

Decision Analysis in a Passive Detection Battlespace

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INTRODUCTION

Military theorists across the millennium have identified the rate of effective decision-making compared to an adversary's as a cornerstone for success on the battlefield.¹ In its most recent conflicts, the US has held tactical dominance because of its well-developed intelligence, surveillance, and reconnaissance (ISR) assets' ability to accelerate the rate of good decisions by eliminating uncertainty in a battlespace. However, today's battlespace with strategic competitors like the People's Republic of China (PRC) is increasingly complex, and US ISR assets will have greater difficulty eliminating uncertainty. In the contested South China Sea, the PRC is complicating the battlespace with passive systems that can detect an incoming aircraft without the aircraft's knowledge that it has been detected. When the PRC has accurate information while its adversary is uncertain, it allows the PRC to make more effective decisions faster. To strike targets and survive, US aircrew will have to adapt their decision-making for an uncertain environment. Therefore, the effectiveness of US warfighter's decision-making in the Chinese passive detection battlespace requires accurate risk assessment by balancing the perceived probability of outcomes with the perceived gravity of consequence. Specifically, the US should educate warfighters to understand uncertainty aversion's effect on probability estimation and loss aversion on perceived consequences to make timely, effective decisions.

PASSIVE SYSTEMS

This paper defines a passive detection system as able to receive electromagnetic energy but has no associated active transmitter. Thus, the system is not used directly for targeting but can pass data to a kinetic system that can target an aircraft. In simplest terms, a passive system looks or listens for an approaching adversary aircraft. Two examples of passive detection

systems utilized by the PRC are maritime E-Stations and multi-static radars using non-cooperative transmitters.

First, the PRC layers their maritime interests in the South China Sea with environmental research platforms to acquire incoming aircraft visually. E-Stations contain Electro-Optical (EO) equipment pointed skyward that can be used to detect stealth aircraft.² Only limited by the fidelity of the equipment, EO sensors can detect any overflying aircraft within a clear line of sight. Moreover, these floating EO sensors are mobile and have a synergistic effect when spread out over vast distances to complicate the battlespace.

Second, the PRC complicates the battlespace by using radars that listen instead of transmitting. A multi-static radar with a non-cooperative transmitter uses several antennas to listen and triangulate received signals from an incoming aircraft to gather range and bearing data. Unlike a traditional radar with an active transmitter to send out signals, the non-cooperative transmitter can be any broadcast signal in the electromagnetic spectrum.³ These signals can be civilian television, FM/AM radio stations, or even High Frequency (HF) signals. Civilian signals are the active component of a passive system and reflect energy off an incoming aircraft to the receiver antennas. Some US assets have the advantage of being able to discern when they have been detected by traditional actively transmitting early warning (EW) radars. However, the pure volume of civilian frequencies an aircraft flies through makes monitoring all potential frequencies impossible, thus creating an asymmetry in information. The passive system knows the aircraft's location, but the aircraft does not know it has been detected. The PRC values assets designed for asymmetric warfare. The most emphasized asset in the Chinese Navy is not the aircraft carrier but the submarine for its ability to move and strike with a cloak of uncertainty.⁴

Similarly, passive systems threaten aircraft asymmetrically as a force multiplier for kinetic systems and clouds an aircrew's perception of risk. An integrated air defense system incorporating both passive systems and a mobile kinetic weapon can detect an adversary aircraft from a distance then move its kinetic asset to a more advantageous position before the aircraft's arrival. Estimating an accurate order of battle (OB) and when a US aircraft should anticipate being detected is difficult when the PRC employs passive sensors. Passive detection simultaneously increases the clarity of the battlespace for the PRC while clouding the enemy's perception. An uncertain battlespace is concerning to a force because of the human element of risk assessment and payoff estimation.

To explain uncertainty's impact on risk assessment in decision-making, it is essential to understand how risk is measured. Military risk is defined as "the estimated probability and consequence of the Joint Force's projected inability to achieve current or future military objectives (risk-to-mission) while providing and sustaining sufficient military resources (risk-to-force)." ⁵ Interpreted mathematically.

$$\text{Risk} = \text{Probability of Losing} (\text{Consequence of Losing})$$

Risk is an objective measure, whereas risk perception is subjective because of the human element in estimating both variables, probability, and consequence.

Firstly, Humans are averse to uncertainty and are inclined to make incredibly risky decisions instead of uncertain decisions. Renowned economist and military analyst Daniel Ellsberg showed that people reliably prefer to choose a known risky option over an uncertain option.⁶ The following illustrates Ellsberg's Paradox by translating his experiment into a passive detection battlespace.

An aircraft has two potential routings to a target. The first has a high level of confidence in OB with an estimated 80% chance the aircraft will strike its target and survive. The second also has a high level of confidence in OB with an estimated 99.99% chance of striking its target and surviving but is through a sea lane that could contain passive sensors. If the aircraft is detected passively in the sea lane, the enemy will move a mobile SAM system next to the aircraft's target reducing the aircraft's survivability by 30%. In this scenario, there are no passive sensors, only an uncertain possibility. Therefore, route one is objectively 19.99% riskier than route two. Based on the Ellsberg Paradox, a commander will prefer the objectively riskier first option because of the uncertainty of the second. Based on the Ellsberg Paradox and the human tendency for uncertainty aversion, decision-makers will inaccurately quantify uncertainty as risk in their decision-making. In a decision tree of possible consequences, the square represents which direction to launch the aircraft, and the circle represents the uncertain events.⁷ A commander's decision tree could be perceived as follows, and just like Ellsberg's findings, they will prefer the riskier known quantity because of uncertainty aversion.

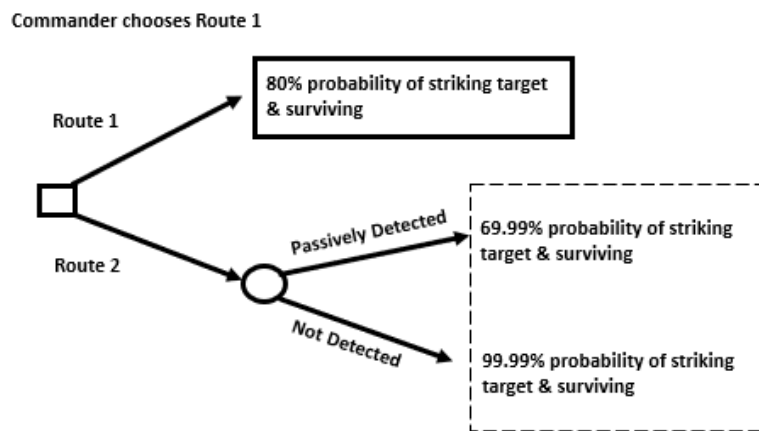


Figure 1: Example decision tree

Secondly, there is also a human element in estimating perceived consequences, and humans are inclined to overestimate loss. Therefore, decision-makers must weigh the uncertainty

with the perceived consequences of losing and winning to make sound decisions. In economics, this is known as weighing risk versus reward. Making decisions in uncertainty is not a novel concept. John von Neuman, known as the father of game theory, created the expected value theorem to measure the total average value of a gamble. The expected value of a consequence can be found by multiplying outcomes by the probability that they will occur and then summing all those values.⁸ Shown here:

$$EV = \sum P(X_i) \times X_i$$

Air Force decision-makers use models like expected value to decide when the perceived payoff is worth the perceived risk. A payoff being the value associated with the outcome of a game.⁹ This process ensures reward is greater than risk. A commander can quantify their perceived risk and conceptualize it in terms of reward. For example, a commander observes uncertain ISR data due to passive sensors in an area and perceives that a specific aircraft type's loss rate will be 50% per day. The aircraft value is \$100M and is assigned a target valued at \$125M. Solely based on the expected value theorem and dollar values, a worst-case scenario can be modeled:

$$\begin{aligned} EV &= .5 (\text{winning value}) + .5 (\text{losing value}) \\ EV &= .5 (125) + .5 (-100) \\ EV &= \$12.5M \end{aligned}$$

This mission is expected to yield a net \$12.5M advantage over the enemy. This data on perceived payoff can now aid that commander in deciding to launch.

The critical issue is that the expected value theorem and mathematical modeling are incomplete, and there is still a human element of estimating consequences. Through experimental studies, humans will make irrational decisions when compared to the expected value theorem. The fundamental divergence from the expected value is the behavioral law of

diminishing marginal utility.¹⁰ In economics, “utility” refers to the total ability for a good or service to satisfy desire, whereas “value” typically relates to currency.¹¹ When thirsty, a human appreciates the first glass of water more than the hundredth. John von Neumann expanded on his work by pioneering the expected utility theorem, which determines that humans deal in utility, not value.¹² Expected utility theorem is the expected value theorem corrected for the human element of decision-making. Utility marginally diminishes, so it is most accurately represented by a square root function of total values involved in a mission’s consequence. A commander may have all the empirical data, but the aircrew executes the mission.

For example, the same situation as above is played out but from the aircrew’s perspective. This assumes utility equals the square root of the previously established variable, value. Expected Utility Theorem shows that:

$$EU = \sum P(U_i) \times U_i \quad \text{Where } U = \sqrt{\text{Total Value of consequences}}$$

$$EU = \text{probability of winning (utility of winning)} + \text{probability of losing (utility of losing)}$$

The aircrew starts with a \$100M aircraft and has the potential to leave the engagement with \$225M if they strike the target or a value of \$0 if shot down.

In this case the starting utility for the aircrew is:

$$U = \sqrt{100}$$

$$U = 10$$

The utility of winning:

$$U = \sqrt{225}$$

$$U = 15$$

The utility of losing:

$$U = \sqrt{0}$$

$$U = 0$$

Therefore, the Expected Utility of the engagement is:

$$EU = .5 (15) + .5(0)$$

$$EU = 7.5$$

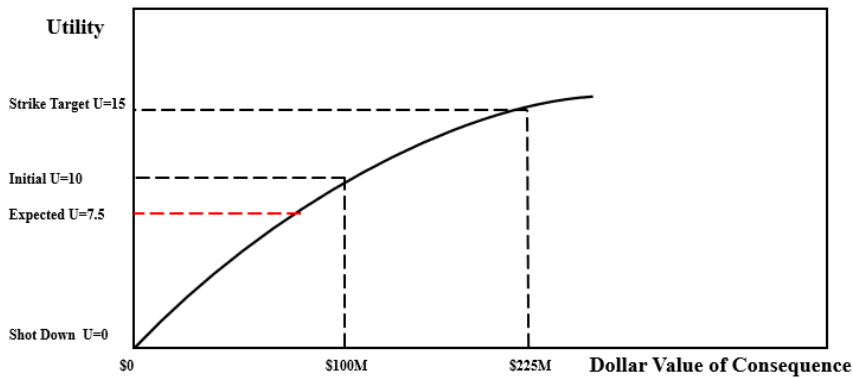


Figure 2: Expected utility

In this scenario, the aircrew's perceived utility of striking the target is less than the starting utility of 10. This illustrates that humans are predisposed to gain more utility from "not losing" than "winning." This strong human element known as loss aversion can cloud a decision-maker's judgment when making split-second decisions.

RECOMMENDATIONS

The examples above display the human disposition to prefer known risk to uncertainty and that loss aversion can affect the evaluation of consequences. This paper seeks first to educate warfighters to understand uncertainty aversion's effect on probability estimation and second, loss aversion on perceived consequences to make timely, effective decisions.

First, understanding consequences require cardinality. There is a well-founded process for quantifying the probability variable of the risk equation known as Acceptable Level of Risk (ALR). ALR defines the maximum allowable aircraft loss rate per day to maintain combat operations in an area of responsibility. Aircrew are expected to employ tactics that probability loss is at or below the acceptable loss rate. This method identifies the probability of risk for each aircraft in an uncertain environment. However, the second variable, the consequence of success,

is incomplete at the tactical level. Based on the US targeting process, strategic and operational level decision-makers have more clarity between target priority and the associated impact on the overall war effort.¹³ The payoffs for a target are clear. The Combat Plans Division (CPD) of an Air Operations Center (AOC) will assess the payoff of striking a target, rank it by assigning a priority based on the commander’s intent, and then publish the Joint Prioritized Target List (JPTL). This process has an element of decision-making capacity that is lost when passed down to the tactical level. In game theory, payoffs are divided into two categories, “Ordinal” and “Cardinal.” Ordinal refers to a ranking of preferred outcomes, whereas cardinal refers to the intensity in which those outcomes are preferred.¹⁴ The JPTL is a prime example of ordinal payoffs, but it is essential for games involving uncertainty to have cardinal payoffs. Based on the doctrine of centralized command and decentralized execution, the mission commander and aircrew executing the mission require an understanding of the intensity in which a target is preferred to maximize outcome.¹⁵ The AFTTP3-3.IPE on Integrated Planning and Execution address consequence versus risk when describing ALR, but it is incomplete.¹⁶

Figure 1.4 Risk Heat Map.

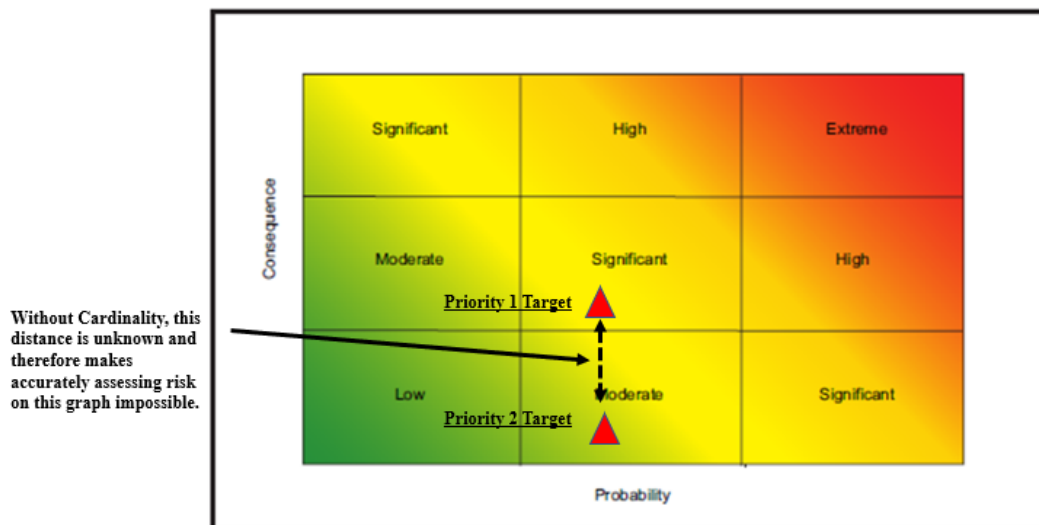


Figure 3: Risk heat map, relationship between probability and consequence to determine ALR

The critical omission to this graph of probability versus consequence is that the vertical axis of this graph is useless to a mission commander if there is no cardinal measurement of target gravity. Uncertainty and perceived risk are dynamic. The aircrew will have the most up-to-date probability evidence, but they require a cardinal measurement of payoff to maximize consequence in an uncertain battlespace. Increasing aircrews' understanding of a target's cardinal impact will allow the aircrew to maximize payoffs as probabilities change.

Second, the Air Force must then educate decision-makers about loss aversion. As shown in the example above, humans are predisposed to prefer "not losing" to winning. Unfortunately, the current ALR guidance is incomplete in that it is entirely loss-focused without addressing loss aversion.¹⁷

Loss Focused

Recommended Addition Example

Table 1.3 Example AOD Guidance Template.

ALR	Tactics, Techniques, Procedures	Implications and Example	Expected Daily Loss Rate	Expected Target Effect
Low	Operate outside known threat weapon engagement zones; mitigate environmental hazards. Factor threats destroyed or neutralized with BDA prior to entering. High confidence of threat OB.	Sustained operations, indefinite duration. Preservation of forces/capabilities is higher priority than mission success. <i>(OEF, NATO Air Policing)</i>	Normal attrition	OEF targets, largely strikes on insurgents engaged in asymmetric warfare
Moderate	Accept only advantageous engagements; (1) destroy, neutralize or suppress factor threats prior to entering with bomb hit assessment or (2) use highly effective onboard defensive system/low risk tactic. High confidence of threat OB.	Unit is combat-ineffective in 60 ±30 days; facilitates sustained air campaign of defined duration. <i>(OPERATION DESERT STORM, Allied Force)</i>	< 1/100	DESERT STORM targets, included a vastly inferior but still lethal integrated air defense system. Required to gain air supremacy.
Significant	Prudently accept increased risk; enter factor threat environments with (1) valid counter-TTP or defensive suite, and (2) if threats are disrupted. Reasonable confidence in threat OB.	Unit is combat-ineffective in 72 hrs; allows for TPFDD back-fill or operational pause to halt losses. <i>(Linebacker 2, Package Q)</i>	< 1/5	Linebacker 2 targets, included industrial centers and infrastructure. Strikes assessed to bring N. Vietnamese to peace talks.
High	Accept disadvantageous engagements; enter factor threat environments with (1) valid counter-TTP or defensive suite or (2) if threats are disrupted.	Unit is combat-ineffective in one ATO day; allows for back-fill on next ATO cycle from in-theater assets or for COD/msn commander to direct "abort." <i>(WW2 Schweinfurt Raid, Op Tidal Wave)</i>	< 1/2	Schweinfurt Targets, assessed to cut Nazi warmaking capability by 30%.
Extreme	Accept any engagement that results in some probability of success. Enter any threat environment.	Unit is combat-ineffective in one sortie, no abort option; force annihilation is acceptable. <i>(WW2 Doolittle Raid)</i>	> 1/2	Doolittle Targets consider vital for US morale to continue war.

NOTE: These terms were chosen to align with CJCSM 3105.01.

Figure 4: Example ALR breakout for an air operations directive (AOD)

Loss aversion has its most pronounced effects when it is unrecognized. It is essential for aircrew to evaluate probability and consequence continuously in terms of payoffs. This cannot be encapsulated with any mathematical solution, so they will “need to leverage some degree of intuitive flair or instinct to evaluate risks and respond appropriately.”¹⁸ The feel for decision-making is developed primarily academically and then concretely through experience. In the absence of experience, a decision maker’s only preparation for the battlespace is written guidance and training.

CONCLUSION

The rate of effective decision-making by the US warfighter will define US relevance in strategic competition. Passive systems create uncertainty in a battlespace that ISR cannot completely illuminate, and there is a human element to both the probability and consequence variables of military risk. In a force of centralized command and decentralized execution, the aircrew will have the most current evidence of a battlespace. Therefore, the aircrew should be trained to measure success in cardinal terms to balance loss aversion and be cognizant of uncertainty aversion to avoid overestimating risk. These two thought processes will aid decision-makers to balance risk versus reward to make effective, timely decisions in the battlespace to strike targets and survive.

END NOTES

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