Strategic Decision Making in the Presence of Adversaries

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1. Overview

In this research, the use of stochastic games for modeling homeland security related decision problems is introduced. This approach offers an alternative approach to the conventional decision analysis techniques as it captures the antagonism inherent in terrorism related decision making problems, where two (or more) decision makers interact adversely. Equilibrium and sensitivity analyses are performed and presented using optimization and simulation. Robustness of the models is investigated with regards to data uncertainty.

The tools developed in this research are applied to the Man Portable Air Defense Systems Problem (MANPADS). We compare our results with the existing results in the literature that uses conventional decision analyses techniques and point out its benefits, similarities, and differences. Our findings on the use of stochastic games also indicate that the application of such games is by no means only restricted to the MANPADS problem, and could be practiced on various security-related problems that involve strategic decision making in the presence of adversaries. On the other hand, we have found that instead of using a robust approach to narrow data uncertainty sets, it is more beneficial to consider large data uncertainty and perform sensitivity analyses on equilibrium points and best response problems for the defender and the attacker.

2. Research Accomplishments

Our research falls into the category of Risk Assessment. Within risk assessment, our work is related to decision analysis to counter terrorism.

We use discounted stochastic games in this research. In stochastic games, the play proceeds from one state to the other according to transition probabilities controlled jointly by two or more players. It consists of states and actions associated with each player. Once the game starts in a state, each player chooses their respective actions. The play then moves into the next state with some probability and continues from thereon. The probability that the game moves into the next state is determined by the current state and the actions chosen in the current state. We apply this natural modeling methodology to analyze the effectiveness of the countermeasures for the MANPADS problem.

We also develop a new methodology called discounted robust stochastic games. This is a robust optimization model for n-person finite state/action discounted stochastic games with incomplete information. We consider n-player, non-zero sum discounted stochastic games in which none of the players knows the true data of the game and each player considers a distribution-free incomplete information stochastic game to be played using robust optimization. In other words, for the unknown data of the model, a player uses a robust optimization approach, where the player wishes to optimize against a worst-case data scenario. Discounted robust stochastic games allow us to use simple uncertainty sets for the unknown data of the game, and eliminate the need to have an a-priori probability distribution over a set of games. We prove the existence of equilibrium points and propose an explicit mathematical programming formulation for an equilibrium calculation.

A crucial property of our approach is that since the data of our models may depend on both the attacker and the defender, the fate of the decision makers is coupled in the process. This property is intimately

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related, in general, to the characterization of security investment decisions in the presence of terrorism threats, and to the MANPADS case in particular.

As in most Game Theory oriented models, solving our models in this research requires the players (decision makers) to optimally response to each others' potential strategic behavior. Hence, the equilibrium strategies of the players could be cast as an optimization problem. In this research, we have developed a generic AMPL script, a mathematical programming language code, to solve our models for equilibrium as well as to perform sensitivity analyses. Using this code, sensitivity analyses that also include simulation, could be performed both on the equilibrium strategies, as well as the on best response problems for the defender and the attacker.

Our research also sheds light to the question of whether using a robust approach or a sensitivity analyses approach to data uncertainty in homeland security related decision models. To this end, a new methodology, discounted robust stochastic games, is developed.

In our work, we apply a stochastic game model and sensitivity analyses to investigate the cost effectiveness of directed infrared countermeasures to protect commercial airliners from a possible MANPADS attack. Our analyses suggest that the countermeasures are cost-effective if the countermeasures costs over a ten year period is around \$10 billion, the attack probability is high (around $4 billion), and if the fatal crash cost is more than about $75 billion. This conclusion is parallel to a conclusion given in a previous report on the topic that uses decision tree analyses. Furthermore, we conclude that if the attack probability is less than 0.4 and the re-play probability is low (around 0.1), then the countermeasures are not cost-effective unless economic costs associated with a fatal crash are very high (above $250 billion). Finally, our results suggest that assuming the attack probability is around 0.2, countermeasures could be cost-effective if economic costs of a fatal crash are above $50 billion, and if the MANPADS threat continues to exist with high probability, given that no attacks occur and no countermeasures are installed.

On the other hand, the use robustness for MANPADS problem present difficulties, as the uncertainty sets for the MANPADS model are quite large. We have discovered that instead of using a robust approach to narrow data uncertainty sets, it is more beneficial to consider large data uncertainty and perform sensitivity analyses on equilibrium points and best response problems for the defender and the attacker. However, if the uncertainty is moderate, robust approach could be adopted, especially if the decision maker is risk averse and wishes to consider worst-case data scenario.

3. Applied Relevance

Our work has been applied to the MANPADS case study problem. In this research, we have developed a generic AMPL script, a mathematical programming language code, to solve our models for equilibrium as well as to perform sensitivity analyses and Monte Carlo simulation. Using this code and a suitable solver, sensitivity analyses that also include simulation, could be performed both on the equilibrium strategies, as well as the on best response problems for the defender and the attacker. This program could be useful if it could be incorporated into RAW. It is very natural to represent stochastic game models via a user-friendly graphical interface that could easily be understood by managers. It could be used by DHS analysts interested in best response analyses for various problem types studied within CREATE, such as biological threats, border security, and etc.