Thinking Ahead: Using Strategic Behavior to Avoid Errors on the Commercial Flight Deck

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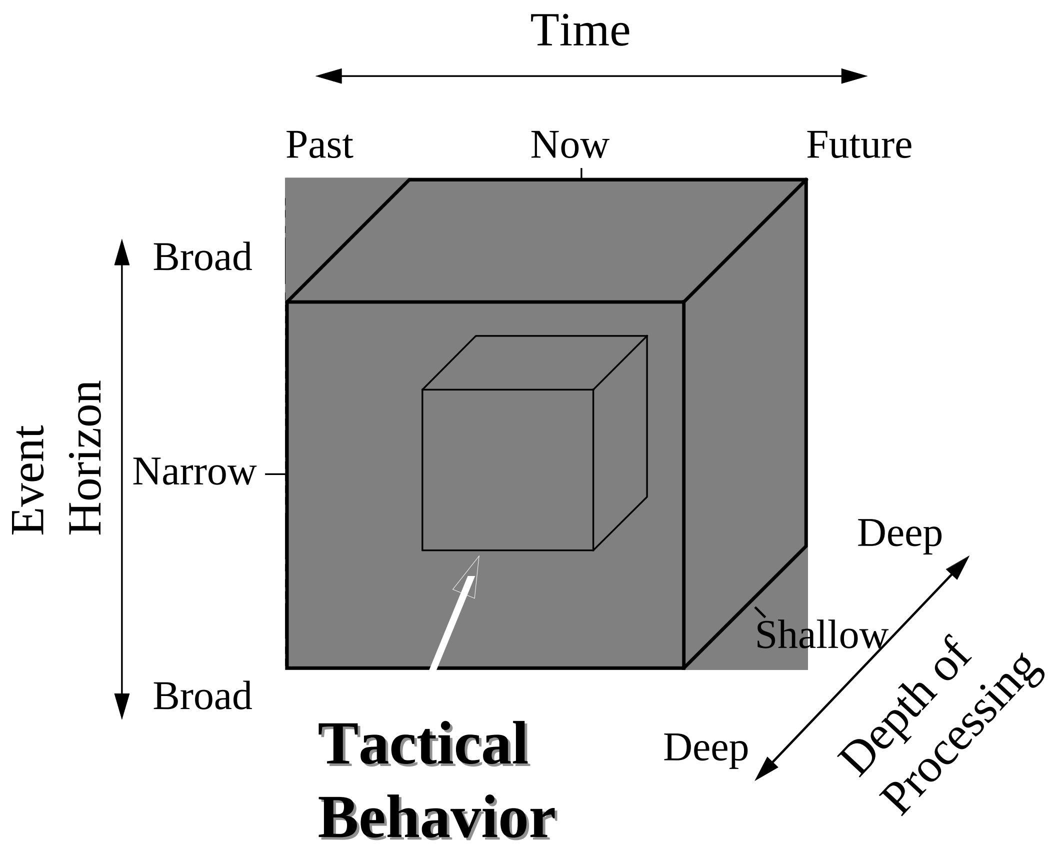
On the flight deck, as in life, one key to survival is staying out of dangerous situations. All species use instinctive behavior to avoid danger, but humans use another ability perhaps even more than instincts: strategic behavior. A strategy is defined by Webster as "the art of devising or employing plans or stratagems toward a goal," or "a careful plan or method." We are probably different than the rest of the animal world in our ability to think ahead. We can create temporally far-ahead goals, and develop complex action plans and strategies to accomplish those goals, often spanning considerable time and involving setting and accomplishing intermediate goals. We can analyze the impact of current and evolving situations on the probability of future goal accomplishment and future events and states. Our society spends a great deal of time (and money) in trying to predict and anticipate events, and often the relationship of actual events to expectations is more important than the actual events themselves (e.g., profits rise, but less than expected, so stock prices fall). We seem to have a propensity to build internal models of the way things should be, both in the sense of an "ideal" now, and in the sense of future states.

It is argued here that this human trait, this desire and ability to plan, predict, and think ahead (strategic behavior) is the best defense for pilots against dangerous situations in the flight domain. It allows pilots to be proactive rather than reactive. It allows them to minimize the number of unanticipated events with which they must deal, and thus avoid catastrophic errors that accompany human performance in unexpected, time critical situations. It allows them to analyze progress, comparing actual states against desired or expected states, and thereby anticipate unusual situations and detect discrepancies. It allows them to develop contingency plans, and to mentally rehearse future actions, "what if" situations, and alternate plans of action. It allows them to react more quickly to time-critical situations because they've "thought it through" before it happens. Thus strategic behavior can help pilots avoid dangerous situations and avoid making errors if those situations do occur (error reduction), and can also help them detect their errors before they lead to serious consequences (error tolerance).

This paper will provide a theoretical framework for defining strategic behavior and will discuss the implications of that framework in terms of the potential benefits and risks associated with strategic behavior. Then, strategic behavior on the flight deck will be described, and design, procedural, and training concepts that encourage strategic behavior, on the one hand, and that help avoid its' pitfalls on the other, will be discussed.

Strategic behavior: A theoretical framework

Strategic behavior is not well defined. While the terms "strategic" and "tactical" are commonly used parlance in flight operations, as well as in many other disciplines and domains, the implications of the terms appear to be rather diverse. A systematic analysis of the factors that differentiate tactical and strategic behavior is underway by this author. Evidence thus far suggests that environmental, situation, task, and operator factors play a role in distinguishing strategic and tactical behavior in the minds of operators. A three-dimensional dynamic model of strategic and tactical behavior is proposed here to convey a general understanding of strategic behavior and to allow hypotheses concerning benefits and risks to be formulated (Figure 1). The model suggests that time, event horizon, and depth of cognitive processing are the major discriminators of tactical and strategic behavior. This model should be considered speculative; only anecdotal and preliminary data have been used to develop it.


Time
Past
Now
Future
Broad
Event Horizon
Narrow
Broad
Deep
Shallow
Deep
Depth of Processing
Tactical Behavior

This corresponds to focus of attention, with tactical behavior being characterized by a narrow focus of attention and strategic behavior being characterized by a broad focus of attention. This scope dimension is also related to flight deck levels of operational focus, that is, systems level, aircraft level, or mission level (Rogers, Schutte & Latorella, 1996). A more narrow focus on individual systems or tasks would be tactical, and moving to a broader level of focus, particularly at the mission level, would be strategic. As the breadth of the event horizon increases, the connections to more information and context expands forward and backward in time. Expanding forward means that more aspects of future situations are considered. Expanding back in time means that more breadth of knowledge and memory are brought to bear on the behavior. Sanford & Garrod (1981) described a widening array of knowledge and experience in terms of working memory with a small explicit focus and a larger implicit focus, and long term memory with a large episodic store and an even larger semantic store. The notion is that with strategic behavior, connections to broader, larger memory stores are available.

The third dimension distinguishing tactical and strategic behavior is depth of processing. Rasmussen (1986) described a normative model of decision phases in the form of a decision ladder where shallow processing (i.e., skill-based short-cuts) is depicted as occurring at the bottom of the ladder and deeper processing (i.e., knowledge-based behavior) is depicted as extending from observations up the “analysis” leg and back down the “planning” leg to the response (Figure 2).

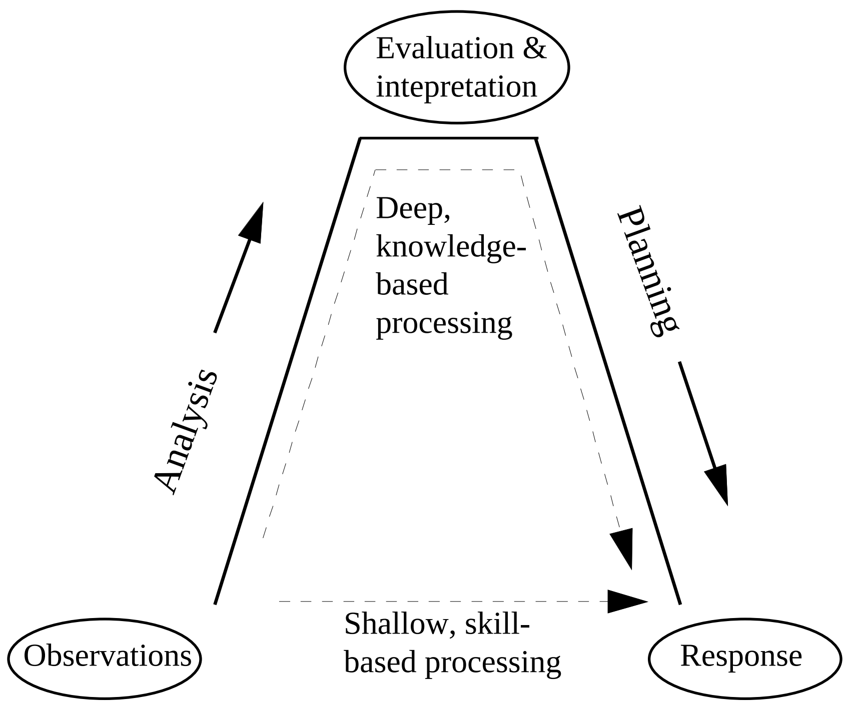


Figure 2. Depth of processing “decision ladder” (based on Rasmussen, 1986)

The shallow, skill-based processing is characterized by perceiving and doing, that is, responding to stimuli without thought. Deep, knowledge-based processing is characterized by evaluating and interpreting, assessing goals, developing plans, etc. It is posited that strategic behavior involves deep, knowledge-based processing, and is much more goal- and plan-oriented. Tactical involves shallow, skill-based behavior, and is characterized more as “doing.” Schutte (P.C. Schutte, personal communication, Dec. 16, 1997) concluded from his informal survey that for tactical behavior, acting takes precedence over thinking, and conversely, thinking takes precedence over acting for strategic behavior.

Hence, as illustrated in Figure 1, tactical and strategic behavior generally are distinguished by concurrent differences in magnitude along the time, event horizon, and depth of processing dimensions. Tactical is more focused in all three dimensions and strategic is more diffuse in all three dimensions. It should be pointed out that the three-dimensional symmetry underlying the depiction of tactical and strategic behavior as cubes is an over-simplification; for example, it is easy to imagine a case where a very narrow focus in terms of event horizon is considered across a long time frame, creating a strategic behavior depiction that is an elongated hexahedron instead of a cube.

The dynamic aspect of this model is that other factors can modulate the size of the tactical and strategic cubes. For example, personality factors, experience level, stress, workload, etc., could make the cubes larger or smaller.

<u>Hypothetical benefits of strategic behavior</u>

Strategic behavior has many potential advantages. Each dimension defining strategic behavior (see Figure 1) offers benefits. In the time dimension, ability to plan and think ahead allows pilots to better balance their workload. Airline training departments teach pilots workload management skills, and an important part of those skills is to anticipate future workload bottlenecks and perform some tasks early, if possible, and rehearse others so that they can be done more efficiently when the bottlenecks occur. Additionally, in the sense that strategic behavior allows one to bring more history, memory, and experience to bear, it provides a direct human performance advantage of having more data on which to base decisions. Consideration of longer-scale trends and a larger database of similar cases can enhance problem solving and decision making as well.

A broader "event horizon" contributes many of the same benefits as the time dimension. Further, the event horizon dimension is where "big picture" situation awareness accrues its' benefits. Situation awareness can vary from focus on perception of elements in the current situation, to comprehension of an overall situation, to projection of future situations (Endsley, 1995). As a bigger picture is formed, both in event horizon and time, more situations can be anticipated and considered earlier, in terms of implications for goals, expectations, and task performance. There is a wealth of evidence that shows that human performance is faster and more accurate when we know what to expect. In fact, this creates one of the major problems in human factors evaluations, especially when trying to investigate the effects of unexpected, rare events: the events are often neither unexpected nor rare in the experiment, so subjects typically perform better than they might in the real world.

The deep cognitive processing associated with strategic behavior has obvious advantages, especially for unusual or novel situations: there is no opportunity for operators to form skill- or rule-based associations and thus the only way to reach the appropriate decision or response is to apply knowledge-based processing. This is still the area where humans have significant advantages over automation. In the fault management arena, for example, Reason (1990) has characterized these unique human abilities as follows: "Human beings owe their inclusion in hazardous systems to their unique, knowledge-based ability to carry out 'on-line' problem solving in novel situations." Knowledge-based processing is characterized by the formation of internal mental models and analysis of goals, formation of plans, and prediction of future states and situations based on those models. This model-based reasoning allows humans to detect anomalies and dangerous trends because we compare actual values and states to expected values and states. Mental models and expectations also help us form our perceptual search strategies, which, if appropriate, help assure that we scan the right data sources and keep track of the right data. Neisser (1976) described a perceptual cycle where knowledge, in the form of schemas or mental models, leads to anticipation of certain kinds of information and directs attention and exploratory movements to particular aspects of the available information. Figure 3 is a modification of Neisser's perceptual cycle to include formation of models of future situations and states as the strategic mechanism by which we base comparison of actual data with expectations and guide our perceptual search.

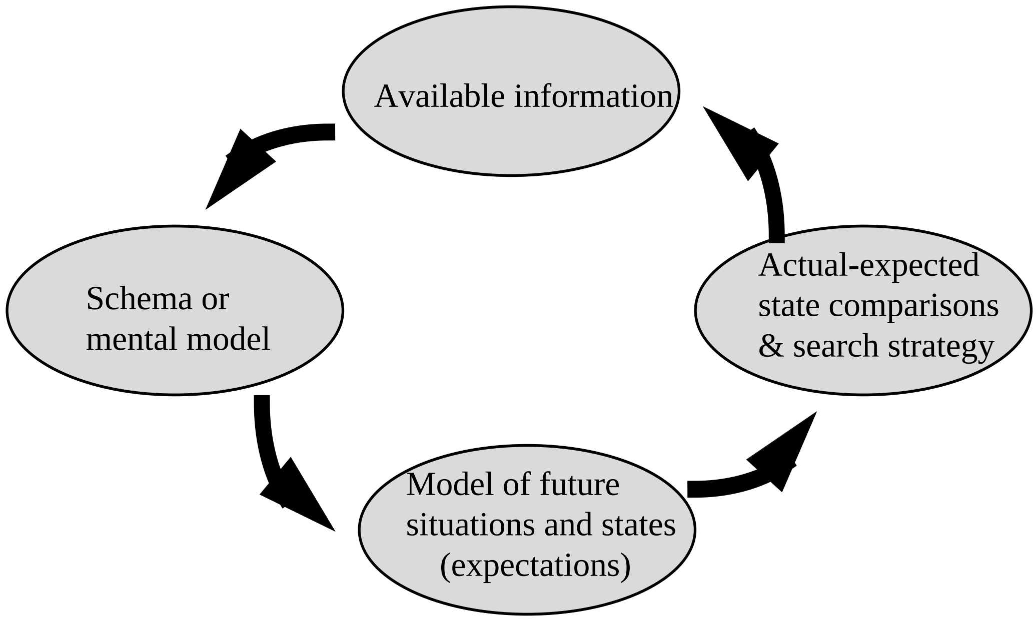


Figure 3. The perceptual cycle underlying strategic behavior (based on Neisser, 1976)

<u>Hypothetical risks of strategic behavior</u>

While strategic behavior has clear and obvious advantages for humans, particularly ones that are involved in inherently risky endeavors, their are also pitfalls of strategic thinking. The same dimensions of strategic behavior that offer benefits create risks. The longer time frame associated with strategic behavior, which allows pilots to balance workload, can have the opposite effect as well. If inappropriately applied, strategic behavior (and the automation that enables it) can create situations in which too many tasks are performed early, leading to periods of boredom and complacency later.

In real time operations, strategic planning must be balanced with the need to perform immediate and real time tasks. Tactically-required tasks must always be attended to first. Bonissone, Dutta, and Wood (1994) argued that both strategic and tactical processes are essential for successful behavior in a dynamic world; pure tactical behavior increases reactivity, but at the expense of strategic goal directed behavior, and pure strategic behavior leads to inadequate flexibility in reacting to a changing world. So errors can occur if too much attention is given to strategic planning at the expense of tactical, real time task performance. Fortunately, in commercial aviation, there is a built-in safety against this threat by having a two person flight crew with one member always assigned to immediate tasks related to aircraft control.

The same concerns are present in relation to the event horizon dimension. One must be careful not to think at the "big picture" level or in terms of future situations exclusively, or he or she might miss some immediate and pressing detail or datum.

Probably the biggest concern with strategic behavior is that associated with knowledge-based processing and its' reliance on mental models. First, knowledge-based processing is "slow, sequential, laborious, and resource-limited conscious processing" (Reason, 1990). Hence it requires a great deal of attention and cognitive resources that management computer for exploring the effects of possible re-routes on fuel/time predictions), also provide important aids to strategic planning. Workload management is taught as an element of crew resource management, and provides valuable guidance in good strategic behavior practices. But we have the opportunity to provide other flight deck aids and techniques to assist pilots in performing strategic behavior more effectively.

Encouraging strategic behavior

The ability and/or inclination to think ahead seems to vary among individuals and experience levels. In life, we associate exclusively short-sighted, think-for-today, focus-on-the-here-and-now behavior with those that are too busy, those that are uninformed or mentally lazy, and youth. Translating these "anti-strategic" traits to flight crews suggests general operational strategies for facilitating strategic behavior:

- Keep high workload conditions that prevent strategic behavior to a minimum
- Provide information in forms that help build situation awareness and good mental models
- Avoid low-workload and complacency-inducing situations that encourage mental "laziness"
- Provide tools that assist young and inexperienced pilots to think ahead as an experienced pilot does.

A good pilot is "ahead of the airplane" most of the time, which means he or she is anticipating, spatially and functionally, where the aircraft is going, what the next "situation" will be, and what it means in terms of his or her tasks and responsibilities.

Design & Procedures. There are many ways that design and procedures can facilitate strategic behavior. The most obvious are design aids such as the flight management computer that directly assist in strategic planning tasks. Procedures such as mandating that a flight plan be filed before the flight also encourage operators to think strategically.

Other features that might encourage strategic planning are less obvious. Procedures could be developed that encourage planning ahead, visualization, contingency planning, and rehearsing future aspects of the flight during periods of low workload. Particularly during pre-flight and cruise, when time is not critical but time-critical situations (i.e., taxi and take-off, and approach and landing, respectively) are imminent, standard procedures which encourage pilots to strategically prepare and plan for upcoming events, may be helpful.

Good graphic displays of the "big picture" and of predicted situations, and perceptually-salient methods for displaying historical and predictive information (e.g., Trujillo, 1994) and comparing actual and expected states (e.g., Abbott, 1990), are all display features that could help pilots perform strategic functions better. Concepts growing out of an ecological approach to design (e.g., Vicente & Rasmussen, 1992), such as interfaces that help users focus on information and situations at different levels of abstraction, and show spatial, functional, and temporal relationships among systems and tasks, could enhance strategic behavior as well.

Other design concepts on the horizon, such as automated aids to help pilots manage their task load (e.g., an aid can remind pilots of upcoming high workload situations, and offer recommendations for items that can be completed ahead of time, or items that could be reviewed or rehearsed ahead of time to allow less attention and effort be expended later), and strategic weather and flight planning displays and aids that will help pilots strategically collaborate with air traffic control and airline operations centers to plan and re-plan the flight, are aimed at allowing some tasks that are performed tactically now to be performed strategically. A general principle guiding flight deck design should be to provide information, displays, processing capability, etc., that allow pilots to perform functions and tasks strategically, form "big picture" situation awareness, and help balance attention and effort between strategic and tactical behavior.

Training. Training may be the area in which the most impact can be made on strategic thinking.

It is assumed that strategic thinking, while an innate human ability, can be improved through training and experience. But ìstaying ahead of the aircraftî is not easy, especially for an inexperienced pilot. As pilots become more proficient and experienced, there may be two factors affecting their ability to improve their strategic thinking. First, experience often reinforces the benefits of strategic thinking. As oneís ìpersonal databaseî of experiences and situations grows, evidence accrues that planning ahead really does pay off in avoiding time-critical situations, reducing the thinking required ìon the fly,î and anticipating potential problems. Explicit training on strategic thinking techniques and advantages could hasten the process of honing the ability to think strategically. The workload management part of training curriculums could give more coverage to contingency planning, rehearsal, visualization, forming expectations, etc. Good pilots rehearse difficult aspects of a flight ahead of time. They more frequently monitor conditions at the destination airport and at alternates. Based on weather and traffic, they anticipate contingencies and are more prepared for them when they occur. All these behaviors could be emphasized more in training with the hope that the average pilot would perform more like the best pilot, or the inexperienced pilot would perform more like the experienced pilot.

Second, as one gains more experience, and common, frequently performed tasks and activities become ìsecond nature,î that is, they require less attention and effort because they can be performed with skill-based or rule-based processing rather than with knowledge-based, more mental resources are available for thinking ahead. Appropriate training may allow inexperienced pilots to learn to more efficiently allocate mental resources sooner. Training pilots to operate in skill-based and rule-based processing modes is acknowledged to have safety and efficiency advantages, but it should be balanced with design features and methods that allow application of strategic thinking skills in situations where they have obvious advantages (e.g., novel situations, contingencies, planning tasks, etc.)

<u>Avoiding the pitfalls of strategic thinking</u>

Design, training and procedures must also help pilots avoid the pitfalls associated with strategic behavior. To the extent that pilot expectations or intentions are known by automated systems, automation aids can highlight data that are inconsistent, alerting pilots to possible confirmation bias or inappropriate plans. Training can help pilots be aware of the problems of complacency and boredom, and perhaps help pilots develop useful workload management strategies for combating low workload situations as well as high workload situations. Design features and training that help pilots form good attention and cognitive allocation strategies, far beyond simple ìvisual scanning,î strategies, might help pilots keep a proper balance between immediate tasks and the need to think ahead.

Perhaps the area that could be most aggressively addressed is combating known types of knowledge-based processing errors and their causes. Since human memory, mental models, and predictions are frail and imperfect, we should be able to develop methods and aids to improve these abilities on the one hand, and guard against known errors on the other. There is a vast literature that has explored how mental models are formed, what factors influence them, and what can be done in training to enhance their accuracy and completeness (e.g., Kempton, 1986; Sein & Bostrom, 1989; Vinze, Sen, & Liou, 1993; Frese et al., 1988; Bayman & Mayer, 1984). These findings could be distilled and applied to training curriculums. Education on methods of improving mental model construction would be useful, but even more basic, education on the types of traps and biases that can result from knowledge-based processes would be invaluable.

Summary

In summary, it is argued that we have an inherent ability to plan, predict, and think ahead. This strategic behavior has advantages and disadvantages in terms of workload, situation awareness and human performance. Human-centered design, training, and procedures that allow pilots to hone and exploit this ability, while safeguarding against its associated pitfalls, will increase aircraft safety through pilot error reduction and tolerance.

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