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Decision Making in Complex Environments

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ABSTRACT

Bayesian probability theory, signal detection theory, and operational decision theory are combined to understand how one can operate effectively in complex environments, which requires uncommon skill sets for performance optimization. The analytics of uncertainty in the form of Bayesian theorem applied to a moving object is presented, followed by how operational decision making is applicable to all complex environments. Large-scale dynamic systems have erratic behavior, so there is a need to effectively manage risk. Risk management needs to be addressed from the standpoint of convergent technology applications and performance modeling. The example of an airplane during takeoff shows how a risk continuum needs to be developed. An unambiguous demarcation line for low, moderate, and high risk is made and the decision analytical structure for all operational decisions is developed. Three mission-critical decisions are discussed to optimize performance: to continue or abandon the mission, the approach go-around maneuver, and the takeoff go/no-go decision.

KEYWORDS

Bayesian Probability Theory, Complex Environments, Operational Decision Theory, Risk Management, Signal Detection Theory

INTRODUCTION

As a general class of phenomena, complex environments contain complex situations and complex 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, then conventional reasoning—especially determinism—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.

This article is an attempt to add some measure of analytic rigor to the discussion.

THE OVERALL MISSION CONTINUATION DECISION

Operational decision theory was created to support operational decision making (ODM). Specifically, this body of knowledge helps identify and optimize operational decisions. Operational decisions are singular among all other classes of decisions and represent the most important command activity. Importantly, ODM provides for the broad situation awareness needed to identify risk and the structural mechanisms necessary to manage a rising risk profile.

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In an effort to redesign pilot training from the ground up, the Advanced Qualification Program (AQP) attempted to understand specific pilot activities, with the objective of directly attacking the causes of controlled flight into terrain (CFIT). They defined observable mission related activities and attempted to integrate these with team related or interpersonal activities (crew resource management [CRM]). Through this and other studies, they realized that various mission tasks were not performed in a linear sequence, but were done selectively and differentially. Furthermore, simulator studies by Smith revealed more astounding results: high performing crews did something unexpected—they prioritized their tasks.

So, while the conventional CRM, what was considered the management of human resources, deconstructed task activities to understand the pilots and crews' tasks, it revealed something else entirely. But what was it? The answer came from Dr. Robert J. Sternberg (1985) and his theory of mental self-government and the theory of the executive. He proposed a "cognitive superstructure" that informed and triggered selective activities according to some rule as yet unidentified. If we understood the characteristics of this superstructure then we had a chance to understand how and why such crews did so well.

In the pilot's task universe, "mission activities" existed side by side with other "task organizing" activities. High performing pilots could differentiate and prioritize, thereby optimizing mission outcome. But what exactly is going on? Smith and Larrieu proposed a radical idea: How humans perform in groups (as a crew) is beside the point. What is critical for mission success is how flight crews and ultimately how well the captain solves problems in a complex environment. Thus, in subsequent work by Smith and Larrieu, nonlinear problem solving took center stage.

This breakthrough came with the following insights.

1. All air carrier mission activities are highly planned, often using sophisticated planning tools.
2. While all activities are planned, excellent pilots do not plan real-time activities. Some are discarded altogether.
3. These pilots prioritize and select tasks using some kind of decision-making process to optimize mission outcome.

This decision-making process gained definition after Keeney and Raiffa (1976) invented a branch of mathematics that dealt with the numerical weighting of multiple attributes, or multi-attribute utility theory (MAUT). 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 is a three-branched network, which captures the planning nature of the activity, the need to prioritize to optimize the outcome, and conforms to the following rules.

1. If the risk to complete the mission is low, then continue with the original mission plan.

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