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TOWARDS A GAME THEORY MODEL OF INFORMATION WARFARE

THESIS

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THESIS

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Abstract

The production and exchange of information has become a central activity in today's global economy. Protecting and securing information as it travels over the vast, mostly public Internet has emerged as perhaps the premiere issue of the Information Age. Thus, the attack and defense of electronic information has formed an entirely new kind of conflict – information warfare.

Information warfare is still in its infancy. Government and private organizations alike poorly understand this ubiquitous form of confrontation. Nevertheless, they cannot avoid devoting ever increasing portions of their budgets to information warfare. Both obtaining other's information and defending one's own information have become critical economic decisions. As with any economic decision, the benefits (i.e. utility) must be commensurate with the resources expended to acquire those benefits.

Game theory could provide a new method for analyzing information warfare. The strategic and tactical decisions that face information warriors are essentially economic in nature. Does the value of the information being defended or sought justify the cost of protecting or seeking it? Game theory could contribute to a better understanding of information warfare strategy and implications.

The application of game theory to information warfare is a complex and massive undertaking. This study is but the first step in exploring the full ramifications of this potential application of game theory.

TOWARDS A GAME THEORY MODEL OF INFORMATION WARFARE

1. Introduction

Information warfare (IW) is a complex problem of competitive negotiations between parties who have incomplete information regarding each other's intentions and capabilities. IW can be characterized as inter-related and repeated discrete engagements among participants who are rational and goal oriented (Libicki, 1997: 40). IW participants often engage in a particular strategy, assess their outcomes, refine their strategy based on these outcomes, and then reengage with their refined strategy. This process is far more rational than the common and incorrect view of IW as the venue of joyriding teenage hackers (Kovacich, 1997: 56).

Although seemingly random IW attacks occur on a regular basis, formalized IW among participants with specific goals is now increasingly relevant. IW is becoming an important part of corporate and military strategy. Corporations and militaries include IW as a formal way of obtaining their goals. IW strategies are also highly interrelated. Specifically, IW participants develop strategies to combat specific strategies of their opponent. Participants must determine if an unsuccessful strategy failed of its own accord or due to the actions of their opponent (Kovacich, 1997: 56).

1.1 Application of Game Theory to IW

Game theory has shed light on similar problems in economics and other social sciences. Game theoretic analysis of nuclear disarmament negotiations provides a particularly relevant foundation for the development of a game theory model of information warfare. Nuclear disarmament negotiations centers on the role of information, much as information warfare does.

Similar concerns of when information should be revealed and protected and how information should be protected, exist in nuclear disarmament negotiations and IW situations (Aumann and Maschler, 1995:xiv-xvi).

Game theory provides a means to represent complex, competitive situations into mathematical models that allow a more rigorous study of the situation at hand. This study involves one class of games that grew out of game theoretic research into nuclear disarmament negotiations, specifically, repeated games of incomplete information. The primary motivation is that this class of games captures many of the elements described above as well as the self-evident point that IW participants generally will not directly know the actions or specific characteristics of their opponent.

Although the nuclear disarmament negotiations studies provide the theoretical basis for this study's proposed IW game model, significant differences exist between those studies and the model for IW. First, the most rigorous analysis in the disarmament studies involves incomplete information on the part of only one of the parties; this study's information warfare model involves incomplete information on all sides. Second, the parties' strategies in disarmament strategies are guaranteed to succeed once employed; again, the information warfare model must account for the uncertainty of strategy success. Finally and most importantly, the general class of games used to model disarmament negotiations has not been the subject of substantial empirical study, which is the primary purpose of this study. These significant differences prevent direct application of the repeated games of incomplete information model to information warfare without first testing its applicability.

1.2 Research Objectives

One of the basic goals of game theory is to better understand behavior in particular social situations. In particular, game theory can provide a means to determine and specify elements influencing decisions and to make behavioral predictions. Before being applied in this manner, the model must be tested in a simplified, controlled situation. Since the game model of this study is a significant modification of existing models, it must undergo empirical testing before it can be applied to actual IW situations. This study will use an experiment to address the following research questions, to be further defined later in this report:

Research question 1: Does the information warfare game model developed in this study provide accurate predictions of actual information warfare behavior? Game theory models can predict the best strategies to play (i.e. those that yield the highest payoff). If the information warfare model developed herein can predict actual game play, then its possible that it can serve in broader studies of information warfare.

Research question 2: Does the information warfare game model support analysis of information warfare experience and learning? Information warfare experience should improve performance in information warfare engagements. So, people participating in this study's information warfare game model should play better if they are more experienced. Similarly, learning more about information warfare strategy should also improve performance. This study will use the information warfare game model to evaluate the impact of learning on information warfare performance.

These two questions will help determine if this study's proposed model could potentially be applied to actual information warfare.

1.3 Applicability of Research

Repeated games of incomplete information could potentially apply to many social situations. However, this class of games has not been the subject of significant empirical study. Experimental research could show the accuracy of these models and show where refinements need to be made in these models. Information warfare provides a specific situation to create an empirically testable game model. In particular, IW provides the means to structure payoffs, probabilities and strategies in a realistic fashion, rather than developing a game model based on conjecture.

Although this study is game theory oriented and concentrates on the game model itself, the eventual goal of this line of research is to better understand information warfare. The game model, after being validated, could predict behavior and provide the means to study why people act as they do in IW situations. Additionally, a refined game model could form the basis of an IW simulation system. This system could be employed by organizations to guide their IW strategy choices. However, these possibilities are several studies beyond the present one.

1.4 Sequence of Presentation

Chapter II presents an overview of relevant literature regarding information warfare and game theory. Particular emphasis is placed on specific information attack and defense strategies and human behavior in information warfare. The discussion of game theory proceeds from a general overview to a detailed development of those aspects of game theory cogent to the proposed game model. Chapter III describes the methodology of research. Chapter IV presents the results of the experiments. Chapter V provides concluding remarks and indicates areas for further research.

2. Literature Review

Initial studies of games appeared in economics literature as early as 1838 when Cournot and others developed models of oligopoly pricing and production (Gibbons, 1992: iii). These early models restricted players to strategies that only involved quantity or price decisions. John Von Neumann and Oskar Morgenstern developed a general theory of games in 1944 that allowed the development and analysis of more complex plans and strategies (Von Neumann and Morgenstern, 1944: 10). In the decades since, research has broadened game theory's scope to include industrial organization, labor relations, military strategy, nuclear disarmament negotiations and other social sciences (Fudenberg and Tirole, 1991:xviii).

What game theory brings to these various fields is the capability to formally model and analyze complex social situations. Developing a mathematical model that represents selected aspects of a complex social situation can allow one to better understand some of the elements influencing that situation. Additionally, if the underlying game model is sufficiently robust, it can form the basis for decision support tools, policy development guidelines, or behavioral analysis. Most social situations are far too complex for exact mathematical analysis thus game theory models cannot provide specific recommendations for specific situations. Nonetheless, game theory can provide general insights and predictions (Aumann and Maschler, 1995: 1-2).

This study is the first step towards applying game theory to the study of information warfare (IW), particularly as it concerns the United States military. Technical advances and increasing global connectivity in the last few years have brought IW to the forefront of national military strategy. The application of game theory to military problems began

contemporaneously with game theoretic research itself. Military problems such as information warfare involve many of the same concerns as game theory. Players' outcomes depend on their opponents' decisions, yet they do not know what their opponents' strategies are when making decisions. Thus each player must evaluate their opponent's capabilities, keeping in mind that their opponent is performing similar evaluations. In military conflicts (such as information warfare) the participants have opposing strategies, thus an attacker attempts to maximize gains while the defender attempts to minimize their losses. Game theory attempts to model and analyze these same concerns (Dresher, 1961: 1-2).

This chapter will first discuss how the motivation for and the methodology of developing the information warfare game model. The basic elements of game theory models, players, payoffs and information, will be presented as the foundation for the IW game model. Then, two methods for representing these elements will be described. Next, the IW game model will be developed based upon the basic game theory elements and representations. Then, this chapter will describe current research that provides the foundation of this study's methodology. Finally, this study's research questions and hypotheses will be presented.

2.1 Information Warfare Game Model Development

The conduct of information warfare provided the key motivation in developing the model for this study. Information warfare can be carried out in many different ways. Multinational corporations, militaries and terrorists have surpassed the lone teenage hacker breaking into computer systems for fun. Information warfare is becoming a formal part of both national and corporate strategy (Kovacich, 1997: 56). Economic factors now drive aspects of information warfare such as the following: which resources to protect, cost/benefit of different strategies,

which resources can be compromised, and how to balance limited resources against unknown threats (Libicki, 1997: 40). Game theory has been used in economics to model and analyze similar decisions (Gibbons, 1992: 1-2). But before a more detailed application of game theory to information warfare can be undertaken, the game model must be developed, tested and evaluated.

The first step in developing the IW game model is to understand the basic elements of a game theory model, such as players, payoffs, and information. The next step is to define how these basic elements are represented, in this case, the normal and extensive forms. Then, the methods for calculating equilibrium are described. Equilibrium provides a game theory model's predictive power because it shows what strategies each player should use in order to maximize utility. If a game model's equilibrium does not correlate with actual play, the game model may not be an accurate representation of the underlying social situation (Aumann and Maschler, 1995: 225). Finally, game model elements, their representation, and the equilibrium calculation methodology are applied to the context of information warfare in order to define the IW Game Model. Thus, the following sections create a game theoretic foundation for the information warfare game model and for calculating its equilibria – Figure 2-1 depicts the construction of the IW game model, as described in the following sections.

2.2 Basic Game Theory Elements

Game theory essentially provides a set of tools and techniques for modeling and analyzing social situations. Although game theory presently involves a multitude of different techniques, the same basic components comprise all game models. The main point is to distill the situation (in this case IW) into formally defined sets that can then be mathematically

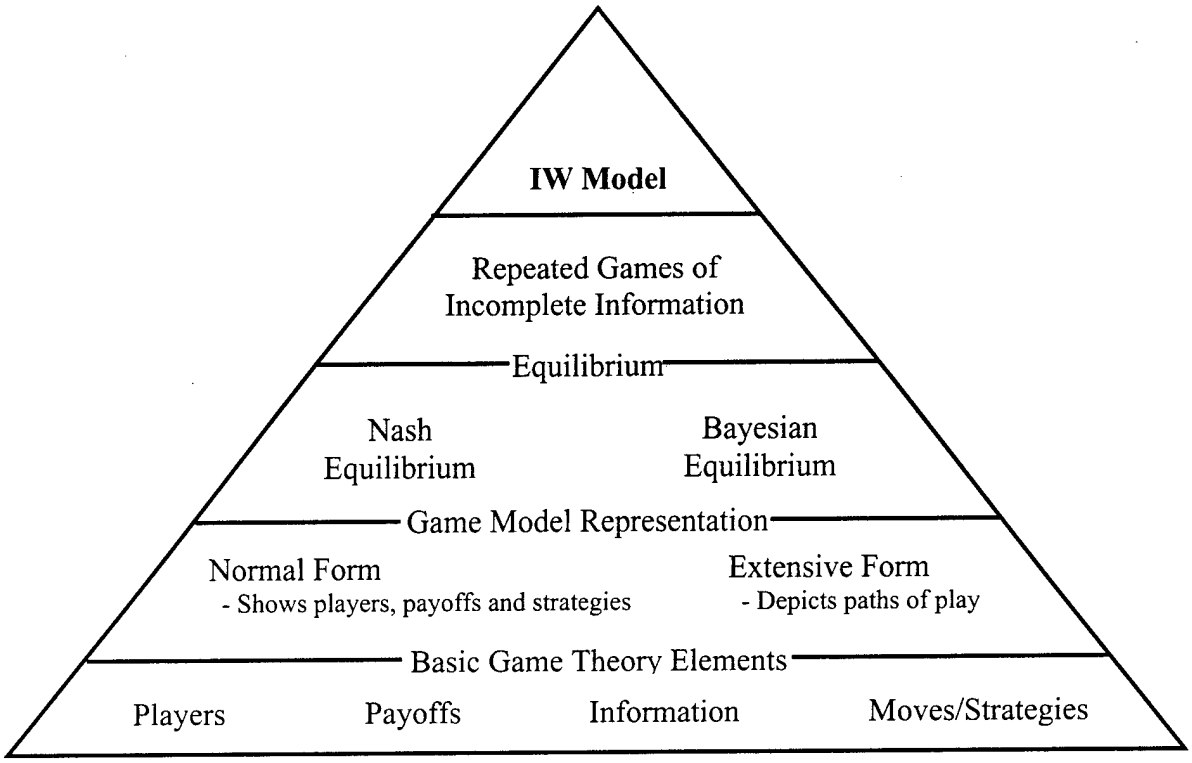

Figure 2-1 Constructing the Information Warfare Game Model

manipulated (Gibbons, 1997: 128-129). This section describes the basic components of game theory to include players, information, and payoffs.

Although the players in the game are not strictly a part of the game model itself, game theory makes several assumptions that should be noted. The players in a game can be individuals, informal teams, or formal organizations; the composition of the players depends upon the situation being modeled (Bornstein and others, 1997: 402). Basic game theory, as formulated by Von Neumann and Morgenstern, generally assumes that players act rationally. Specifically, a player's main goal is to maximize the utility or value that they can derive from the game. Additionally, players generally assume that all the other players are also acting rationally. Assumptions of rationality, while not a perfect representation of human behavior, provide useful, generalizable behavior approximations (Erev and Roth, 1998: 850). The IW game model

assumes rational game play.

Information forms a key component of rational behavior – perfect rationality requires complete information. Thus, the players access to information forms an important part of the game model. In game theory, information regarding payoffs and moves are of primary concern. Perfect information means that players know all the actions available to themselves and their opponents. Perfect information also involves the concept of game history, which is the knowledge of all moves made thus far in the game, also referred to as perfect recall. Complete information means that players know the payoffs available from all possible courses of game play (Gibbons, 1997: 127-128). Incomplete information can take on several definitions, however, for this study incomplete information means that players will not know the payoffs of their opponents. Similarly, imperfect information means that players cannot directly observe the actions of their opponents.

In games of incomplete information, such as the IW game, players must utilize their beliefs in order to estimate what their opponent's payoffs and what moves they have made. Game theory typically models beliefs as probability distribution functions over their opponent's possible set of moves and payoff structures (Aumann and Maschler, 1995: 71-72). However, a player's beliefs do not have to be strictly rational in order for them play rationally. McLennan shows that short-term irrational beliefs (i.e. beliefs that yield suboptimal immediate payoffs) are justifiable in that they allow the player to more quickly adjust their beliefs so that they are more accurate - thus increasing their long run payoffs (McLennan, 1985: 889-890). Reny discusses situations where players must abandon strictly rational beliefs at certain points in the game to achieve long-term equilibrium (Reny, 1995: 1-2). Player beliefs thus form a key component of games involving incomplete information (Erev and Roth, 1998: 853-855).

Payoffs, the utility that players receive from game play, are the prime driver of game play. In purely rational game play, the players' primary motivation is to maximize their payoffs. Payoff representations must be clearly discernible and players must be able to immediately and inherently determine the value of the payoffs. Thus, most game models represent payoffs in purely numeric or monetary terms (Von Neumann and Morgenstern, 1944: 16). Expected utility (expected payoffs) drives game play in games that involve incomplete or imperfect information. Expected utility in a game theory context is a probability distribution over the sets of all possible strategies and their payoffs. In general terms, players will estimate the likelihood of each possible course of game play, discount their own payoff based on their estimate and then form a strategy to obtain the highest expected payoff (Gibbons, 1992: 30-31).

The payoff function of the game captures all the possible payoffs in the game. Payoff functions can be one of three types: zero sum, constant sum or non-zero sum. Zero sum games involve players' whose goals directly conflict; thus a player can only win what the other player loses. Constant sum games require that only one player receive a non-zero payoff at any one time. Non-zero sum games have no restrictions on the game's payoff structure thus a player's payoff is related only to the course of play (Aumann and Maschler, 1995:224-225). The IW game is a non-zero sum game.

2.3 Game Model Representation

Now that the game theory elements have been described, the next layer of the pyramid in Figure 2-1, game model representation, can be presented. Game model representations exist to clearly and logically depict the elements (players, payoffs, moves, etc.) of the game model. Two forms, the normal form and extensive form, will be used to represent the IW game model. The

normal form representation of a game shows the game's players, strategies, and payoffs (Gibbons, 1992: 3). The extensive form provides a richer device for depicting the order of moves and paths of play in the game (Fudenberg and Tirole, 1993: 77-78). These two forms simply capture different aspects *of the same game model* – using both representations does not signify two different games (Fudenberg and Tirole, 1993: 85).

In order to demonstrate these forms, the simple mixed pennies game will be used. The mixed pennies game will also be used later to demonstrate equilibrium calculations. In this 2-player game, both players have a penny. They choose (privately) which face, heads or tails, will be up. They then conceal the penny in their hands, with the chosen face up. Finally, they simultaneously reveal their coins. If the pennies match, (i.e. same face showing) player 1 gets both pennies. Otherwise, player 2 gets both pennies.

Table 2-1 Normal Form for Mixed Pennies Game

	Player 1	
Player 2	Heads	Tails
Heads	-1,1	1,-1
Tails	1,-1	-1,1
	Strategy Set - *S*	S = (Heads, Tails)
	Payoff Function - μ_i	$\mu_i(s_1, s_2)$
	where i indicates the player	- e.g. μ_1(Heads, Heads) = -1

Table 2.1 shows the normal form for the matching pennies game. Other elements can be expressed in the normal form, such as the probability of each strategy being played or information (Gibbons, 1992: 33). The normal form representation of these other elements will be

described when they are used. Figure 2-2 shows the extensive form for the mixed pennies game.

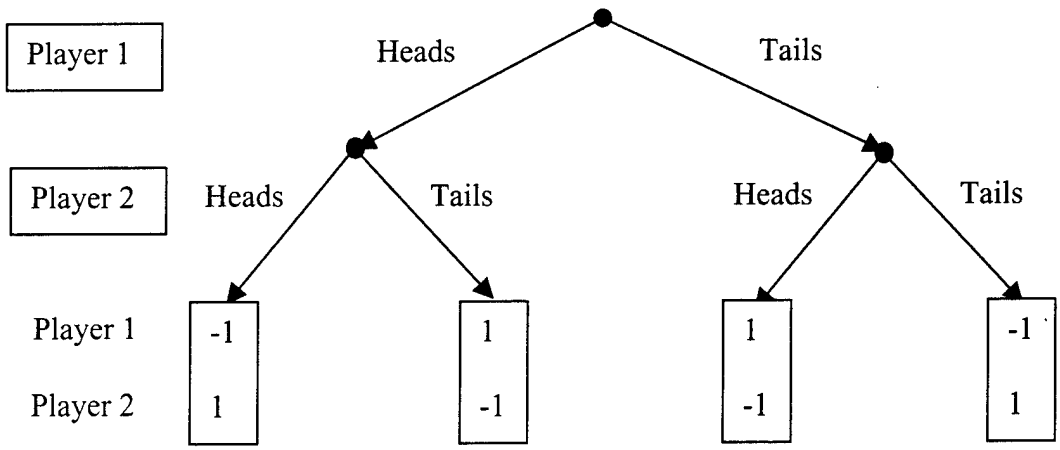

Figure 2-1 Extensive Form for Mixed Pennies Game

The extensive form is particularly useful in games where the order of moves (e.g. chess) is very important and directly effects the options available for the other player.

2.4 Equilibrium and Strategy

The game model elements and representations shown above provide the pieces for describing and performing equilibrium calculations. The equilibrium of a game shows the move or combination of moves that maximizes each player's payoffs. A game reaches equilibrium, in a game theoretic sense, when each player's strategy is strategically stable and self-enforcing. A strategically stable or self-enforcing strategy implies that no player can benefit by deviating from the equilibrium strategy. Equilibrium strategies are sometimes referred to as best response strategies because each player plays a strategy that they predict is the best response to their opponent's predicted strategy. Game theory refers to the equilibrium concept described above as Nash equilibria. Determining the Nash equilibrium of a game essentially involves *solving* the game – finding a unique, optimal course of play for each player (Gibbons, 1992: 8). The Nash

equilibrium is the basic equilibrium form of game theory and most other forms of equilibrium are extensions of it. Nash proved that an equilibrium point exists in all strategic, normal form games (Gibbons, 1992: 33).

Information warfare demonstrates equilibrium behavior when opponents realize that they must account for their opponent's strategy when selecting their own. For instance, suppose there is a computer hacker who is equally expert at the two strategies of breaking into a particular company's network and at obtaining company passwords (he can only do one of these strategies at a time). Assume that the hacker will realize a very high payoff by penetrating the network but receive a much smaller payoff by obtaining passwords. Further assume that the company will realize a large loss if their network is penetrated and a much smaller loss if they lose some of their passwords. Also suppose that the target company knows the hacker's strategies and employs a strategy to make their network impenetrable.

The equilibrium in this "game" is for the hacker to obtain passwords and the company to protect their network, so long as the situation remains as described above. Although the hacker would get a much higher payoff by penetrating the network, the company's network defense strategy prevents him from realizing any payoff from this attack. So, the hacker will obtain passwords so that he can at least obtain some payoff. Likewise, the company will maintain their network defense because they would much rather suffer the small password loss than the large network loss. One can see that neither party can benefit by deviating from their strategy, so this information warfare scenario is in equilibrium. The following sections present a more formal analysis of equilibrium and equilibrium calculation.

2.4.1 Calculating Nash Equilibrium

Elimination of dominated strategies was the first approach to finding a game's equilibrium. A dominated strategy is a strategy that cannot benefit a player regardless of the course of play or the opponent's moves. A strongly dominated strategy yields payoffs that are lower than all other strategies, regardless of the opponent's move. Thus, a player can never benefit by playing a strongly dominated strategy. Weakly dominated strategies yield payoffs that are generally lower than all other strategies. Table 2.2 shows dominated strategies in a payoff matrix (Player 1 payoffs listed first, strongly dominated strategies are italicized).

Table 2-2 Dominated Strategies

	Player 1			
Player 2	Strategy 1	*Strategy 2*	Strategy 3	Strategy Payoff Sum – Player 2
Strategy A	3,1	*0*,2	0,3	6
Strategy B	0,*0*	*0,0*	2,*0*	0 – Strongly Dominated
Strategy C	2,3	*0*,0	0,1	4 – Weakly Dominated
Strategy Payoff Sum – Player 1	5	*0 – Strongly Dominated*	2 – Weakly Dominated	

Theoretically, all strategies other than the equilibrium strategy are either strictly or weakly dominated. Thus, a careful, iterated elimination of dominated strategies yields the Nash equilibrium solution of the game. However, finding dominated strategies can be unintuitive or impossible, particularly in games of incomplete information (Gibbons, 1992: 9-13; Fudenberg and Tirole, 1993: 437). Nonetheless, elimination of dominated strategies forms a key part of determining the equilibria for this study's information warfare model.

2.4.2 Bayesian Equilibrium

Bayesian equilibrium extends the Nash equilibrium concept to account for instances when players cannot calculate their opponent's strategy with certainty. Incomplete information or the structure of the game can cause this uncertainty. Bayesian equilibrium consists of mixed strategies. A mixed strategy is a probability distribution over all actions in the strategy set. Actions may have 0 probability associated with them, meaning that they will not be played under any circumstance. A mixed strategy that assigns probability 1 to an action means only that single strategy is played; this is a pure strategy (Gibbons, 1992: 150).

The mixed pennies game described above in Table 2-1 and Figure 2-2 has no pure strategy Nash equilibrium. The following process shows the mixed strategy calculation for this game. Suppose player 1 thinks that player 2 will play heads with probability ρ and tails with probability $1 - \rho$. Using the payoff matrix, player 1's payoff from playing heads is $\rho * (-1) + (1 - \rho) * 1 = 1 - 2\rho$; player 1's payoff from playing tails is $2\rho - 1$. Solving the inequality $1 - 2\rho > 2\rho - 1$ shows that player 1 will play heads if $\rho < ½$ and is indifferent when $\rho = ½$. Thus, player 1's mixed strategy involves player 1 drawing ρ randomly from the interval (0,1) and selecting his strategy according to the above rules (Gibbons, 1992: 33).

2.5 Game Model of this Study – Repeated Game with Incomplete Information

The preceding sections present a brief overview of basic game theory – its elements, how to represent those elements, and how to use the elements and representation to calculate equilibrium. The repeated game with incomplete information extends basic game theory to account for more complex, realistic social situations. It is one of the better-understood models in game theory and can be a good approximation of some long-term social situations (Fudenberg

and Tirole, 1993: 145).

The incorporation of incomplete information represents the most significant extension of the repeated game model. Two major findings form the foundation for game theory's treatment of incomplete information. All information, in a game theoretic sense, can be captured in the payoff function of the game. Thus, one can model any lack of information as an imperfect knowledge of payoff functions. Second, the addition of a chance mechanism to basic game models could allow the modeling of incomplete information without the development of an entirely new game model (Aumann and Maschler, 1995: 67).

The repeated game with incomplete information model was selected as the foundation for the information warfare game model for two primary reasons. First, this model focuses on the role of information; specifically, how should one employ their information, how should one protect their information and how does one proceed when they lack complete information (Aumann and Maschler, 1995: 155). Information warfare centers on these same issues. Second, the model incorporates time (in the form of game repetitions) and how time affects game play (Gibbons, 1992: 80). Information warfare also takes place over time. For instance, a hacker may first probe a network to detect any weaknesses and then launch various attacks in an attempt to determine the best penetration strategy – time plays an important role in how the hacker attacks the network (Libicki, 1997: 40).

2.5.1 Representation of Incomplete Information

The concept of player types represents information unknown to the other players. Specifically, the player's type designates their particular payoff function and the set of all player types represents all possible payoff functions. Recent research has extended the notion of player

types to encompass differing player beliefs, differing strategy sets and many other possible unknowns; however, unknown payoff functions will be this study's focus. Players may or may not know all of their own or their opponent's possible types; in fact they may not know their own type until far into the game (Aumann and Maschler, 1995: 156-158).

At the game's outset, each player's actual type is determined by chance. A probability distribution function exists over the set of player types that associates a probability estimate for the "choice of chance" at the game's outset. The player type probability distribution function can play an important part of equilibrium calculation in these games (Fudenberg and Tirole, 1993: 213-214).

Baseball batters provide a good example of player types. When a pitcher faces a new hitter, they do not know if they are facing a power hitter such as Mark McGuire or a contact hitter such as Tony Gwynn (this example ignores scouting reports and other hitting styles). They must make a guess (captured in the game model by the choice of chance) about the hitter's type and pitch accordingly. In the beginning, they assume that there is a 50-50 chance of the hitter being each type. As the at-bat proceeds, they will be able to refine their guess about the hitter's type based on what they observe. For example, if the pitcher begins to suspect that the hitter is a power hitter, they could assign more probability to the power hitter type.

The differing payoff functions (for each player type) create a different game for each intersection of player types. A matrix over all possible player types, as shown in Table 2.3, represents all possible games that can arise from the intersections of the different player types. For instance, there is a power hitter vs. power pitcher "game" and a power hitter vs. feel pitcher "game". Each of the games in the matrix will have its own actual payoffs and equilibrium. The probability of each game in the matrix (i.e. each cell) being the actual game played is the

conditional probability of each player's type as shown in Table 2.3. In the game selection or player type matrix shown in Table 2.3, each player can be one of two possible types, thus four possible games or matchups can actually be played (Aumann and Maschler, 1995: 70-73).

Table 2-3 Game Selection Matrix

	Pitcher Type and Probability	
Hitter Type and Probability	"Power" Pitcher (PP) $P(PP) = \eta$	"Feel" Pitcher (FP) $P(FP) = 1-\eta$
Power Hitter (PH) $P(PH) = \varepsilon$	G_{11} $P(G_{11}) = \eta\varepsilon$	G_{21} $P(G_{21}) = (1-\eta)\varepsilon$
Contact Hitter (CH) $P(CH) = 1-\varepsilon$	G_{12} $P(G_{12}) = \eta(1-\varepsilon)$	G_{22} $P(G_{22}) = (1-\eta)(1-\varepsilon)$

2.5.2 Equilibrium in the Repeated Game with Incomplete Information – Single Repetition

Although the above matrix shows four different games that can be played, it must be pointed out that only one game is actually being played. The matrix is simply a tool used to represent the players' lack of knowledge about payoff functions. To further illustrate the

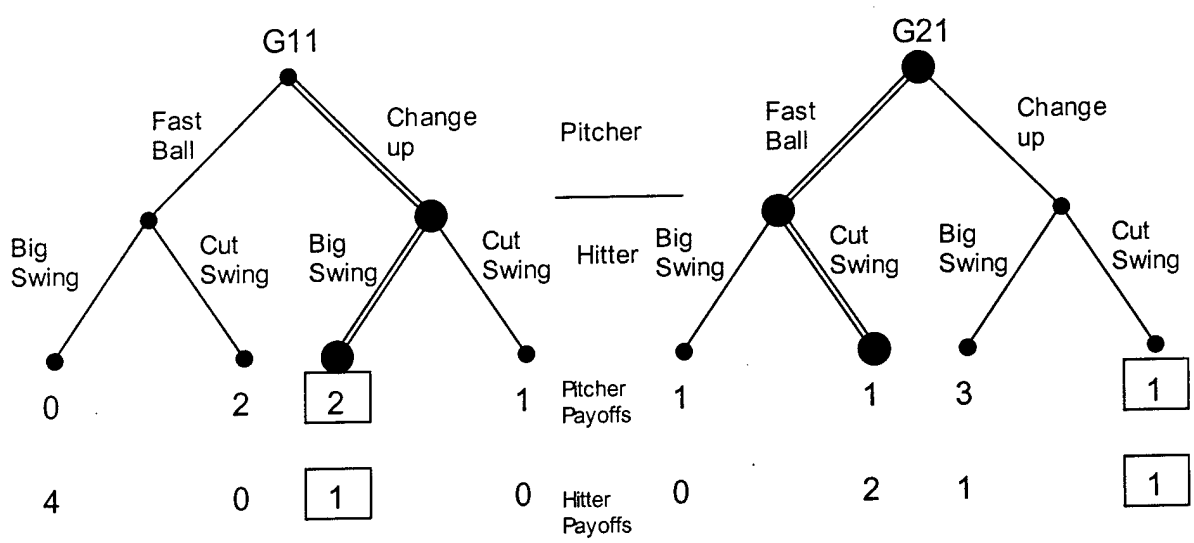

Figure 2-3 Repeated Game Extensive Form

relationship between the above Player Type matrix and the game being played, consider the extensive form representations of game G_{11} and game G_{21} in Figure 2.3. Note that the hitter is the same type in both games, a power hitter. The example also assumes that the bases are loaded with no outs. The payoffs represent runs and runs batted in for the hitter and outs for the pitcher.

In this case, chance has determined that the hitter is a power hitter. The pure Nash equilibrium for each game is highlighted above. To continue the analysis from the perspective of the hitter, one can see that a mixed strategy will be played. Since the hitter does not know what type of pitcher he is facing, he must use both his swings. The probability associated with each game (i.e. the probability assigned to each pitcher type) will determine the mix of swings. From the player type matrix, $P(G_{11}) = \eta\varepsilon$ and $P(G_{21}) = (1-\eta)\varepsilon$. The expected utility for the hitter taking a big swing is $\eta\varepsilon(1) + (1-\eta)\varepsilon(0) = \eta\varepsilon$; likewise, the expected utility from a cut swing is $\eta\varepsilon(0) + (1-\eta)\varepsilon(2) = 2\varepsilon - 2\eta\varepsilon$. These calculations are examples of the Von Neumann-Morgenstern utility function (Bloomfield, 1994: 413).

The hitter will take a big swing when the expected utility of the big swing > cut swing. Solving $\eta\varepsilon > 2\varepsilon - 2\eta\varepsilon$ yields $\eta > 2/3$. Thus, the hitter's mixed strategy, when he is a power hitter is as follows. He randomly selects η from the interval (0..1), if $\eta > 2/3$, then he takes a big swing, otherwise he takes a cut swing. Although modern power hitters almost always take a big swing, power hitters such as Ted Williams would reserve their big swing and realized better overall numbers as a result. Note that the above example was created for this report, however the method of calculation is drawn from Aumann and Maschler (Aumann and Maschler, 1995: 253-257).

2.5.3 Equilibrium with Repetition

The above example shows one repetition of the game (i.e. one pitch). Now repeated repetitions are accounted for in the model. The model actually assumes an infinite number of repetitions, also referred to as an infinite horizon. More accurately, the concept of infinite repetition refers to the players' belief about the number of repetitions; if players know the number of repetitions, overall game play may change (Gibbons, 1992: 88). In the repeated case, players attempt to maximize their payoffs over the long run. Additionally, they will use information gained through repeated game play to refine their beliefs about their opponent's type (Fudenberg and Tirole, 1993: 214).

In the above baseball example, the hitter would observe the pitches thrown, the velocity of pitches, etc. and refine the estimate of η (recall that η is the probability that the pitcher is a power pitcher) as the at bat proceeds. For instance, if they were facing a power pitcher, η would increase over time. So instead of selecting η from the interval (0..1), he would select from the interval (0.25..1), decreasing the interval to (0.667..1), which means he would always take a big swing (since η would always be greater than 2/3) – reaching equilibrium for that game (Gibbons, 1992: 154).

2.6 IW Model Overview

At this point, all the basic pieces are in place for the construction of the information warfare model. As mentioned in the repeated game model introduction, the information warfare model is based on the class of repeated games of incomplete information as described in section 2.5. However, several modifications and extensions have been made to the basic model so that it can better fit information warfare. The following sections describe the IW Model.

2.6.1 IW Model Features

The IW Model involves probabilistic strategies. Classical game theory assumes that strategies are always successful; the actions of the opponent may affect the outcome, but the strategy itself is not called into question. In many cases, such as information warfare, the actions themselves will not always succeed – regardless of the opponent's actions. Probabilistic outcomes could have a strong impact on game play. Specifically, players' risk aversion will have a much stronger impact on strategy. For instance, a risk-seeking individual is much more likely to play a strategy that has a high payoff but a low probability of success. Theoretically, the game model can capture behaviors such as risk aversion (Aumann and Maschler, 1995: 67). However, this concept has not been experimentally tested.

The IW Model also involves the related concepts of symmetric incomplete information and symmetric strategies. This concept means that both players are ignorant of their opponent's type, payoffs and moves. The majority of both theoretical and experimental research involves one-sided incomplete information (Aumann and Maschler, 1995: 224-225). Symmetric strategies involve games in which the players' strategies have no direct relationship with each other. The IW Model's strategies are diametrically opposed. Specifically, each strategy directly counters a specific strategy of the opponent. Information warfare provided the motivation for this concept since information defenders can develop specific strategies to thwart a certain type of attack.

2.6.2 IW Model Components

First, the IW Model's player definitions are provided. Player 1 is the Defender and Player 2 is the Attacker. Defenders attempt to protect the information that is most valuable to

them and attackers attempt to obtain information valuable to them. There are three types of each player: social, infrastructure and node. Each player type prefers one type of information to all others (i.e. realizes higher payoffs for defending/obtaining it). Additionally, attackers and defenders of the same type will have the same relative ranking of information, but the actual valuation of the information will differ. These divisions are drawn from IW literature, as indicated below.

The Social player type refers to a player who prefers to obtain or protect personal or sensitive information such as passwords, names, phone numbers, etc. This information cannot be directly used against systems but may be harmful nonetheless. Institutions such as banks or insurance companies would be social. This player-type is based upon the prevalent social engineering information warfare tactic that typically involves low-tech infiltration such as using false identities, facility intrusion, or email scams. For example, a common hacking technique involves a hacker calling an employee while claiming to be a system administrator and requesting the employee's passwords. Social engineering is the cheapest and easiest method of information warfare (Kivacich, 1996: 5; Cohen, 1995: WWWeb).

The Infrastructure player type refers to a player who prefers to obtain or protect information relating to the computer network itself such as Internet addresses, network architecture, or TCP/IP port assignments. Organizations such as telecommunications companies or Internet service providers would be this type of player. Although technically challenging and risky (i.e. high risk of detection and legal prosecution), infrastructure or network attacks can be very costly, even devastating, to the victim (Kivacich, 1996: 5; Cohen, 1995: WWWeb).

The Node player type refers to players who prefer to obtain information relating to computer equipment such as hardware addresses, computer configurations, file names or

encryption keys. Companies performing data processing, graphics or other computer aided design and software development would be this type of player. For instance, a hacker that obtained a computer's hardware address and configuration files (e.g. IO.SYS, AUTOEXEC.BAT in Microsoft Windows) could remotely administer or disable that computer (this is a known problem of Microsoft's Internet Explorer) (Microsoft Corporation, 1998: WWWeb; Cohen, 1995: WWWeb).

A further distinction is made between the defenders and attackers in the IW Model. Information defenders in the corporate world generally have an array of sensing and logging technology (e.g. security audit logs, network sniffers, intrusion detection systems, etc.) that allow them to observe attacks against them (Cohen, 1995: WWWeb). The IW Model accounts for this by allowing defenders to determine the attacker's move by carefully observing the payoffs they (the defender) receive.

Now the actions available to players are described. Defenders have three possible actions: 1) Social Engineering Defense, 2) Infrastructure Defense and 3) Node Defense. In the experiment, players will be provided with descriptions of their actions. For instance, a social engineering defense could involve employee-training programs, phone monitoring, and increased physical security. Again, all the defense strategies allow the defender to observe the attacker's move. Likewise, attackers also have three possible actions: 1) Social Engineering Attack, 2) Infrastructure Attack and 3) Node Attack. These actions show the symmetric nature of the IW Model described earlier. As discussed previously, each action will have a probability of success associated with it. Since the player's type determines the value of the information received from each action, player type will determine the player's preferred strategy. However, the preferred strategy may not yield the highest payoffs during actual game play. This results from the actions

of the opponent, whose strategy may impede the player's ability to play the preferred strategy. In fact, this will generally be the case. Players will know all the actions available to their opponent.

Finally, the payoffs for the IW Model are defined in general terms. For this game, players attempt to obtain or defend information important to them. The information's value depends upon the player's type; for simplicity, each piece of information will be worth a certain amount of US dollars. Specific types of information will be specified in the actual games, but in any game, there will be three types of information to be defended and attacked: social information (passwords, employee information, etc.), infrastructure information and node information. The relative value of each piece of information within and between player types will be manipulated in the experiment, as discussed later. For example, a Social-type Attacker, who successfully obtains his opponent's password (a social piece of information) could gain $70 while his opponent, a Node-type Defender, loses $30. The IW Model is a non-zero sum game, more accurately modeling the real-world situation (Aumann and Maschler, 1995: 157).

Each action's success probability will determine the expected payoff (expected utility) of a particular action. Players will not know the game's success probabilities for themselves or their opponent. Thus, players must refine their expected utility calculations as the game proceeds. This game's success probabilities allow an action to either succeed or fail – if the action fails, the player gains nothing, if the action succeeds they gain their full payoff. From the example above, if the social attack succeeds, that attacker gains $70 and the defender loses $30 (i.e. the social defense failed). However, if the social defense succeeds, neither player gains or loses anything (obviously this is a win for the defender).

2.7 General IW Model Definition and Notation

This section presents the general IW Model. The general model defines inherent characteristics of the IW Model such as the affect of player type, course of play, and payoff calculations.

2.7.1 Player Type Selection

Section 2.5.1 discussed player type or game matrices that show the conditional probability of each possible game; the matrix cells represent each possible combination of Attacker and Defender types. The matrix for this game is similar to the example described in previous sections. Again, the players are actually playing one game, but their differing and unknown types allow for many different payoff combinations. Table 2-4 shows the Game Selection Matrix for the IW Model, note that G in the table means Game.

Table 2-4 IW Model Game Selection Matrix

	Attacker Types			
Defender Types	$A_{S(Social)}$ $P(A_S) = \eta$	$A_{I(Infrastructure)}$ $P(A_I) = \varepsilon$	$A_{N(Node)}$ $P(A_N) = \rho$	$\eta,\varepsilon,\rho \geq 0$; $\eta+\varepsilon+\rho = 1$
D_S $P(D_S) = \kappa$	G_{SS} $P(G_{SS}) = \eta\kappa$	G_{SI} $P(G_{SI}) = \varepsilon\kappa$	G_{SN} $P(G_{SN}) = \rho\kappa$	
D_I $P(D_I) = \tau$	G_{IS} $P(G_{IS}) = \eta\tau$	G_{II} $P(G_{II}) = \varepsilon\tau$	G_{IN} $P(G_{IN}) = \rho\tau$	
D_N $P(D_N) = \varphi$	G_{NS} $P(G_{NS}) = \eta\varphi$	G_{NI} $P(G_{NI}) = \varepsilon\varphi$	G_{NN} $P(G_{NN}) = \rho\varphi$	
$\kappa,\tau,\varphi \geq 0$ $\kappa+\tau+\varphi = 1$				

The game selection matrix is presented mostly for completeness in developing the IW Model. In this study, it will have no affect on game play or equilibrium calculations. The reason for this is that players are only aware of the payoff function in the game that they are actually

playing. In order to utilize a game selection matrix in equilibrium calculations, players must know all the possible payoff functions (Aumann and Maschler, 1995: 210). Additionally, players will only play one stage game throughout the experiment, that is to say that their type will not change during repetitions of the game. Since this study does not develop a generalized equilibrium, the game selection matrix is not directly relevant. Nonetheless, its presentation is important for model completeness and for model refinement in subsequent research.

2.7.2 General Extensive Form

Figure 2-4 shows the general extensive form of the game. The payoff nodes represent the specific pieces of information. Their actual value will depend upon which game (from the game selection matrix) is being played. Its important to note that the extensive form for the IW Model does not indicate order of moves, both players move simultaneously in this game.

The payoffs shown in the tree (social, infrastructure, and node) are determined based

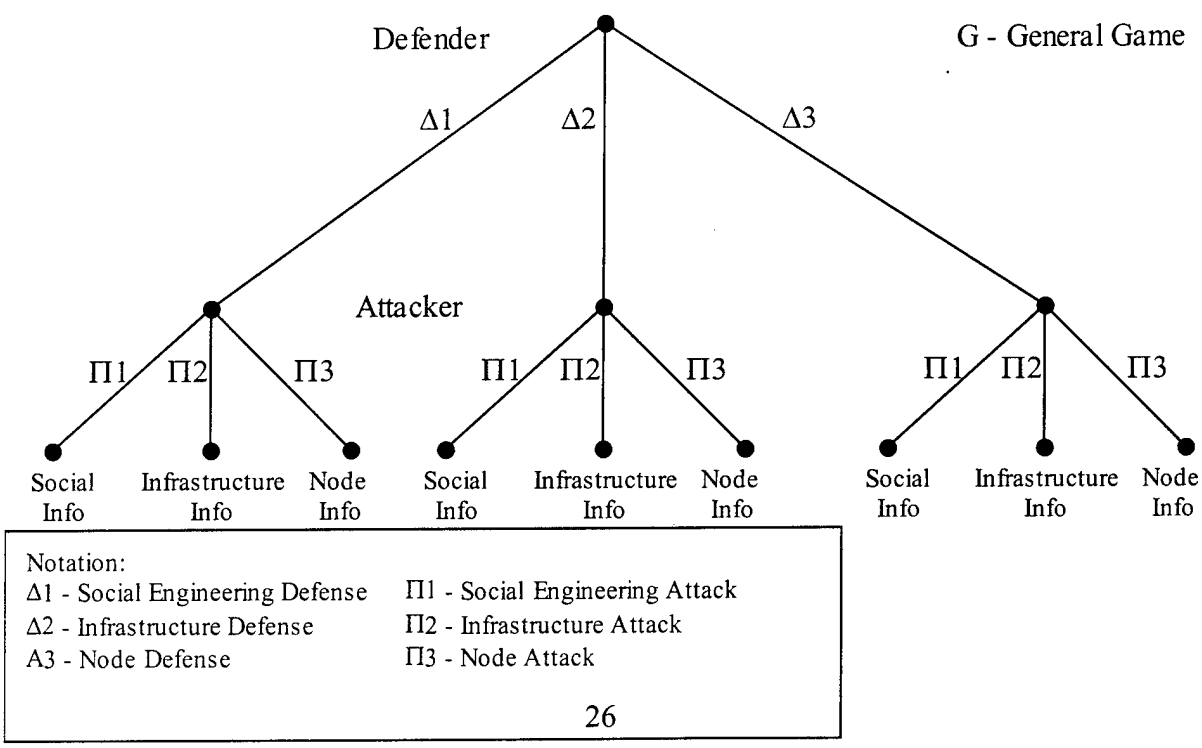

Figure 2-2 IW Model Extensive Form

upon the actual game being played (from the game matrix) and the path of play. In other words, the course of game play and the players' types determine the actual and expected payoff values. For example, at payoff node Social1 (the numbers are used to distinguish the nodes, they do not imply different information) the defender's actual payoff is determined by the value of social information (names, addresses, passwords, etc.) in the game G. Similarly, the attacker's actual payoff is determined by the value of social information in the game G. Expected payoffs (expected utility) are calculated by multiplying the action's success probability by its actual payoff.

2.7.3 General Normal Form

Table 2-5 shows the General Normal Form for the IW Model. Each cell of the matrix shows the payoffs that both players will realize from that course of play. Additionally, the

Table 2-5 IW Model General Normal Form

	Defender		
Attacker	Social Defense	Infrastructure Defense	Node Defense
Social Attack	P(ϑ(Δ1)=1) * Social Info ***P(ϑ(ΠI)=1) * Social Info*** P(ϑ(Δ1)=1) + P(ϑ(Π1)=1) = 1	P(ϑ(Δ2)=1) * Social Info ***P(ϑ(ΠI)=1) * Social Info*** P(ϑ(Δ2)=1) + P(ϑ(Π1)=1) = 1	P(ϑ(Δ3)=1) * Social Info ***P(ϑ(ΠI)=1) * Social Info*** P(ϑ(Δ3)=1) + P(ϑ(Π1)=1) = 1
Infrastructure Attack	P(ϑ(Δ1)=1) * Infra. Info ***P(ϑ(ΠII)=1) * Infra. Info*** P(ϑ(Δ1)=1) + P(ϑ(Π2)=1) = 1	P(ϑ(Δ2)=1) * Infra. Info ***P(ϑ(ΠII)=1) * Infra. Info*** P(ϑ(Δ2)=1) + P(ϑ(Π2)=1) = 1	P(ϑ(Δ3)=1) * Infra. Info ***P(ϑ(ΠII)=1) * Infra. Info*** P(ϑ(Δ3)=1) + P(ϑ(Π2)=1) = 1
Node Attack	P(ϑ(Δ1)=1) * Node Info ***P(ϑ(ΠIII)=1) * Node Info*** P(ϑ(Δ1)=1) + P(ϑ(Π3)=1) = 1	P(ϑ(Δ2)=1) * Node Info ***P(ϑ(ΠIII)=1) * Node Info*** P(ϑ(Δ2)=1) + P(ϑ(Π3)=1) = 1	P(ϑ(Δ3)=1) * Node Info ***P(ϑ(ΠIII)=1) * Node Info*** P(ϑ(Δ3)=1) + P(ϑ(Π3)=1) = 1

realized payoff is discounted by the success probability of the action being played to yield the

expected utility. Thus, the payoffs shown below are expected payoffs, not actual payoffs. Table 2-5 lists the Defender's payoff above the Attacker payoff; for additional clarity the Attacker's payoffs are in a different font than the Defender's.

The symbol ϑ represents the strategy success function, for example $\vartheta(\Delta 1) = 1$ means that the Defender strategy $\Delta 1$ (Social Engineering Defense) succeeded; conversely, $\vartheta(\Delta 1) = 0$ means that the Defender Strategy $\Delta 1$ failed. Thus, the notation $P(\vartheta(\Delta 1) = 1)$ means the probability that $\Delta 1$ will succeed. Recall that only one player's strategy can succeed for any course of play (i.e. the attack succeeds and the defense fails or vice-versa).

Two important facts should be noted from the normal form for the IW Model. First, the attacker, in effect, determines the payoff that the defender receives. This is because it is the attacker who decides what information to seek, the defender can only attempt to defend that information by utilizing the best defense strategy for the information sought by the attacker. Second, as noted before, the defender can determine the attacker's strategy by observing their payoffs (i.e. they will know whether they lost social, infrastructure or node information). This additional information should allow the defender to reach their equilibrium strategy more quickly than the attacker.

2.8 IW Model Equilibrium Calculations

This section describes the equilibrium calculations used for the IW Model, based on the elements and representations shown in previous sections. Three specific games are developed from the IW Model in order to test the hypotheses presented later in chapter 2. These games each have different equilibria that were produced by changing the expected payoffs for each action. Specifically, each action's payoff and success probability was manipulated to yield the

various equilibrium points required to test the study's hypotheses. Essentially, each of three games are different player type matchings, so they represent different cells from the game selection matrix. Before presenting these games and their equilibrium strategies, the equilibrium methodology applied to all the games is discussed.

First, the fact that a finite (fixed number of actions and players) game in strategic, normal form (as in Table 2-5) has at least one equilibrium point must be reemphasized. This is the Nash Existence Theorem, the proof is omitted here, but can be found in Gibbons, Myerson and other game theory texts (Gibbons, 1992: 45-48; Myerson, 1991: 95-98). Calculating the actual equilibria involves the following 3 steps: 1) Eliminate strongly dominated strategies, 2) Develop strategy support sets 3) Develop a probability distribution, or strategy randomization, that yields the highest possible payoff. A strategy support set contains all the moves that will be used in game play; these are also referred to as equilibrium supports. The strategy randomization across the support set provides the probability that a player will make each particular move in the support set (Myerson, 1991: 98).

Although this probability distribution is often referred to as strategy randomization, one should not infer that player's make moves based on some random event, such as the throw of a die (Gibbons, 1992: 38-45; Myerson, 1991: 91-94). Rather, the strategy randomization shows players' uncertainty about their opponent's next move. For instance, a baseball pitcher does not flip a coin to decide between a fast ball and a curve ball. The pitcher instead makes a "guess" about what the hitter may be looking for and pitches accordingly (this analogy ignores issues such as scouting, coaching, etc.). Developing the best response strategy profile is relatively straightforward, however, a shareware software tool (Gambit) was used to verify the manual calculations. Gambit was developed at the California Institute of Technology and provides

several equilibrium calculation algorithms for normal and extensive form games. The Enumerated Mixed (EnumMix) algorithm was used for this study, since it performs the same calculations as described above (McKelvey, 1997: WWWeb).

2.8.1 Strategy Representation

A best strategy response profile is an expression of probability for each action available to a player. Each action is assigned a probability that the player will play that action at any given time. Thus, the equilibrium strategy is the set of probabilities for every action that maximizes the player's payoff.

Table 2-6 Strategy Representation

Defender Strategy Profile		**Attacker Strategy Profile**	
$P(\Delta 1) = L$	Probability of Defender playing action $\Delta 1$	$P(\Pi 1) = S$	Probability of Attacker playing action $\Pi 1$
$P(\Delta 2) = M$	Probability of Defender playing action $\Delta 2$	$P(\Pi 2) = T$	Probability of Attacker playing action $\Pi 2$
$P(\Delta 3) = 1\text{-}L\text{-}M$	Probability of Defender playing action $\Delta 3$	$P(\Pi 3) = 1\text{-}S\text{-}T$	Probability of Attacker playing action $\Pi 3$

Table 2-6 shows the Defender's mixed strategy: (L, M, 1-L-M) and the Attacker's mixed strategy is (S, T, 1-S-T). Determining the equilibrium strategy involves finding values for L and M and S and T so that each player's payoff is maximized given their opponent's mixed strategy. The representation in Table 2-6 will hold for the remainder of the report.

2.8.2 Forming a Best Response Strategy Profile and Determining Equilibrium

The best response methodology will now be illustrated using one of the four specific games of this study. The game G_{SS} (Attacker and Defender type is Social), which has a mixed

strategy equilibrium, will provide the example. Table 2-7 shows this game's normal form, with expected payoffs. Its important to note that the Defender's success probability determines how much information is protected, thus:

Expected Defender Payoff = [(Probability of Action Success * Actual Loss) – Actual Loss] * (-1)

The Attacker's expected payoff is more straightforward since it simply indicates how much payoff the Attacker can expect to receive, thus the expected payoff for the Attacker is:

Expected Attacker Payoff = Probability of Action Success * Actual Payoff

Table 2-7 Normal Form for Game G_{SS}

				Defender					
Attacker		Δ1			Δ2			Δ3	
	Success Probability	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff
	0.7	-70	-21	0.75	-70	-17.5	0.55	-70	-31.5
Π1	***0.3***	***70***	***21***	***0.25***	***70***	***17.5***	***0.45***	***70***	***31.5***
	0.5	-50	-25	0.4	-50	-30	0.6	-50	-20
Π2	***0.5***	***40***	***20***	***0.6***	***40***	***24***	***0.4***	***40***	***16***
	0.5	-25	-12.5	0.5	-25	-12.5	0.63	-25	-9.25
Π3	***0.5***	***55***	***27.5***	***0.5***	***55***	***27.5***	***0.27***	***55***	***15.125***

The next step in calculating the best response strategy profiles is to eliminate dominated strategies. Recall that a strongly dominated strategy is an action that *never* yields a better payoff than any other action. Using expected payoffs, Table 2-7 shows that Π2 and Δ1 are strongly dominated. All other actions are a best response in at least one case. Thus the support for this game is {Π1, Π3} X {Δ2, Δ3}; this notation indicates that play will occur stochastically among the four cells outlined in Table 2-7.

Finally, the best response strategy profile (a probability distribution) can be calculated. Because Π2 and Δ1 are not in the support, their probability of being played is zero, thus L and T

= 0. To determine $P(\Delta 2)$, $P(\Delta 3)$, $P(\Pi 1)$, and $P(\Pi 3)$, the following four equations are solved:

$$P(\Pi 1) + P(\Pi 3) = 1$$
$$P(\Delta 2) + P(\Delta 3) = 1$$
$$-17.5 \times P(\Pi 1) - 12.5 \times P(\Pi 3) = -31.5 \times P(\Pi 1) - 9.25 \times P(\Pi 3)$$
$$17.5 \times P(\Delta 2) + 31.5 \times P(\Delta 3) = 27.5 \times P(\Delta 2) + 15.125 \times P(\Delta 3)$$
$$P(\Pi 1) = 0.18 :: P(\Pi 3) = 0.82$$
$$P(\Delta 2) = 0.63 :: P(\Delta 3) = 0.37$$

Therefore the best response strategy profile, ***at equilibrium***, for the Attacker is (0.18, 0.0, 0.82). Likewise, the best response strategy profile for the Defender is (0.0, 0.63, 0.37). The Gambit program produced identical results. To review what this really means, the Attacker's best response strategy is to play $\Pi 1$ (Social Attack) 18% of the time and $\Pi 3$ (Node Attack) 82% of the time. Also recall that this ratio indicates both the Attacker's best guess about the Defender's type and his/her best response to the hypothesized Defender type. Equilibria for the other games used in this study will be shown where needed.

2.9 Game Theory Experiments

Now that the IW Model is fully defined, it must be tested and evaluated. This section summarizes several game theoretic experiments in order to provide a foundation for this study's methodology for testing and evaluating the IW Model. In particular, what aspects of the model should tested? What are the best methods for accomplishing these tests? And what other considerations must be accounted for when testing the model? Although game theory is most often used as tool to analyze economic or social situations and not the model itself (Gibbons, 1997: 45), there are several examples of experiments that validate and refine game models or aspects of a particular game model. These final examples provide the primary basis for this study.

2.9.1 Equilibrium Experiments

Equilibrium is a central concept in game theory; a given model's predictive power rests in its equilibrium. However, in some classes of repeated games that involve signaling, equilibria, as derived from the model, are unintuitive to people given the context of the game. Brandts and Holt performed an experiment to study game play in such situations. Their experimental manipulations involved the information that players had about their opponent's type and the payoff distributions (some treatments had payoffs that varied dramatically while others had payoffs closer together). They found that people generally do not play unintuitive equilibrium strategies, although they would benefit by doing so; this occurs even if the equilibrium strategy was suggested to the players. Brandts and Holt refined their game model and predictions continuously throughout the experiments; in particular, they provided additional instructions to focus the subject's attention on the predicted equilibrium strategy (Brandts and Holt, 1992: 1350-1366).

Ochs performed a study to test the mixed strategy predictions of three different equilibrium models. Specifically, he compared the predictions of Nash equilibrium, a quantal equilibrium model and an adaptive learning model. His experimental treatments involved the manipulation of the games' payoff functions to produce either highly symmetric or asymmetric payoffs; specifically, one treatment's game placed both players best payoff in the same cell, the second treatment placed each player's best payoff in different cells and the final treatment had zero-sum payoffs. He then compared the expected payoff distributions to the distributions actually realized in the experiments. He found that Nash equilibrium predictions worked best with the symmetric and zero-sum games while the adaptive learning model better fit the

asymmetric model (Ochs, 1995: 202-217).

Bloomfield performed a similar study to compare the predictions of adaptive learning and Nash equilibrium models when payoffs are publicly disclosed, thus his treatment variable was whether the opponent's payoffs were revealed or not. He found that adaptive learning provided better predictions when the payoffs were not revealed. Conversely, play converged to Nash equilibrium predictions when payoffs were revealed. This study reinforces two key elements of general equilibrium theory. First, providing payoff information allows the players to more strategically calculate payoffs and equilibria strategy. Second, payoff information causes the players to act less predictably, since unpredictability is a key determinant in calculating mixed strategy mixed equilibrium this result increases the predictive power of mixed strategy Nash equilibria (Bloomfield, 1994: 411-436).

These studies demonstrate the importance of and methodology for manipulating and testing equilibrium play. As stated previously, equilibrium is the key prediction of a game model and determining if people play equilibrium strategies is an important step when evaluating a new game theory model. These studies support this conclusion and show how to test equilibrium play.

2.9.2 Equilibrium Support Tools

Although equilibrium is the most important prediction of a game model, its more important that the game model allows the development and testing of hypotheses about people's behavior in the actual social situation underlying the game model (Gibbons, 1997: 1). In this study, the IW Model should allow an analysis of information warfare behavior. In particular, do information warfare technologies improve an individual's performance in information warfare

operations? These IW technologies (described shortly) are analogous to the game theory concepts of fictitious play and pattern recognition.

Fictitious play is a learning and behavior model in which player's hold beliefs about their opponent's intentions in order to form behavior rules. These behavior rules then guide their own game play. Each player's set of beliefs and behavior rules are refined as the game progresses and more information is obtained. The basis for this refinement is the history of the game, i.e. the moves that each player has made through the course of the game. Players assess the game's history in order to determine what moves they could have made in order to realize better payoffs. They then use this assessment to refine their behavior rules. Fudenberg and Kreps show that fictitious play converges to mixed strategy equilibrium without the demand for rigorous probabilistic equilibrium calculations by the players. So, tools that support fictitious play reduces the players' computational burden, perhaps improving game play (Jordan, 1993: 368-386; Fudenberg and Kreps, 1993: 320-367).

Sonsino, Jordan, and Fudenberg and Kreps show that the ability to recall and analyze the history of the game can reduce the players' computational burden and lead to quicker, tighter convergence to mixed strategy equilibrium. However, players will have difficulty remembering and analyzing histories in repeated games (due to the number of game repetitions) (Bloomfield, 1994: 411-436). Thus, providing players with a tool that tracks the history of the game and provides some pattern analysis capability could improve convergence to mixed strategy equilibrium.

The learning tools suggested by the above studies parallel actual technologies used during information warfare. On the defensive side, network intrusion detection devices, network monitoring devices, and system configuration audits essentially provide game histories. They

also give the defender more information about their employed strategies, thus allowing more educated strategy refinement. On the offensive side there are less analogous technologies, however, network mapping tools, penetration analyses, and social engineering (e.g. posing as a systems administrator and polling users about their network) contribute to an attackers ability to learn about and refine their strategy selection (Management Analytics, 1995: WWWeb).

2.10 Research Objectives and Hypotheses

This study's purpose is to test the information warfare game model, a variation of the repeated game with incomplete information model described earlier. As pointed out previously, this class of games seems to capture several elements of information warfare. As alluded to in preceding discussions, a game model's equilibrium is its most important component – without an accurate equilibrium, the game model possesses little predictive power. Section 2.10.1 shows how equilibrium play in the IW Model will be tested. An equally important question regards how people "play" the information warfare game. Specifically, are people learning about the strategies and their opponent as the game progresses? The research studies discussed previously indicate that people reach equilibrium more quickly with fictitious play and pattern recognition tools. Since these tools are analogous to actual IW technologies, determining if the learning tools improve game play will also shed light on the effectiveness of IW technologies. In order to answer these questions, a fully randomized experimental design will be conducted, manipulating the game type (pure strategy and mixed strategy), role (attacker or defender), and the presence on information.

2.10.1 Measuring Equilibrium

To give a general indication of the predictive accuracy of the IW Model, the number of rounds to

reach equilibrium (NORRE) for each subject will be measured and reported. Lower NORRE values indicate that a player has reached equilibrium quickly, demonstrating that they are playing in accordance with the IW Model's predictions. A more detailed description of the NORRE metric is provided in Chapter 3.

2.10.2 Impact of Information Warfare Experience

People with information warfare experience should converge to equilibrium more quickly than those without prior experience. Persons with IW experience will be more familiar and more comfortable with the IW strategies and terminology presented during the experiment. Their experience should result in their NORRE values being lower than those without. Hypothesis 1 tests this conclusion:

Hypothesis 1: Information warfare experience will cause a faster convergence to the mixed strategy equilibria of games G_{SS} and G_{NS}.

2.10.3 Pure Strategy Play

A pure strategy is one in which a single action is the best response; thus only one action is ever played. In games with pure strategy equilibrium, all actions but the one being played are dominated (either strongly or weakly). Game G_{NI}, Attacker type Infrastructure and Defender type Node, provides the pure strategy equilibrium game for the experiment. Table 2-8 shows its Normal Form.

The NORRE score for the pure strategy equilibrium game serves two purposes. First, if players do not play the pure strategy equilibrium, it will indicate a possible flaw in the IW game model. This is because the pure strategy equilibrium is simpler than mixed strategy equilibrium since it requires players to only recognize one best strategy. Second, the pure strategy game will

provide a basic measure of each subject's ability to recognize game theoretic equilibria. For this study, this ability will be referred to as game theoretic rationality, or rationality for short. The rationality measure provided by the pure strategy equilibrium allows a multitude of personal characteristics (logical reasoning, probabilistic reasoning, concentration, etc.) that lead to better game performance to be captured in one measurement. Better game performance in the pure strategy game should lead directly to better performance in the mixed strategy game due to the factors mentioned above. The full use of game theoretic rationality will be described in Chapter 3.

Table 2-8 Normal Form for Game G_{NI}

	Defender								
Attacker		Δ1			Δ2			Δ3	
	Success Probability	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff
	0.5	-50	-25	0.25	-50	-37.5	0.6	-50	-20
Π1	***0.5***	***25***	***12.5***	***0.75***	***25***	***18.75***	***0.4***	***25***	***10***
	0.75	-25	-6.25	0.5	-25	-12.5	0.67	-25	-8.25
Π2	***0.25***	***75***	***18.75***	***0.5***	***75***	***37.5***	***0.33***	***75***	***24.75***
	0.75	-75	-18.75	0.85	-75	-11.25	0.55	-75	-33.75
Π3	***0.25***	***50***	***12.5***	***0.15***	***50***	***7.5***	***0.45***	***50***	***22.5***

Equilibrium play in the pure strategy game G_{NI} motivates Measure 1 and Hypothesis 2:

Measure 1: The number of rounds to reach equilibrium in the pure strategy game G_{NI} (equilibrium strategies - (Δ1, Π2)) as indicated in Table 2-8 will be measured and reported.

Hypothesis 2: Lower NORRE scores in the pure strategy game G_{NI} will correlate with lower NORRE scores in the mixed strategy games.

2.10.4 Mixed Strategy Play

Predicting mixed strategy play is critical for the utility of the IW Model (as discussed in Section 2.8). The mixed strategy games will be used to generate the target variables of the study. Specifically, the number of rounds to reach equilibrium in the mixed strategy games will be the focus of determining the effect of experimental manipulations. Two mixed games are necessary to ensure that observed game play is not due to unexpected characteristics of the actual game. Thus, the use of two mixed strategy games increases the generalization of the IW Model. If subjects reach equilibrium more quickly in one game than in the other, it indicates an underlying problem with the IW Model (as discussed in previous sections).

Table 2-9 Normal Form for Game G_{NS}

	Defender								
Attacker		Δ1			Δ2			Δ3	
	Success Probability	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff	Success Prob.	Actual Payoff	Expect Payoff
	0.7	-50	-15	0.75	-50	-12.5	0.65	-50	-17.5
Π1	***0.3***	***70***	***21***	***0.25***	***70***	***17.5***	***0.35***	***70***	***24.5***
	0.5	-35	-17.5	0.4	-35	-21	0.55	-35	-15.75
Π2	***0.5***	***40***	***20***	***0.6***	***40***	***24***	***0.45***	***40***	***18***
	0.75	-75	-18.75	0.6	-75	-30	0.65	-75	-26.25
Π3	***0.25***	***50***	***12.5***	***0.4***	***50***	***20***	***0.35***	***50***	***17.5***

Measure 2: The number of subjects that converge to the mixed strategy equilibrium when playing game G_{SS} as indicated in Table 2-7: Attacker strategy profile = (0.18, 0.0, 0.82), Defender strategy profile = (0.0, 0.63, 0.37).

Measure 3: The number of subjects that converge to the mixed strategy equilibrium when playing game G_{NS} as indicated in Table 2-9: Attacker strategy profile = (0.58, 0.42, 0.0), Defender strategy profile = (0.86, 0.14, 0.0).

2.10.2 Learning Processes and Tools

Section 2.9.2 suggests that tools that support learning processes, such as fictitious play, could improve mixed strategy convergence. The question here is if equilibrium convergence improves when players can reference and analyze the history of the game. The following hypotheses address these issues:

Hypothesis 3.a: Learning tools will cause faster convergence to the mixed strategy equilibrium of game G_{SS} shown in table 2-7.

Hypothesis 3.b: Learning tools will cause faster convergence to the mixed strategy equilibrium of game G_{NS} shown in table 2-9.

2.11 Summary

This chapter laid the foundation for the information warfare game model and then developed the IW Model itself. Then, research that supports this study's research questions and methodology was presented. Finally, this study's research questions were described. With these elements in place, Chapter 3 will discuss how the research questions were addressed with an experiment.

3. Methodology

This chapter describes the research methodology used to investigate the measures and hypotheses proposed in Chapter 2. The first two sections of this chapter describe the overall experimental design for the study. The third section discusses the study's constructs and measures. The fourth section describes the methods used to evaluate the experiment's results and the hypotheses.

3.1 Experimental Design

A between subjects Analysis of Covariance (ANCOVA) design was used for this

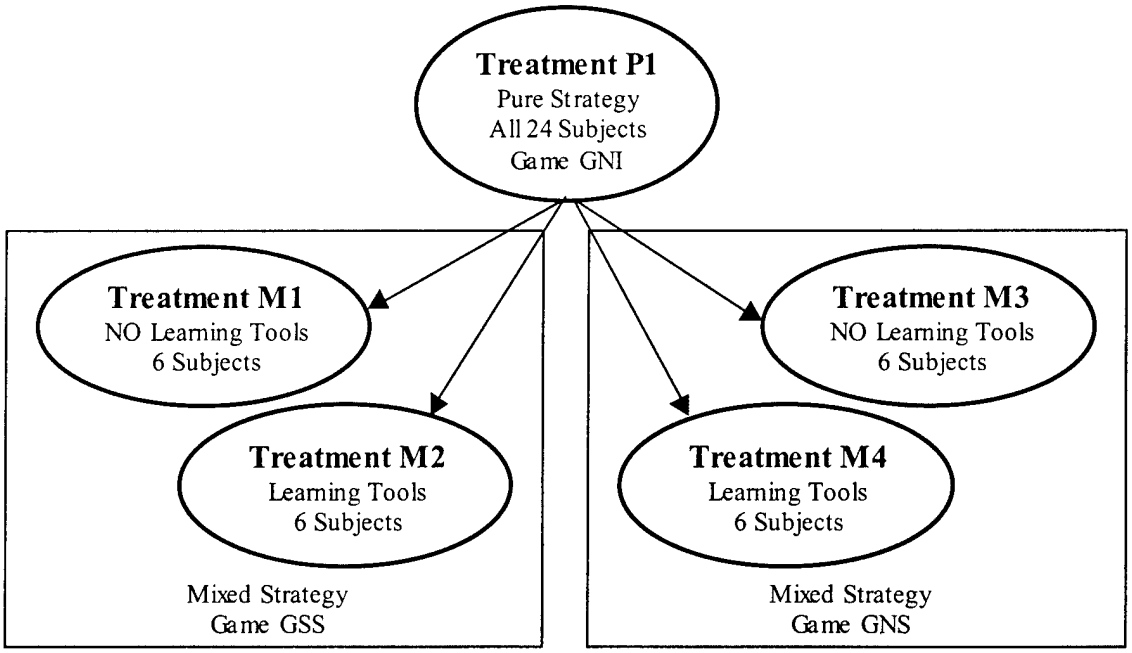

Figure 3-1 Experimental Design

experiment. The ANCOVA was used to determine the effects and interactions of the

experimental manipulations and is explained in detail later in this chapter. Figure 3-1 depicts the experiment's design. The covariate, rationality, was measured for all 24 subjects in the first treatment condition. Likewise, information warfare experience was measured for all 24 subjects with a self-reported Yes or No question (i.e. yes they have IW experience or no they do not). The next treatment conditions involved the effect of learning tools on equilibrium convergence. Two different mixed strategy games helped ensure that no unknown characteristics of the game itself caused the observed equilibrium behavior. The treatment conditions are described in more detail later in the chapter.

3.1.1 Subject Assignment

Experimental subjects were graduate students at the Air Force Institute of Technology (AFIT). All subjects were active duty US Air Force officers. All 24 subjects participated in the first treatment condition, P1, in order to measure the rationality covariate. Then, six subjects were randomly assigned to each of the four mixed strategy treatment conditions. Thus all subjects participated in two sessions, the first being P1 and the second being one of the mixed strategy conditions (M1, M2, M3, or M4).

Many subjects were information technology managers, software developers, or had taken information courses. Chapter 2 hypothesized that prior experience with information warfare should enhance game play. Therefore, subjects were asked whether they had information warfare experience. The subjects were provided a definition of IW experience and answered "yes" if they felt that they fit the definition and "no" if they did not.

3.1.2 Experimental Methodology Overview

The experiment was conducted in an AFIT computer lab using software developed for

this study. The author used Microsoft Visual Basic and Microsoft Access to develop the experimental software. The software features a graphical user interface, with standard Microsoft Windows features; since all Air Force officers at AFIT receive training in using Microsoft Office products, the software presented no initial learning problems. A database developed in Microsoft Access contained the information on the actual games being played (i.e. payoff tables) and logged all actions played. In treatment conditions M2 and M4, the experimental software provided the tools to support learning (described more thoroughly in the next section). A backup database was maintained in case the primary became corrupted during the course of the experiment.

As mentioned previously, experimental sessions were conducted in groups of six subjects, each subject worked on a separate computer. Nothing besides the experimental software was allowed while the experiment was in progress. The use of calculators, other SW programs, paper, etc. was prohibited. Thus, there were 8 experimental sessions, with all subjects participating in treatment P1 and then randomly assigned to one of the mixed strategy conditions. Because the sessions were conducted in an open, classroom environment, a critical factor in all sessions was to prevent players from learning the identity of their opponent. Subjects who know the identity of their opponent could play differently than they otherwise would because of interpersonal relationships. Steps to maintain opponent anonymity are outlined shortly.

Each session began with the experimenter briefing the subjects on the purpose of the experiment and the basic workings of the software. Then, the experimenter answered any questions. When the question period was complete, the experiment commenced. The key to maintaining opponent anonymity was to ensure that no subject stops game play while the other subjects continue to play; if a subject were to stop, their opponent would notice the delay in

game play and surmise their opponent's identity. Thus, if any subject stopped game play for a moment, all subjects were asked to pause. The second set of sessions also involved a briefing to describe the learning tools in conditions M2 and M4.

Subjects were randomly assigned the role of defender or attacker and they maintained this role throughout the treatment. However, they were again randomly assigned a role during the mixed strategy treatments. Thus, subjects could have been a defender once, twice, or never. Each defender played every attacker in each treatment. So, each experimental session actually involved each subject playing three rounds of the same game. This configuration allowed nine measurements for each session for a total of 72 data points. Because the games were so simple, learning effects after round 1 were minimal and constant across all subjects.

Subjects played 40 game repetitions during all sessions and all rounds. Recall from chapter 2 that Nash equilibria are strategically stable, thus once they are reached players have no incentive to deviate. However, player's may not immediately recognize the best mixed strategy, thus several repetitions may reflect their strategy refinement. Forty repetitions were sufficient to recognize equilibrium play and should prevent subject fatigue or boredom (Bloomfield, 1997: 411-436). Players were not told the number of repetitions; thus they were playing with an infinite horizon. The equilibria calculated for this study would not be valid for a finite horizon game, such as when players are told the numbers of repetitions. Finite horizons typically have different equilibria than infinite horizon games. Additionally, infinite horizons involve equilibria that maximize immediate and long-term payoff (Myerson, 1991: 308-309).

3.2 Treatment Conditions

Chapter 2 described the specific games that were used in the experiment. Recall from section 2.10 that manipulating payoffs and success probabilities produced the games with the required equilibrium types (i.e. one pure strategy equilibria and two mixed strategy equilibrium). Thus, the actual games are realizations of the IW Model.

3.2.1 Equilibrium Types

Treatment condition P1 involved the pure strategy game G_{NI}. This game is the simplest because its equilibrium strategy involves the play of only one strategy. Thus, when subjects reach equilibrium, they (both the attackers and defenders) will play only the singular equilibrium strategy. Condition P1 provided both Measurement 1 and the rationality covariate.

Treatment conditions M1 and M2 involved the mixed strategy game G_{SS}. This game is more complex than the pure strategy game because it requires players to recognize the best combination of strategies and the best ratio to play them in. When subjects reach equilibrium, the observed frequency of actions played should match the equilibrium ratio predicted by the model (see section 2.10). Conditions M3 and M4 used the mixed strategy game G_{NS}. This game simply has different payoffs for each player than game G_{SS}. Conditions M1 and M3 do not involve learning tools, providing the control for learning tools and measurements two and three.

3.2.2 Equilibrium Support/Learning Tools

As described in Chapter 2, learning tools consisted of devices that support pattern recognition and player recall. Thus conditions M2 and M4 provided players with two learning aids to support the fictitious play model described in section 2.10.5. The first learning tools

records and displays all payoffs that the player has received thus far. Additionally, it calculates the average payoff from the current strategy; thus players were provided with an approximation of their expected payoffs.

Second, players were provided with a direct support for the fictitious learning model – a game history. The game software listed the strategy used in each turn and the payoff received for that move. Players were able to analyze their moves and payoffs for the entire course of the game – learning which moves were more effective. Thus, they should have been better equipped to determine the best mix of strategies.

These tools support both general learning and specifically support the fictitious play model. As mentioned in chapter 2, these tools should result in a faster and tighter convergence to equilibrium play. The learning tools treatment conditions (M2 and M4) tested hypotheses 3.a and 3.b, respectively.

3.3 Constructs and Measures

Recall from chapter 2 that the overall point of this study is to determine the effectiveness and accuracy of the IW Model. The power of a game theoretic model lies in its prediction of equilibrium behavior. Thus, the primary purpose of the experiment is to measure equilibrium play. The following subsections describe equilibrium convergence and the use of covariates.

3.3.1 Equilibrium Convergence

Equilibrium play is attained when subjects consistently play the strategy profile predicted by the IW Model as shown in section 2.9. Subjects will initially play by trial and error. As more repetitions of the game are played, they should be able to estimate the expected value of each strategy. This expected value then provides the basis for a pure or mixed strategy. Since

equilibria are strategically stable, players cannot benefit by deviating. Specifically, if players deviate from the equilibrium strategy, they will see a rapid decrease in their payoffs. Thus game play was characterized by a period of random strategy play followed by a convergence to the equilibrium strategy.

The number of rounds to reach equilibrium (NORRE) is the primary measure of equilibrium convergence. Thus, NORRE is the dependent variable in all treatment conditions. NORRE was measured for each subject. A scatter plot helps show what NORRE actually represents. The scatter plot's X-axis shows the turn and the Y-axis shows the action played. The plot can then be visually examined to determine the turn at which play has reached equilibrium. Figure 3-2 shows a fictitious 20 round session of the defender playing game G_{SS}. The Defender's equilibrium for this game is to play action 2 ($\Delta 2$) with probability 0.67 and action 3 ($\Delta 3$) with probability 0.33. This ratio exists in Figure 3-2 following turn 9; thus the NORRE value for this session is 9.

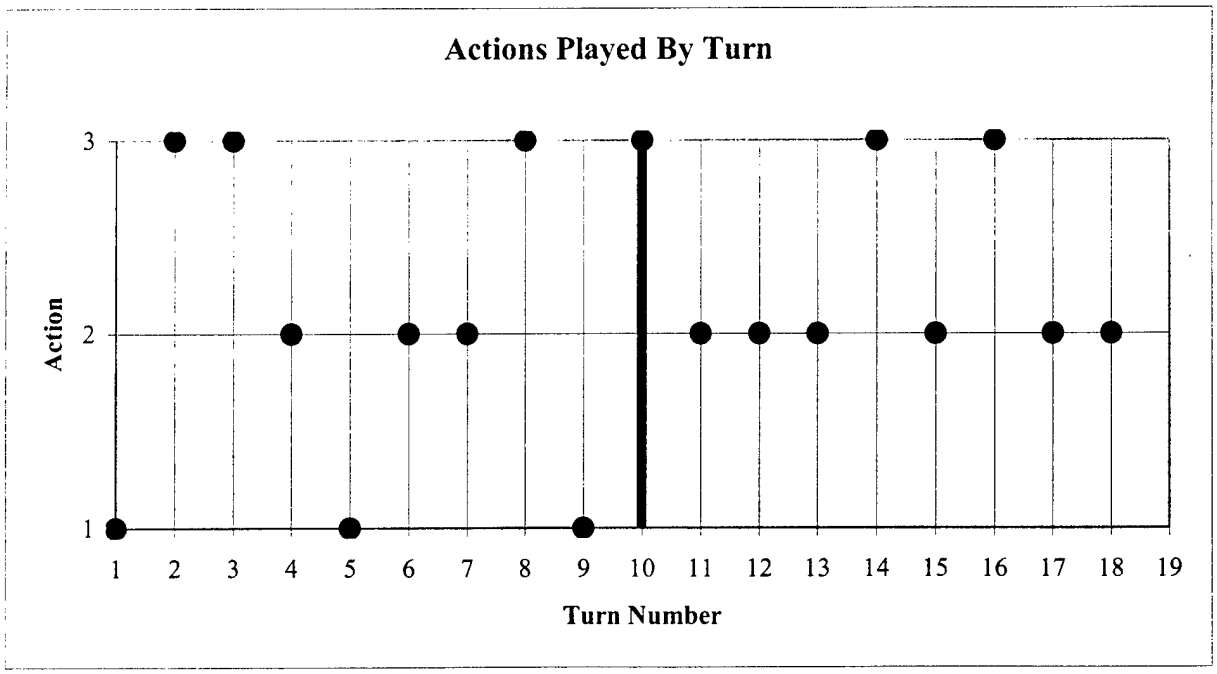

Figure 3-2 Equilibrium Calculation Plot

3.3.2 Game Theoretic Rationality and Experience

Game theoretic rationality captures the ability of subjects to recognize and play game theory equilibria. The ability to recognize game theory equilibria depends on many characteristics such as mathematical ability, attentiveness, and the ability to ignore extraneous information. Rather than attempting to capture these various elements, game theoretic rationality was measured by using the number of turns to reach equilibrium measure described above. Specifically, treatment condition P1 provided the basic rationality measure for the subsequent M1-M4 treatments.

High game theoretic rationality should allow a player to quickly converge to equilibrium. Thus, a subject with high game theoretic rationality should reach equilibrium in fewer turns than a subject with lower game theoretic rationality. Therefore, the NORRE measures from treatment P1 provided the rationality covariate used in the analysis of later treatments. Specifically, lower NORRE values should equate to higher game theoretic rationality.

In treatments M1-M4 subjects reached equilibrium at different turns. The rationality covariate allowed the variation due to innate ability to be removed from the overall variation in the number of turns to reach equilibrium. Thus, the impact of the learning tools became clearer as the variation due to rationality was removed.

As discussed previously, information warfare experience could result in bias. Specifically, information warfare experience could cause faster equilibrium convergence because subjects can apply their experience to the IW Model. As mentioned in section 2.11, the impact of IW experience was tested in Hypothesis 1 and was also used as a covariate.

3.4 Hypothesis Assessment and Statistical Analysis

The number of turns to reach equilibrium (NORRE) is the primary measurement of this study. NORRE provides the basis for determining if players have reached equilibrium and then comparing the time to reach equilibrium across subjects and treatment conditions. The following subsections describe the methods used to make these assessments. The mixed game NORRE score is the dependent variable in all statistical analyses.

3.4.1 Determining the Impact of IW Experience and Learning Tools

Figure 3-3 shows the full 2 X 2 X 2 factorial design of the ANCOVA. The fixed factors include learning tools (presence or absence), pure game role (defender or attacker), and mixed game role (defender or attacker). The mixed game type (G_{SS} and G_{NS}) is not shown as a separate factor, but will be tested to determine its effect. If a significant main or interactive effect due to game type is identified, game type will be added to the analysis, effectively producing a 2 X 2 X

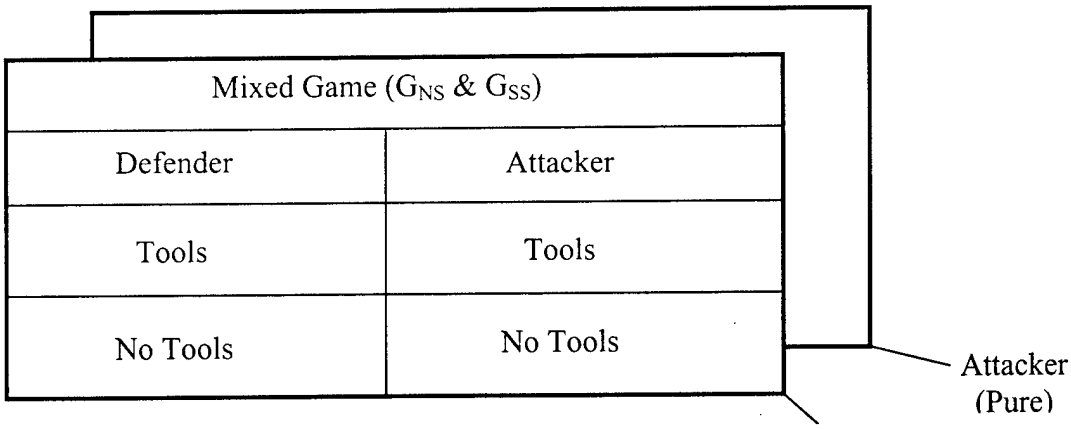

Figure 3-3 ANCOVA Factorial Design. Each of the above matrices is repeated for the two mixed strategy games.

2 X 2 design. Each subject's pure strategy game NORRE scores was averaged and included as a covariate in the ANCOVA. IW experience was the second covariate, as already explained. IW Experience, Tools use, and the role (i.e. defender or attacker) terms are all dummy/indicator variables coded as a zero (0) or one (1).

The general significance of each term (including the IW Experience covariate) was assessed by using an F-statistic. The F-statistic is the ratio of variation between treatment groups (as shown in Figure 3-2) to the variation among all groups. The F-statistics were considered significant (i.e. the alternative hypothesis that a meaningful relationship exists between the independent variable and the dependent variable is accepted) at an $\alpha < 0.05$. This level of significance indicates a 5% chance of falsely rejecting the Null hypothesis that no meaningful relationship exists between the independent and dependent variables of concern.

If a meaningful relationship is found to exist, the eta-squared (eta^2) index was used to assess its strength. The eta^2 index ranges between 0.0 and 1.0; larger values indicate a stronger relationship between the independent and dependent variables. So, the eta^2 index shows the amount of variation in the dependent variable, the mixed game score, attributable to the independent variable (such as tools, defender, etc.).

Finally, a general linear regression model was used to determine the direction (positive or negative) of the independent variables' effects. The independent variables' sign was used to judge the hypotheses. Specifically, pure strategy score, IW experience, and Tools use should all have negative coefficients according to hypotheses 1-3. Finally, the squared Pearson correlation coefficient (R^2) was assessed to determine the overall explanatory power of the regression model. The R^2 is the ratio of explained to unexplained variation, ranging between 0.0 and 1.0 with higher values indicating more explanatory power.

3.5 Summary

This chapter presented the overall experimental design and the methodology with which the design will be implemented. Then, the methods for data collection and analysis were presented. Chapter 4 will present the results from the experiment and the initial analysis of these results.

4. *Analysis of Data*

4.1 Introduction

This chapter presents an assessment of experimental manipulations, reports measurements, and provides an analysis of collected data. Recall from Chapter 3 that the mixed game score is the dependent variable in all analyses unless otherwise noted. The implications of this data in terms of the experimental hypotheses are addressed in Chapter 5.

4.2 Equilibrium Measures

This section presents two measurements of overall performance in the pure strategy game and the mixed strategy games. Overall performance is measured in terms of the number of rounds to reach equilibrium. The percentage of subjects who reach equilibrium indicates the percentage of subjects who attained equilibrium in at least one round. Both measurements are shown in Table 4-1.

Table 4-1 Equilibrium Measurements

Game	**Percentage Attaining Equilibrium**	**Mean Score**
Pure Strategy (G_{NI})	54.2%	33.583
Mixed Strategy (G_{SS})	50%	36.278
Mixed Strategy (G_{NS})	35.7%	36.444

These measurements show that a slim majority of subjects reached equilibrium in the pure strategy game and in the mixed strategy game G_{SS}. Although a majority of subjects did not reach equilibrium in the mixed strategy game G_{NS}, the subjects who did reach equilibrium reached it more quickly. The implications of these findings are discussed in Chapter 5.

4.3 Mixed Game Analysis

The effect of the specific mixed strategy game (G_{SS} or G_{NS}) played in treatments M1-M4 on the mixed game score was assessed using the full ANCOVA design, with the Mixed Game indicator variable left in. Although it cannot be proved that the game played did not have an effect (this would be an attempt to prove the Null hypothesis) its important to determine if the game played did have a significant effect. If it does, it must be included in the ANCOVA and any additional statistical analysis. As a reference, when Mixed = 0, game G_{SS} was played, "Def1" indicates that the subject was a defender in the pure strategy game, and "Def2" indicates that the subject was a defender in the mixed strategy game. Table 4-2 presents the Mixed Game ANCOVA summary.

Table 4-2 Mixed Game ANCOVA Summary

Source	Degrees Freedom	F Statistic	Significance (p)
Pure Average Score	1	4.327	0.042
Mixed Game	1	1.701	0.198
Mixed * Tools	1	3.219	0.078
Mixed * Def1	1	2.546	0.116
Mixed * Def2	1	2.659	0.109
Mixed * Tools * Def1	1	2.466	0.122
Mixed * Tools * Def2	1	1.593	0.212
Mixed * Defender Both	1	3.945	0.052
Mixed * Tools * Defender Both	1	3.280	0.076
Overall $R^2 = 0.419$			

A review of the ANCOVA and summary shows that there were no significant effects or interactions due to the mixed game played at a significance level of $\alpha \leq 0.05$. Thus, the mixed game played is omitted from further analysis. However, it should be noted that the mixed game played did have some effects. It particularly effected the interactions between the mixed game and the use of tools and between the mixed game and those who were defenders in both rounds.

Thus, this data suggests that the mixed game type did, in fact, cause some differences in equilibrium scores. This observation is discussed further in Chapter 5.

4.4 Pure Strategy Score and Information Warfare Experience Covariate Analysis

This section presents an analysis of the effects of the pure strategy score and IW experience covariates. Table 4-3 presents the complete ANCOVA Summary. Although the full model presented in Table 4-3 explains only about 22% of the variation in the mixed game scores, it still provides enough explanatory power to assess this study's hypotheses.

Table 4-3 ANCOVA Summary

Source	**Degrees Freedom**	**F Statistic**	**Significance (p)**	**Eta squared**
Pure Score Average	1	0.314	0.577	0.005
IW Experience	1	4.876	0.031	0.073
Tools	1	0.186	0.668	0.003
Def1	1	0.651	0.423	0.010
Def2	1	0.146	0.703	0.002
Tools * Def1	1	4.178	0.045	0.063
Tools * Def2	1	5.795	0.019	0.085
Def1 * Def2	1	0.113	0.738	0.002
Tools * Def1 * Def2	1	2.781	0.100	0.043
Overall $R^2 = 0.215$				

The IW Experience F-statistic 4.876 at a significance of $p = 0.031$ indicates that the Null hypothesis can be rejected at $\alpha \leq 0.05$. The regression model reported that the IW Experience coefficient $\beta_1 = -5.536$. IW Experience caused an improvement in the mixed strategy game score. So, Hypothesis 1 is supported by the data.

The pure score average F-statistic 0.314 at a significance of $p = 0.577$ indicates that the Null hypothesis (i.e. that the pure score average correlates with differences in the mixed strategy

score) cannot be rejected at $\alpha \leq 0.05$. The evidence does not show that the pure average score effects the mixed strategy score. So, Hypothesis 2 is not supported by the data.

4.5 Manipulation and Interaction Effects

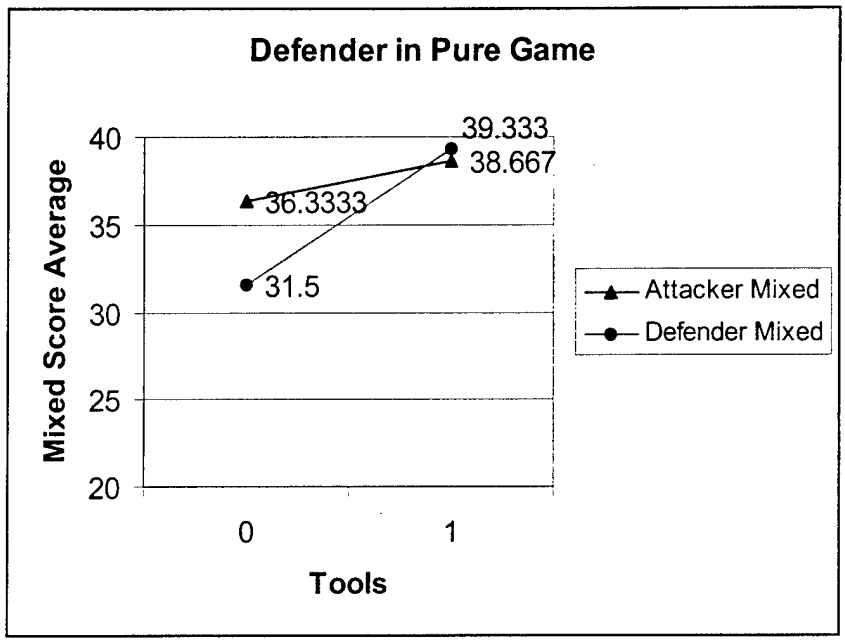

Figure 4-1 Defender and Tools Interaction

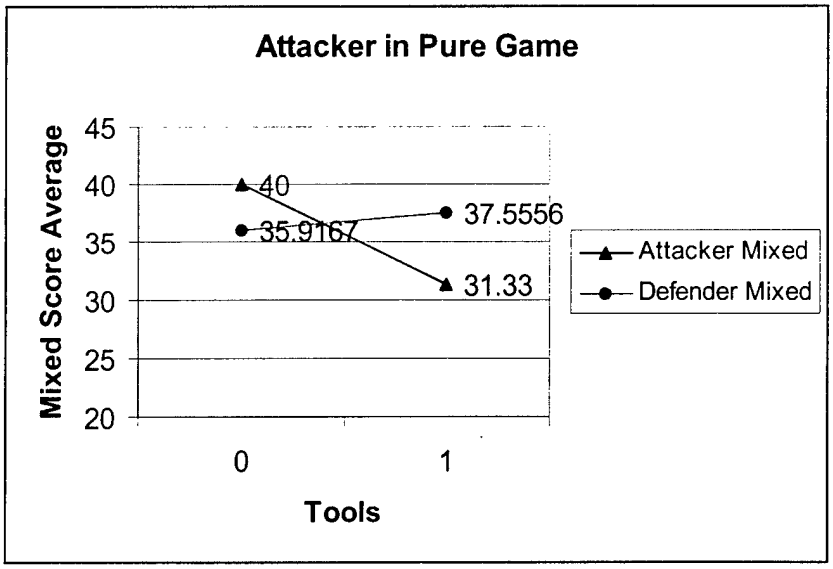

Figure 4-1 Attacker and Tools Interaction

The primary manipulation in this experiment was the application of learning tools. The interactions between tools and the subject's role (i.e. defender or attacker) must also be accounted for. Figures 4-1 and 4-2 show the interactions between Defender in the pure game and tools and Defender in the mixed game and tools. The interaction reveals that subjects who were Defenders in both games (i.e. the pure strategy and mixed strategy games) did worse with tools.

The summary statistics for learning tools from the ANCOVA are shown in Table 4-3. Overall, the evidence does not support the hypothesis that the application of learning tools had any effect on the mixed game score. However, the interactions between player role and tools are all significant at $\alpha \leq 0.05$. The interaction tables suggest that subjects who were attackers in both games benefited from the learning tools (Mean without tools = 40, Mean with tools = 31.33). Conversely, tools hurt equilibrium performance for subjects who were defenders in both games (Mean without tools = 31.5, Mean with tools = 39.33). For subjects who switched from attacker to defender or vice-versa, no significant effects due to tools appeared. Overall, there is mixed support for hypotheses 3.a and 3.b.

A final interaction of interest is that of subjects who were defenders in both games. Table 4-3 shows the summary statistics for defenders in both games from the ANCOVA. The F-statistic of 0.113 at $p = 0.738$ indicates that defenders in both games did not perform significantly differently than other subjects.

4.6 Summary

This chapter presented and analyzed data gathered during the experiments. It also related this data to the study's hypotheses. Chapter 5 presents an assessment of the data analysis presented here. It also provides further explanations of the observed data. Finally it provides the limitations of this study and recommendations for further study.

5. Conclusions and Recommendations

5.1 Introduction

The purpose of this study was to develop and evaluate a game theory model of information warfare, based upon the repeated games of incomplete information model. A key component of a game theory model is its ability to predict equilibrium. Thus, a critical measurement in this research was how many people reached equilibrium play. Another important facet of a game theory model is its ability to analyze behaviors such as experience and learning. So this study attempted to measure the effect of IW experience. Additionally, learning during an IW engagement could improve performance. Thus, this study manipulated the availability of learning tools and measured its effects on equilibrium performance.

This section will assess the measurements presented in Chapter 4. Likewise, this section will assess the results and conclusions for each hypothesis. Next, some general non-statistical observations from the experiment will be discussed. The final sections will discuss this study's limitations and recommendations for further research.

5.2 Equilibrium Measures

The percentage and mean scores of subjects who reached equilibrium (Table 4-1) indicate that a slim majority of subjects reached equilibrium. Indeed, the key limitation of this study was the relatively small proportion of subjects that reached equilibrium play. This limitation and its implications will be discussed in detail later in this Chapter. However, the fact the many subjects did not reach equilibrium in this experiment does not suggest that they were playing irrationally. Instead, an informal analysis of general game play suggests that players were playing logically

and reasonably, on average; this observation will be discussed in detail later in this Chapter. The remainder of this section will discuss equilibrium play in the pure strategy and the mixed strategy games.

5.2.1 Pure Strategy Equilibrium Play

Approximately 54% of subjects reached equilibrium in the pure strategy game with an average score of 33.5. As discussed in Chapter 2, equilibrium play in the pure strategy game indicates a general understanding of the IW game and its strategies. The fact that a slim majority reached equilibrium suggests that most subjects understood the basic scenario and strategies of the IW Model.

5.2.2. Mixed Strategy Equilibrium Play

Game play in the mixed strategy games was of central interest in this study. A mixed strategy is much more representative of real-life, where one must both respond to and anticipate the moves of the opponent – which cannot be done by playing a single strategy. However, only 50% of subjects reached equilibrium in game G_{SS} and 35.7% in game G_{NS}. Thus, the data suggests that the majority of subjects did not fully understand the mixed strategy games.

The fact that the averages are so close in the mixed strategy games (36.3 and 36.4, respectively) indicates that once subjects did understand the mixed game G_{NS}, they were able to reach equilibrium more quickly than in game G_{SS}. This may result from the fact that the equilibrium in game G_{NS} was subtler than that in G_{SS}. Specifically, the equilibrium in G_{SS} was driven purely by playing the two strategies with the best total expected value. G_{NS}, on the other hand, was driven more by the success probabilities of the strategies, which was unknown to the players. In other words, subjects had to determine which strategies were the most likely to

succeed in game G_{NS} – which was difficult given that they only had 40 turns to play the game.

5.3 Information Warfare Experience and Pure Strategy Score

This study postulated that prior experience with information warfare would improve equilibrium performance. Similarly, better performance in the pure strategy game was hypothesized to correlate with improved performance in the mixed strategy games. As discussed in Chapter 2, the pure strategy score could capture a multitude of factors such as probabilistic reasoning, concentration, logic, etc. that would effect the mixed strategy score. This section will discuss the effects of IW experience and the pure strategy score.

5.3.1 Hypothesis 1

Hypothesis 1 suggested that IW experience would improve performance in the mixed strategy games. The data presented in Chapter 4 provides support for this hypothesis.

Experience with information warfare could influence game play in several ways. First, the general scenario would be more familiar and less disconcerting to those with IW experience. Second, less learning would be required to become familiar with the basic strategies of the game so more effort could be focused on determining the best strategies. Additionally, those with IW experience may have been familiar with the scenario presented in the experiment.

5.3.2 Hypothesis 2

Hypothesis 2 posited that better equilibrium play in the pure strategy game would correlate with better equilibrium performance in the mixed strategy games. The data presented in Chapter 4 provides no support for this hypothesis.

The primary reason for the lack of any relationship between pure strategy play and mixed

strategy play is the fact that few subjects ever reached equilibrium in either game. Basically, there was not a sufficient amount of data on which to base any conclusion. Nonetheless, it is not completely surprising that pure strategy play would have no bearing on mixed strategy play. The mindset of pure strategy play is different than that of mixed play. In pure strategy play, one is concentrating on playing a single strategy – no matter what the opponent does. In mixed strategy play, on the other hand, the player must continually concentrate on the opponent's actions and adjust his or her own strategy accordingly.

Additionally, mixed strategy play involves randomizing one's own play in order to keep the opponent off balance (in pure strategy games, it does not matter what the opponent does). Finally, this result suggests that there may be little reason to maintain support for a pure strategy style of play in the IW Model since it has no impact on real world play.

5.4 Hypothesis 3 – Effect of Learning Tools

Hypotheses 3.a and 3.b posited that learning tools would improve equilibrium play in the mixed strategy games. The learning tools would allow players to better determine what strategy mix yielded the best payoff. This section discusses learning tool effects and the interactions with the player's role (i.e. attacker or defender).

5.4.1 Hypotheses 3.a and 3.b

The data presented in Chapter 4 provide no support for the hypothesis that learning tools improve equilibrium play, in general. Again, the main reason for this finding is that an insufficient percentage of subjects reached equilibrium to support any conclusions. An additional reason is that players may have been playing in a different style than that supported by the learning tools.

The learning tools used in the experiment were based on a learning process. As discussed in Chapter 2, this learning process requires that players be given more information about the history of the game. This information then supports the fictitious play model. Recall that fictitious play involves players studying the game's history, determining what moves would have been better, and applying the refined strategy to future turns. However, if players are reacting purely to the moves of their opponent or to the payoffs that they have received, they may not be actively trying to learn more about the game. Indeed, game play in this experiment distinctly showed a best response as opposed to an adaptive learning style of play (this statement will be discussed shortly). Thus, more information such as that provided by the learning tools could have little impact on game play.

The research discussed in Chapter 2 suggested that people generally employ learning when playing more complex games, such as the IW Model, thus learning tools were used. However, the particular structure of the payoffs in the mixed strategy games may have prevented players from employing a learning strategy; this statement will be discussed in more detail shortly.

5.4.2 Interactions between Tools and Player Role

Although tools failed to show any effect on equilibrium play in general, the ANCOVA interactions revealed that tools impacted defenders and attackers differently. Since, tools impacted attackers and defenders in opposite ways, the overall effect due to tools could have been cancelled out. In any case, the interactions provide the basis for the following observations.

As noted in Chapter 2, defenders had access to more information than attackers. Specifically, defenders could determine the attackers' moves by observing their own payoffs.

This additional information was based upon information warfare technologies such as network monitoring devices. However, this additional information directly contributes to a best response as opposed to a learning style of play. So, the information provided by the learning tools could be extraneous or even distracting. This conclusion is supported by the interaction data provided in Chapter 4. Specifically that the mean score for defenders without tools (31.5) was less (better) than with tools (39.3). Obviously such a post hoc conclusion requires validation. The implications of this finding on information warfare are discussed later in this report.

Proceeding from the above discussion would suggest that attackers should benefit from learning tools. Since they are at an initial informational deficit, they cannot directly employ a best response strategy. Instead, they must analyze the relative successes of their own strategies and determine the best mix. A learning process would support the attacker's strategy analysis. The interaction data presented in Chapter 4 supports this conclusion. Specifically, the mean score for attackers with tools (31.33) is less than without tools (40.00). Indeed, the attackers in this study could not reach equilibrium without the learning tools. Again, this post hoc conclusion requires further validation. The implications of this finding on information warfare will be discussed later in this report.

5.5 General Observations Regarding Game Play

When calculating the number of turns to reach equilibrium, several general "themes" emerged. As mentioned previously, a general best response strategy was played even when equilibrium was not reached. A best response strategy is one in which the player alters their strategy to counter their opponent's moves, even if the response is less optimal than the equilibrium strategy. Additionally, players seemed to recognize which strategy had the highest

probability of success and would favor that strategy, even if its expected value was lower than other strategies. For example, the social attack strategy may have had a payoff of 70, but would only succeed 15% of the time whereas the client attack may have only had a payoff of 40 but succeeded 40% of the time. In this case, many subjects favored the more successful client attack, although they would have realized a greater long-run payoff with the social attack. Most likely, the short time span of the game (40 turns) prevented players from determining the expected value for each strategy. These observations suggest that subjects were playing rationally, even when not reaching equilibrium. This is a significant observation since most formal models of social behavior, particularly game theory, rest on the assumption of rationality.

The player type as a component of the repeated games of incomplete information model was discussed in Chapter 2. In the IW Model, the player's type determined what type of information (social, network, or client) they preferred. In this discussion, it was suggested that the player type might not influence the IW Model equilibrium because players would be unaware of their type. Additionally, the payoffs and success probabilities were configured (unintentionally) so that the equilibrium strategy did not necessarily match up with the player's type. During equilibrium analysis, it was found that many players did in fact play according to their type. Specifically, they would play the strategy that best protected their preferred information, even if it was not the best equilibrium strategy. The fact that player types were not accounted for in the equilibrium calculations is a significant limitation of this study, and is discussed shortly. However, the fact that some players discerned their type suggests that they understood the underlying IW Model.

5.6 Study Limitations

This study's limitations will be presented in two parts. First, limitations of the IW Model and equilibrium calculation will be presented. Then, limitations of the study's methodology will be discussed. In each subsection, possible extensions to the IW Model will be introduced, where appropriate.

5.6.1 IW Model and Equilibrium Limitations

As noted previously, the primary limitation of this study was the inability of subjects to reach equilibrium. As discussed in previous sections, problems with equilibrium calculation seem to be the main problem. Little evidence emerged that raised questions about the IW Model itself.

The 40-turn horizon of actual game play contributed to subjects' inability to calculate expected values, determine probabilities, and generally calculate the best equilibrium strategy. Forty turns may simply have not been long enough for players to determine the equilibrium strategy. A more serious problem is that equilibrium for finite horizon and infinite horizon games can be different. Chapter 2 suggested that since players would not know how many turns they were playing, they would be playing as if there were an infinite horizon. Consequently, equilibrium was calculated based upon an infinite horizon. The assumption of an infinite horizon may have been incorrect. Since players knew that they would only be participating in the experiment for a finite period, they knew the game could not last forever. Thus, they could have played in accordance with finite-horizon equilibrium. Future research could compare equilibrium results between finite-horizon equilibrium and infinite-horizon equilibrium.

The strategy success probability could also have affected equilibrium play. Since

equilibrium was calculated based upon the expected values (i.e. the pure payoff multiplied by the success probability) players would have to determine the probabilities to determine equilibrium. Additionally, success probabilities obscured a player's type, sometimes yielding an equilibrium strategy that did not coincide with the player type. Overall, success probabilities must be more rigorously incorporated into the general IW Model and players must be given more information about their success probabilities.

Finally, the fact that player types were not incorporated into equilibrium calculation may have prevented some subjects from reaching equilibrium. The assumption that player types would not have an impact on actual game play was apparently incorrect. Thus, equilibrium calculations should account for player type (as demonstrated in Chapter 2). Accounting for player type could produce a more robust and accurate model of information warfare.

5.6.2 Experimental Methodology Limitations

One key limitation was that the roles, defenders and attackers, were randomly assigned. As shown in Chapter 4, the role had a significant interaction with tools. So, better control over role assignment may have increased statistical reliability. Specifically, the numbers of subjects in the various interaction groups (such as defender in the pure strategy game, attacker in the mixed game with tools) were not equal. This results in unequal variances between groups.

The small number of subjects presented another limitation. Although the multiple turns allowed more data points to be collected, the small number of subjects reduced overall variation. Additionally, the multiple turn configuration causes an large increase in data points for even a small increase in subjects. For instance, 8 more subjects, evenly distributed across treatments would have resulted in 128 data points rather than 72. The multiple turn configuration is a

strength of the study, however, the limited subject pool was a limitation.

Another limitation of the study was the calculation of the number of rounds to reach equilibrium. A more rigorous method for calculating equilibrium could improve the variation in equilibrium scores in this study. First, it could allow equilibrium to be reached in fewer turns. Second, it would increase consistency across subjects. Surface response analysis and other optimization methods are possible routes to improve equilibrium score calculation.

5.7 Recommendations for Future Research

The first recommendation for future research would be to include some of the equilibrium calculation enhancements discussed in previous sections. These enhancements could improve the rate of equilibrium attainment and improve all findings. Additionally, the enhancements would improve the utility of the IW Model. Indeed, a future study based on these enhancements could be performed with the same methodology and software in which this study was performed.

Incorporating more aspects of information warfare into the IW Model presents another avenue for future research. More detailed strategies and scenarios are fairly simple extensions. Deeper extensions include the addition of more strategies and the ability to employ multiple strategies in the same turn. Budgetary considerations, such as rationing a limited budget over all turns would also be an interesting extension. Finally, incorporating learning directly into the model could shed light on equilibrium behavior. Specifically, during each turn the success probabilities of the strategies could be adjusted to reflect the experience gained while conducting the information warfare operation.

Case study research could also help develop the IW Model. A specific information

warfare operation could be studied and it's various elements, such as the strategies used and the relative payoffs could be incorporated into the IW Model's payoff matrix. Then, theoretical equilibrium could be calculated from the model. Next, the actual operation could be studied to see if the participants played at equilibrium. Even if they did not play at equilibrium, the exercise could possibly show better strategies, weaknesses in the information defense policies, or opportunities for technology improvements.

As a final note, the key component of this line of research is to develop a model that allows information warfare simulations, analysis of information warfare behavior, and suggests methods for improvement in information warfare operations. Further refinement of the game theory IW Model itself and the incorporation of more information warfare components into the model are two major avenues of research towards these goals.

5.8 Final Conclusions

Overall, the results of this study show that developing a game theory model of information warfare holds promise for better understanding and analyzing the behavior of IW participants. Additionally, the IW Model could shed light on how to conduct IW operations, such as this study's brief analysis of learning tools and their application to IW technologies. Despite the fact that many subjects did not reach equilibrium when playing the game, their rational style of play suggests that a formal method for analyzing information warfare, such as game theory, is not fruitless. This study's experimental methodology and, in particular, the experiment's software provide some of the tools necessary to develop and test game theory models of information warfare.

Even from this limited study, several conclusions about information warfare and how to

model it emerged. Although much work remains before a more robust game theory IW model is realized, this study shows that the realistic possibility of completely developing such a model exists.

Vita

Captain David A. Burke was born on 29 April 1973 in Dunedin, Florida. He graduated from Citrus High School in Inverness, Florida in June 1991. In August of that year, he began undergraduate studies at Boston College where he graduated Magna Cum Laude with a Bachelor of Arts Degree in Computer Science in May of 1995.

As a Distinguished Graduate of the Air Force Reserve Officer Training Corps, he received his regular commission on 20 May 1995. Captain Burke was stationed at United States Strategic Command Headquarters at Offutt Air Force Base for three years. There, he served as the Missile Warning Systems Section Chief in the Command and Control, Communications, and Computers Directorate. In May 1998, he entered the Graduate Software Systems Management Program at the Air Force Institute of Technology. Upon graduation, he will be assigned to the Phillips Laboratory at Kirtland Air Force Base, New Mexico.

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Appendix A: Experimental Scenario and Help Screens

Defender Scenario

You are the Chief Information Officer (CIO) for Megalith, Inc., a United States conglomerate of financial and manufacturing firms. At the latest meeting of senior executives, you learned that one of Megalith's European competitors, Orwell Inc., has decided to engage in offensive information warfare against your company. Orwell hopes to gain sensitive information and to disable Megalith's information systems. The US State Department has stated that they cannot intervene on your behalf because of sensitive diplomatic negotiations with Orwell's home nation. Thus, it's up to you to defend Megalith's information systems.

You have since learned that Orwell has developed three general attack strategies, which are briefly described below. Each month, Orwell will devote all of its resources to one of these strategies.

1. **Social Engineering**: This strategy involves the use of non-technical methods to obtain sensitive information, penetrate corporate networks, or disrupt information system operation. Social Engineering involves methods such as: password guessing, posing as network administrators to obtain passwords, using false identities over the phone or in person, physical penetration of computer or corporate facilities, monitoring telephones, and accessing employee computers while they are away from their desks.
2. **Client Attack:** This strategy involves disrupting or compromising desktop computers that all employees use at Megalith. Client Attacks involve methods such as: computer viruses (particularly email attachment viruses), log-in spoofing (i.e. a false log-in screen is displayed to obtain the user's password), and changing computers' startup and configuration files (which can be done remotely in Windows95/98).
3. **Network Attack**: This strategy involves disrupting or compromising Megalith's computer network; this can impede email, file sharing, printer use, and the use of shared applications (among other

things). Network attacks are directed at file servers, routers (devices that connect and control the network's cabling), domain name servers (computers that allow the use of human friendly names such as www.megalith.com), and any other component on the network.

Your Information Security department has developed three defense strategies to counter each of the above attacks. Each month, you will select one of these strategies to employ. Although each defense strategy counters a specific attack, they also have limited effectiveness against the other attack strategies. Your defense strategies are not cumulative. Thus, you will begin anew each month. At the end of each month, you will receive a report indicating the costs of any information resources that were compromised. Your defense strategies are described below:

1. **Social Engineering Defense:** This strategy primarily involves training programs. Users are trained on proper password selection, when and how to change passwords, recognizing network administrators, proper information to discuss over networks of phones, and other computer security precautions. Additionally, corporate facilities are secured against intrusion (i.e. guards, security alarms, etc.) Finally, security background checks can be used for computer users and especially system administrators.
2. **Client Defense:** The main defense here is virus protection. All desktop computers are installed with virus protection programs that monitor all files and email attachments. Additionally, desktops are protected against remote access and administration (most of this is done through Windows). Finally, file encryption can be used to protect sensitive files and email.
3. **Network Defense:** Network firewalls are the primary network defense. Network firewalls are devices that prevent network access from unauthorized locations. Secure routers supplement network firewall protection. Additionally, network communications can be encrypted to prevent unauthorized interception.

Attacker Scenario

You are the Chief Information Officer for Orwell Inc., a European conglomerate of manufacturing and financial firms. Your biggest competitor, the US-based Megalith Inc., has steadily eroded Orwell's market share and profitability in the last few months. At the last meeting of senior executives, it was decided that Orwell Inc (i.e. you) would employ offensive information warfare to gain Megalith's secrets and to disrupt its information systems. Hopefully, this will improve Orwell's ability to compete with Megalith. Representatives from Orwell have already persuaded your national government to "look the other way" while you conduct your information warfare operations. Thus, you may employ whatever strategies you desire.

You have since assembled a team of professional computer crackers (hackers only penetrate systems, crackers penetrate **and** disrupt) and they have developed three general attack strategies. Each month, you will devote all of your resources towards one of these strategies. At the end of each month, you will receive a report indicating the value resulting from your information warfare operations. Your attack strategies are described below:

4. **Social Engineering**: This strategy involves the use of non-technical methods to obtain sensitive information, penetrate corporate networks, or disrupt information system operation. Social Engineering involves methods such as: password guessing, posing as network administrators to obtain passwords, using false identities over the phone or in person, physical penetration of computer or corporate facilities, monitoring telephones, and accessing employee computers while they are away from their desks.
5. **Client Attack:** This strategy involves disrupting or compromising desktop computers that all employees use at Megalith. Client Attacks involve methods such as: computer viruses (particularly email attachment viruses), log-in spoofing (i.e. a false log-in screen is displayed to obtain the user's password), and changing computers' startup and configuration files (which can be done remotely in

Windows95/98).

6. **Network Attack**: This strategy involves disrupting or compromising Megalith's computer network; this can impede email, file sharing, printer use, and the use of shared applications (among other things). Network attacks are directed at file servers, routers (devices that connect and control the network's cabling), domain name servers (computers that allow the use of human friendly names such as www.megalith.com), and any other component on the network.

You have also discovered that Megalith Inc. has learned of your intentions. They have developed three counter strategies to defend against your attacks. Likewise, they will employ one of these strategies each month. Their defenses are not cumulative; they must start a new defense each month. Here is what you have learned about their defenses:

4. **Social Engineering Defense:** This strategy primarily involves training programs. Users are trained on proper password selection, when and how to change passwords, recognizing network administrators, proper information to discuss over networks of phones, and other computer security precautions. Additionally, corporate facilities are secured against intrusion (i.e. guards, security alarms, etc.) Finally, security background checks can be used for computer users and especially system administrators.
5. **Client Defense:** The main defense here is virus protection. All desktop computers are installed with virus protection programs that monitor all files and email attachments. Additionally, desktops are protected against remote access and administration (most of this is done through Windows). Finally, file encryption can be used to protect sensitive files and email.
6. **Network Defense:** Network firewalls are the primary network defense. Network firewalls are devices that prevent network access from unauthorized locations. Secure routers supplement network firewall protection. Additionally, network communications can be encrypted to prevent unauthorized interception.

ATTACKER GAME HELP

PAYOFF MATRIX

The Payoff Matrix indicates the value of information resources you gain when your Attack Strategy ***succeeds***. If your Attack Strategy fails, you gain nothing. The actual value that you obtain depends upon both the Attack Strategy that you chose and the Defense Strategy chosen by your opponent. In the highlighted example below, you receive $70Million ***if and only if*** the Social Attack strategy succeeds and the Social Defense was used. Its important to note that the Defender may or may not lose the same amount that you receive (this is not a zero sum game). In the below example, the Defender may only lose $50Million although you gained $70Million. Indeed, the Defender's payoff matrix may look much different than yours. ***Thus you should not immediately assume that the Defender values their strategies in the same way that you do.***

	Social Defense	Client Defense	Network Defense
Social Attack	70	70	70
Client Attack	50	50	50
Network Attack	25	25	25

Notice that you will not be able to determine the actual Defense Strategies employed by the Defender. Thus, you should concentrate on determining which Attack Strategies succeed most often (see below for more information).

STRATEGY SUCCESS

Although it appears that your Attack Strategies yield the same payoffs regardless of the Defense strategy, this is not the case. The Defense Strategies will be more effective against some of your attacks than against others. For example, if you use a Social Attack while the Defender uses a Network Defense, you may have a higher chance of success than if your opponent used a Social Defense. So, if you have achieved a high-level of success for a few turns and then suddenly realize less success, its quite likely that the Defender has employed a different Defense Strategy that is more effective against your current Attack Strategy. For instance, if you have played the Social

Attack/Network Defense scenario above and suddenly experience several losing turns, the Defender may have switched to a Social Defense to counter your Social Attack.

The "Approximate Chance of Success" area of your Game screen shows the ***averaged, approximate*** chance of success for each of your strategies. *THESE VALUES ARE ONLY A GUIDE TO HELP GET YOU STARTED.* You will notice that Attack Strategies are more effective against particular types of Defenses. Additionally, you may notice that an Attack Strategy with a low overall chance of success may be very effective against one type of Defense. For instance, the Network Attack may be very effective against the Client Defense (60% or better) but ineffective against other defenses (25% or worse).

A KEY FACTOR IN SELECTING THE BEST STRATEGY OR COMBINATION OF STRATEGIES IS DETERMINING WHEN YOUR ATTACK STRATEGIES ARE MOST EFFECTIVE.

DEFENDER GAME HELP

PAYOFF MATRIX

The Payoff Matrix indicates the costs of compromised information resources when a particular Defense Strategy *fails*. The actual cost depends upon the Defense Strategy chosen ***and*** the Attacker's Strategy. The sample payoff matrix below shows that you will lose $70Million if your Social Defense Strategy ***fails*** against a Social Attack. However, if your Social Defense succeeds, you lose nothing. Two important items should be noted here. First, when your Defense strategy succeeds, the Attacker gains nothing. However, when your Defense Strategy fails, the Attacker may or may not gain the same amount that you have lost (i.e. this is not a zero-sum game). In the below example, if your Social Defense strategy fails and you lose $70Million, the Attacker may only realize a gain of $50Million. Indeed, the Attacker's payoff matrix may look much different that yours. ***Thus, you should not immediately assume that the Attacker values their strategies in the same way that you do.***

	Social Defense	Client Defense	Network Defense
Social Attack	-70	-70	-70
Client Attack	-50	-50	-50
Network Attack	-25	-25	-25

Notice that if your Defense strategy does fail, you will be able to determine the strategy that the Attacker used by noticing how much money you lost. In the above example, you would be able to determine that your opponent used a Social Attack.

STRATEGY SUCCESS

Although you cannot directly select your own payoff, you will quickly notice which of your strategies are more effective (***i.e. those that succeed more often***). Additionally, your Defense Strategies are more effective against

some attacks than they are against others. Thus, your Social Defense may be very effective against a Social Attack, but only moderately effective against a Client Attack.

The "Approximate Chance of Success" area of your Game screen shows the ***averaged, approximate*** chance of success for each of your strategies. ***THESE VALUES ARE ONLY A GUIDE TO HELP GET YOU STARTED.*** You will notice that Defense Strategies are more effective against particular types of Attacks. Additionally, you should notice that a Defense Strategy with a low overall chance of success may be very effective against one type of attack. For instance, the Network Defense may be very effective against the Network Attack (60% or better) but ineffective against other attacks (25% or worse).

A KEY FACTOR IN SELECTING THE BEST STRATEGY OR COMBINATION OF STRATEGIES IS DETERMINING WHEN YOUR DEFENSE STRATEGIES ARE MOST EFFECTIVE.

GAME ENHANCEMENTS

Three Average Payoff boxes, one for each move, have been added to the upper, left-hand side of the Game Form. These boxes show the average payoff for each move, averaged over the number of turns that you have played the move. Each box's average is updated after you use that move. The example below shows how this works:

Suppose that you have played 5 turns so far, as shown in the table below: (NOTE: All three strategies will be shown on the game form.

TURN	MOVE	PAYOFF RECEIVED	AVERAGE PAYOFFS	
1	Client Attack	0	Client Attack = 0	Social Attack = 0
2	Social Attack	75	Client Attack = 0	Social Attack = 75
3	Client Attack	25	Client Attack = 12.5	Social Attack = 75
4	Social Attack	0	Client Attack = 12.5	Social Attack = 37.5
5	Social Attack	50	Client Attack = 12.5	Social Attack = 41.67

Since your goal is to make as much possible, you should favor strategies that have the highest Average Payoffs. *Keep in mind that the Average Payoff will become more accurate as more turns are played.*

Below the Average Payoff boxes is a scroll-box that shows the moves and payoffs for each turn of the game. This box allows you to see what moves you have made previously and what payoff you received for those moves.

Appendix B: Experiment Instructions and Checklist

Instructions

Thank you for participating in this experiment. This experiment involves playing a simple Information Warfare based game. You may terminate your participation in this experiment at any time. The experiment is designed to proceed uninterrupted, however, if you need to pause for any reasons please notify the experimenter immediately. Please do not use writing materials, calculators, or other external devices during the experiment. Also, please do not have any other software applications open on your computer during the experiment. Finally, please do not speak to other subjects during the experiment (in particular, do not reveal your strategies or winnings/losses). Thank you for your cooperation.

If you encounter a software error during the experiment, please cease all activity and notify the experimenter immediately. Likewise, if you have a question during the experiment, please notify the experimenter immediately.

The purpose of this experiment is to test and validate a game theory model that encompasses some basic aspects of information warfare. Game theory is a technique frequently used in economics and other social sciences to model social behavior. The primary motivation for developing a game theory model is to simplify complex social situations. The simplified model can then allow better understanding of people's actions and the reasons for their actions. Additionally, game theory models can provide limited predictive power in some social situations.

The inclusion of information warfare attributes is a significant extension of current game theory models. Thus, only basic, high-level aspects of information warfare are included in this study's model. **Please keep in mind that this is essentially a game theory study – not an Information Warfare study. During the course of the experiment, please do not become concerned with the technical implications of the Information Warfare scenario presented. Your goal is to maximize your payoffs**

while minimizing your losses – REGARDLESS OF WHAT PREVIOUS IW EXPERIENCE MAY INDICATE.

Each of you will have three strategies available. These strategies and the overall scenario will be explained in detail when you begin the experiment. Your overall goal is to determine and employ the combination of strategies that yields you the best ***long-term*** payoff. Under some conditions, it may be advantageous to use a combination of two or all three strategies to keep your opponent unaware of your actions. At other times, it may be better to use only one strategy. During the first few turns, you should complete the following actions:

1) Determine your best strategy(s), i.e. those that seem to succeed most often **and** that yield the best, long-term payoff.

2) If no single strategy seems best, determine the combination of strategies that yields higher long-term payoffs.

3) Attempt to determine the preferred strategy(s) of your opponent and alter your strategy accordingly.

4) When you believe you have found the best strategy or combination of strategies, continue using it unless your overall payoffs seriously decline.

EXPERIMENT PROTOCOL

1) Place subject number cards at workstations as follows: Odd numbers on far-wall, starting from left to right, Even Numbers on near-wall, starting right to left.

2) Seat subjects at numbered workstations, ensuring that all number pairs (i.e. 1 & 2, 5&6, etc.) are matched.

3) Have subjects log into their AFIT computer accounts. Verify that all subjects are logged in.

4) Have subjects open experiment database and STOP.

FILE LOCATION:_____

5) Verify that all subjects have gained access to experiment database.

6) Distribute All-Subject, Session 1 Instructions. Experimenter then reads instructions aloud.

7) Ask subjects to enter their Subject Number (from card) and to answer the questions on the Subject Identification form.

8) Ask subjects to read "The Scenario" form to themselves and hit Continue button when complete.

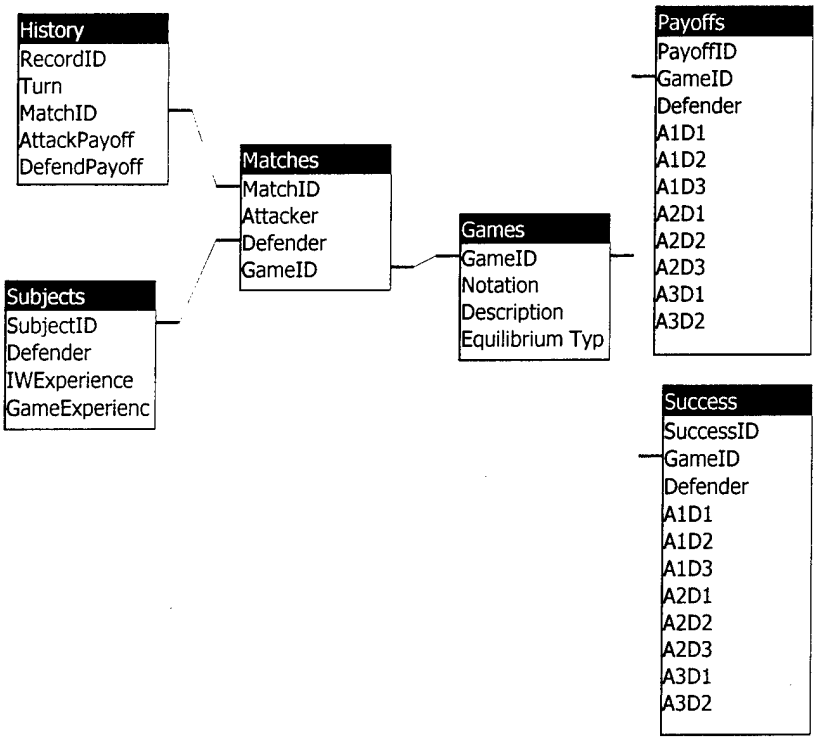
9) Ask subjects to hit the "Move Help" button on the Game Form, read the instructions, hit the "Done" button, and then STOP. Notify subjects that the Move Help button is accessible throughout the experiment.

10) When all Subjects have read the Move Help screen, they may begin making moves.

11) Ask subjects not to leave until dismissed by the experimenter.

12) If questions or software errors arise, have all subjects stop.

Appendix C: Experiment Database Tables and Relationships


History
RecordID
Turn
MatchID
AttackPayoff
DefendPayoff
Matches
MatchID
Attacker
Defender
GameID
Subjects
SubjectID
Defender
IWExperience
GameExperienc
Games
GameID
Notation
Description
Equilibrium Typ
Payoffs
PayoffID
GameID
Defender
A1D1
A1D2
A1D3
A2D1
A2D2
A2D3
A3D1
A3D2
Success
SuccessID
GameID
Defender
A1D1
A1D2
A1D3
A2D1
A2D2
A2D3
A3D1
A3D2

Appendix D: Experiment Software Displays

Subject Data Form

Please Complete The Information Below Then Click Continue

Subject Number 40

Your name is only used for identification. It will not be used for data analysis or released.

Last Name

First Name

Select 'Yes' for IW Experience ONLY if you have served in an Information Security position or have taken an IW course.

IW Experience

- ○ Yes
- ◉ No

Select 'Yes' for Game Theory Experience ONLY if you have worked with Game Theory Modeling or similar stochastic models in an Economics or other Social Science course. Game Theory experience does not denote proficiency playing games.

Game Theory Experience

- ○ Yes
- ◉ No

Continue

Game Form

Payoff Matrix

Units in Millions, US $

	Social Defense	Client Defense	Network Defense
Social Attack	-50	-50	-50
Client Attack	-35	-35	-35
Network Attack	-75	-75	-75

Select Move:

Game Help

Make Move

Approximate Chances of Success		Average Payoff
Social Defense	40%-60%	0
Client Defense	40%-60%	0
Network Defense	40%-60%	0

Last Month Payoff:

Move Success

Payoff Received: 0

Previous Month's Payoffs and Moves

Turn	DefendAction	DefendPayoff
1		0
2		0
3		0
4		0
5		0
6		0
7		0
8		0
9		0
10		0
11		0

New Features Help

Appendix E: Experiment Software Source Code

```
Option Compare Database
Option Explicit

Private Sub Continue_Click()
Dim FindSubject As QueryDef
Dim SubjectRecord As Recordset, ErrorRecord As Recordset
Dim Query As String
Dim Subject As Integer, Counter As Integer

On Error GoTo ErrorHandler

Begin:
If IsNull(SubjectNumber) Then
    MsgBox "Please Select Your Subject Number"
Else
    Subject = SubjectNumber
    Query = "SELECT * FROM Subjects WHERE SubjectID =" & Subject
    Set FindSubject = CurrentDb.CreateQueryDef("FindSubject" & Subject,
Query)
    Set SubjectRecord = FindSubject.OpenRecordset
    SubjectRecord.MoveFirst
    DefenderBox = SubjectRecord("Defender")
    SubjectRecord.Edit
        SubjectRecord("IWExperience") = IWExperience
        SubjectRecord("GameExperience") = GameExperience
        SubjectRecord("LastName") = LastNameBox
        SubjectRecord("FirstName") = FirstNameBox
    SubjectRecord.Update
    CurrentDb.QueryDefs.Delete "FindSubject" & Subject
    CurrentDb.QueryDefs.Refresh
    DoCmd.OpenForm "GameForm"
    If DefenderBox = True Then
        DoCmd.OpenForm "DefenderScenario"
    Else
        DoCmd.OpenForm "AttackerScenario"
    End If
    DoCmd.Close acForm, "SubjectIdentification"
End If
GoTo Out

ErrorHandler:
    Set ErrorRecord = CurrentDb.OpenRecordset("Errors", DB_OPEN_DYNASET)
    With ErrorRecord
        .AddNew
        !BlownUpCount = -1 ' Indicates that Error Occurred on Subject ID Form
        !ErrorDesc = Err.Description
        !ErrorNumber = Err.Number
        .Update
    End With
    For Counter = 1 To 1000
        Next Counter
    Resume Begin

Out:
End Sub
```

```
Private Sub FeaturesHelpButton_Click()

    If Forms!GameForm!DefenderBox = True Then
        DoCmd.OpenForm "DefendToolsHelp"
    Else
        DoCmd.OpenForm "AttackToolsHelp"
    End If

End Sub

Private Sub Form_Open(Cancel As Integer)
    Dim Payoff As Integer
    Dim i As Integer
    Dim Subject As Integer
    Dim Match As Integer
    Dim Game As Integer, BlownUp As Integer
    Dim Defender As Boolean, TableExists As Boolean
    Dim Move1Sum As Single, Move2Sum As Single, Move3Sum As Single
    Dim Query As String

    Dim PayoffRecord, MatchRecord, SuccessRecord, TurnRecord, HistoryRecord
As Recordset
    Dim ErrorRecord As Recordset
    Dim FindPayoff, FindMatch, FindSuccess As QueryDef
    Dim MatchTable As TableDef
    Dim MatchField As Field

On Error GoTo Common_Error
BlownUp = 0

Begin:
Defender = Forms!SubjectIdentification!DefenderBox
Subject = Forms!SubjectIdentification!SubjectNumber
Forms!GameForm!DefenderBox = Defender
Forms!GameForm!SubjectBox = Subject
TurnBox = 1

If Defender = True Then
    Move1Label.Caption = "Social Defense"
    Move2Label.Caption = "Client Defense"
    Move3Label.Caption = "Network Defense"
    'Set text color to Blue
    Move1Label.ForeColor = 16711680
    Move2Label.ForeColor = 16711680
    Move3Label.ForeColor = 16711680
    Query = "SELECT * FROM Matches WHERE Defender =" & Subject
    DmoveBox.Visible = True
    DmoveBox.Enabled = True
    DmoveBox.TabStop = True
    DefendHistory.Visible = True
    DefendHistory.Enabled = True
Else
    Move1Label.Caption = "Social Attack"
    Move2Label.Caption = "Client Attack"
    Move3Label.Caption = "Network Attack"
```

```
    'Set text color to Red
    Move1Label.ForeColor = 255
    Move2Label.ForeColor = 255
    Move3Label.ForeColor = 255
    Query = "SELECT * FROM Matches WHERE Attacker =" & Subject
    AMoveBox.Visible = True
    AMoveBox.Enabled = True
    AMoveBox.TabStop = True
    AttackHistory.Visible = True
    AttackHistory.Enabled = True
End If
Set FindMatch = CurrentDb.CreateQueryDef("FindMatch" & Subject, Query)
Set MatchRecord = FindMatch.OpenRecordset
MatchRecord.MoveFirst
Game = MatchRecord("GameID")
Match = MatchRecord("MatchID")
GameBox = Game
MatchBox = Match
CurrentDb.QueryDefs.Delete "FindMatch" & Subject
CurrentDb.QueryDefs.Refresh
Query = "SELECT * FROM Payoffs WHERE GameID =" & Game
Set FindPayoff = CurrentDb.CreateQueryDef("FindPayoff" & Subject, Query)
Set PayoffRecord = FindPayoff.OpenRecordset
PayoffRecord.FindFirst "[Defender] = " & Defender
A1D1Payoff = Str$(PayoffRecord("A1D1"))
A1D2Payoff = Str$(PayoffRecord("A1D2"))
A1D3Payoff = Str$(PayoffRecord("A1D3"))
A2D1Payoff = Str$(PayoffRecord("A2D1"))
A2D2Payoff = Str$(PayoffRecord("A2D2"))
A2D3Payoff = Str$(PayoffRecord("A2D3"))
A3D1Payoff = Str$(PayoffRecord("A3D1"))
A3D2Payoff = Str$(PayoffRecord("A3D2"))
A3D3Payoff = Str$(PayoffRecord("A3D3"))
CurrentDb.QueryDefs.Delete "FindPayoff" & Subject
CurrentDb.QueryDefs.Refresh
Query = "SELECT * FROM Success WHERE GameID =" & Game
Set FindSuccess = CurrentDb.CreateQueryDef("FindSuccess" & Subject, Query)
Set SuccessRecord = FindSuccess.OpenRecordset
SuccessRecord.FindFirst "[Defender] = " & Defender
A1D1Success = Str$(SuccessRecord("A1D1"))
A1D2Success = Str$(SuccessRecord("A1D2"))
A1D3Success = Str$(SuccessRecord("A1D3"))
A2D1Success = Str$(SuccessRecord("A2D1"))
A2D2Success = Str$(SuccessRecord("A2D2"))
A2D3Success = Str$(SuccessRecord("A2D3"))
A3D1Success = Str$(SuccessRecord("A3D1"))
A3D2Success = Str$(SuccessRecord("A3D2"))
A3D3Success = Str$(SuccessRecord("A3D3"))
If Defender = True Then
    Move1Sum = SuccessRecord("A1D1") + SuccessRecord("A2D1") +
SuccessRecord("A3D1")
    Move2Sum = SuccessRecord("A1D2") + SuccessRecord("A2D2") +
SuccessRecord("A3D2")
    Move3Sum = SuccessRecord("A1D3") + SuccessRecord("A2D3") +
SuccessRecord("A3D3")
Else
```

```
    Move1Sum = SuccessRecord("A1D1") + SuccessRecord("A1D2") +
SuccessRecord("A1D3")
    Move2Sum = SuccessRecord("A2D1") + SuccessRecord("A2D2") +
SuccessRecord("A2D3")
    Move3Sum = SuccessRecord("A3D1") + SuccessRecord("A3D2") +
SuccessRecord("A3D3")
End If
CurrentDb.QueryDefs.Delete "FindSuccess" & Subject
CurrentDb.QueryDefs.Refresh
If Move1Sum >= 2 Then
    Move1Success = "Better than 60%"
ElseIf Move1Sum >= 1.5 Then
    Move1Success = "40%-60%"
ElseIf Move1Sum >= 1 Then
    Move1Success = "30%-40%"
Else
    Move1Success = "Less than 30%"
End If
If Move2Sum >= 2 Then
    Move2Success = "Better than 60%"
ElseIf Move2Sum >= 1.5 Then
    Move2Success = "40%-60%"
ElseIf Move2Sum >= 1 Then
    Move2Success = "30%-40%"
Else
    Move2Success = "Less than 30%"
End If
If Move3Sum >= 2 Then
    Move3Success = "Better than 60%"
ElseIf Move3Sum >= 1.5 Then
    Move3Success = "40%-60%"
ElseIf Move3Sum >= 1 Then
    Move3Success = "30%-40%"
Else
    Move3Success = "Less than 30%"
End If
'Set up match payoff table for defender - attacker will simply link to it
If Defender = True Then
    'Check if Match Table already exists
    TableExists = False
    For Each MatchTable In CurrentDb.TableDefs
        If MatchTable.Name = "Match" & Match Then
            TableExists = True
        End If
    Next
    If TableExists = False Then
        Set MatchTable = CurrentDb.CreateTableDef("Match" & Match)
        Set MatchField = MatchTable.CreateField("Turn")
        MatchField.Type = DB_INTEGER
        MatchTable.Fields.Append MatchField
        Set MatchField = MatchTable.CreateField("SuccessNumber")
        MatchField.Type = DB_SINGLE
        MatchTable.Fields.Append MatchField
        Set MatchField = MatchTable.CreateField("DefenderMoved")
        MatchField.Type = DB_BOOLEAN
        MatchField.DefaultValue = False
```

```
        MatchTable.Fields.Append MatchField
        Set MatchField = MatchTable.CreateField("DefenseSuccess")
        MatchField.Type = DB_BOOLEAN
        MatchField.DefaultValue = False
        MatchTable.Fields.Append MatchField
        Set MatchField = MatchTable.CreateField("AMove")
        MatchField.Type = DB_TEXT
        MatchField.AllowZeroLength = True
        MatchTable.Fields.Append MatchField
        Set MatchField = MatchTable.CreateField("DMove")
        MatchField.Type = DB_TEXT
        MatchField.AllowZeroLength = True
        MatchTable.Fields.Append MatchField
        CurrentDb.TableDefs.Append MatchTable
        CurrentDb.TableDefs.Refresh
        Set TurnRecord = CurrentDb.OpenRecordset("Match" & Match)
        Set HistoryRecord = CurrentDb.OpenRecordset("History")
        For i = 1 To 40
            'Now create turn Entries
            TurnRecord.AddNew
            TurnRecord("Turn") = i
            TurnRecord("AMove") = ""
            TurnRecord("DMove") = ""
            TurnRecord.Update
             'Setup History Table Records
            HistoryRecord.AddNew
            HistoryRecord("MatchID") = Match
            HistoryRecord("Turn") = i
            HistoryRecord.Update
        Next
    End If
End If
GoTo Out ' skip error handling

'Labels Section

Common_Error:
    If BlownUp > 40 Then
        Resume Fatal
    ElseIf Err.Number = 3012 Then
        If StrComp(Query, "SELECT * FROM Matches WHERE Defender =" & Subject)
= 0 Then
            CurrentDb.QueryDefs.Delete "FindMatch" & Subject
            CurrentDb.QueryDefs.Refresh
        ElseIf StrComp(Query, "SELECT * FROM Matches WHERE Attacker =" &
Subject) = 0 Then
            CurrentDb.QueryDefs.Delete "FindMatch" & Subject
            CurrentDb.QueryDefs.Refresh
        ElseIf StrComp(Query, "SELECT * FROM Payoffs WHERE GameID =" & Game)
= 0 Then
            CurrentDb.QueryDefs.Delete "FindPayoff" & Subject
            CurrentDb.QueryDefs.Refresh
        ElseIf StrComp(Query, "SELECT * FROM Success WHERE GameID =" & Game)
= 0 Then
            CurrentDb.QueryDefs.Delete "FindSuccess" & Subject
            CurrentDb.QueryDefs.Refresh
```

```
        End If
        Resume Begin
    Else
        BlownUp = BlownUp + 1
        Set ErrorRecord = CurrentDb.OpenRecordset("Errors", DB_OPEN_DYNASET)
        With ErrorRecord
            .AddNew
            !BlownUpCount = BlownUp
            !ErrorDesc = Err.Description
            !ErrorNumber = Err.Number
            .Update
        End With
        Resume Begin
    End If

Fatal:
    MsgBox "An Error has Occurred in Form_GameForm:Class Module Load_Form.
Notify Experimenter"
    GoTo Out

Out:

End Sub

Private Sub GameHelpButton_Click()

    If Forms!GameForm!DefenderBox = True Then
        DoCmd.OpenForm "DefenderHelp"
    Else
        DoCmd.OpenForm "AttackerHelp"
    End If

End Sub

Public Sub MakeMove_Click()
    Dim MatchReady As Boolean
    Dim Defender As Boolean
    Dim AttackerMove As String, DefenderMove As String, MoveString As String
    Dim InitPayoff As Integer, i As Integer, MsgResponse As Integer, BlownUp
As Integer, WaitCount As Integer
    Dim Turn As Integer, Match As Integer, Game As Integer
    Dim AttackerPayoff As Single, DefenderPayoff As Single, SuccessProb As
Single
    Dim RandomNumber As Single

    Dim TurnRecord As Recordset, ErrorRecord As Recordset
    Dim MatchTable As TableDef

On Error GoTo ErrorHandler

BlownUp = 0
Defender = Forms!GameForm!DefenderBox
Turn = Forms!GameForm!TurnBox
Match = Forms!GameForm!MatchBox
Game = Forms!GameForm!GameBox
If Defender = True Then
```

```
DefenderMove:
    If IsNull(DmoveBox) Then
        GoTo No_Move
    End If
    DefenderMove = ConvertMove(DmoveBox, True)
    Set TurnRecord = CurrentDb.OpenRecordset("Match" & Match,
DB_OPEN_DYNASET)
    TurnRecord.FindFirst "[Turn] = " & Turn
    WaitCount = 0
    While TurnRecord.EditMode = dbEditInProgress
        If WaitCount > 35000 Then
            MsgResponse = MsgBox("Move processing may be taking too long.
Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
    Wend
    TurnRecord.Edit
    TurnRecord("DMove") = DefenderMove
    TurnRecord.Update
    DoCmd.Hourglass True
    WaitCount = 0
    While TurnRecord("AMove") = ""
        If WaitCount > 35000 Then
            MsgResponse = MsgBox("Move processing may be taking too long.
Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
    Wend
    AttackerMove = TurnRecord("AMove")
    DoCmd.Hourglass False
    'Get Initial Payoff
    MoveString = AttackerMove & DefenderMove
    InitPayoff = FindPayoff(MoveString)
    SuccessProb = FindSuccess(MoveString)
    WaitCount = 0
    While TurnRecord.EditMode = dbEditInProgress
    If WaitCount > 35000 Then
            MsgResponse = MsgBox("Move processing may be taking too long.
Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
```

```
    Wend
    TurnRecord.Edit
    Randomize
    TurnRecord("SuccessNumber") = Rnd()
    If TurnRecord("SuccessNumber") < SuccessProb Then
        DefenderPayoff = 0
        TurnRecord("DefenseSuccess") = True
        MoveSuccessBox = "Successful!"
    Else
        DefenderPayoff = InitPayoff
        TurnRecord("DefenseSuccess") = False
        MoveSuccessBox = "Unsuccessful!"
    End If
    TurnRecord("DefenderMoved") = True
    TurnRecord.Update
    TurnRecord.Close
    LastPayoffBox = PayoffBox
    PayoffBox = DefenderPayoff
    Call UpdateHistory(DefenderPayoff, DefenderMove, Match, Turn)
    Beep
Else
AttackerMove:
    If IsNull(AMoveBox) Then
        GoTo No_Move
    End If
    AttackerMove = ConvertMove(AMoveBox, False)
    MatchReady = False
    'Ensure that the Match Table exists
    WaitCount = 0
    While MatchReady = False
        For Each MatchTable In CurrentDb.TableDefs
            If MatchTable.Name = "Match" & Match Then
                MatchReady = True
            End If
        Next
        If WaitCount > 1000 Then
            MsgResponse = MsgBox("Match initialization may be taking too
long.  Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
    Wend
    Set TurnRecord = CurrentDb.OpenRecordset("Match" & Match,
DB_OPEN_DYNASET)
    TurnRecord.FindFirst "[Turn] = " & Turn
    WaitCount = 0
    While TurnRecord.EditMode = dbEditInProgress
        If WaitCount > 35000 Then
            MsgResponse = MsgBox("Move processing may be taking too long.
Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
```

```
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
    Wend
    TurnRecord.Edit
    TurnRecord("AMove") = AttackerMove
    TurnRecord.Update
    DoCmd.Hourglass True
    WaitCount = 0
    While (TurnRecord("DMove") = "") Or (TurnRecord("DefenderMoved") = False)
        If WaitCount > 35000 Then
            MsgResponse = MsgBox("Move processing may be taking too long.
Notify the Experimenter.  Continue Waiting?", vbYesNo)
            If MsgResponse = vbYes Then
                WaitCount = 0
            Else
                GoTo Out
            End If
        End If
        WaitCount = WaitCount + 1
    Wend
    DefenderMove = TurnRecord("DMove")
    DoCmd.Hourglass False
    'Get Initial Payoff
    MoveString = AttackerMove & DefenderMove
    InitPayoff = FindPayoff(MoveString)
    SuccessProb = FindSuccess(MoveString)
    If TurnRecord("DefenseSuccess") = False Then
        AttackerPayoff = InitPayoff
        MoveSuccessBox = "Successful!"
    Else
        AttackerPayoff = 0
        MoveSuccessBox = "Unsuccessful!"
    End If
    LastPayoffBox = PayoffBox
    PayoffBox = AttackerPayoff
    Call UpdateHistory(AttackerPayoff, AttackerMove, Match, Turn)
    Beep
End If
'Check if 40 turns completed
If Turn = 40 Then
    MsgBox "You Have Completed The Experiment. Please Wait Quietly Until
Released.  Thanks for Your Participation"
    GoTo Out
End If

'Normal End of Turn Processing
Turn = Turn + 1
Forms!GameForm!TurnBox = Turn
GoTo Out

'LABELS SECTION

No_Move:
```

```
    MsgBox "Please Select a Move!"
    If Defender = True Then
        DmoveBox.SetFocus
    Else
        AMoveBox.SetFocus
    End If
    GoTo Out

ErrorHandler:

    BlownUp = BlownUp + 1
    Set ErrorRecord = CurrentDb.OpenRecordset("Errors", DB_OPEN_DYNASET)
    With ErrorRecord
        .AddNew
        !BlownUpCount = BlownUp
        !ErrorDesc = Err.Description
        !ErrorNumber = Err.Number
        .Update
    End With
    If Defender = True Then
        Resume DefenderMove
    Else
        Resume AttackerMove
    End If

Abort:
    MsgBox "Experiment Terminated!"
    DoCmd.Hourglass False
    DoCmd.Close acForm, "GameForm"

Out:
End Sub

Public Function FindPayoff(Move As String) As Integer

    If Move = "A1D1" Then
        FindPayoff = Int(Forms!GameForm!A1D1Payoff)
    ElseIf Move = "A1D2" Then
        FindPayoff = Int(Forms!GameForm!A1D2Payoff)
    ElseIf Move = "A1D3" Then
        FindPayoff = Int(Forms!GameForm!A1D3Payoff)
    ElseIf Move = "A2D1" Then
        FindPayoff = Int(Forms!GameForm!A2D1Payoff)
    ElseIf Move = "A2D2" Then
        FindPayoff = Int(Forms!GameForm!A2D2Payoff)
    ElseIf Move = "A2D3" Then
        FindPayoff = Int(Forms!GameForm!A2D3Payoff)
    ElseIf Move = "A3D1" Then
        FindPayoff = Int(Forms!GameForm!A3D1Payoff)
    ElseIf Move = "A3D2" Then
        FindPayoff = Int(Forms!GameForm!A3D2Payoff)
    ElseIf Move = "A3D3" Then
        FindPayoff = Int(Forms!GameForm!A3D3Payoff)
    End If

End Function
```

```
Public Function FindSuccess(Move As String) As Single

   If Move = "A1D1" Then
        FindSuccess = Forms!GameForm!A1D1Success
    ElseIf Move = "A1D2" Then
        FindSuccess = Forms!GameForm!A1D2Success
    ElseIf Move = "A1D3" Then
        FindSuccess = Forms!GameForm!A1D3Success
    ElseIf Move = "A2D1" Then
        FindSuccess = Forms!GameForm!A2D1Success
    ElseIf Move = "A2D2" Then
        FindSuccess = Forms!GameForm!A2D2Success
    ElseIf Move = "A2D3" Then
        FindSuccess = Forms!GameForm!A2D3Success
    ElseIf Move = "A3D1" Then
        FindSuccess = Forms!GameForm!A3D1Success
    ElseIf Move = "A3D2" Then
        FindSuccess = Forms!GameForm!A3D2Success
    ElseIf Move = "A3D3" Then
        FindSuccess = Forms!GameForm!A3D3Success
    End If

End Function

Public Sub UpdateHistory(Payoff As Single, Move As String, Match As Integer,
Turn As Integer)

    Dim HistoryQuery As QueryDef
    Dim HistoryRecord As Recordset, ErrorRecord As Recordset
    Dim Query As String
    Dim BlownUp As Integer

    On Error GoTo Error_Handler
    BlownUp = 0

Begin:
    If Move = "A1" Then
        Move = "Social Attack"
        Forms!GameForm!Move1Turns = Forms!GameForm!Move1Turns + 1
        Forms!GameForm!Move1Payoffs = Forms!GameForm!Move1Payoffs + Payoff
        Forms!GameForm!Move1Average = Forms!GameForm!Move1Payoffs /
Forms!GameForm!Move1Turns
    ElseIf Move = "A2" Then
        Move = "Client Attack"
        Forms!GameForm!Move2Turns = Forms!GameForm!Move2Turns + 1
        Forms!GameForm!Move2Payoffs = Forms!GameForm!Move2Payoffs + Payoff
        Forms!GameForm!Move2Average = Forms!GameForm!Move2Payoffs /
Forms!GameForm!Move2Turns
    ElseIf Move = "A3" Then
        Move = "Network Attack"
        Forms!GameForm!Move3Turns = Forms!GameForm!Move3Turns + 1
        Forms!GameForm!Move3Payoffs = Forms!GameForm!Move3Payoffs + Payoff
        Forms!GameForm!Move3Average = Forms!GameForm!Move3Payoffs /
Forms!GameForm!Move3Turns
    ElseIf Move = "D1" Then
```

```
        Move = "Social Defense"
        Forms!GameForm!Move1Turns = Forms!GameForm!Move1Turns + 1
        Forms!GameForm!Move1Payoffs = Forms!GameForm!Move1Payoffs + Payoff
        Forms!GameForm!Move1Average = Forms!GameForm!Move1Payoffs /
Forms!GameForm!Move1Turns
    ElseIf Move = "D2" Then
        Move = "Client Defense"
        Forms!GameForm!Move2Turns = Forms!GameForm!Move2Turns + 1
        Forms!GameForm!Move2Payoffs = Forms!GameForm!Move2Payoffs + Payoff
        Forms!GameForm!Move2Average = Forms!GameForm!Move2Payoffs /
Forms!GameForm!Move2Turns
    ElseIf Move = "D3" Then
        Move = "Network Defense"
        Forms!GameForm!Move3Turns = Forms!GameForm!Move3Turns + 1
        Forms!GameForm!Move3Payoffs = Forms!GameForm!Move3Payoffs + Payoff
        Forms!GameForm!Move3Average = Forms!GameForm!Move3Payoffs /
Forms!GameForm!Move3Turns
    End If
    Query = "SELECT * FROM History WHERE MatchID = " & Match
    Set HistoryQuery = CurrentDb.CreateQueryDef("FindHistory" & SubjectBox,
Query)
    Set HistoryRecord = HistoryQuery.OpenRecordset
    HistoryRecord.FindFirst "[Turn] = " & Turn
    If DefenderBox = True Then
        While HistoryRecord.EditMode = dbEditInProgress
            Wend
        HistoryRecord.Edit
            HistoryRecord("DefendAction") = Move
            HistoryRecord("DefendPayoff") = Payoff
        HistoryRecord.Update
        HistoryRecord.Close
        DefendHistory.Requery
    Else
        While HistoryRecord.EditMode = dbEditInProgress
            Wend
        HistoryRecord.Edit
            HistoryRecord("AttackAction") = Move
            HistoryRecord("AttackPayoff") = Payoff
        HistoryRecord.Update
        HistoryRecord.Close
        AttackHistory.Requery
    End If
Delete_Query:
    CurrentDb.QueryDefs.Delete "FindHistory" & SubjectBox
    CurrentDb.QueryDefs.Refresh
    GoTo Out

Error_Handler:
    If Err.Number = 3167 Then
        Resume Delete_Query
    ElseIf Err.Number = 3012 Then
        CurrentDb.QueryDefs.Delete "FindHistory" & SubjectBox
        CurrentDb.QueryDefs.Refresh
        Resume Begin
    Else
        BlownUp = BlownUp + 1
```

```
        Set ErrorRecord = CurrentDb.OpenRecordset("Errors", DB_OPEN_DYNASET)
        With ErrorRecord
            .AddNew
            !BlownUpCount = BlownUp
            !ErrorDesc = Err.Description
            !ErrorNumber = Err.Number
            .Update
        End With
        Resume Begin
    End If

Out:

End Sub

Public Function ConvertMove(Move As String, Defender As Boolean) As String
'Converts Move from User's Name to A1/D1 Notation

    If Defender = True Then
        If Move = "Social Defense" Then
            ConvertMove = "D1"
        ElseIf Move = "Client Defense" Then
            ConvertMove = "D2"
        Else
            ConvertMove = "D3"
        End If
    Else
        If Move = "Social Attack" Then
            ConvertMove = "A1"
        ElseIf Move = "Client Attack" Then
            ConvertMove = "A2"
        Else
            ConvertMove = "A3"
        End If
    End If

End Function
```

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13. ABSTRACT (*Maximum 200 Words*)

The repeated game of incomplete information model, a subclass of game theory models, was modified to include aspects of information warfare. The repeated game of incomplete information model was first developed to analyze nuclear weapons disarmament negotiations. The central role of information in this model suggested its applicability to IW, which focuses on the defense and acquisition of information. A randomized experimental design was utilized to determine how people behave in a laboratory IW setting and to test the IW game model's basic predictions. The impact of experience and learning on IW performance was also assessed during the experiment. IW experience and devices that support learning during an IW engagement improved performance in some situations. The IW game theory model was shown to have some predictive capability and, with further development, could support further IW analysis and simulation.

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