1982). A key aspect of search is metacognitive: the processes of monitoring and evaluating the results of the search, and deciding when it should be terminated.

Klein's RPD model includes optional processes that test and modify the results of automatic recognition. According to Klein, if time is available before an option must be implemented, decision makers will verify it by a process of *mental simulation*. They mentally "watch" the action and its outcomes unfold in the relevant environment, to see what might go wrong. If problems are discrovered, the action will be modified if possible, and rejected if necessary. If an option proves inadequate, another typical action might then be retrieved. If no further actions are associated with this type of situation, the decision maker might start over, attempting to find another way of "seeing" the situation.

Metacognition plays several roles in mental simulation:

(1) *Whether or not to verify an option:* If confidence is high and/or time is short, mental simulation might not occur. The decision maker will simply implement the initially generated response.

(2) *How to mentally simulate*. A mental simulation involves imagining a single path through a tree of branching possibilities (e.g., Figure 1). It involves implicit choices regarding the most promising branch to "search": e.g., which possible sequences of events will, if explored, turn out to be the most informative regarding evaluation of an action.

(3) *Interpreting the results of mental simulation.* If an option fails to achieve a goal, the decision maker may attempt to modify the option. But there is also the possibility of discounting or changing the goal ("That goal wasn't really as important as I thought"; "There's another way I can achieve that objective").

Each of these points can be contrasted with the standard normative approach to decision making:

(1) In recognition-based processing, options are considered serially rather than in parallel. Experience makes it likely that the first response generated will be "good enough" without modification. Evaluation (which is the heart of the normative approach) can therefore be by-passed altogether if time is not available.

(2) When options are evaluated, it is not done by generating all possible outcomes and then taking a weighted average of their utilities. The action is evaluated concretely, in terms of a selected set of specific, visualizable outcomes, not in terms of unrealizable, abstract "averages." If the decision maker considers only the "worst-case" possibilities, for example, he or she is guaranteed that no matter what happens, the chosen action will not do worse than a certain minimum outcome.

(3) In normative models, evaluative criteria and the importance weights associated with them are fixed at the beginning of the analysis. There is no mechanism by means of which goals can be better understood and adjusted in the light of a realistic candidate action. Yet in many

situations decision makers may have firmer intuitions about the "right thing to do" than about abstract assessments of how much one goal is worth in terms of another.

Mistakes can be made, of course, at any of these points: (1) Too much time may be spent evaluating an action or, conversely, an inadequate initial response may be accepted without scrutiny. (2) An exclusive worst-case focus may cause the decision maker to accept an option that fails to exploit opportunities. Attempting to mentally simulate both best and worst case outcomes, on the other hand, can overtax the decision maker's memory, computational resources, and available time. (3) Goals may be compromised more than is necessary in order to retain an inadequate initial response.

A key point, however, is that strategies of this kind are not mistaken *simply by virtue of* deviating from normative procedures. Strategies of this kind may be the most effective way to tap an experienced decision maker's knowledge, especially under conditions of limited time.

The present research looks at the strategies employed by pilots in making diversion decisions, and potential errors associated with those strategies. To what extent do pilot decision processes resemble analytical procedures? To what extent do they involve straightforward recognition and retrieval of appropriate responses? And to what extent is an important role played by metacognitive strategies for evaluating responses and allocating attention? The focus of the experiment is on the selection of events for inclusion within a mental simulation (item 2 in the above lists): Under conditions of uncertainty about weather, what choices do pilots make in "mentally simulating" the outcomes of diversion options?

3.0 PILOT DIVERSION DECISIONS: EXPERIMENTAL STUDY

This research investigates how commercial airline pilots make decisions about diversion in the face of uncertain bad weather. The ultimate goal is to find ways to support and improve such decisions. However, we do not start out with a preconceived notion of how the decisions should be made. Analytical approaches to the study of decision making assume that the correct decision, or the best procedure for making the decision, can be identified prior to the experiment and used to evaluate the subjects' performance. By contrast, the premise of this study is that in complex real-world problems, an essential first step for discovering good solution methods is to look at what effective, experienced decision makers actually do.

3.1 Method

3.1.1 Subjects

Fifty active-duty pilots served as subjects. Pilots were individually asked to participate in the study in the pilot's lounge of the United Airlines flight operations center at Dulles Airport. Subjects were not preselected in any way for the study, other than the requirement that they be active-duty pilots. With three exceptions, all pilots who were asked to participate, and who had adequate time between flights to complete the study, did so. Pilots were offered $5 for completing the study.

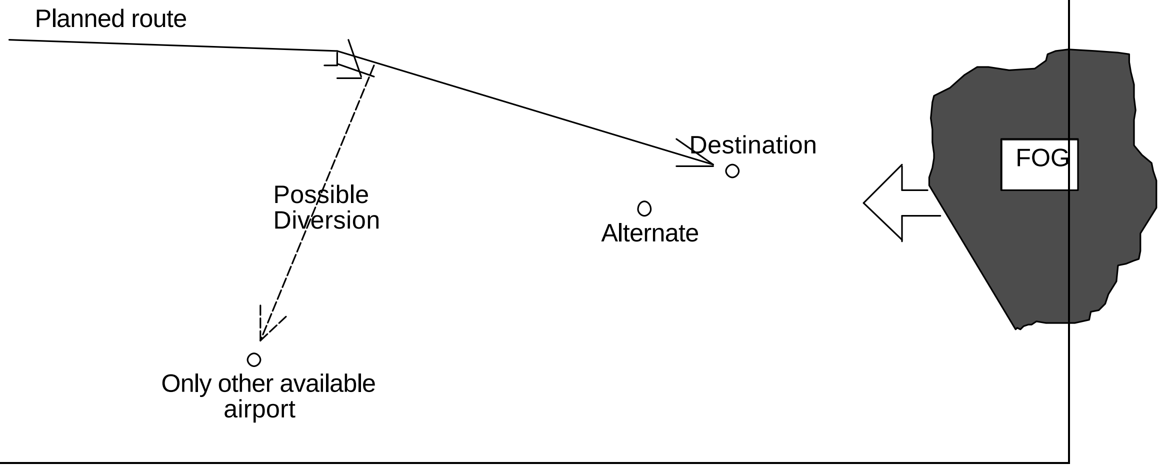
3.1.2 Materials

The experiment was conducted entirely with paper and pencil. Subjects recieved a packet containing a background questionaire, instructions, and 13 pages of scenarios. They filled in their experimental responses in blanks provided on each scenario page. Completing the entire questionaire took between 10 and 30 minutes.

The instructions describe a situation that is common to each scenario. The pilot imagines that he or she is captain of a flight that experiences unexpected delays enroute, reducing fuel reserves, and that subsequenctly the pilot receives unexpected information about a zero-visibility, zero-ceiling fog bank moving toward the destination and alternate. The information for each scenario is graphically presented and consists of a worst-case, expected-case, and best-case prediction for the weather at the time the flight is expected to arrive at the destination. In each scenario, the pilot has a now-or-never choice of diverting to a third airport, which is unaffected by the weather problem, or continuing on to the destination or alternate. If diversion to the third airport does not take place now, fuel limitations will make it impossible. No other airports are available. In the instructions for half the pilots, the company dispatcher recommends diverting to the third airport (mentioning factors such as adequate runway capacity, facilities for maintaining the aircraft, connecting flights, and passenger facilities); for the other half of the subjects, the dispatcher recommends continuing on the original flight plan (mentioning the lack of adequate runway capacity, etc.). A complete set of instructions is contained in Appendix A.

The primary study consisted of ten scenarios, which were constructed based on the following premises (Figure 2). The aircraft is currently enroute on a west-to-east flight. Its destination is located somewhat to the east of the alternate. The fog bank is at present somewhere to the east of the destination and is moving in from east to west. It is uncertain where the fog bank will be at the time the aircraft is scheduled to arrive in the area. The possiblities are: (a) the fog bank will reach neither the destination nor the alternate, (b) it will reach the destination but not the alternate, or (c) it will reach both the destination and the alternate, at the scheduled time of arrival.

Figure 2. Basic premises for scenario construction.



The ten scenarios thus comprise the three possible fog-bank locations (neither destination nor alternate affected, destination only affected, destination and alternate affected) crossed with best-case/expected-case/worst-case, with the constraint that in any given scenario the expected case prediction is (by definition) the same or better than the worst-case prediction and the best-case prediction is (by definition) the same or better than the expected-case prediction. The actual scenario conditions in the primary study were the following:

Scenario #	1	2	3	4	5	6	7	8	9	10
Worst case	DA	DA	DA	DA	DA	DA	D	D	D	
Expected case	DA	DA	DA	D	D		D	D		
Best case	DA	D		D			D			

DA = both destination and alternate affected
D = only destination affected
[blank] = neither destination nor alternate affected

In the secondary study, only expected case predictions were provided. The three scenarios in the secondary study were simply:

Scenario #	E-1	E-2	E-3
Expected case	DA	D	

Appendix B contains samples of scenarios from the primary and secondary studies.

3.1.3 Design

The major independent variables in the study were: (1) dispatch recommendations (divert/do not divert), which was varied between subjects, and (2) scenarios, all of which were presented to all subjects. A third major variable (which was not controlled) was (3) years of commercial flying experience.

25 subjects had 20 years or more commercial flying experience and were somewhat arbitrarily regarded as the "more experienced" group; 25 subjects with 19 or fewer years commercial flying experience were regarded as the "less experienced" group. All but 2 of the less experienced group had 14 or fewer years experience. By this criterion, it turns out that approximately equal numbers of subjects are assigned to combinations of the two major between-subjects variables (dispatch recommendations and experience):

Number of subjects	Less experience	More experience
Dispatch Advice: Divert	13	12
Continue	12	13

The secondary study, with the same subjects, varied the amount of weather-prediction information provided to subjects. This study involved presentation of 3 scenarios in which only the expected weather situation was displayed (as compared with best-case, expected, and worst-case in the primary study). Independent variables were the same as in the primary study (except that there were only 3 rather than 10 scenarios). Half the subjects received the primary study before the secondary study, and half received the secondary study before the primary study. Thus, a minor independent variable was (4) the order of presentation of the two studies.

A final minor independent variable was (4) the order in which scenarios were presented: For half the subjects, scenarios were presented in order of increasing attractiveness of continuing rather than diverting (from scenario 1 to scenario 10 in the primary study, and from scenario 1 to scenario 3 in the secondary study). For the other half of the subjects, the order was reversed (from scenario 10 to scenario 1 in the primary study, and from scenario 3 to scenario 1 in the secondary study).

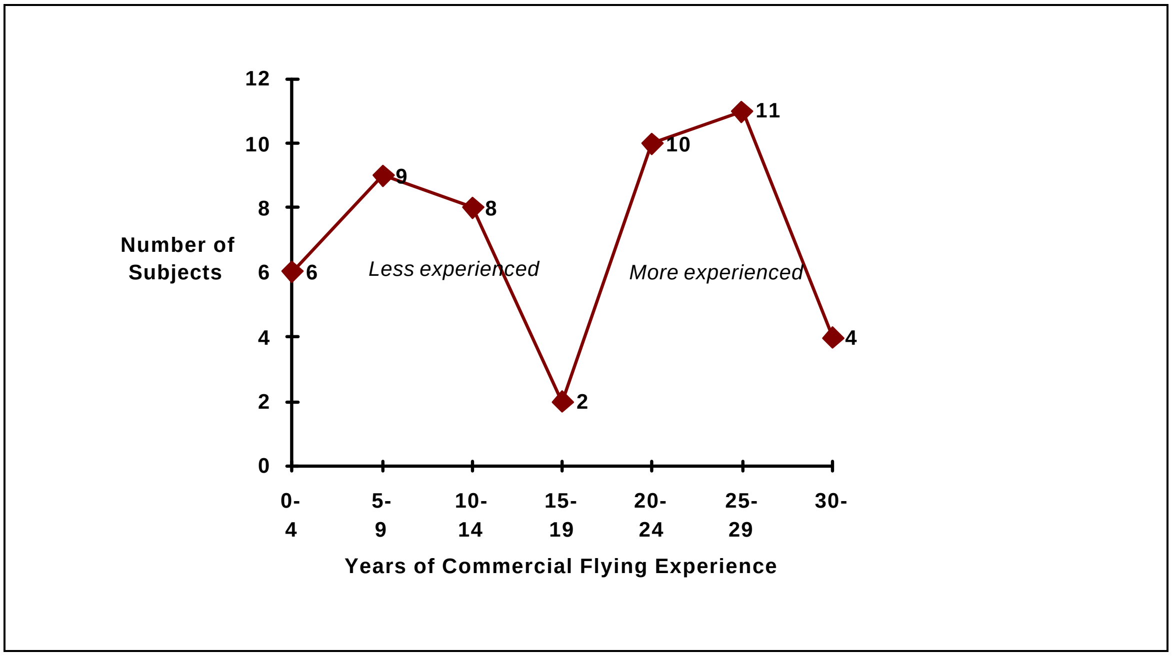
The dependent variables in both studies were (a) the subject's decision whether to divert to the third airport or to continue, and (b) the subject's assessment of confidence in his or her decision, on a scale of 0 to 100.

3.2 Results and Discussion

3.2.1 Subjects' Background and Experience

Subjects were asked to fill out a brief questionaire asking their number of years commercial flying experience, number of years flying experience of any kind, currrent rank and number of years at that rank, and approximate number of hours flown in the last five years.

Examination of years of commercial flying experience suggested a convenient division of the subjects into two equal-sized groups: *more experienced pilots* - those with 20 or more years experience, and *less experienced pilots* - those with less than 20 years experience. The actual distribution of this variable was bimodal, with only 2 subjects in the 15 to 19 years experience range:



Rank (as Captain, First Officer, or Second Officer) was highly correlated with the two categories of experience. Thus, 20 of the 25 "highly experienced" pilots were currently Captains, while 18 of the 25 "less experienced" pilots were First Officers:

Number of subjects	**Captains**	**First Oficers**	**Second Officers**
Less experienced	3	18	4
More experienced	20	4	1

There was a slight tendency for non-commerical flying experience to vary inversely with commercial exerpience. Thus, of the 25 pilots who had less than 20 years commercial flying experience, 9 had more than 10 years non-commercial flying experience. But only 4 of the 25 pilots with 20 years or more commercial flying experience had more than 10 years of non-commercial experience.

3.2.2 Diversion Decisions

Our primary interest is the effect of experience on cognitive strategies for handling uncertainty and advice. The data analysis addresses this question in three stages. In this section, we look at diversion decisions per se, and the impact of experience and dispatch advice on such decisions as a function of scenario. The next section (3.2.3) looks more closely at which aspects of the scenario information influenced diversion decisions. The third step, in Section 3.2.4, involves a more direct attempt to identify qualitative strategies that would account for the effects of experience on pilots' diversion decision performance.

Figures 3 and 4 show the percentage of diversions as a function of dispatch advice (to divert or to continue), for less experienced and more experienced subjects respectively.

As expected, the proportion of subjects who chose to divert is 100% in scenario 1, where even in the best case both alternate and destination are under fog. Every subject also chose to divert in scenario 2, where the only possibilitiy of a clear airport is the alternate, and even that depends on occurence of the best case. Also as expected, the proportion of subjects choosing to divert descends to 0% in scenario 10, where even in the worst case, both the destination and alternate are clear.

Effects of experience and dispatch advice must therefore be looked for in scenarios 3 through 9. An analysis of variance was applied to the diversion decision data from these scenarios (3 through 9 only). In this analysis, scenarios is a within-subjects variable, while dispatch advice, order of scenario presentation (best first or worst first) and order of primary and secondary studies are between-subjects variables. Years of commercial flying experience is treated as a continuous covariate.

In this analysis, the independent variable (diversion decisions) takes only the values of zero (continue) or one (divert). To guard against biases in the use of a discrete independent variable, the same analysis was applied to the pilots' assessments of confidence that diversion was the correct decision. (Pilots assessed confidence in whatever decision they chose in a particular scenario, on a 0-to-100 scale. If they chose to continue, the assessment was subtracted from 100 to obtain their preseumed confidence that diversion was the correct choice.) This analysis was identical in terms of significant and insignificant results with the analysis based directly on diversion decisions.

There were no significant main effects or interactions for the between-subjects variables: Neither dispatch advice nor years of experience had an effect on the total number of diversion decisions. Nor did the secondary between-subjects variables, order of scenario presentation and order of study presentation. There was, however, a highly significant main effect of scenarios (F(6,204)=12.096; p<.001), and a significant three-way interaction of scenarios, dispatch advice, and experience (F(6,204)=3.283; p=.004). No other effects were significant up to the .05 level.

These results, along with Figures 3 and 4, suggest that:

Figure 3. Less experienced pilots

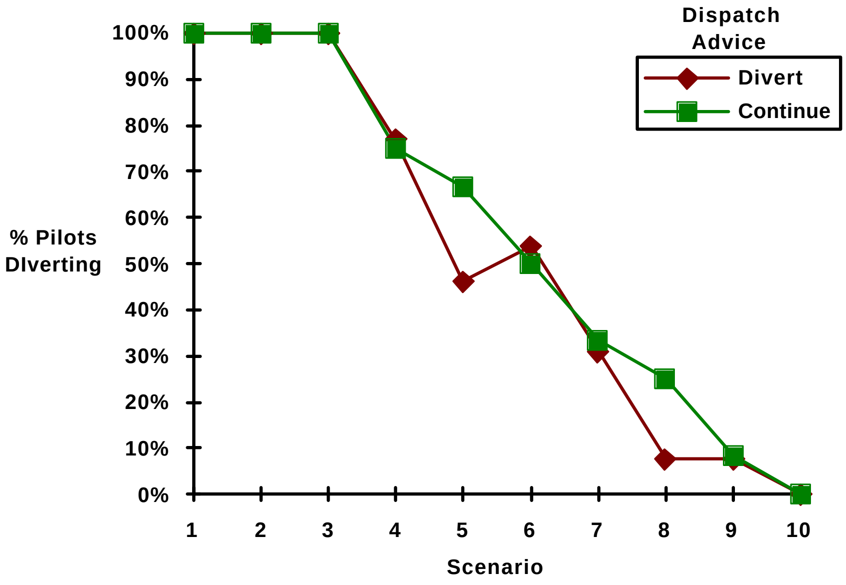
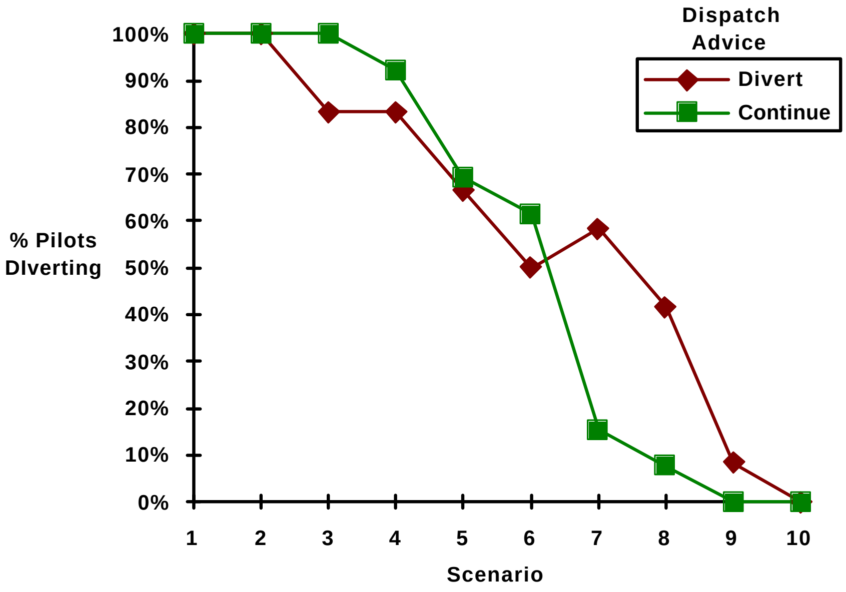


Figure 4. More experienced pilots



(i) Regardless of experience, subjects tended to divert less as scenarios grew more attractive (going from scenario 1 to scenario 10).

(ii) Dispatch recommendations affected diversion decisions only for the more experienced subjects and only in scenarios 7 through 9. A *post hoc* test of the advice-by-experience interaction for scenarios 7, 8 and 9, confirms the existence of an interaction of experience and advice at those scenarios (F(1,34)=5.281; p=.028). A test of the advice-by-experience interaction for scenarios 3, 4, 5, and 6 was insignificant (F(1,34)=.548; p=.464).

(iii) The apparent tendency for a contrary effect of dispatch advice at scenarios 3 through 6 (more diversions when dispatch recommended continue) is not supported. A *post hoc* test of the effect of dispatch advice at scenarios 3 through 6 was insignificant (F(1,34)=.173); p=.680).

The key result here is (ii). In scenarios 7 through 9, the experienced pilots were more likely to divert if dispatch recommended diversion than if dispatch recommended continuation. By contrast, diversion decisions by less experienced pilots were unaffected by dispatch recommendations. Moreover, diversion decisions in scenarios 3 through 6, even by experienced pilots, were unaffected by dispatch recommendations.

The distinction between scenarios 3 through 6 and scenarios 7 through 9 is an important one in terms of risk taking. In each of scenarios 3 through 6, the worst case involves both destination and alternate under fog. In other words, there is a chance that continuing the flight will result in a "no options" situation, i.e., both available airports may be closed. In scenarios 7 through 9, by contrast, the worst case involves either the alternate open or both the destination and the alternate open. Thus, even in the worst foreseeable circumstance, in these scenarios the pilot will have a place to land.

To what extent was the pilots' performance consistent with a "worst-case" strategy? This question (to which we return in the following two sections) is important both for undertstanding the propensity to take risks and for understanding when and why experienced pilots were affected by dispatch advice. A pure worst-case strategy has two components:

(1) *The worst case as a sufficient condition for diverting.* If the worst case involves both destination and alternate in fog (i.e., scenarios 1 through 6), then divert.

(2) *The worst case as a necessary condition for diverting.* Divert *only if* the worst case involves both destination and alternate in fog (i.e., continue in scenarios 7 through 10).

The pure worst-case strategy appears in Figures 5 and 6 superimposed on the actual responses of pilots. The analysis of these data suggests the following:

(i) The worst-case criterion is not a *sufficient* condition for diversion for all pilots. For both the more experienced and less experienced pilots, diversion is significantly less than 100% in scenarios 4, 5, and 6. (*Post hoc* comparisons of diversion rates with 100% were significant: scenario 4, F(1,34) =5.546, p=.024; scenario 5, F(1,34)=12.437, p=.001; and scenario 6, F(1,34)=14.687, p=.001).)

Figure 5. Less experienced subjects

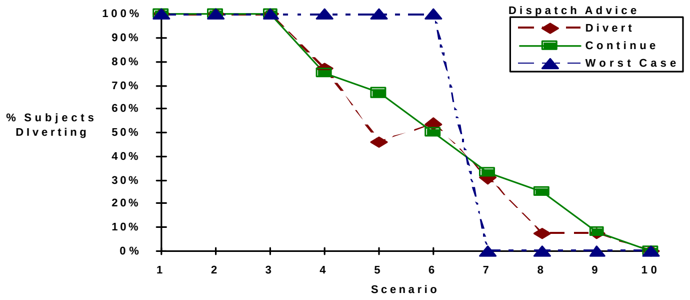
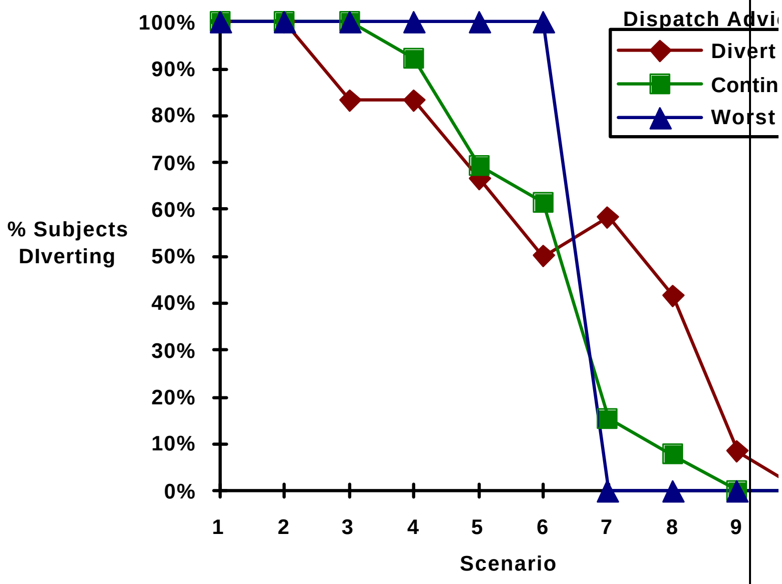


Figure 6. More experienced subjects



Thus, regardless of experience, some pilots, at least some of the time, will continue on a flight even when there is the possibility of a no-options situation.

(ii) The worst-case criterion is not a *necessary* condition for diversion for all pilots either. The interaction between experience and dispatch advice at scenarios 7, 8, and 9 is relevant here. For less experienced pilots, the percentage of diversions is significantly greater than 0% in scenarios 7 and 8 regardless of dispatch advice (scenario 7, F(1,24)=11.294, p=.003; scenario 8, F(1,24)=4.571, p=.043). Some of these pilots choose to divert even though (a) dispatch may be recommending continuation, and (b) there is no possibility of a no-options situation.

For experienced pilots, on the other hand, whether or not a worst-case prediction of no place to land is necessary for diversion appears to depend on dispatch advice. For these pilots, diversion is not significantly different from 0% when dispatch recommends continuation (scenario 7, F(1,12)=1.000, p=.337; scenario 8, F(1,12)=2.182, p=.165) . But diversion is significantly above 0% in scenarios 7 and 8 when dispatch does recommend diversion, even though the worst case involves an open airport (scenario 7, F(1,11)=15.400, p=.002; scenario 8, F(1,11)=7.857, p=.017).

An interesting hypothesis is that the role of the worst case criterion in the decision making process of experienced pilots changes as a function of dispatch advice. When dispatch recommends continuation of the flight, experienced pilots might use the worst-case as a necessary condition for diversion; i.e., they will continue as long as the worst case permits some option of landing. When dispatch recommends diversion, however, they may no longer require a no-options situation to justify diversion. We shall examine this hypothesis more closely in the following sections.

3.2.3 The Impact of Predictive Cues on Diversion Decisions

"Scenarios" is not an independent variable with intrinsic interest. The real influence on diversion decisions is the mix of best case, expected case, and worst case predictions that characterizes the scenarios. A series of planned comparisons between specific sets of scenarios permits closer examination of the impact of these predictive cues on decision making, and may shed light on hypotheses regarding decision-making strategies.

Since (by definition) not all combinations of prediction mode (best case/expected case/worst case) and predicted outcome (destination and alternate, destination, neither) are possible, the analysis cannot be fully orthogonal. Some effects cannot be estimated at all levels of other cues, and thus some interactions cannot be estimated. Nevertheless, a variety of comparisons are possible, as indicated in the following table.

Scenario Differences	**DA vs D**	**D vs neither**
Worst Case	4-7 5-8 6-9	9-10*
Expected Case	2-4* 3-5	5-6 8-9
Best case	1-2*	2-3* 4-5 7-8

* = Omitted from statistical test due to lack of variability, but used for estimation

Consider as an example the lower right cell of the table: i.e., how the impact of changing the best case prediction from destination to neither alternate nor destination is estimated. Scenarios 4 and 5 are alike in their worst-case weather forecasts (both predict destination and alternate under fog), and they are alike in their expected-case forecasts (both predict only the destination under fog). They differ only in their best-case forecast: Scenario 4 predicts the destination will be under fog, and scenario 5 predicts neither destination nor alternate under fog. A comparison of rates of diverting under scenarios 4 and 5 thus provides one estimate of the impact of the change in best-case predictions from destination to neither destination nor alternate. Notice that scenarios 7 and 8, and scenarios 2 and 3, are also alike in their worst-case and expected-case forecasts, but differ in the best-case prediction in the same way as scenarios 4 and 5. We thus have three estimates of the impact of this particular change in the best-case prediction, under different conditions of worst-case and expected-case forecasts. A pooled estimate is obtained by averaging the three.

The two-way interactions which can be estimated in the same manner are the following:

Best Case (D/neither) X Expected Case (DA/D)	(2-3) - (4-5)*
Best Case (D/neither) X Worst Case (DA/D)	(4-5)-(7-8)
Expected Case (D/neither) X Worst Case (DA/D)	(5-6)-(8-9)

* = Omitted from statistical test due to lack of variability

In both tables, an asterisk represents a comparison that involves scenarios 1, 2 or 10, i.e., the scenarios which were omitted from the analysis of variance because of the absence of any variability in the diversion decisions. These comparisons do not play a role in the statistical tests. An identical analysis, however, was done on the pilots' assessments of confidence in their diversion decisions. With this variable, scenarios 1, 2, and 10 could be included in the analysis since subjects differed somewhat in their confidence even when they did not differ in their final decision. The results of this analysis were highly similar in terms of statistical significance and insignificance to the analysis based on diversion decisions, with exceptions that are noted in the tables below.

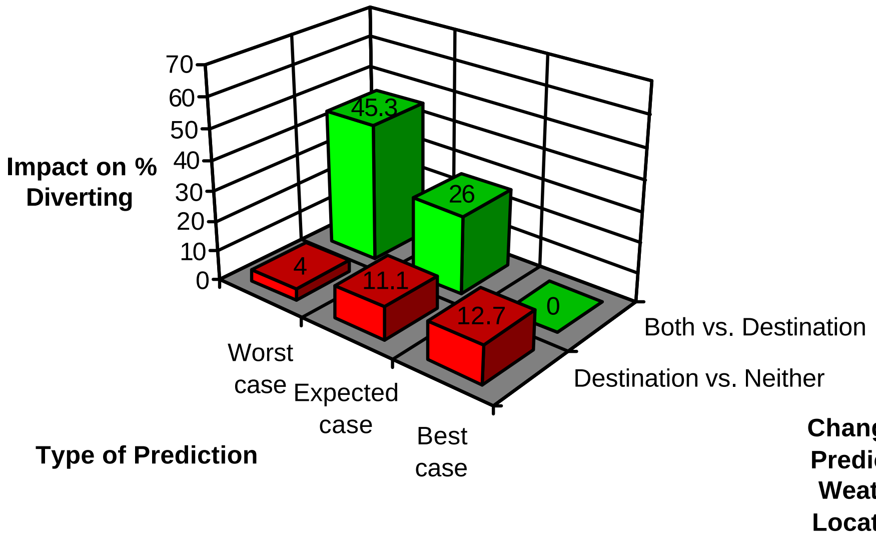
A series of planned comparisons as described above was carried out both for the main effect and the experience-by-advice interaction, with the following results:

Main effects	**DA vs D**	**D vs neither**
Worst Case	F(16,34)=6.693;p<.001	Not Significant
Expected Case	F(16,34)=2.425;p=.015	F(16,34)=1.951; p=.050 (not significant in test based on confidence)
Best case	(Significant only in test based on confidence)	F(16,34)=2.378;p=.017

Figure 7 depicts the estimated impacts of different prection modes and outcomes on diversion decisions across all subjects. These main effect comparisons reveal that every type of prediction (worst-case, expected-case, and best-case) was used by pilots in some way during their diversion decisions. By far the largest impact on diversion decisions, however, was the change in worst case predictions from destination and alternate to destination only. The next largest impact is the change in expected case predictions from destination and alternate to destination only. A smaller impact, but still highly reliable, is represented by the change in best case predictions from destination to neither destination nor alternate. (The estimates in Figure 7 represent all relevant scenarios, including 1, 2, and 10.)

None of the interactions were significant, either in the test based on diversion decisions or the test based on confidence assessments.

Figure 7. Effect of Weather Information on Diversions

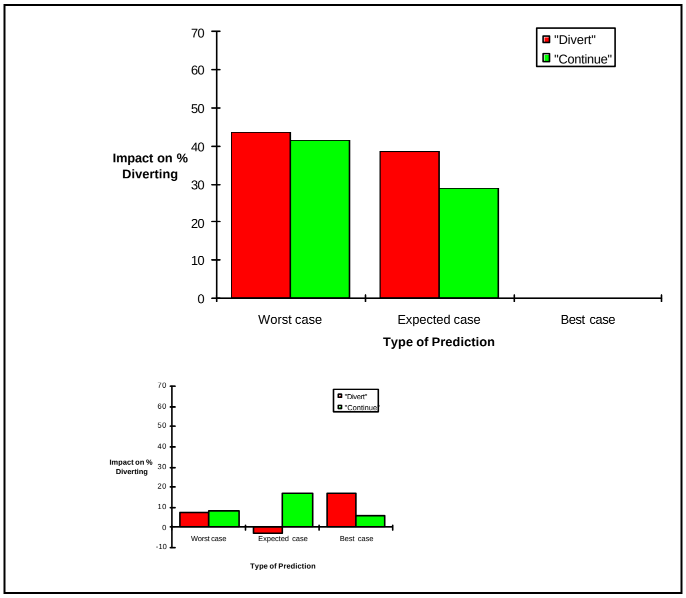


The next table examines the impact of the advice X experience interaction on prediction cue usage:

Advice X Experience	**DA vs D**	**D vs neither**
Worst Case	F(1,34)=6.441; p=.016	Not significant
Expected Case	Not significant	F(1,34)=6.036; p=.019
Best case	Not significant	Not significant

The interaction of experience and dispatch advice affects the impact of changes in worst-case predictions, from destination and alternate to destination, and the impact of changes in expected-case predictions, from destination to neither destination nor alternate. The results of the analysis based on confidence assessments were identical. No other effects or interactions were significant (up to the .10 level) in either analysis.

Figures 8 through 11 depict the effects of pilot experience and dispatch advice on cue usage. Notice that for the less experienced pilots, there is virtually no difference in the impacts of cues as a function of dispatch advice (Figures 8 and 9). Whether dispatch recommends diversion or continuation of the flight, these pilots rely in their decision making primarily on worst case and expected case changes from destination and alternate to destination only. For more experienced pilots, however, the difference caused by dispatch advice is striking. When dispatch recommends continuation of the flight, these pilots rely predominantly on a worst-case criterion (Figure 11). When dispatch recommends diversion, however, the pattern of cue impacts shifts, with a reduced reliance on worst-case changes (from both destination and alternate to destination), and an increased reliance on expected case changes (from destination to neither destination nor alternate) (Figure 10).


Impact on % Diverting
70
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10
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"Divert"
"Continue"
Worst case
Expected case
Best case
Type of Prediction
Impact on % Diverting
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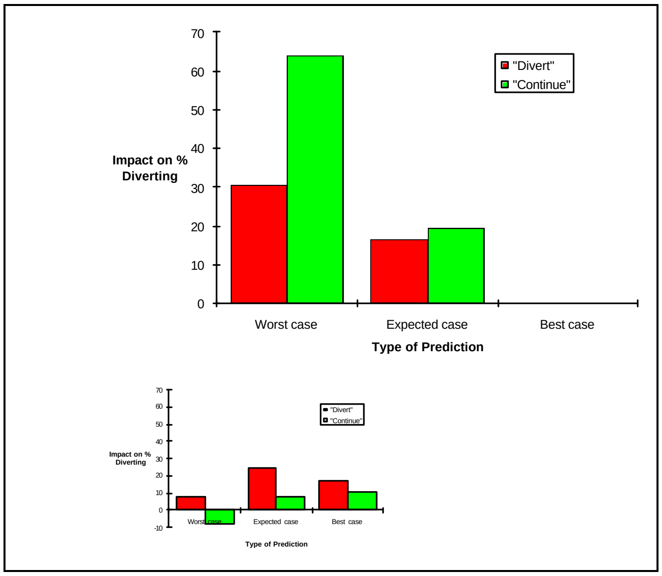
"Divert"
"Continue"
Worst case
Expected case
Best case
Type of Prediction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"Divert"
"Continue"
Worst case
Expected case
Best case
Type of Prediction

3.2.4 Individual Differences and Decision Strategies

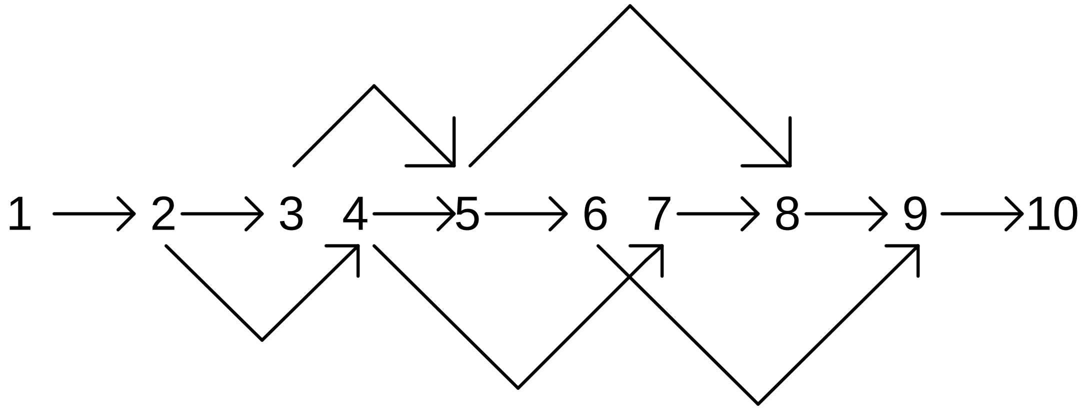
Thus far, we have looked at diversion decisions by scenario after aggregating across individual pilots. We have not been able to make definitive statements about the patterns of responding, or the decision strategies, of individual pilots as a function of experience or dispatch advice. In this section, we turn to a more intensive look at how individual pilots handled weather uncertainty and advice.

In the previous section we found differences between the more experienced and less experienced groups of pilots in their responses to scenarios 7, 8, and 9, and found similarities in the responses of the two groups to scenarios 3, 4, 5, and 6. In particular, a significant percentage of the experienced pilots responded to dispatch advice in scenarios 7, 8, and 9, but less experienced pilots did not. In scenarios 3, 4, 5, and 6 a significant percentage of both groups was willing to continue to the destination despite the chance of a no-options situation, and independently of dispatch recommendations. The principal question for this section is how responses to the two clusters of scenarios are related for *individual* pilots. What are the patterns of responding, across all the scenarios, that pilots tended to adopt? In particular, do the same experienced pilots who *respond* to dispatch advice in scenarios 7 through 9 also *fail* to respond to dispatch advice in scenarios 3 through 6? Do the same experienced and inexperienced pilots who adopt worst-case or even more cautious criteria for diversion in scenarios 7 through 9 adopt risk-taking criteria in scenarios 3 through 6? An alternative hypothesis is that there is a subgroup of pilots within both the experienced and inexperienced groups, that is willing to take more risks than the other pilots.

It turns out that some of these questions about individual pilot strategies boil down to a question about "rationality." If the same pilots were risk-taking in certain scenarios between 3 and 6 and cautious in certain other scenarios between 7 and 9, that pattern of responses could be regarded as "irrational" in a very specific and minimally theory-laden sense.

There are 2^{10} different patterns of diverting or continuing across the 10 scenarios in this study, but only 16 of these "make sense." The basis for regarding the other patterns as irrational is that they imply choices of options that are *dominated* by other options. (If one option dominates another option, the dominating option is as least as good as the other option in all relevant respects and better in at least one respect. There is *no possible reason* for preferring the dominated option over the dominating one, other than inattention or an actual change in goals and values.) For example, suppose a pilot decided to continue in scenario 4 (a risk-taking response, since the worst case involves both destination and alternate in fog) but to divert in scenario 7 (a cautious response, since even the worst case involves the alternate clear of fog). Such a strategy implies a preference for scenario 4 over scenario 7, yet scenario 7 dominates scenario 4. If the pilot thinks scenario 7 is bad enough to justify diversion, he *must* also think that scenario 4 is bad enough to justify diversion -- since scenario 4 is exactly the same as scenario 7 in two respects (its expected-case and best-case predictions), and is *worse* than scenario 7 in the remaining respect (its worst-case prediction). Patterns of responding that divert in both scenarios 4 and 7, *or continue in both scenarios 4 and 7*, are defensible in a way that diverting in scenario 7 but not in scenario 4 is not.

The rational strategies are implied by the following relationships among the scenarios:



The scenario on the left of an arrow is worse in exactly one respect than the scenario on the right of that arrow and is otherwise the same. Thus, if a pilot decides to continue the flight in any given scenario (e.g., scenario 4), he should also decide to continue in any scenario linked to it by arrows on its right (e.g., scenario 7). Conversely, if he decided to divert in any scenario (e.g., 7), he should also decide to divert in any scenario linked to it by arrows on its left (e.g., scenario 4).

The following pairs of scenarios, one from the set 3 through 6 and the other from the set 7 through 9, are linked by arrows or chains of arrows in that way: 3/8; 3/9; 4/7; 4/8; 4/9; 5/8; 5/9; 6/9. Thus, for example, if the rationality constraint imposed by dominance is satisfied, it would preclude any one pilot from choosing both to continue in scenarios 3, 4, or 5 and to divert in scenarios 8 or 9.

Appendix C describes the non-dominated patterns of responding, along with the number of subjects that adopted each as a function of experience and dispatch advice. Of the 16 "rational" strategies, 11 were actually adopted by at least one of the 50 pilots in this study. Only one subject out of the 50 adopted one of the 2^{10} - 16 indefensible strategies. (That subject chose to continue in scenario 5 and to divert in scenario 6.) This finding strongly supports the hypothesis that risk-taking responses (in scenarios 3 through 6) and cautious responses (in scenarios 7 through 9) belong to different, coherent patterns of decision making.

It is convenient to divide the possible patterns of responding into three groups:

- *Risk-taking* strategies lead a pilot, on some occasions, to continue to the destination despite a worst-case possibility of both alternate and destination under fog. For these strategies, a worst case with no options is not a sufficient deterrent to continuing.
- *Worst-case* strategies apply a consistent worst-case criterion for both diverting and continuing. They insist on diverting if the worst case allows for no landing options (worst case as a sufficient condition for diverting). They insist on continuing if the worst case allows a possibility of landing, even if only at the alternate (worst case as a necessary condition for diverting).
- *Cautious* strategies use the worst case criterion as a sufficient condition for diverting, but not as a necessary condition. They may choose to divert even when the worst case is not a no-options situation.

The following table shows how these strategies are defined in relation to the worst-case criterion:

	Worst Case = Destination And Alternate	
	Sufficient for Diverting?	**Necessary for Diverting?**
Risk-Taking Strategy	No	--
Worst-Case Strategy	Yes	Yes
Cautious Strategy	Yes	No

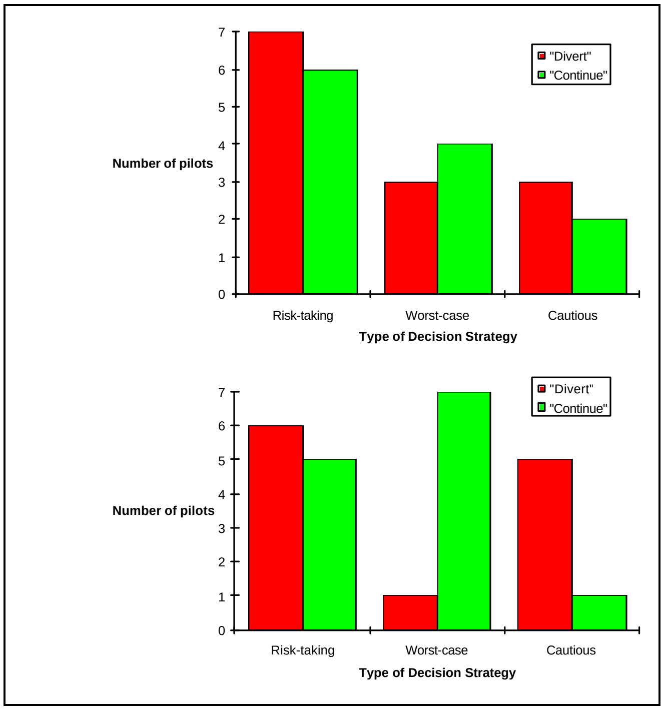
Figures 12 and 13 show the number of subjects who adopted each type of strategy as a function of experience and dispatch recommendations. The analysis of these data support the findings of the previous section and extend them to individual subjects:

(i) There is an approximately equal number of pilots in both the more experienced and less experienced groups that were willing to accept the risk of a no-options situation. The number of risk-taking pilots was not responsive to dispatch recommendations at either experience level.

(ii) For less experienced pilots, there was no effect of dispatch advice on the strategy type adopted (✌^{2} non-significant).

(iii) The less experienced non-risk-taking pilots seem to divide fairly evenly into those who use a worst-case strategy and those who use a cautious strategy -- independently of dispatch advice.

(iv) More experienced non-risk-taking pilots, on the other hand, were likely to adopt a consistent worst-case strategy when dispatch recommended continuing, but to adopt a cautious strategy when dispatch recommended diversion ($\chi^2(2) = 8.14$; p=.027). This suggests a higher-order *strategy for strategy selection* on the part of these subjects. A plausible meta-strategy of this sort is the following: The experienced non-risk-taking subjects take the dispatch recommendation as their starting point. Their processing task is essentially to examine that recommendation for potential flaws. If they find none, the dispatch recommendation is implemented. If they do find a flaw, an alternative option may be considered and itself examined for potential flaws.



A meta-strategy of this sort accounts nicely for the experienced, non-risk-taking data. When dispatch recommends continuation, these subjects attempt to rebut the recommendation by looking at the worst case prediction. If it involves destination and alternate under fog (the no-options situations of scenarios 1 through 6), the dispatch recommendation cannot be implemented, and these subjects choose to divert. If the worst case does not involve both airports under fog (scenarios 7 through 9), the recommendation is implemented. On the other hand, if dispatch recommends diversion, these pilots seek to rebut it by examining the positive side of continuing - i.e., the opportunities afforded by the expected or best cases. If these look good (e.g., neither destination nor alternate under fog), then the possibility of continuing is considered. As a check against flaws in that option, however, the pilots also look at the worst case. If the worst-case prediction involves no options, they return to the dispatch recommendation and divert. Otherwise, they continue. In this way, a meta-strategy of provisional advice acceptance and attempted rebuttal leads naturally to a worst-case strategy for advice to continue and a cautious strategy for advice to divert.

In sum, three groups of subjects appear to handle uncertainty and dispatch advice in qualitatively different ways: (1) less experienced non-risk-takers, (2) more experienced non-risk-takers, and (3) risk-takers. Figures 14 through 17 plot the percentage of diversions by scenario for these three groups.

Three observations regarding these figures are pertinent:

(i) Figures 15 and 17 confirm that the effect of dispatch advice on experienced pilots (in Figure 4) was due to the non-risk-taking pilots. The pilots who paid attention to dispatch advice in scenarios 7 through 9 were not the same pilots who took risks and disregarded dispatch advice in scenarios 3 through 6. The experienced non-risk-takers did not continue when there was a possibility of a no-options situation (in scenarios 1 through 6), *even if dispatch suggested continuing*. When dispatch recommended continuing, these pilots were almost unanimous in adopting a worst-case strategy (divert in scenarios 1 through 6 and continue in scenarios 7 through 10). When dispatch recommended diversion, they adopted a cautious strategy, tending to divert in scenarios 7 and 8 as well. The experienced risk-taking pilots (Figure 17) show no effect of dispatch advice at all.

(ii) The risk-taking pilots are (by definition) willing to continue at some point in scenarios 1 through 6. Some of these pilots, however, behaved *cautiously* in other scenarios, viz., choosing to *divert* in scenarios 7 and/or 8, even though the worst case in those scenariosis was not a no-options outcome. Thus the curves in Figures 16 and 17 between scenarios 6 and 7 and between scenarios 6 and 8 are non-monotonic (with respect to improving worst-case outcomes). This non-monotonicity does not violate dominance constraints, since scenario 7 is better than scenario 6 in one respect (the worst case), but worse in others (the expected case and best case). Similarly, scenario 8 is better than scenario 6 in the worst case, but worse in the expected case. (The non-monotonicity between scenarios 5 and 6, however, is caused by the single subject who adopted a dominated strategy.)

Risk-taking and caution on the part of these pilots may be opposite sides of the same coin. Both may be the effects of a *tradeoff* strategy, in which pilots weigh the costs of continuing against its advantages. With such a strategy, the pilot might be willing to continue despite a no-options worst case, if the expected case or best case is very good (e.g., neither alternate nor destination under fog). Similarly, such a pilot might choose to divert rather than continue even if there is no possibility of both alternate and destination under fog, if the expected case or best case are *not* very good (e.g., destination, but not alternate, under fog).

(iii) The cautious strategy, in combination with disregard for dispatch recommendations, leads to unncecessary diversions. Both the risk-taking subjects and the non-risk-taking, less experienced pilots often chose to divert even though dispatch recommended against it and there was no chance of both destination and alternate being closed.

Figure 14. Less experienced, non-risk-taking pilots

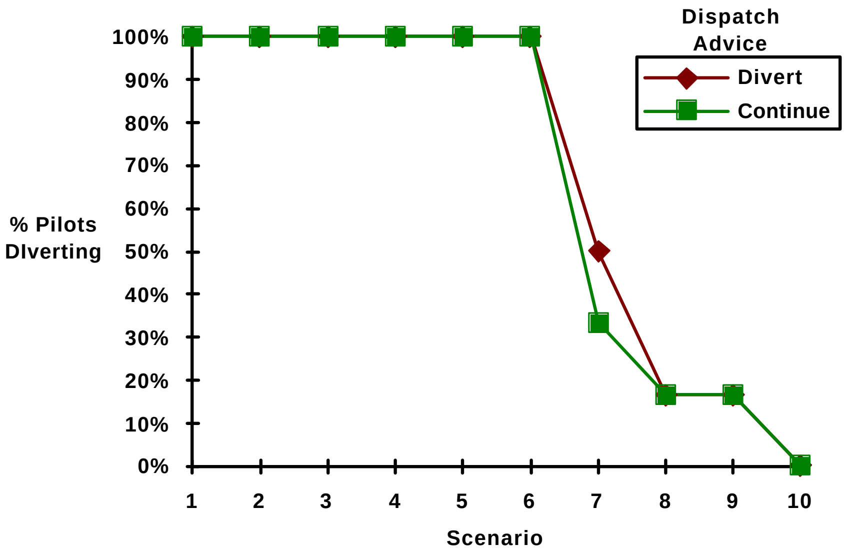


Figure 15. More experienced, non-risk-taking pilots

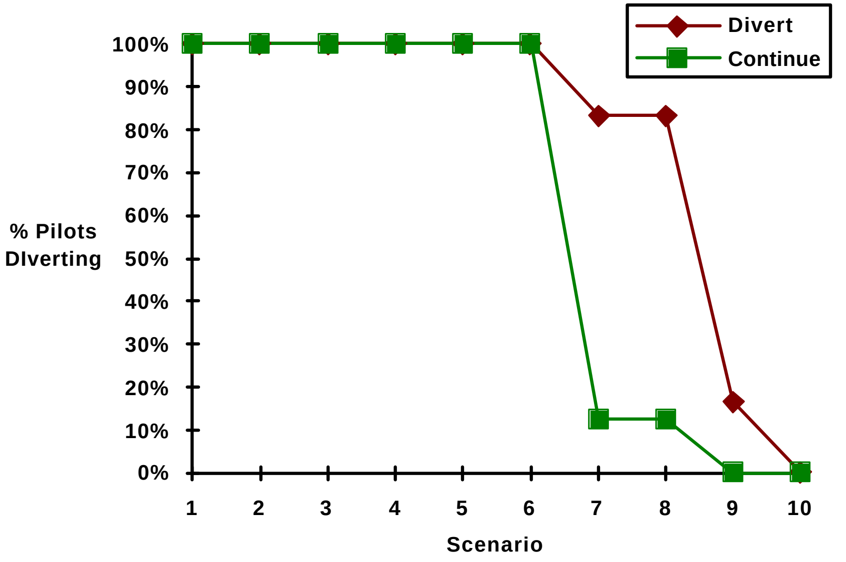


Figure 16. Less experienced, risk-taking pilots

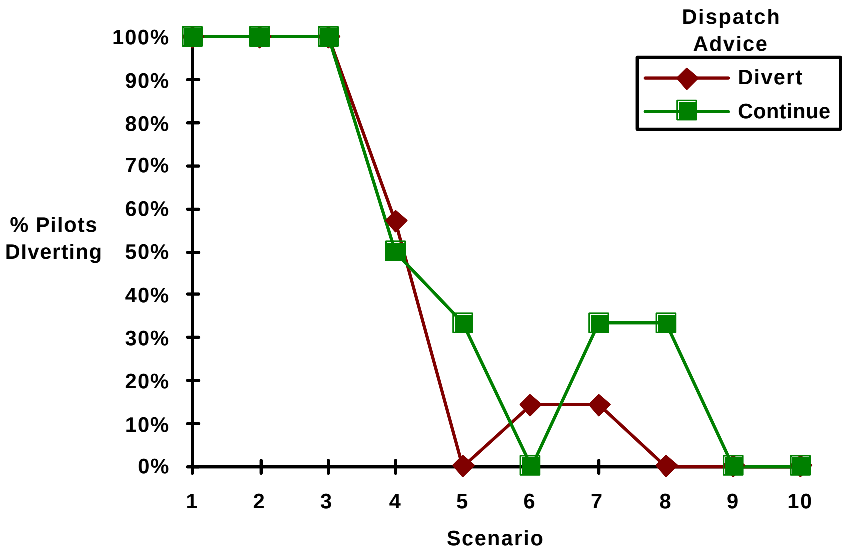
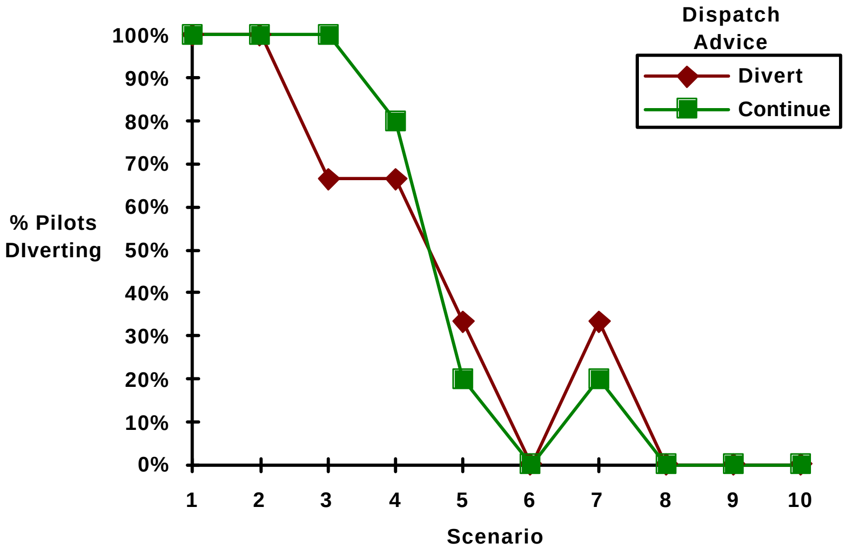


Figure 17. More experienced, risk-taking pilots



Decision making strategies cannot be definitively identified from decision making performance, even in a systematically varied set of scenarios. Nevertheless, performance in such scenarios does place significant constraints on what those strategies can possibly be. In particular, each pilot's pattern of responses across the ten scenarios has implications for the *minimum* set of cues that he or she must have considered. We turn now to a more detailed analysis of the predictive information used by these three groups of pilots.

Each non-dominated pattern of diversion decisions can be characterized by a relatively simple logical rule (shown in Appendix C). The appropriate rule can be derived by taking the conjunction of the descriptions of all the scenarios in which the pilot does in fact divert and then logically simplifying. Simplification removes redundancies due to the definitions of best case, expected case, and worst case.[3] "Or worse" is understood in all the rule conditions for diversion because of dominance constraints and logic.[4]

It does not follow that a pilot actually used a rule because his or her performance can be described by it. Indeed, performance for each group of pilots could also be described by a set of regression weights on the cues. These rules, however, define the minimal conditions for any account of performance. Satisfaction of these rules must be implied by the actually used procedures.

The second table in Appendix C displays the rules for each of the three groups of pilots, as a function of dispatch advice. The rules are organized by how many different predictive cues they refer to, providing a lower bound on the number of cues that pilots actually used. The number of pilots in each group whose behavior fits the rule is in parentheses.

Figures 18 through 21 abstract from the table to describe how the number of relevant cues varied across the three groups as a function of experience and dispatch advice.

---

[3] For example, the conjunctive condition in the following rule,

"Divert if and only if (worst case = destination or worse) and (expected case = destination or worse)"

simplifies to

"Divert if and only if (expected case = destination or worse)."

If the expected case involves the destination under fog, the worst case must be at least that bad.

[4] "If (expected case = destination), then divert"

implies

"If (expected case = destination and alternate), then divert"

by dominance.

"If divert, then (expected case = destination)"

implies

"If divert, then (expected case = destination) or (expected case = destination and alternate)"

by rules of the propositional calculus.

Figure18. Less experienced, non-risk-taking pilots.

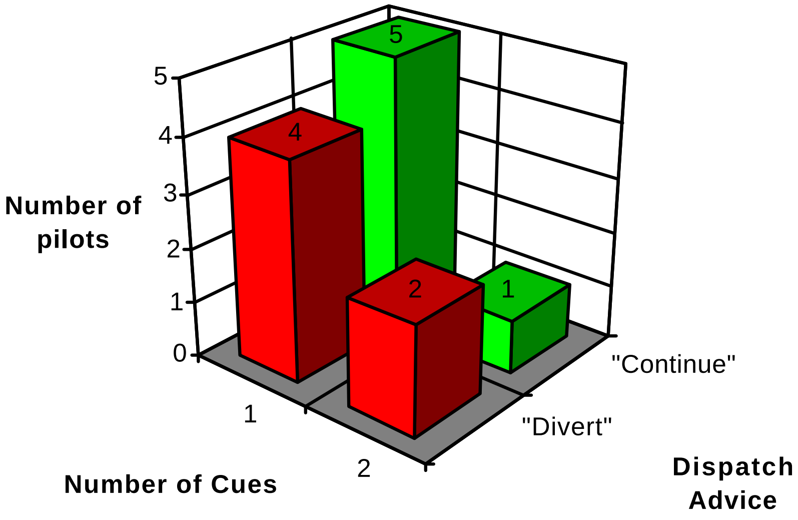


Figure 19. More experienced, non-risk-taking pilots.

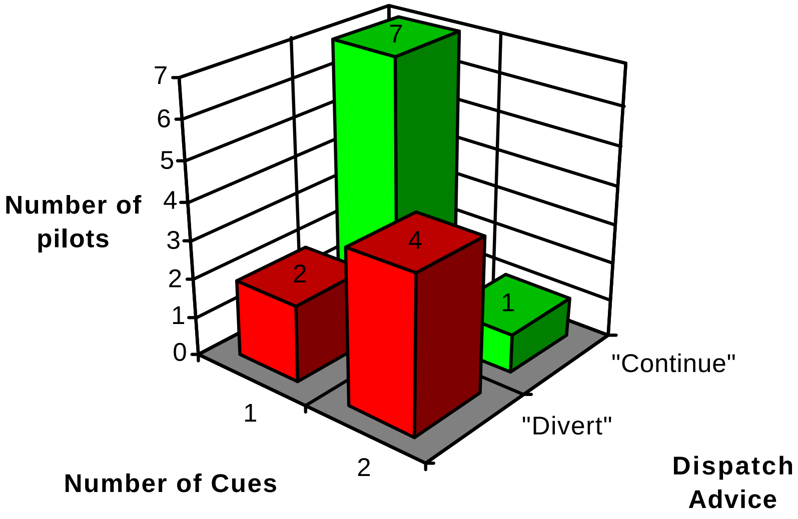


Figure 20.Less experienced, risk-taking pilots.

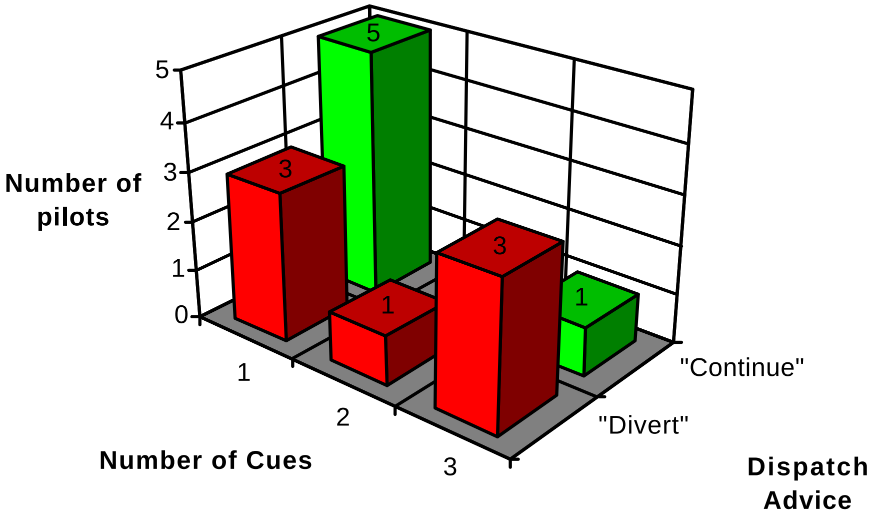
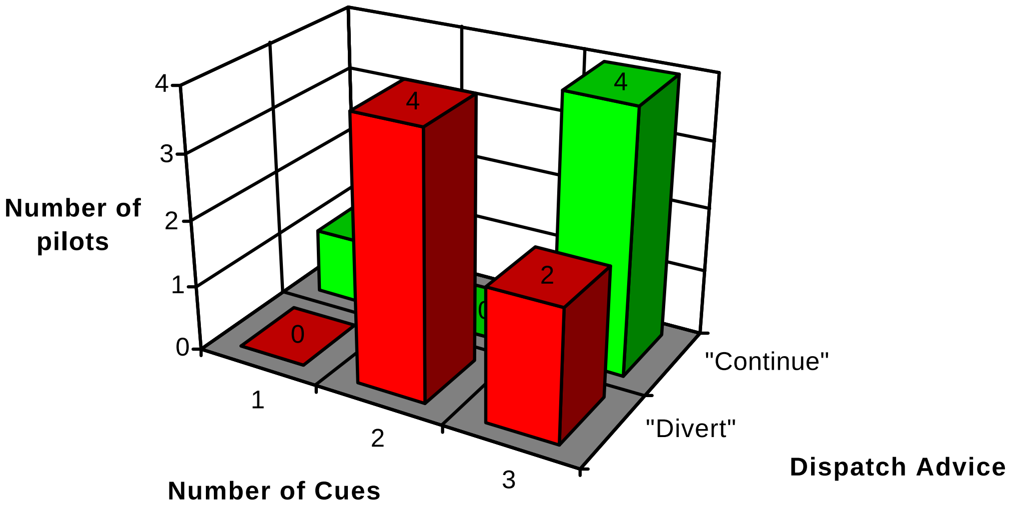


Figure 21. More experienced, risk-taking pilots.



Two comparisons are of interest:

(i) Among the non-risk-taking pilots, the more experienced pilots and the less experienced pilots used virtually the same average number of cues: 1.36 cues per subject for the more experienced group and 1.25 per subject for the less experienced group. But there is a crucial difference in the way they allocated this workload. The less experienced subjects used approximately the same number of cues under both dispatch advice conditions (1.16 for advice to continue, 1.33 for advice to divert). By contrast, the more experienced subjects varied their workload according to the needs of the situation, using an average of 1.67 cues when dispatch advised diversion and only 1.125 when dispatch advised continuation. A test of the association of dispatch advice with the number of cues used was significant for the experienced subjects ($\chi^2(1)$=4.381; p=.036), but not for the less experienced subjects.

A key function of the meta-strategy utilized by the non-risk-taking experienced pilots may be efficient allocation of processing capacity among cognitive tasks. As noted above, these pilots seem to have taken the dispatch recommendation as their starting point. The focus of their processing is not to develop a plan from scratch, but to examine the dispatch recommendation for potential problems. If dispatch recommends continuation, only the worst case is relevant as a potential source of problems (i.e., a no-options situation). Only if dispatch recommends diversion must both the worst case and the expected (or best) case be used: The pilot checks to see if there is a significant *advantage* of continuing (despite the dispatch recommendation), and then makes sure there is not a significant *down side* to continuing. Mental work is focussed where it is needed most.

(ii) Risk-taking subjects used more cues on average than non-risk-taking subjects (2.04 cues per subject for risk-takers and 1.31 cues per subject for non-risk-takers). This finding must be interpreted carefully: By the nature of the scenarios, there are no possible three-cue strategies that *non*-risk-taking subjects could have used (see Appendix C). Nevertheless, risk-taking subjects were significantly more likely than non-risk-taking subjects to use strategies involving *more than one* cue (A test of the association between risk-taking and use of more than one cue was significant: $\chi^2(1)$= 5.059, p=.025). The finding that risk-taking subjects tended to choose multi-cue strategies is not trivial, since there are risk-taking one-cue strategies that they could have used, just as there are two-cue strategies that non-risk-taking subjects could have used.

The importance of multi-cue strategies for the risk-taking pilots is supported by the finding that such strategies are related to experience.The tendency to use more than one cue is greatest for the more experienced risk-takers; 1.69 cues were used on the average by the less experienced risk-taking pilots, and 2.27 cues were used by the more experienced risk-taking pilots. A test of the association between experience and use of more than one cue, within the group of risk-taking pilots, was highly significant ($\chi^2(1)$= 6.993, p=.008).

The use of multi-cue strategies supports the idea that risk-taking subjects made their decisions in terms of *tradeoffs* rather than *goals*. In particular, while non-risk-taking subjects may have compared outcomes to all-or-none criteria (e.g., avoiding a no-options situation), most of the risk-taking subjects tried to weigh the available information, balancing the positive against the negative aspects of an option. More experienced risk-taking pilots may have been better at integrating a larger amount of predictive information within the same strategy.

3.3 Secondary Study

3.3.1 Introduction

If weather predictions were to be provided in real-time cockpit displays, one display design option would be to provide only a single forecast (e.g., the expected or most likely weather at the destination) rather than worst case, expected case, and best case. In such a display, uncertainty is compounded: Even if the expected weather, for example, involves only the destination under fog, the possibility of a no-options situation cannot be ruled out. The question arises, how would such a display interact with the cognitive processes of experienced and inexperienced pilots? How, for example, do pilots deal with the risk of a no-options situation when such a possibility is not made explicit, e.g., by a worst-case display? The secondary study addresses this question by providing only expected-case predictions.

The results may amplify and shed light on the primary-study conclusions about pilot cognitive processes. In that study, we found differences between more and less experienced pilots in the selective use of worst-case, expected-case, and best-case forecasts, for both risk-taking pilots and for non-risk-taking pilots. The finding of consistent differences due to experience suggests that a key component of expertise involves the selective handling of predictive modalities. If this is so, such differences would be expected to disappear in the present study, when no selection is possible.

3.3.2 Results and Discussion

Figure 22 shows the percentage of diversion decisions by scenario in the secondary study, as a function of dispatch advice. Recall that in scenario E-1, the expected case involves both destination and alternate under fog; scenario E-2 involves an expectation of only the destination under fog; and scenario E-3 involves an expectation of neither destination nor alternate under fog.

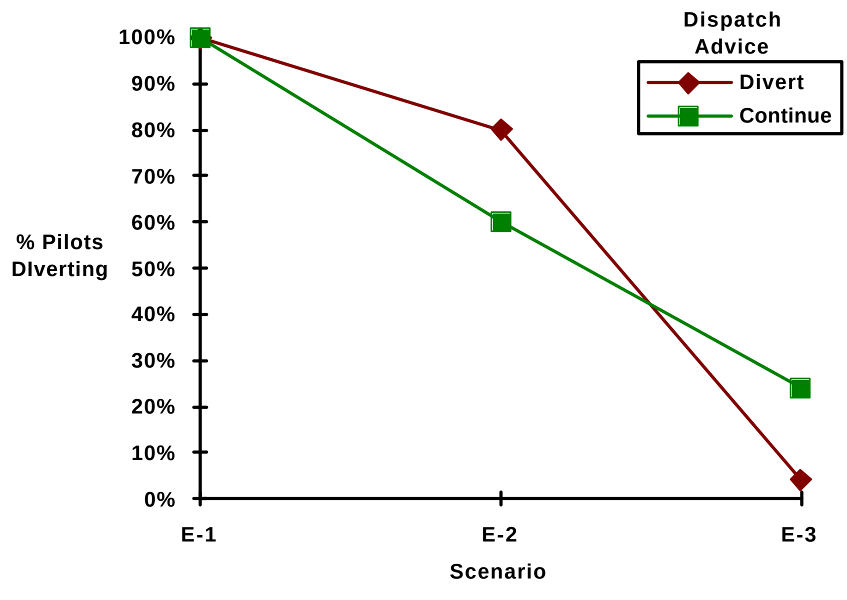


Figure 22. All pilots

Unsurprisingly, all subjects chose to divert when the expected case involved both destination and alternate under fog. An analysis of variance was therefore performed on the diversion data from scenarios E-2 and E-3. The independent variables were the same as in the primary study: Between-subjects variables were dispatch advice, the order of presentation of the primary and secondary studies, and whether scenarios were presented in order of increasing or decreasing attractiveness. Scenarios was a within-subjects variable, and years of commercial flying experience was again treated as a continuous regressor.

The scenarios variable was highly significant (F(1,34)=12.954; p=.001). However, no other variables or interactions were significant up to the .05 level, with one exception to be noted below. In particular, when pilots were provided only with expected case infomation, there was no obvious advantage of experience: Neither the main effect of experience nor its interactions with dispatch advice and scenarios were significant. Moreover, the pilots were not significantly responsive to dispatch advice regardless of experience (F(1,34)=3.423; p=.073).

There was, however, a less obvious advantage of experience. The interaction between experience, the order of the primary and secondary studies, and scenarios was significant (F(1,34)=4.633; p=.039). Figures 23 and 24 show the nature of this interaction. Experienced pilots appear to have benefited from initial exposure to the primary experiment in a way that less experienced pilots did not. Thus, in scenario E-2, where the expected case involves only the destination under fog, the experienced pilots were far more likely to divert if they had seen the primary study first than if they had not. Presumably, they were sensitized by that study to the possibility of a no-options worst case even under relatively mild expected-case conditions.

Two conclusions from this study are salient:

(i) *The expected-case display does not support expert decision processes.* This display does not provide the information required to implement the cognitive processes characteristic of experienced pilots -- i.e., the process of provisionally accepting dispatch advice and then testing it by selective examination of worst case predictions (if the advice is to continue) or expected/best case and worst-case predictions (if the advice is to divert). The absence of a difference between experienced and inexperienced pilots, and the failure of either group to respond to dispatch advice, supports this conclusion. The one effect of experience that *was* obtained confirms this conclusion further. That effect involved the ability of experienced pilots to apply lessons from the primary study to the secondary study, rather than any strategies specific to the secondary study *per se*.

(ii) *Virtually all subjects became risk-takers under certain circumstances.* Scenario E-3 involves an expectation of neither the destination nor the alternate under fog. Nevertheless, it does not exclude the possibility of a no-options situation (as in fact is the case in scenario 6 from the primary study). Yet 86% of the pilots chose to continue in this situation. This percentage remained at 84% even when the pilots had experienced the primary study first.

Figure 23. Less experienced pilots.

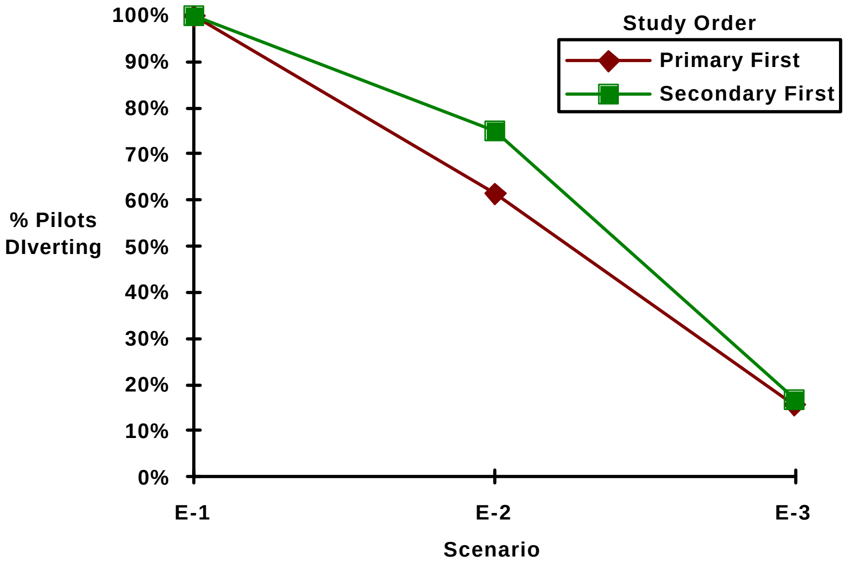
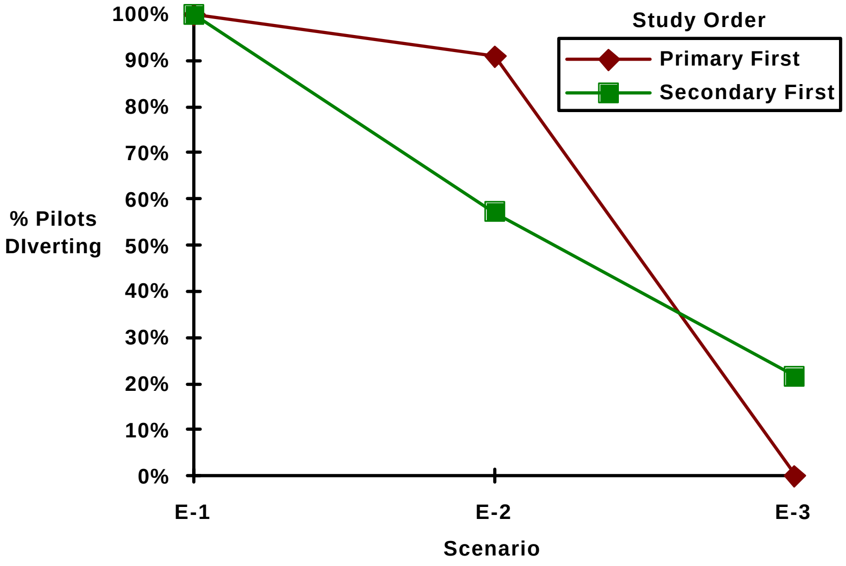
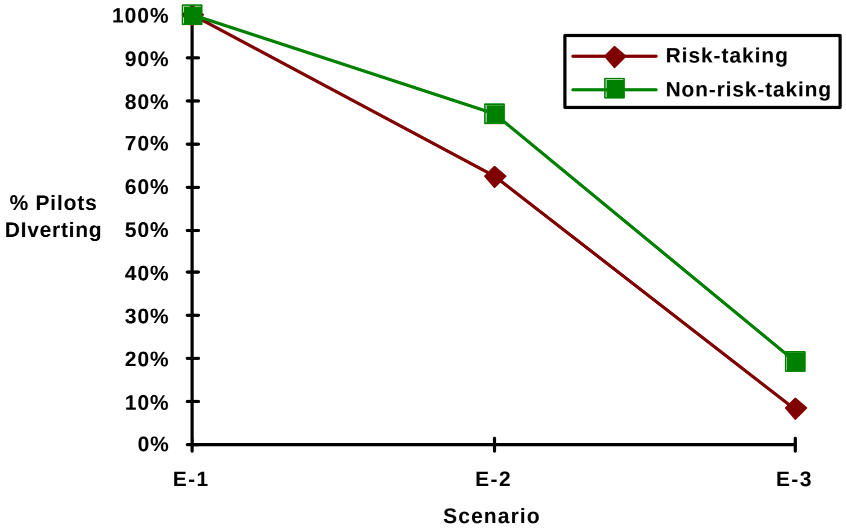


Figure 24. More experienced pilots.



There was no correlation between risk-taking in the primary study and risk-taking in the secondary study. Figure 25 shows that subjects who were identified as risk-taking in the primary study were only slightly (and non-significantly) more likely to continue to the destination in the secondary study compared to subjects identified as non-risk-taking. This supports the hypothesis that risk-taking in the primary study was the result of a specific processing strategy (looking at multiple predictive cues and trading off advantages and disadvantages) rather than the result of a "risk-taking" trait. The tradeoff strategy cannot be used when only expected-case information is provided, and thus cannot contribute to risk-taking.

Figure 25.Correlation with Risk-Taking in Primary Study.



4.0 SUMMARY AND CONCLUSIONS

Diversion decisions were experimentally studied in order to identify commercial airline pilots' decision strategies. In particular, we were interested in how the pilots processed informationa about weather forecasts and dispatch recommendations in order to make a choice about diverting to a new destination, and in how experinece affects that processing . We will summarize the results under three headings: Taking Advice, Taking Chances, and Decision Strategies.

Taking Advice. One can imagine at least four different ways of responding to advice (such as dispatch recommendation): (1) slavishly following it, (2) factoring it into an evaluation to be balanced as one among several considerations, (3) examining it for potential problems and accepting it if none are discovered, and (4) ignoring it altogether. In this study, we found no evidence for (1) or (2). Pilots either ignored dispatch advice altogether (4), or adopted a strategy of accepting it provisionally and looking for potential problems (3).

The more experienced pilots were more likely to divert when dispatch recommended diversion than when dispatch recommended continuing, and more likely to continue when dispatch recommended continuing than when dispatch recommended diversion. By contrast, diversion decisions by the less experienced pilots were completely unaffected by dispatch recommendations.

For experienced pilots, the use they made of best-case/expected-case/worst-case information depended on the dispatch recommendation. When dispatch recommended continuing, experienced pilots focussed on worst-case information: If the worst-case involved both destination and alternate under fog conditions, they did not continue *despite* the dispatch recommendation. When dispatch recommended diversion, however, experienced pilots tended to look at expected-case or best-case information in addition to the worst-case: If the expected or best case looked good *and* the worst case involved only the destination (but not the alternate) under fog, then experienced pilots tended to continue despite the dispatch recommendation to divert.

Information use by the less experienced pilots was not influenced by the dispatcher's recommendation.

Taking chances. A similar number of pilots in both the experienced and inexperienced group can be classified as "risk-taking": These pilots were willing to continue into a situation in which there was some chance (if only worst-case) of both the alternate and destination being below minimums. They were not influenced by dispatch advice. On the other hand, they made considerable use of the available predictive information, apprarently balancing advantages and disadvantages of continuing to the destination.

Decision Strategies. Three qualitatively different processing approaches can be tentatively identified among these subjects: (1) The less experienced, but non-risk-taking pilots presented a mix of pure worst-case and what we have called "cautious" strategies. In the former case, a necessary and sufficient condition for diverting was that the worst-case prediction involve both alternate and destination under fog. In the latter case, this no-options situation was sufficient for diverting, but not necessary. These cautious pilots might divert anyway, if the expected case or best case was not itself very promising (e.g., destination and alternate clear). As noted, these less experienced pilots made no use of the advice from dispatch, nor did it influence the way they processed the predictive information. One result was unncessary diversions by pilots using the cautious strategy, when dispatch recommended continuing and there was no danger of a no-options situation.

(2) By contrast, the non-risk-taking, *experienced* pilots centered their decision making process around the dispatch recommendation. They took it as a starting point, and then looked for information to critique or rebut it. Thus, if dispatch recommended continuing, these pilots adopted the worst-case strategy. They made sure there was no chance of ending up with a no-options situation (worst case equal to both destination and alternate under fog). If dispatch recommended diversion, however, these pilots adopted the cautious strategy. They tried to determine if continuing might be desirable (i.e., expected case or worst case equal to neither airport under fog), and if diversion was unnecessary (worst-case not equal to both destination and alternate under fog).

These experienced pilots thus had a "meta-strategy" that allowed them to adopt a different first-order approach depending on the situation. *Such a meta-strategy enabled them to take advantage of the information provided by dispatch (a) without slavishly following it even when it was wrong, and (ii) without significantly increasing their processing workload.*

(3) Risk-taking pilots seem to have utilized a third type of strategy. They were more likely than either of the other two groups to consider multiple possible outcomes (e.g., worst-case *and* expected case *and* best case) in their decisions. These pilots were willing to accept a worst-case possibility of no options, as long as the expected case or best case was good. Conversely, they sometimes chose to divert if the expected case or best case was not so good, even though there was no possibility of a no-options situation (and even though dispatch might have recommended continuing). The risk-taking pilots thus appear to use a tradeoff evaluation strategy, in which worst-case outcomes may be outweighed by the advantages of continuing.The more experienced risk-taking pilots used a larger amount of information than the less experienced risk-taking pilots.

In the secondary experiment, pilots were given only information about the expected case. For half the subjects, this condition was presented prior to the best/expected/worst-case condition; for the other half, it was presented after. This display did not support the kinds of problem-solving strategies observed with the richer display. In this condition differences among pilots based on experience or risk-taking disappeared. Dispatch advice had no effect even on the experienced pilots. Virtually all pilots were willing to accept some implicit risk, i.e., a choice that might lead to a no-options situation.

A paper-and-pencil test of this sort necessarily introduces potential artifacts. All these conclusions are subject to qualification: (1) Dispatch advice may be more salient in the real-world, where it is communicated verbally and where the people behind the advice may be personally known to the pilot. Under those circumstances, it might have more effect than we observed in this study. (2) Pilots may have been willing to take risks because they did not understand how probable or improbable a worst-case outcome was. In the real world, where a richer set of weather data might be provided, they might have a better feeling for how much basis there is for a worst-case prediction. (3) It is hard to draw firm conclusions about processing strategies without explicitly tracing those processes, e.g., through tracking eye movements, information requests, or think-aloud protocols. For example, any of the "strategies" that we found could be modeled, in prinicple at least, either by a regression approach, with different weights assigned to predictive cues, or by rules that employ different all-or-nothing goals.

Nevertheless, there are corresponding disadvantages in adopting a less experimentally controlled and more "naturalistic" approach. A lot can be learned from performance under systematically varied circumstances, and a complementary use of experimentation and less formal observation may be ideal. Most importantly, the finding of significant differences among subjects based on experience is itself a validation of the approach. Such differences confirm that the primary experiment taps processes that are characteristic of expertise. Experts and non-experts would not be expected to differ in a task that bore no relation to the tasks within which expert experience was acquired.

The results support the view that experienced decision makers may solve problems in a way that is qualitatively different from the approaches of less experienced decision makers. But the results also support a concept of expertise that goes beyond a stock of specialized recognitional templates, to include *domain-specific methods* for processing information. Such methods, or metacognitive strategies, evolve through long experience (20 years in the present study). They may enhance both the accuracy and the efficiency of cognitive processes.

Implications for Cockpit Displays

Design of displays to support decision making has often veered between two extremes: *technology-driven* and *status-quo-driven*. In the first case, the problem-solving strategy is determined by a technology, such as mathematical optimization, decision analysis, or a favored artificial intelligence reasoning method, without regard for the user. In the second case, the users' current methods are simply "automated" without regard to whether they are the best way to solve the problem.

An alternative approach to display design, called Personalized and Prescriptive Aiding, is jointly *user-driven* and *problem-driven*. The designer's goal is (1) to adapt the system to the cognitive capabilities and preferences of the user, without necessarily duplicating the status quo, and (2) to solve the problem effectively, but without imposing techniques that fail to exploit the user's potential contribution (Cohen, Leddo, and Tolcott, 1989; Cohen, in press).

Personalized and Prescriptive Aiding involves the following components:

- Understanding the decision making processes and strategies of potential users, including individual differences. This may involve interviews, observation of performance, simulator tests, or formal experiments.
- Understanding the problem and effective methods for solving it. This may involve mathematical modeling, elicitation of expert knowledge, or a combination of expert judgment and analysis, depending on the problem.
- Comparison of user decision making strategies with effective methods, to identify the strengths and weaknesses of different user strategies.
- Design of displays and user-system interactions that facilitate the strengths and guard against the weaknesses of a user's approach. Such systems support user-preferred problem-solving strategies, while providing prompts and other safeguards against potential pitfalls associated with those strategies. The result should be a system which performs better than either the user or a technology-driven model by itself.

The present study addresses the first three steps of this process: (1) We have identified a variety of pilot strategies for making diversion decisions. (2) We have identified an effective strategy for making such decisions, based jointly on the performance of the experienced pilots and on our own analysis of the problem. And (3) we have noticed specific strengths and short-comings of the other strategies when compared with the effective expert strategy.

The identification of an effective decision strategy in step (2) is equivalent to adopting the following plausible assumptions:

- Dispatch advice, though fallible, has value. Dispatchers have access to a bigger picture than the individual pilot, in terms of the overall traffic flow, availability of facilities, and weather.
- Flying into a situation where there is a significant chance of all airports' falling below minimums should be avoided, regardless of dispatch advice.
- Diversion is undesirable when there is no possibility of a no-options situation and dispatch recommends continuing.

- A process that arrives at the same decisions in less time, or by consulting fewer cues, is preferable to one that takes more time, or consults more cues.

These assumptions, of course, match the behavior of the more experienced, non-risk-taking pilots.

The following table summarizes the strategies we have observed together with their strengths and weaknesses, in the light of these assumptions:

STRATEGIES	Avoids No-Options Situations?	Avoids Unnecessary Diversions?	Incorporates Dispatch Advice?	Uses Time/ Resources Efficiently?
Accept Advice+Rebut	✓	✓	✓	✓
Worst-Case	✓	✓	No	✓
Cautious	✓	No	No	No
Tradeoffs	No	No	No	No

The final step of display design (4) is beyond the scope of this paper. Some concepts for a personalized and prescriptive commercial flight replanning aid were described in a previous paper (Cohen, Leddo, and Tolcott, 1989), and a subset of these concepts has been implemented in a demonstration cockpit display system. Nevertheless, some simple and tentative display hypotheses can be derived from the above analysis, for diversion situations of the kind described:

- Dispatch advice should always be displayed.
- The worst-case weather forecast should always be displayed.
- When dispatch advice is to divert (or if there is no dispatch advice), the expected-case weather forecast should also be displayed. Otherwise, it should not be displayed.

At least one of these display features addresses each of the shortcomings that were identified in the various pilot decision strategies:

No-options situations: The tradeoff strategy can lead to acceptance of a possible no-options situation, by trading off the worst-case disadvantages against advantages in the expected or best case. Prominent and consistent display of the worst-case scenario, in the absence of counterbalancing displays of expected- and best-case predictions, should discourage this strategy.

Unnecessary diversions: Both the cautious and tradeoff strategies can lead to unnecessary diversions, by putting undue weight on a poor expected- or best-case forecast (even though the worst-case does not dictate diversion), and disregarding dispatch recommendations to continue. Displaying only the worst-case prediction when dispatch advises continuing, should discourage this effect.

Dispatch advice: Tradeoff, cautious, and worst-case strategies all disregarded dispatch recommendations. The result is both unnecessary diversions, as just described, and also disruptive continuations (when there is no chance of landing at the destination and dispatch recommends diversion for logistical or other reasons). Prominent and consistent display of dispatch advice should encourage integration of dispatch advice into decision making. At the same time, display of worst-case predictions (and expected-case predictions when dispatch recommends diversion) should guard against too uncritical an acceptance of dispatch recommendations.

Efficient use of time/resources: Both cautious and tradeoff strategies use information (expected case and/or best case) that in some situations is both unnecessary and leads to less appropriate decisions. Only necessary information should be provided: i.e., dispatch advice and the data required to validate or invalidate it. When dispatch recommends continuation, the required data consist only of the worst-case forecast.

A display design within these guidelines would be consistent with natural metacognitive strategies for verifying and, if necessary, modifying an initial option (see Section 2.3 above). It supports a process of "mental simulation" in which the decision maker "observes" selected concrete outcomes of an option. It allows for the exercise of pilot judgment and knowledge in evaluating the appropriate aspects of an evolving weather situation and in arriving at his or her own conclusion regarding the validity of a dispatch request. At the same time, it channels less experienced or less appropriate strategies toward a more expert-like approach.

APPENDIX A

Task Instructions

You are the Captain of Flight 34 from San Francisco to New Albagon on the east coast of South America. The alternate is Tritanta. At takeoff, the predicted weather for both New Albagon and Tritanta was satisfactory.

Flight 34 took off with enough fuel to hold for 1 hour at New Albagon and then proceed to Tritanta. But unexpected delays enroute have reduced the maximum holding time at New Albagon to 30 minutes before proceeding to Tritanta. Tritanta has two long runways that are fully operational.

You are now about 45 minutes away from New Albagon. At this moment, the weather at New Albagon and Trintanta is still satisfactory, but the predicted weather situation at New Albagon and/or Tritanta has changed.

At your present position, it is possible to divert to Far Crossway. But if you proceed any farther toward New Albagon, such diversion will be impossible. In short, if you want to go to Far Crossway, you must go now.

According to dispatch, Far Crossway is not a desirable diversion possibility. There are no facilities for maintaing the aircraft, no connecting flights to New Albagon, and no facilities for processing passengers.[*]

There are no other airports besides Far Crossway, New Albagon, and Tritanta within range of the aircraft.

This booklet contains 13 pages. Each page pictorially describes a slightly different change in the prediction about the weather at New Albagon and Tritanta. For each page, you are asked to make a decision: whether to divert now to Far Crossway or proceed to New Albagon.

A sample situation is the following:

---

[*] For half the subjects, this paragraph was replaced by the following:

According to dispatch, Far Crossway is a desirable diversion possibility. There are facilities for refueling and maintaing the aircraft, numerous connecting flights to Destination, and ample facilities for processing passengers.

The planned route to New Albagon is shown by the heavy line. The fog bank at the right is associated with predicted 0 celing/0 visibility conditions. It is shown *in its predicted position at the time your aircraft will arrive at New Albagon*. The fog bank is moving from east to west (i.e., to the left), and is presently located somewhere to the right of the projected location. As noted, the weather at both New Albagon and Tritanta is currently satisfactory.

In all the situations there is uncertainty regarding where the fog bank will be when your flight arrives at New Albagon. In most of the situations, you will be shown three possibilities: a best case, representing the slowest likely movement of the fog bank; a worst case, representing the fastest likely movement; and an average case, representing a "best guess" taking into account the probabilities of moving at different speeds. In a few of the situations, you will be shown only the average, or most likely, case.

YOUR RESPONSES

Please go through the scenarios in order, without referring back to an earlier one. For each situation, please indicate whether you would divert to Far Crossway or continue to New Albagon.

Also indicate your confidence in the correctness of your decision on a scale of 1 (extremely uncertain) to 100 (very certain). This is not the same as how good the option is (It might even be pretty bad), but rather, your degree of confidence that it is *better* than the other available option. In other words, how sure are you that the goodness score of your chosen option really is higher than the score of the other option? How surprised would you be if another pilot, whose judgment you respected, made a decision different from yours?

APPENDIX B

Sample scenario from Primary Study

Sample scenario from Secondary Study

APPENDIX C

Non-dominated Strategies, Number of Subjects, and Logical Rules

										Number	of Subjects			
STRATEGIES Scenarios: Diversion = ✓										More Exper'd		Less Exper'd		Divert if and only if . . .
1	2	3	4	5	6	7	8	9	10	Div	Con	Div	Con	Rule
														Risk-taking
														False
✓														b=DA
✓	✓									2				e=DA & b=D
✓	✓		✓											w=DA & b=D
✓	✓		✓			✓								b=D
✓	✓	✓									1	3	3	e=DA
✓	✓	✓	✓							1	3	3	1	w=DA & (e=DA or b=D)
✓	✓	✓	✓		*	✓				1		1*		e=DA or b=D
✓	✓	✓	✓	✓						1				w=DA & e=D
✓	✓	✓	✓	✓		✓				1	1			(w=DA & e=D) or b=D
✓	✓	✓	✓	✓		✓	✓						2	e=D
														Worst Case
✓	✓	✓	✓	✓	✓					1	7	3	4	w=DA
														Cautious
✓	✓	✓	✓	✓	✓	✓						2	1	w=DA or b=D
✓	✓	✓	✓	✓	✓	✓	✓			4	1			w=DA or e=D
✓	✓	✓	✓	✓	✓	✓	✓	✓		1		1	1	w=D
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					True

w = worst case
e = expected case
b = best case

* This rule is the closest approximation to the responses of the subject who used a dominated strategy. He also diverted in scenario 6.

Div = dispatch advises to divert

Con = dispatch advises to continue

Strategies organized by number of cues and subject

		Number of cues in strategy		
Divert if and only if . . .	**Dispatch Advice**	**1 Cue**	**2 Cues**	**3 Cues**
Less Experienced, Non-risk-taking (n=12)	**Continue**	w=DA (4) w=D (1)	w=DA or b=D (1)	*
	Divert	w=DA (3) w=D (1)	w=DA or b=D (2)	*
More experienced, Non-risk-taking (n=14)	**Continue**	w=DA (7)	w=DA or e=D (1)	*
	Divert	w=DA (1) w=D (1)	w=DA or e=D (4)	*
Risk-taking (n=24)	**Continue**	e=DA (4) e=D (2)	(0)	w=DA & (e=DA or b=D) (4) (w=DA & e=D) or b=D (1)
	Divert	e=DA (3)	e=DA or b=D (2)** e=DA & b=D (2) w=DA & e=D (1)	w=DA & (e=DA or b=D) (4) (w=DA & e=D) or b=D (1

w = worst case
e = expected case
b = best case

* No 3-cue rules exist for non-risk-taking strategies.

** This rule is the closest approximation to the responses of the subject who used a dominated strategy.