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A Simple Game-Theoretic Approach to Suppression of Enemy Defenses and Other Time Critical Target Analyses

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SUMMARY

When planning operations against time-critical targets (TCTs), commanders typically think about how much capability they need to kill enemy forces. However, they also consider how their strategies will affect the enemy's behavior. TCT operations include suppression of enemy air defenses (SEAD), interdiction of moving forces, and attacks against theater ballistic missiles (TBMs). Convincing an enemy not to fire surface-to-air missiles (SAMs), not to move his forces, or not to launch TBMs is an equally good outcome as actually defeating his capabilities. This approach is what military analysts today refer to as "effects-based operations."

Traditional methods of planning TCT operations are not adequate to analyze these effects. Planners typically seek to determine how much capability the United States would need in order to defeat an enemy who exerts maximum effort. This approach was valid during the Cold War when an enemy faced with a nuclear air strike was expected to activate all of his air defenses at the outset of the conflict. However, in the types of military campaigns that the United States faces today, an intelligent enemy is not expected to pursue a fixed, highly aggressive strategy. Rather, he is expected to adjust his behavior in response to U.S. capabilities and actions. For example, an opponent faced with air strikes will consider the value of his SAMs, the value of the target under attack, and the level of resources U.S. forces are devoting to SEAD before he decides how much air resistance to mount. This behavior has been seen in recent conflicts such as Operation Allied Force (Kosovo) and Operation Desert Storm (Iraq). Under certain conditions, an intelligent enemy might conclude that his best option is not to fire SAMs at all. If military planners can understand how these factors influence an enemy's decisionmaking, then they can determine what capabilities and strategies the United States would need in order to paralyze an opponent.

Researchers within RAND Project AIR FORCE have developed a method that military planners can use to analyze the effects of U.S. strategy and capabilities on the enemy in TCT operations. The method uses the mathematical techniques of game theory to understand how each side of a military conflict influences the other's decisionmaking and how one side can compel the other to follow a preferred course of action.

GAME THEORY PROVIDES A METHOD FOR ANALYZING TCT OPERATIONS

Game theory was developed in the 1920s as a way of using mathematics to model human decisionmaking in competitive situations. It is ideally suited for analyzing military situations. A military conflict can be represented as a two-player game in which the interests of both sides are diametrically opposed. If one side wins, then the other side must lose. Both sides are free to choose between a variety of moves and to adjust

their strategy over the course of several turns. The advantage of game theory is that analysts do not know in advance what the enemy will do. Thus, they are forced to account for the realistic situation in which an intelligent enemy may decide for himself what his best move is. Analysts draw conclusions about the factors that compel each side to adopt a given strategy.

Military planners can apply these principles to TCT operations through game theoretic analysis. The method consists of the following steps:

- **Determine the tactical options available to each side.** Analysts assume that each opponent can choose between a range of possible actions. For example, in a simple SEAD operation, the attacker (called "Blue") can choose to fly a strike aircraft, such as an F-16 CG, or to fly a SEAD aircraft, such as an F-16 CJ. The strike aircraft attempts to get past enemy air defenses and to strike a target on the ground. The SEAD aircraft detects radio emissions from active SAM radars and attempts to destroy them. The defender (called "Red") can choose to activate his SAM radars or to leave them inactive. Analysts may construct games in which each side has more than two options. The arithmetic is more complex, but the principles are the same. (See pages 3-4.)

- **Assign a numerical value to each possible outcome.** Commanders in the field routinely make value judgments about the strength of their capabilities, the probability that their weapons will hit a target, and the potential gain or loss of a particular engagement. Analysts can represent these judgments in mathematical terms by determining the measures of effectiveness (MoEs) for each capability. For example, Figure S.1 shows the MoEs in the simple SEAD game from Blue's point of view. Analysts judge that a Blue strike aircraft is worth five points. Thus, if Blue flies a strike aircraft and Red activates his SAMs, then the aircraft is likely to be shot down and Blue will lose five points. If Blue flies a strike aircraft and

	Red SAM engages	Red SAM does not engage
Blue flies strike	–5	1
Blue flies SEAD	5	0

Figure S.1—Analysts Assign Notional MoEs to Each Outcome

Red does nothing, then Blue will win one point for moving past enemy defenses. Conversely, analysts judge that a Red SAM is also worth five points. If Blue flies a SEAD aircraft and Red SAMs engage, then Blue will win five points for likely hitting a SAM. If Red does not activate its SAMs, then Blue will gain nothing from the encounter. (See page 4.)

- **Calculate all possible strategies and their outcomes.** Intelligent opponents vary their tactics in order to appear unpredictable to the enemy. Thus a combatant's overall strategy is determined by how often he chooses one tactical option over another. Analysts may calculate all possible strategies and the mathematical outcomes of each strategy. This information may be presented using a graph such as Figure S.2. The MoEs from Figure S.1 are reproduced to the right of the graph. The x-axis represents the percentage of the time that Red chooses not to activate his SAMs. The y-axis represents the percentage of the time that Blue chooses to fly a strike aircraft. The shaded bands represent the outcome of each combination from Blue's point of view. Using this chart, analysts can understand how each combatant may alter his strategy based on the other side's actions. For example, if Blue perceives that Red withholds his SAMs most of the time, then Blue may choose to fly more strike aircraft than SEAD (upper right corner). This is a good outcome for Blue because his strike aircraft can continue on to strike enemy targets. However, Red may turn the engagement in his favor by activating his SAMs more often (upper left corner). This is a bad outcome for Blue because he will lose a high percentage of strike aircraft. Blue may reverse the outcome again by increasing the proportion of SEAD aircraft (lower left corner). Based on this kind

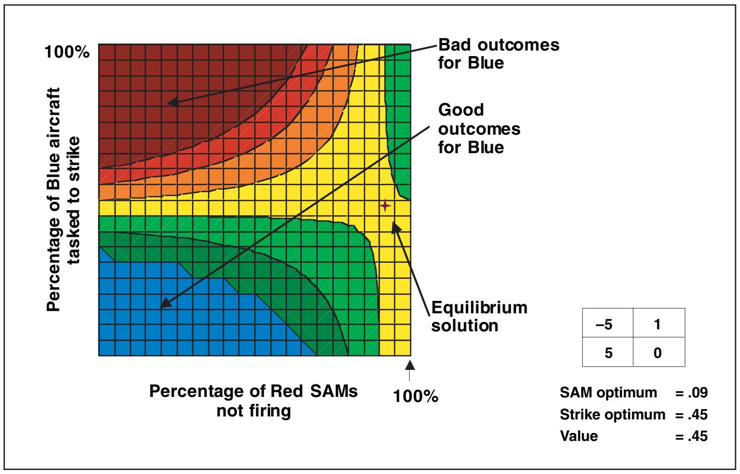

Figure S.2—Analysts Calculate the Results of Each Combination of Strategies

of analysis, planners can anticipate how an enemy is likely to respond to a given strategy. (See pages 5-6.)

- **Find each side's optimum strategy**. The optimum strategy is the best strategy that each side can pursue without the other side being able to turn the engagement in his favor. Experience teaches that as opponents in a game adjust to each other's actions, each player will eventually settle on his optimum strategy, also called the "equilibrium solution." In military terms, the optimum strategy is not necessarily the most desirable outcome, but rather the best that one can do against an opponent of given strength. Figure S.2 shows the optimum strategy for each side of the simple SEAD game. The cross on the right shows that Blue's optimum strategy is to fly strike aircraft 45 percent of the time, while Red's optimum strategy is to fire SAMs only 9 percent of the time. If Red fires SAMs more often, then Blue can move the outcome toward the lower left corner by increasing his SEAD. If Red fires fewer SAMs, then Blue can move toward the upper right corner by flying more strike aircraft. (See pages 6-7.)

- **Determine the expected result of the game.** Having found each side's optimum strategy, analysts check to see whether the outcome of the encounter favors Blue or Red. In the SEAD example, Blue gains an average score of .45 even if Red plays his optimum strategy. This type of finding is very important to analysts because it indicates that even if both sides play intelligently, Blue will have a positive result. Moreover, it indicates that if Red correctly ascertains his situation, then he would rather not participate at all. (See page 7.)

A benefit of game theoretic analysis is that it tells planners how much capability they would need in order to achieve the best outcome for their side. Planners can adjust MoEs to represent better and more valuable aircraft, more costly SAMs, more valuable targets, and other variables. For example, if Blue's strike aircraft were to carry nuclear bombs, then analysts might raise the value of striking the target from 1 to 100. In this scenario, Blue would need to fly strike aircraft only 5 percent of the time and would gain an average overall score of 4.54. Red could do nothing to prevent this loss, even if he fires SAMs 90 percent of the time (his optimum strategy).

This document provides additional illustrations to show how planners can adapt game theoretic analysis to TCT operations such as more complex SEAD operations, interdiction of moving forces, and anti-TBM missions. (See pages 14-39.)

WHEN PLANNING TCT OPERATIONS, ANALYSTS SHOULD CONSIDER THE EXPECTED DURATION OF THE WAR

As described above, planners may use game theoretic analysis to model single TCT engagements with fixed MoEs. However, MoEs may change over the course of a conflict, depending on how long each side expects the war to last. Therefore, when analyzing real-world situations, planners should also consider the implications of longer conflicts with multiple engagements. For example, if a combatant expects a short conflict, then he is likely to place a higher value on achieving his operational objectives, such as striking a target or shooting down an enemy aircraft, than on preserving his own capabilities, such as aircraft and SAMs. This is the case in the nuclear air strike scenario described above. Conversely, if a combatant anticipates a long conflict, then he is likely to place a high value on his limited capabilities and to use them more sparingly until the last few engagements of the war. (See pages 42-49.)

Game theoretic analysis shows that if opponents hold different views about the duration of the war, the side that is correct will have an advantage. Each side will play what he believes to be the optimum strategy and will be surprised to find that his opponent does not play as expected. For example, if Blue correctly anticipates a short war (i.e., Red's targets are high-value) and Red conserves his SAMs, then Blue can inflict heavy damage with a small proportion of strike aircraft. If Blue is incorrect (i.e., Red's targets turn out to be low-value), then Red can shoot down Blue's much-needed strike aircraft with only a small proportion of SAMs. In a real conflict, an intelligent commander faced with this scenario would ask himself whether his opponent is mistaken or whether his opponent knows something that he himself does not. In a planning context, this scenario underscores the importance of understanding MoEs from the opponent's point of view. (See pages 50-52.)