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MISSION-READY ADAPTIVE DECISION AIDS: THE NEW PERFORMANCE MODEL FOR CREW STATION DESIGN

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Discussed are three theories: 1) Bayesian probability theory, 2) signal detection theory, and 3) operational decision theory. To combine the three is to come to an understanding of how one can operate effectively in complex environments. Complex environments present unique challenges from a human performance perspective. They require applying uncommon skill sets to allow for optimization of performance. Applying analytic methods to clarify and respond to mission critical events is most urgent. The analytics of uncertainty is presented. Three mission critical decisions are discussed: to continue or abandon the mission, to perform the approach go-around maneuver, and to determine the takeoff go-no go. These are at the heart of optimizing mission level performance.

As a general class of phenomena, complex environments contain complex situations and systems. Complex environments are one of the most challenging to consider, in large measure because of our inability to understand and predict; they can be fraught with uncertainty. If one is planning to operate in a complex environment by employing large-scale dynamic systems, conventional reasoning cannot be used. Complex entities are non-deterministic by nature because complexity theory informs us that complex systems exhibit novel behavior and emergent properties, rendering these entities and phenomena to a class by themselves residing outside of conventional wisdom.

Tackling the decision problem for large scale dynamic systems utilized in the field of aviation is of immediate importance yet is arguably the most difficult. This is because very little is understood with respect to optimizing the performance of such systems, and previous attempts have not considered the levels of uncertainty associated with such systems.

The Overall Mission Continuation Decision

Operational decisions are singular among all other classes of decisions and represent the most important command activity. Operational decision theory supports operational decision making (ODM) and helps identify and optimize operational decisions. ODM provides for the broad situation awareness needed to identify risk and the structure to manage a rising risk profile.

An advanced qualification design team defined observable mission related activities. They realized various mission tasks were *not* performed in a linear sequence. High performing crews did something unexpected—they prioritized their tasks.

What is critical for mission success is how well flight crews and the captain solve problems in a complex environment. Non-linear problem solving took center stage. This breakthrough came with the following insights: all air carrier mission activities are highly planned, often using sophisticated planning tools. While all activities are planned, excellent pilots do not plan real-time activities. Some are discarded altogether. These pilots prioritize and select tasks using some kind of decision-making process to optimize mission outcome.

This decision making process gained definition after Keeny and Raiffa invented a branch of mathematics that dealt with the numerical weighting of multiple attributes. This defined operational

decisions, identified key decisions and specified triggers that activate certain decision pathways. High performing pilots were selecting optimum pathways, but this had yet to be understood.

An operational decision for pilots is now defined by Smith and Hastie (1992) as containing three unique components:

1. It must often be performed using incomplete information.
2. Once airborne, it is always performed under increased time compression.
3. Consequences of poor decisions are often catastrophic, placing the aircraft, crew, passengers, and the corporation in jeopardy.

Determining Risk

The operational decision for the air transport mission conforms to the following rules.

1. If the risk to the completion of the mission is low, then continue with the original mission plan.
2. If the risk to the mission is moderate, then modify the mission to either reduce or stop the risk from rising.
3. If the risk is high, abandon the mission plan and activate available alternatives. This we refer to this as “divert—reject—abandon.”

The nature of risk means we must deal with it or it can get worse—it will be a rising risk. In aviation systems, unless decisive action is taken during critical events, risk will continue to rise to a point where one experiences a catastrophic mission failure. This point is called the critical event horizon.

Rising risk can be explained by using the risk continuum. The risk continuum is organized into three zones. When risk rises it passes through zone one (low risk), to zone two (moderate risk). If the encountered event is critical enough, or if risk has not been mitigated, it will likely become high risk, zone three. Each zone has a certain action. For low risk, continue with the mission plan. For moderate risk, modify the mission plan to arrest the rise or lower the risk. For high risk, where catastrophic failure is probable, abandon the mission plan and immediately implement survival measures.

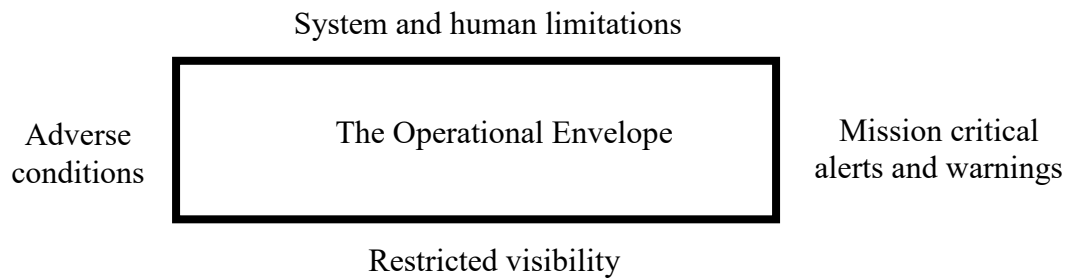
Operational Envelope

Four hostile agents create boundary conditions. These boundaries define when it acceptable to operate and when it is not. They are the edges of an operational envelope. See Figure 1. Low risk resides within the envelope. Risk factors that impact the mission but do not place the aircraft outside the boundaries should be considered as moderate. The operational strategy will be to modify but not abandon the mission.

Hostile agents come from four general directions. These are:

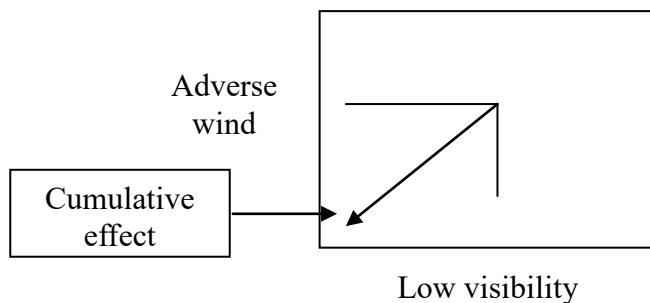
1. Any adverse condition, such as adverse wind, freezing precipitation, and so forth.
2. Restricted visibility. This can often limit the ability to land at a particular airport, causing great concern if insufficient fuel remains to proceed to an alternate airport.
3. Mission critical alerts and warnings. This could be such things as terrain alert, traffic alert, or thunderstorm detection.
4. Human and system limitations. System limitations could be speed or altitude, where human limitations could be fatigue, task overload, or inexperience.

Figure 1. Operational envelope created by boundary conditions.



Some agents are more dangerous, have more energy, or can bind with other agents, causing a dangerous “cumulative effect” if undetected. Figure 2 shows the combined vector is the resolved hypotenuse of the triangle formed. The combined vector travels to the corner of the mission space; this is a rising risk situation that must be addressed immediately.

Figure 2. The cumulative effect, when two sides of the operational envelope and bonded together to create a high risk situation.



Let us look at an example of risk, the operational envelope, and the cumulative effect. On December 12, 2005, flight 1248 attempting to land at the Chicago-Midway airport crashed (National Transportation Safety Board, 2007). At the time a significant Midwest snowstorm made the weather exceptionally poor. The flight crew had to deal with four hostile agents that had entered the mission space:

1. Braking action advisories in effect with fair to poor braking action reported.
2. Short runway with no overrun.
3. Adverse wind, with an 8 knot tailwind reported.
4. Low visibility and approaching landing minimums.

Using the operational envelope, we can see that the mission should be immediately abandoned. To attempt the approach and landing leaves the rising risk unchecked and it will pass beyond the critical event horizon, resulting in catastrophic mission failure. In this case this is precisely what happened.

Mission performance is optimized by first understanding the prevailing risk and then knowing what to do about it. When risk begins to rise, the flight crew must prioritize or discard activities to manage a rising risk profile. If risk mitigation measures are not effective, and the risk is high or projected to go to high, then the mission plan must be abandoned, and survival measures must be taken.

The Unstable Missed Approach Decision

Bayesian Probability

Bayesian probability is based on the concept that the likelihood of an event can be understood in terms

of a moving dynamic, which in turn acquires additional relevant information over time. Bayesian probability helps flight crew members determine the level of risk and uncertainty caused by certain events. A change in the operational environment causes the emergence of an event. These impedimenta can be referred to as *risk*, which is the level of uncertainty that the mission will succeed. Low risk means that mission success is essentially assured, while high risk may signify mission failure is most likely. This level of uncertainty is the problem space where the initial projection is expressed as a hypothesis P(H) that the condition will deteriorate.

1. P(H) is the probability of encountering a mission critical event and its impact on the mission.
2. P(E) is additional evidence that has been encountered expressed in probabilistic terms.
3. P(E/H) is an updated figure of merit for E given that H is true.
4. P(H/E) is the unknown that we wish to determine. It is the updated level of uncertainty.

Problem Solving Under Conditions of Uncertainty

Our case study involves an operation where it is critically important that the onset of instability be determined notwithstanding the uncertainty associated with other events.

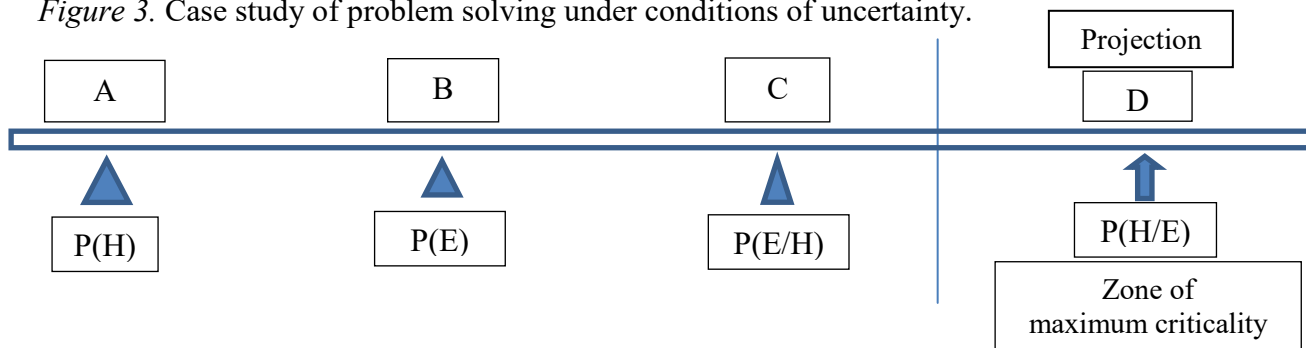
- At point A on the trajectory, an operational parameter has been exceeded. The likelihood that this out-of-tolerance condition will result in the onset of instability at the approaching point D, is key operational knowledge to maintain the integrity of the operation. This is represented by P(H). See Figure 3.
- Additional evidence is obtained at point B, and is represented by P(E). This evidence may be germane to the operation, and it could influence the determination of the onset of instability.
- At the conditional point along the trajectory, identified as point C, P(E) is assessed. Given that P(H) is true, P(E) is updated and given a value commensurate with this updated evidence. This probability is represented by P(E/H).

It is necessary to determine at point D on the trajectory whether the onset of instability will occur. If it is highly probable that instability will occur, then best practices dictate that the mission should be abandoned prior to reaching this limit. This probability is the determined value of P(H/E). This is the unknown that we wish to discover, or, in another way of presenting it, this is the unknown in the mathematical equation that represents all three previous points.

The mathematical equation is represented below.

$$P(H/E) = \frac{P(H) * P(E/H)}{P(E)}$$

Figure 3. Case study of problem solving under conditions of uncertainty.



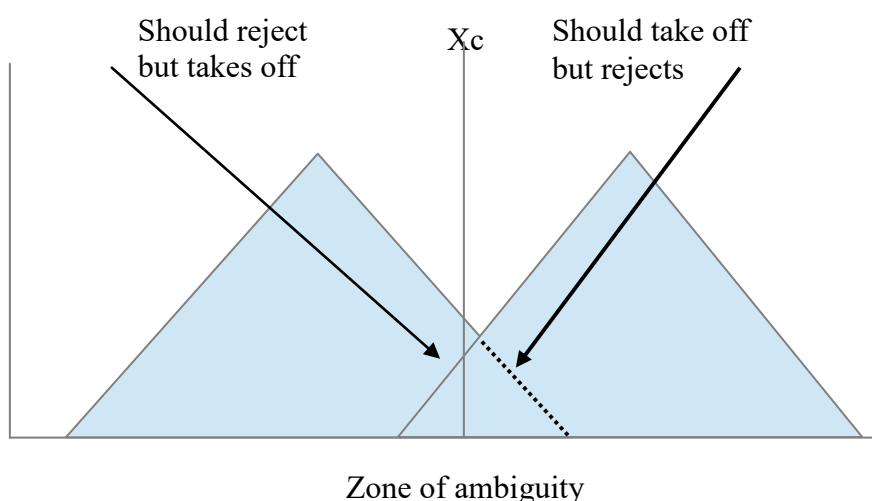
The Takeoff “Go/No-Go” Decision

In takeoff operations in large transport aircraft, the crew is constantly monitoring the environment and aircraft to assess the emergence of any operational risk. When the danger is either high or low, the decision is relatively straightforward. However, when the value is in the midrange, the decision becomes difficult. This region is called the zone of ambiguity.

Unexpected Operational Difficulties

X_c labels the decision criteria that is used to make the optimum decision. This situation is more complex than first realized when the area surrounding X_c is examined more closely. This is shown in Figure 4.

Figure 4. Zone of ambiguity is where the two areas overlap, showing where decisions become difficult.



Optimizing the Decision Function

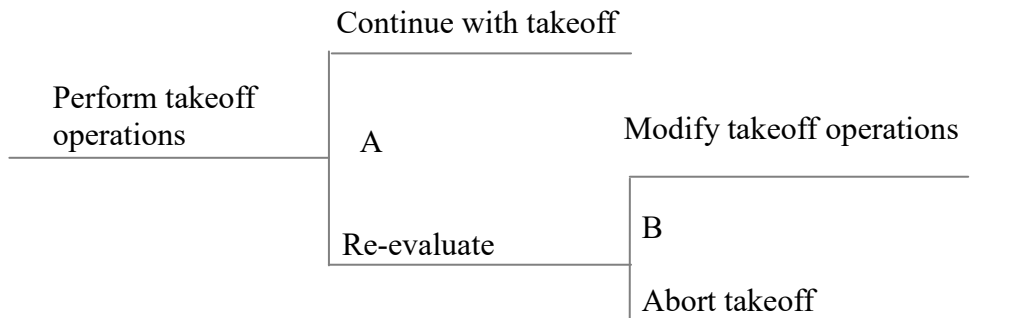
The analytical approach focuses on improving the discrimination between the two states (danger—should reject; low risk—can continue). This should be the primary goal of improvements in technology. But improvements in “discriminatory training” are also necessary. This corresponds to changing the relationship between the distributions by moving the distributions farther apart.

Operational Analysis of the Takeoff Decision

We will use the takeoff operation to show the decision analytic structure and its properties. The decision structure is represented in Figure 5. The key choice points are depicted. They involve the choice of continuing takeoff as planned, continuing takeoff with modifications to the operational plan, or aborting takeoff due to significant danger. In this example, the key choice points involve the primary choice to continue the takeoff as planned or reevaluate the takeoff plan. The secondary choice is contingent on the first—either to modify the operation to accommodate a rising risk or to abort the takeoff due to excessive risk. The key activities associated with each choice point are the mechanism by which the decision is executed. It is important to realize that an optimum decision selection criterion, called an alternative, is the ability to select the most accurate decision path with respect to the prevailing risk at the time. Choice Point A represents the primary binary decision. Notice that this entails the evaluation of risk. This is important for many reasons. Risk analysis is critical in selecting

the correct path. While execution of the proscribed maneuver is important, it is at Choice Point B after the risk is examined. Many studies as well as documented operational experience have suggested that the takeoff accident rate is excessive. But while this insight is important they focus mostly on the maneuver execution phase rather than first examining the higher-order skill requirements involving the optimization of the operational decision.

Figure 5. Decision analytic structure with key choice points.



Conclusion

A serious challenge facing aircrews is maintaining an acceptable level of risk while performing a mission. Key to their success is to determine with accuracy and clarity if a low risk situation prevails or is anticipated. If so, then crews can continue with the mission as planned. If a moderate risk posture is evident, then crews must modify the mission plan accordingly. If the risk posture is judged to be high, then crews must discontinue the current plan.

The effective management of risk involves the optimum placement of the decision criteria, which we have labeled X_c , along the risk dimension. It also involves the reduction of the ambiguity zone through discrimination methods. Current data shows that the probability that crews will not make the correct abort decision with respect to accurate assessment is 54 percent while 46% were correct. Flight crews are incorrectly assessing risk and aborting takeoffs at an alarming rate.

Among the many solutions that have been proposed to reduce takeoff accidents, several proposals have involved moving the decision criteria, X_c . However, such an administrative adjustment of the decision criteria should not be undertaken without a careful analytical study of improving the discrimination capabilities of prevailing risk.

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