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On studying the effect of information warfare on C2 decision making

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THESIS

ON STUDYING THE EFFECT OF
INFORMATION WARFARE
ON C2 DECISION MAKING

Donald J. Dishong

June, 1994

Thesis Co-Advisors: Carl R. Jones
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The goal of practitioners of information warfare is always concerned with affecting the decisions made by the enemy. With a clear understanding of how the enemy makes decisions, it is easier to target the processes which are involved in making those decisions. The purpose of this thesis is to demonstrate whether information warfare, when directed at a command and control decision maker, can be administered in quantified amounts which can be used to change what would normally be a good tactical decision into a bad one. This thesis uses a software package called Tactical Tic-Tac-Toe to simulate command and control decisions being made in an information warfare environment. The three measures of effectiveness of winning battles, winning missions (aggregate battles), and increasing one's won-to-loss ratio are used to evaluate the quality of the decisions being made. Fog of War, Tactical Delay, Area Delay, and Communications Delays are combined to determine their effects on command and control under these measures of effectiveness. Data shows that delaying one's immediate opponent from grasping the tactical picture serves to greatly enhance the chances of increasing one's effectiveness. Further, delaying the enemy's understanding of "pieces" of the strategic picture (which might not be viewed as immediately tactically important), also dramatically increases effectiveness.

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ON STUDYING THE EFFECT OF INFORMATION WARFARE ON C2 DECISION MAKING

by

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ABSTRACT

The goal of practitioners of information warfare is always concerned with affecting the decisions made by the enemy. With a clear understanding of how the enemy makes decisions, it is easier to target the processes which are involved in making those decisions. The purpose of this thesis is to demonstrate whether information warfare, when directed at a command and control decision maker, can be administered in quantified amounts which can be used to change what would normally be a good tactical decision into a bad one. This thesis uses a software package called Tactical Tic-Tac-Toe (T4), to simulate command and control decisions being made in an information warfare environment. The three measures of effectiveness of winning battles, winning missions (aggregate battles), and increasing one's won-to-loss ratio are used to evaluate the quality of the decisions being made. Fog of War, Tactical Delay, Area Delay, and Communications Delays are combined to determine their effects on command and control under these measures of effectiveness. Clearly the data shows that delaying one's immediate opponent from grasping the tactical picture serves to greatly enhance the chances of increasing one's effectiveness. Further, delaying the enemy's understanding of "pieces" of the strategic picture (which might not be viewed as immediately tactically important), also dramatically increases effectiveness.

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I. INTRODUCTION

Military warfare has always been a dynamic process which has reflected the technical advances of the societies practicing it. History teaches us that warfare strategies and tactics have evolved in their complexity from their earliest roots. Ancient warfare strategies consisted of spotting the enemy first, and attacking with rocks, sticks, and anything else which could be picked up and used as a weapon. Spotting one's adversary, evaluating the threat posed by that adversary, determining whether to attack, and planning the attack were phases of what was probably the earliest command and control (C2) process.

Today's warfare relies on a much more sophisticated process to achieve much the same result. Now we spot the enemy with satellites and other sophisticated surveillance equipment. We evaluate the threat using supercomputer models to aid in our analysis, and we plan the attack using joint forces. Finally we might execute the attack using laser-guided munitions launched from standoff attack aircraft, dropping bombs through elevator chutes in the tops of enemy buildings. The result is the same as with the ancient approach, because ultimately the threat from the enemy is eliminated.

In essence, warfare is a simple idea. Enemies perceive a threat from one another, and then wreak havoc on each other to eliminate that threat. Some of the difficulty in practicing the art of warfare is rooted in the complex ways in which we as human beings interact with each other, how we communicate with one another, and how we choose to resolve our conflicts. Certainly entire libraries could be filled with works which strive to explain some of these complex issues. There is however, a common thread which appears in warfare, be it simple survival or more devastating theater nuclear warfare. That common denominator is that all throughout the process, people make decisions. They make good decisions, bad decisions, quick decisions, or possibly ill-informed decisions. None the less, the process of warfare is filled with decision-making.

A. OVERVIEW

This thesis is an attempt to examine the effects of information warfare (IW), especially those which result when the warfare is directed toward command and control (C2) decision-makers. IW is both an old and a new idea. That is, the concept dates to the earliest writings on warfare (Wu, 1944). As will be discussed later, recent changes in information technology have brought similarly advanced changes in the concept of IW.

This thesis investigates how human decision-making in the stressful environments found in military conflict can be altered. The goal of practitioners of IW is always concerned with affecting the decisions made by the enemy. With an understanding of the effort required to force changes in decision making, it is easier to target the processes which are involved in making those decisions.

B. PURPOSE OF THESIS

The purpose of this thesis is to examine whether IW, when directed at a C2 decision-maker, can be administered in quantified amounts that can be used to change what would normally be a good tactical decision into a bad one.

C. SCOPE OF THESIS

The next war will be fought in a new and unique battlefield area called cyberspace. The cyberspace is lined with information highways, and like any major highways, these information highways will carry vital supplies to and from the front. The new-age weapons which will decide the outcome on this new battleground will be unlike any the world has previously witnessed. C2 warfare will permeate the battle field. The Armed Forces Staff College Student Text on Joint C2 Warfare, defines C2 warfare as the integrated use of operations security (OPSEC), military deception, psychological operations (PSYOP), electronic warfare (EW), and physical destruction, mutually supported by intelligence to deny information to, influence, degrade, or destroy adversary command and control (C2) capabilities and to protect friendly Command and Control against such actions (Joint, 1993).

Information is the new prize in warfare, and to be able to control it, we must first understand how it is transmitted, received, comprehended, processed, stored, and displayed. This thesis is a small step in accomplishing these things. It is a first step in the long process of constructing the foundation with which we must build our knowledge base. By using the results of this study, we can continue our march toward understanding.

There are studies which focus on understanding the decision-making process in humans. Likewise, there are studies which focus primarily on explaining offensive and defensive IW tactics. The purpose of this thesis is to serve as a bridge between these two areas of research. It is an effort to understand first whether decision making in a dynamic warfare environment is vulnerable to IW tactics. Working from a common understanding of IW, and how it is basically carried out, the thesis then examines decision-making in a military situation under the added stress imposed by IW. It is an examination with an attempt at quantifying the level of IW needed to affect the quality of decisions made in such an environment.

II. DISCUSSION OF INFORMATION WARFARE

The term "information warfare" is in vogue in the military community as of late, but the idea of IW predates all of modern warfare history. It is a precept that has been used by clever military leaders to defeat their enemies since the beginning of organized warfare. Why then has the idea of IW taken on special significance once again? To understand the answer, we must reflect on the nature of change that has occurred in warfare over the years. To non-students of military history, these changes, when considered individually, may seem subtle and irrelevant. To those who make it their business to understand warfare though, these changes are dramatic to say the least. Alan Campen, in his book on information war, talks about the incredible importance of IW, as it was used in Desert Shield/Desert Storm.

> The United States unveiled a radically new form of warfare in the Persian Gulf in 1991. By exploiting *knowledge*, it devastated Iraq's formidable military machine, astonished the world, confounded defense critics, surprised itself and quite possibly changed the standards for performance of U.S. forces in armed conflict. By leveraging *information*, U.S. and allied forces brought to warfare a degree of flexibility, synchronization, speed and precision heretofore unknown (Campen, 1992).

So what is IW, and how can it be so important? Perhaps the best way to render a definition is to look at each word by itself. Most of us have a general idea of what information is. For our purposes, let's define information as knowledge of a specific event or situation. For information to be knowledge, it must have meaning to us. Therefore, if it is to have meaning to us, we must clearly differentiate information from the term, data. Data is perhaps better thought of as raw information; that is, it is information in a form which doesn't necessarily convey meaning to the user. For example, in a computer file, 1's and 0's represent data. However, the 1's and 0's eventually are turned into words which combine to give us information.

The next word to define is warfare. If one were to look up warfare in the dictionary, there would likely be a definition which included phrases such as, "armed conflict" and "battles." But as we will learn, warfare has evolved to the point where these definitions are outdated. Warfare need not, and often does not necessarily entail the use of arms. At least not arms in the sense we are familiar with such as rifles and bullets. Warfare can be conducted without ever firing a shot. And that, to a large degree, is what IW is all about. So for the purposes of this paper, the author will define warfare as a manifestation of hostilities, usually between nations, with the intent of effecting control over the opponent nation's actions or policies. Therefore, information warfare can be broadly defined as:

> attempts by one opponent to gain control over an adversary's actions or policies through manipulation of the adversary's information processes.

Information processes include all facets of information collecting, storing, processing, transporting, and displaying. Manipulation might include simply intercepting and examining the content of the information. Or it might include something more drastic such as destroying, altering the contents or display of, or delaying the transport of information. With this starting basis, we can now understand why the concept of IW is hardly something new. In fact, military historians almost always include the works of Sun Tzu as they try to understand military conflict. Author George Orr, in his book on *Combat Operations C^3I: Fundamentals and Interactions*, writes about the "modern" flavor of many of Sun Tzu's observations. Sun Tzu's *The Art of War* was written somewhere around 350 BC, yet it clearly details the importance of information warfare (albeit not by its recently coined name) to leaders in their quest to win wars. Sun Tzu taught that skillful strategists should be able to subdue the enemy's army without engaging it, conquer its cities without destroying them, and overthrow the enemy state without bloodshed (Orr, 1983).

III. TACTICAL TIC-TAC-TOE (T4)

The best approach in examining human decision-making would be to carry out an experiment in the actual environment in which decision-makers operate. Though preferred, obviously this approach is the most difficult one to take in any experiment. It is difficult to marshall the resources in time, money, and personnel to carry out "live fire" testing. The next preferred scientific approach would be to carry out an experiment using live subjects in a controlled environment such as a laboratory. This approach also consumes a lot of resources, but is generally cheaper and more workable than live testing. The simplest approach however, is to carry out a simulation using automated tools to simulate the environment, subjects, and decision processes. This is the approach which will be used in this thesis.

The simulation in this thesis will use a software package called Tactical Tic-Tac-Toe (T4). T4 was developed at the Naval Post Graduate School for use in the Command Control and Communications (C3) curriculum. The simulation is carried out using personal computers. The program essentially is a modified version of the well known Tic-Tac-Toe game which is played by kids everywhere. In T4, two adversaries (or teams of adversaries) are pitted against each other in an effort to win Tic-Tac-Toe (TTT) matches. Simulated X- and O-players calculate their best move according to a preprogrammed strategy, and simultaneously attempt to take a square. Unlike conventional Tic-Tac-Toe, T4 uses a double-wide grid (6x3 instead of 3x3), which presents twice as many squares to fill with X's and O's. In conventional Tic-Tac-Toe, there are eight possible ways in which to construct a scoring combination, but in T4 there are 26 ways to score. For each side of the T4 board, there are the eight combinations of ways to score found in conventional Tic-Tac-Toe (for a total of 16 scoring combinations). But there are also 10 "Crossover" scoring combinations as well (Tic-Tac-Toe's which start on one side of the board and cross into the next side). The board layout and all scoring possibilities are displayed graphically in Appendix A.

In T4, we can model the characteristics of team members, as well as the conditions under which the contest will take place. The next two sections summarize T4 characteristics and conditions. This is followed by a section of T4 definitions.

A. T4 CHARACTERISTICS & CONDITIONS

- Replications - this is the number of games played per contest
- Player Style - each player can be modeled as Total Offense, Balanced Offense, Balanced, Balanced Defense, Total Defense, and Random

- Fog-of-War (FOW) - both a Regular and Crossover FOW value are chosen, ranging from 0 to 100%

- Initial and Subsequent Turn Conflict Resolution - this allows the user to determine how conflicts will be resolved when both players attempt to occupy the same square on the same turn

- Mission Assigned - players are assigned a mission from several choices, including Victory Left, Victory Right, Victory Crossover, Victory Overall, Survival Left, Survival Right, Survival Crossover, and Survival Overall

- Tactical Delay - a one through nine step delay can be assigned a player, in reference to his direct opponent on his side of the board

- Area Delay - a one through nine step delay can be assigned to the opponent of a player's partner (i.e. the right side X-player and the left side O-player)

- Communications Delay - a one through nine step delay can be assigned between partners on the same side of the board (i.e. the left and right side X-players)

B. T4 PLAYER STYLES

The T4 player styles are explained as follows:

- Total Offense - on a given turn, a player on either side of the board (left or right) attempts to score a TTT on his own side. This simulates a tactical engagement where a member is concerned only with winning his immediate battle

- Balanced Offense - A team gives equal weight to offense (scoring a TTT) and defense (blocking a TTT). In the case of a tie, an offensive move is chosen

- Balanced - Team offense and defense with a random tie breaker

- Balanced Defense - same as Balanced Offense except ties are broken by choosing a defensive move

- Total Defense - blocking opponent's TTT's are top priority

- Random - no strategy is used when choosing a move

C. T4 TERMS DEFINED

FOW is a miliary term which describes the general state of uncertainty which is inherent in military conflict. One can think of FOW as the haze which clouds the true reality of a situation. In many situations, military leaders must make plans and execute decisions without knowing all of the pertinent facts. Through the FOW, the enemy might appear to be stronger than he is in reality. The tactical picture may appear to a commander as if an full-scale attack is eminent, even when it really is not. T4 models this characteristic and adds uncertainty to the outcomes of player's moves. A player's best calculated move may be to the center square, but when the FOW is factored in, his piece ends up in a corner square. This FOW feature is set before-hand in terms of the percentage of the true calculated value of a move which may be added or subtracted (i.e. a move may be calculated to be worth 3.2, but a FOW value of 50% would cause the move to be randomly valued between 3.2 plus or minus 50% of 3.2, or between 1.6 and 4.8).

Players in T4 attempt to move simultaneously. Obviously this means that opponents might attempt to occupy the same space on a given turn. There exists a method to resolve conflicts of this nature. The first and subsequent "winners" might be randomly chosen, alternated, or chosen according to a weighting factor.

A team is assigned a mission. A Victory mission is won if a team wins more TTT's than his opponent. A Survival mission is one in which a team wins if it at least ties its opponent in number of TTT's achieved.

T4 delays reflect the real delays in intelligence faced by military units. A Tactical Delay of two time steps means that you are delayed in seeing what your opponent's move is for two complete turns. You continue to make moves, but you are essentially operating blindly because you are not aware of where your opponent has recently moved. Not only does this mean you cannot effectively block your opponent's scoring attempts, but you might attempt to move into squares which you will only later learn that your opponent has occupied. This is crucial, because you don't get another chance to occupy a square on that turn, so you have lost your chance to move.

Area Delay operates on a similar principle. This delay is between a player and his partner's opponent. Obviously this delay becomes more important when "Crossover" missions are assigned. These require coordinated effort on the part of the left and right players.

Comm Delay is between the left and right players of a team. With this delay, players are unable to see what their partner is doing for the length of the delay. Like Area Delay, this delay is more vital durring "Crossover" missions.

The complete configuration used for this simulation is described in Appendix B.

D. MEASURES OF EFFECTIVENESS

For the thesis to be of value in simulating reality, it is important to model the T4 simulation correctly and to choose meaningful measures of effectiveness (MOE's). The simulation lends itself to some useful MOE's. The number of TTT's scored by the "friendly" O-team obviously serves to give an effective measure of how we are doing in the simulation. The simulation also offers us the opportunity to measure progress in terms of missions completed by either side. Finally, there is the capability to add a degree of fidelity to our MOE by using the total friendly TTT's minus the total enemy TTT's. This friendly-to-enemy TTT casualty ratio adds the real life concern of Commanders in considering the human cost of friendly losses in achieving enemy losses.

As stated earlier, the goal of this thesis is to demonstrate whether IW, when directed at a C2 decision-maker, can be administered in quantified amounts which can be used to change what would normally be a good tactical decision into a bad one. It was pointed out earlier that IW results in destroying, altering the contents or display of, or delaying the transport of information. The closest things T4 offers in terms of IW are the FOW and Delay features. Therefore, these features are varied to determine if and how they affect the MOE's.

IV. EXPERIMENT PLAN - A C2 DECISION UNDER RISK

The following is the detailed experiment plan used for this T4 simulation. For an introduction to T4 experiments, the reader is directed to read Eugene Zarrillo's thesis on a systems evaluation approach to T4 (Zarrillo, 1993).

A. INTRODUCTION

1. Purpose and Scope

This experiment provides insight as to the impacts "fog of war" and various "delays" have on a commander's ability to win engagements, and successfully complete his assigned mission. Additionally, the experiment determines whether FOW and delays affect the friendly-to-enemy casualty ratio. FOW and delay are effects which result from the waging of IW against an opponent.

Specifically, this experiment answers the following questions:

- What impact does FOW have on the number of engagements won, mission accomplishment, and the friendly-to-enemy TTT casualty ratio?
- Does more timely tactical intelligence impact the number of engagements won, mission accomplishment, or the friendly-to-enemy TTT casualty ratio?

- Does more timely area intelligence impact the number of engagements won, mission accomplishment, or the friendly-to-enemy TTT casualty ratio?

- Does more timely communications intelligence impact the number of engagements won, mission accomplishment, or the friendly-to-enemy TTT casualty ratio?

- Are there any interactions between the four factors (FOW, Tactical Delay, Area Delay, Comm Delay) which impact the number of engagements won, mission accomplishment, or the friendly-to-enemy TTT casualty ratio?

a. Approach

The experiment uses T4 as a C3 simulator to generate data to answer the above questions.

b. Anticipated Results

It is believed this experiment will indicate mission effectiveness (either in terms of numbers of friendly missions successfully completed, or a larger delta between the number of friendly versus enemy missions completed) diminishes with increasing FOW. Additionally, it is also expected that the data will show that timely (delays of zero) Tactical, Area, and Comm intelligence leads to higher mission success rates than when delays are experienced.

B. EXPERIMENTAL DESIGN

1. Setup

a. Physical

The T4 simulation is run on a Macintosh microcomputer with output generated in a spreadsheet format (Microsoft Excel).

b. Test Subjects

Computer simulated players for the T4 runs.

c. Special Equipment

None.

d. Schedule of Trials

Conducted 5-18 May 1994.

2. Hypotheses

Null hypotheses are given for each of the categories of effects. Although not specifically listed, alternative hypotheses exist for each null hypothesis. For each null hypothesis that is rejected, it should be understood that there is support for an alternative hypothesis.

a. FOW Effects

H_0-1: FOW levels have no effect on the number of engagements (TTT's) won by the friendly side.

H_0-2: FOW levels have no effect on the number of friendly missions completed.

H_0-3: FOW levels have no effect on the friendly-to-enemy TTT casualty ratio.

b. Tactical Delay Effects

H_0-4: More responsive intelligence systems (Tactical Delay of zero) affect the number of engagements (TTT's) won by the friendly side.

H_0-5: More responsive intelligence systems (Tactical Delay of zero) have no effect on the number of friendly missions completed.

H_0-6: More responsive intelligence systems (Tactical Delay of zero) affect the friendly-to-enemy TTT casualty ratio.

c. Area Delay Effects

H_0-7: More responsive intelligence systems (Area Delay of zero) affect the number of engagements (TTT's) won by the friendly side.

H_0-8: More responsive intelligence systems (Area Delay of zero) have no effect on the number of friendly missions completed.

H_0-9: More responsive intelligence systems (Area Delay of zero) do not affect the friendly-to-enemy TTT casualty ratio.

d. Communications Delay Effects

H_0-10: More responsive intelligence systems (Comm Delay of zero) do not affect the number of engagements (TTT's) won by the friendly side.

H_0-11: More responsive intelligence systems (Comm Delay of zero) have no effect on the number of friendly missions completed.

H_0-12: More responsive intelligence systems (Comm Delay of zero) do not affect the friendly-to-enemy TTT casualty ratio.

3. Assumptions

The key assumption in this experiment is that computer simulated players perform closely enough to actual human players such that the experimental results can be considered valid. Also, each factor's population mean is normally distributed with equal variance within each population. Finally, each simulation run is considered independent.

4. Statistical Design of Experiment

The experiment is structured as a $5x4^k$ full factorial experiment with K equal to three. K represents the three factors Tactical Delay, Area Delay, and Comm Delay. The fourth factor in the $5x4^k$ experiment represents 5 different FOW levels (0%, 25%, 50%, 75%, and 100%). This leads to a total of 135 different combinations of FOW, Tac Delay, Area Delay, and Comm Delay.

Fifty replications were run for each combination. The total number of trials was 5x27x50=6,750. Table 1 illustrates the combinations of the factors (F = FOW, T = Tac Delay, A = Area Delay, & C = Comm Delay) which were included in the simulation. An entry of 3, 2, 1, 0 would indicate a FOW value of 3 (equal to 75%), a Tactical Delay value of 2 steps, an Area Delay of 1 step, and a Communications Delay of 0 steps.

TABLE 1 T4 COMBINATIONS

F	T	A	C		F	T	A	C		F	T	A	C
0	0	0	0		0	0	1	2		■	■	■	■
0	0	0	1		0	0	2	0		■	■	■	■
0	0	0	2		0	0	2	1		4	2	2	0
0	0	1	0		0	0	2	2		4	2	2	1
0	0	1	1		■	■	■	■		4	2	2	2

5. Measures

Three MOE's are used. These are:

- Total number of friendly (O-player) TTT's
- Total number of assigned friendly (O-player) missions successfully completed
- Total number of friendly TTT's minus the total number of enemy TTT's (O-X TTT's)

C. DATA DESCRIPTION

1. Raw Data

A sample of the raw data is contained in Appendix C.

2. Data Problems

No significant data problems were encountered.

3. Data Coding Scheme

Tactical, Area, Comm Delay:

0 - No Time Delay

1 - One Turn Time Delay

2 - Two Turn Time Delay

Fog of War:

0 - 0% Level

1 - 25% Level

2 - 50% Level

3 - 75% Level

4 - 100% Level

4. Data Table

Given the following abbreviations, a sample data table follows:

Fog of War = FOW Tac Delay = TD Comm Delay = CD

Area Delay = AD Mission Completed = MC Friendly TTT's = OTTT

Friendly minus Enemy TTT's = OXT

FOW	TD	CD	AD	MC	OTTT	OXT
0	1	1	0	1	4	2
1	1	2	0	0	7	-1
3	2	0	1	0	6	3
.	.	.	.	.	.	.
.	.	.	.	.	.	.

5. Data Reduction

Eight columns of data out of the approximately 200 total columns were manually extracted from the Microsoft Excel spreadsheet containing the raw data. No other data reduction was accomplished. Raw data in the extracted eight columns was coded directly according to the data coding scheme detailed previously, then imported into Minitab for analysis. Note that the O-X columns in the data table were created from the individual O and X columns in the original spreadsheet. An example of the reduced data set is contained in Appendix D.

D. ANALYSIS

1. Analysis Plan

The reduced data, generated from 50 replications of each combination of the four factors (total of 6,750 trials), was analyzed using the Minitab statistics package. A four-factor ANOVA (Analysis of Variance) was conducted for each of the three measures listed previously to determine if significant differences existed between population means.

First, the author used this statistical technique to identify significant differences between the mean total number of friendly (O-player) TTT's under five different FOW levels, Tactical, Area, and Communications Delays of zero, one, and two units. The author then identified interactions between various combinations of the four factors.

Likewise, this statistical technique was used to identify significant differences between the mean number of missions successfully completed under five different FOW levels, Tactical, Area, and Communications Delays of zero, one, and two units. This application of ANOVA was aimed at explicitly answering the questions posed previously.

Additionally, the author identified interactions between various combinations of the four factors.

Finally, the author used this statistical technique to identify significant differences between the mean total TTT difference (friendly TTT's - enemy TTT's) under five different FOW levels, Tactical, Area, and Communications Delays of zero, one, and two units. Finally, the author identified interactions between various combinations of the four factors.

2. Methodology

The author extracted the data of interest from the raw data, which were the four main factors (FOW, Tactical Delay, Area Delay, and Comm Delay), the O-player TTT's, the total score (representing missions completed), and the difference in total TTT's between the O- and X-players. The author then encoded the data in accordance with the data coding scheme detailed previously. Following this, the encoded data was imported as a text file into Minitab for analysis (an example of Minitab analysis results are contained in Appendix E).

Next, the data was analyzed. Three four-factor ANOVA tests were run. One Anova test was run with the O-player TTT's as the measure of interest. In the second test, the total Mission Score was the measure of interest. Finally, in the third test the number of O-X TTT's was the measure of interest.

Based on a significance level of $\alpha = 0.05$, the author evaluated the results of the four-factor ANOVAs to identify significant effects of the main factors and their interactions. Results with P-values less than or slightly above α were flagged for further investigation. One, two, and three-factor ANOVA tests were performed on those factors and interactions identified as potentially significant in the previous step. A significance level of $\alpha = 0.05$ was used.

Dot plots of the four factors versus number of O-player TTT's, total Mission Score, and O-X TTT's, were constructed, and tables of means by factor levels were constructed to show interaction between all two-factor combinations. Table data from Minitab were then used to construct graphical plots visually depicting any and all interactions between each combination of two factors.

In order to substantiate the assumption that each factor's population mean was normally distributed, the author constructed normal probability plots. This was done for the O-player TTT's measure by sorting the O-player TTT's, running a Minitab NSCORES, and plotting the O-player TTT's versus the NSCORES output. The author repeated the process for the Mission Score, and the O-X TTT measure (an example plot is contained in Appendix F).

E. RESULTS OF ANALYSIS

Analysis results were derived from Minitab statistical output products.

1. Results for O-player TTT's as Measure of Interest

The P-values resulting from the four-factor ANOVA test for O-player TTT's indicated potential significant interactions between FOW*Tac Delay*Area Delay, Tac Delay*Area Delay*Comm Delay, Tac Delay*Area Delay, Tac Delay*Comm Delay, Area Delay*Comm Delay, and FOW*Tac Delay (i.e., P-values less than or close to α). The three single delay factors Tac, Area, and Comm had P-values $< \alpha$ indicating possible significant impact on mission accomplishment.

These factors and combinations were investigated further using three, two, and one-factor ANOVA tests using a significance level of $\alpha = 0.05$. The three-factor ANOVA run on FOW*Tac Delay*Area Delay resulted in a P-value of 0.005 which indicated a significant interaction between these three factors. The three-factor ANOVA run on Tac Delay*Area Delay*Comm Delay resulted in a P-value of 0.034 which indicated a significant interaction between these three factors. The two-factor ANOVA run on Tac Delay*Area Delay indicated significant interaction between these two factors. The two-factor ANOVA run on Tac Delay*Comm Delay indicated significant interaction between this combination of two factors. The two-factor ANOVA run on Tac Delay*Comm Delay indicated significant interaction between this combination of two factors. Also, the two-factor ANOVA run on FOW*Tac Delay indicated significant interaction between this combination of two factors. Finally, results of the amplifying tests confirmed the single delay factors Tac, Area, and Comm had significant impact on mission accomplishment.

The dot plots for FOW versus O-player TTT's indicate no FOW value has more impact than the other on O-player TTT's. The dot plots for the three delays versus Mission Score tend to indicate an impact. Each successively higher delay on the X-player results in a higher delta between the O and X-player TTT's.

The interaction plots for O-player TTT's versus the three delays and the O-X TTT's versus FOW show no clear contradictions to the results of the ANOVA tests. The normal plot for O-player TTT's reflects a straight line which substantiates the assumption the sample data came from a normal distribution.

2. Results for Mission Score as Measure of Interest

The P-values resulting from the four-factor ANOVA test for Mission Score indicated potential significant interactions between Tac Delay*Area Delay, (i.e., P-values less than or close to α). The three single factors Tac Delay, Area Delay, and Comm Delay had P-values $< \alpha$ indicating possible significant impact on mission accomplishment.

These factors and combinations were investigated using two, and one-factor ANOVA tests using a significance level of $\alpha = 0.05$. The two-factor ANOVA test run on Tac Delay*Area Delay resulted in a P-value of 0.0 which indicated significant interaction between these two factors. These amplifying tests confirmed the single factors, Tac Delay, Area Delay, and Comm Delay had significant impact on mission accomplishment.

Dot plots for FOW versus Mission Score indicate no FOW value has more impact than the other on mission completion (as measured by Score). Dot plots for the delays versus Mission Score indicate an impact. Each successively higher delay on the X-player results in higher scores for the O-player.

None of the interaction plots for Mission Score show strong interactions. This doesn't necessarily contradict the ANOVA tests, because there is little fidelity in a measure which only has two values (0 or 1). Since the Mission Scores for the O-player are equal to 0 or 1 (obviously not a normal distribution), it is meaningless to plot the NSCORES versus O Mission Scores line to show normality.

3. Results for O-X TTT's as Measure of Interest

The P-values resulting from the four-factor ANOVA test for O-X indicated potential significant interactions between FOW*Tac Delay*Area Delay, Tac Delay*Area Delay*Comm Delay, Tac Delay*Area Delay, Tac Delay*Comm Delay, and Area Delay*Comm Delay (i.e., P-values less than or close to α).

The three single delay factors Tac, Area, and Comm had P-values < α indicating possible significant impact on mission accomplishment.

These factors and combinations were investigated further using three, two, and one-factor ANOVA tests using a significance level of α= 0.05. The three-factor ANOVA run on FOW*Tac Delay*Area Delay resulted in a P-value of 0.043 which indicated a significant interaction between these three factors. The three-factor ANOVA run on Tac Delay*Area Delay*Comm Delay resulted in a P-value of 0.087 which indicated a possible significant interaction between these three factors. The two-factor ANOVA run on Tac Delay*Area Delay indicated significant interaction. The two-factor ANOVA run on Tac Delay*Comm Delay indicated significant interaction between this combination of two factors. Also, the two-factor ANOVA run on Area Delay*Comm Delay indicated significant interaction between these two factors. Finally, tests confirmed the single delay factors Tac, Area, and Comm had significant impact on mission accomplishment.

The dot plots for FOW versus O-X TTT's indicate no FOW value has more impact than the other on O-X TTT's. Plots for the three delays versus Mission Score tend to indicate an impact. Each successively higher delay on the X-player results in a higher delta between the O- and X-player TTT's.

The interaction plots for O-X TTT's versus the three delays and the O-X TTT's versus FOW show no clear contradictions to the results of the ANOVA tests. The normal plot for O-X TTT's reflects a straight line, which substantiates the assumption the sample data came from a normal distribution.

F. CONCLUSIONS

1. Hypotheses Results (Interpretations)

The following table summarizes the results of the T4 experiment. The first column groups the results by effect. The second column lists the relevant hypothesis. The third column shows whether the null hypothesis was accepted or rejected, and the last column gives the conclusions resulting from each outcome.

2. Additional Interpretations

The data from the ANOVA tests indicates that while each of the three delays (Tac, Area, and Comm) are statistically significant in and among themselves, they are particularly significant when combined together in any fashion for each of the MOE's except Mission Score. When Mission Score is the operative MOE, only the combination of Tac and Area Delay combine in a significant fashion.

Also, while the data from the ANOVA tests indicates that each of the three delays (Tac, Area, and Comm) are statistically significant, Tactical Delay (delay between opponents on the same side of the board) is clearly the most significant delay.

TABLE II SUMMARY OF EXPERIMENT RESULTS

EFFECT	**HYPOTH**	**DEC**	**RESULT**
FOW	H_01	Acc	Levels don't affect the friendly TTT's
	H_02	Acc	Levels don't affect the friendly missions completed
	H_03	Acc	Levels don't affect the friendly-to-enemy TTT casualty ratio
Tac Delay	H_04	Acc	More responsive intelligence affects the friendly TTT's
	H_05	Rej	Evidence supports that more responsive intelligence affects the friendly missions completed
	H_06	Acc	More responsive intelligence affects the friendly-to-enemy TTT ratio
Area Delay	H_07	Acc	More responsive intelligence affects the number of friendly TTT's
	H_08	Rej	Evidence supports more responsive intelligence affects the friendly missions completed
	H_09	Rej	Evidence supports more responsive intelligence affects the friendly-to-enemy TTT ratio
Comm Delay	H_010	Rej	Evidence supports more responsive intelligence affects the number of friendly TTT's
	H_011	Rej	Evidence supports more responsive intelligence affects the number of friendly missions completed
	H_012	Rej	Evidence supports more responsive intelligence affects the friendly-to-enemy TTT ratio

The interaction plots are of particular interest in this experiment (Figures 4 through 21, Appendix F). The plots are used to visually depict interactions between the various combinations of factors. Interactions are indicated when significant slope differences exist between lines representing similar combinations of factors. Statistically, there are no additional significant interactions demonstrated by the plots beyond those resulting from the ANOVA tests. However, there are still observed phenomena which deserve mention. For example, Figure 6 shows the combined effects of FOW and Area Delay on the mean number of O TTT's. One would expect that as FOW and Area Delay levels are increased, the O TTT's would respond uniformly in a linear fashion. However, what occurs is different than expected. At the highest level of Area Delay, the highest TTT score occurs for the largest FOW value.

The same type of phenomena is demonstrated in most of the other interaction plots. This effect, while not statistically relevant (as indicated by the ANOVA P-values), is indicative of interactions which need to be explained. The interactions might be random (most likely for the FOW examples), or they might be the result of some different underlying cause. Regardless, further studies of these interactions are necessary to pinpoint their causes.

3. Real World Meaning of Results

Clearly this data shows that delaying one's immediate opponent from grasping the tactical picture serves to greatly enhance the chances of increasing one's effectiveness for the three given MOE's of winning battles, winning missions (aggregate battles), and increasing one's won-to-loss ratio. Further, by delaying the enemy's understanding of "pieces" of the strategic picture (which might not be viewed as immediately tactically important), one can see that effectiveness increases. Finally, if one can combine delaying information to the immediate tactical opponent, as well as to other components of the enemy side, the best advantage can be gained.

V. DISCUSSION OF EXPERIMENT RESULTS

The effects of delaying information to the adversary are clearly shown by the simulation. In reality, all IW tactics are geared to delaying information to the enemy. T4 clearly demonstrates that IW can be effectively administered in quantified amounts which, when targeted at the C2 decision-maker, are sufficient to change what would normally be a good tactical decision into a bad one.

Surprisingly, FOW did not prove to be significant in the T4 experiment. In reality, FOW is a nebulous concept which to date, cannot be harnessed by one side over the other. In the experiment, FOW is modelled as a feature which arbitrarily adds or subtracts value to an assigned move. In the long run, the effects of such a process would tend to cancel out. Half of all moves would tend to appear better than calculations truly indicate, while half of all moves would appear worse. The net effect is not unlike what must occur in reality. FOW affects both sides in conflict, often causing commanders to error on the side of caution, and equally as often causing them to error on the side of risk.

The simulation does not indicate which IW tactics are most effective in targeting the C2 decision-maker. Likewise, the simulation does not indicate the specific level of effort necessary to effect such changes, however it does indicate that such answers do in fact exist. The next logical step in this process is to take the simulation a step further, by conducting live testing in a laboratory setting.

VI. SUGGESTED FOLLOW-UP STUDIES

The next step in this process would be to design and conduct a full experiment in which testing of live subjects is carried out. For example, this type of experiment might be conducted in the Decision Evaluation Facility for Tactical Teams (DEFFT) located at NPS. This facility simulates the CIC area on U.S. naval ships. The facility contains a network of server-controlled workstations which locate, and monitor "tracks" of shipping and air traffic. The lab offers controllers the ability to monitor test subjects as they attempt to navigate a carrier battle group through a multitude of geographic settings. Subjects must evaluate the threats from their environment, and determine whether the tracks are "friendlies" or "bogeys." The test subjects operate according to assigned rules of engagement (ROE's). Such a setting would be ideal for testing the effects of IW against a C2 decision-maker. The controllers can simulate IW attacks against the fleet, and the responses from test subjects could be evaluated to determine the quantity and type of IW attacks necessary to force a "bad" decision.

VII. CONCLUSION

This thesis serves as a small step in understanding the effects of IW on the C2 decision-maker. It is not intended to provide a final answer to any specific question, but rather it is designed to aid in the research into the complex area of IW. The results of the T4 experiment indicate that there is reason to dig further into the effects of IW on the C2 decision-maker.

This simulation shows that information, when delayed to an opponent, can affect the outcome of a conflict. This might seem intuitive, but until the Desert Shield/Storm (DS/DS) conflict, high-tech IW was relatively unknown. It will be some time before the full details of the cyberspace warfare used in DS/DS are released for public consumption, but unquestionably this section of the battleground proved pivotal. What is clear is that the future battles waged over information may well decide the war before shots are ever fired. As far-fetched as this might seem, it is a notion which the U.S. military is taking very seriously.

It should not be forgotten that the U.S., arguably the world's leading user of information technology, also stands to be most affected by the successful refinement of IW tactics. The threats arrayed against our nation are currently constituted by many emerging third world countries, and radical extremist fundamentalist groups. These groups often operate in a non-traditional military fashion, employing tactics such as surprise and quickness. These tactics are exactly those which serve as the most devastating to a complex technological society such as the United States. The correct IW tactics employed in the right amounts, coupled with surprise and quickness, could be lethal to much of the information machinery which runs our society. It is therefore all the more important that we attempt to study and understand this "new" form of warfare.

APPENDIX A: T4 BOARD LAYOUT & SCORING POSSIBILITIES

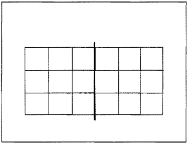

Figure 1 T4 Basic Board

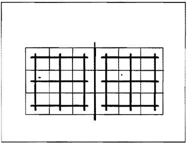

Figure 2 T4 Regular Scores

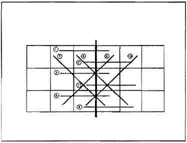

Figure 3 T4 Crossover Scores

APPENDIX B: T4 SIMULATION PLAYER CONFIGURATIONS

The T4 simulation runs were structured so that the O-player was the controlled player (i.e. the "friendly"). The O-settings were held constant throughout the runs, and were set as follows:

- Balanced
- FOW = 0%
- Conflict Resolution - Random at 50%
- Mission - Victory Overall
- Tactical, Area, & Comm Delay = 0

Some of the X-player (i.e. "the enemy") settings were varied, while some were held constant throughout all of the runs. The X-player settings were as follows:

- Balanced
- FOW - varied from 0 to 100% in steps of 25%
- Conflict resolution - Random at 50%
- Tactical, Area, & Comm Delay varied from 0 to 2 steps with all combinations included

APPENDIX C: T4 RAW DATA

Date	Turn	O Msns M1	X Msns M1	OL Player TAC	OR Delay TAC	XL TAC	XR TAC	O Score Total	X
5/14/94	8	VO	SO	0	0	22	22	1	0
5/14/94	8	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	8	VO	SO	0	0	22	22	1	0
5/14/94	6	VO	SO	0	0	22	22	0	1
5/14/94	8	VO	SO	0	0	22	22	0	1
5/14/94	6	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	0	1
5/14/94	6	VO	SO	0	0	22	22	1	0
5/14/94	8	VO	SO	0	0	22	22	0	1
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	1	0
5/14/94	7	VO	SO	0	0	22	22	0	1
5/14/94	6	VO	SO	0	0	22	22	1	0

APPENDIX D: T4 REDUCED DATA SET

0	0	0	0	0	1	-1	0	7	-7
0	0	0	0	0	1	-1	2	6	-4
0	0	0	0	0	1	-1	2	2	0
0	0	0	0	1	0	1	4	2	2
0	0	0	0	1	0	1	4	1	3
0	0	0	0	0	1	-1	2	2	0
0	0	0	0	0	1	-1	0	7	-7
0	0	0	0	0	1	-1	3	5	-2
0	0	0	0	0	1	-1	1	3	-2
0	0	0	0	0	1	-1	2	4	-2
0	0	0	0	1	0	1	4	3	1
0	0	0	0	1	0	1	3	2	1
0	0	0	0	0	1	-1	3	8	-5
0	0	0	0	1	0	1	4	2	2
0	0	0	0	1	0	1	6	0	6
0	0	0	0	0	1	-1	1	8	-7
0	0	0	0	1	0	1	4	0	4
0	0	0	0	0	1	-1	0	6	-6
0	0	0	0	0	1	-1	2	2	0
0	0	0	0	0	1	-1	2	3	-1
0	0	0	0	1	0	1	3	1	2
0	0	0	0	0	1	-1	1	4	-3

APPENDIX E: MINITAB ANALYSIS RESULTS

Factor	Type	Levels	Values				
FOW	fixed	5	0	1	2	3	4
Tac Dly	fixed	3	0	1	2		
Area Dly	fixed	3	0	1	2		
Comm Dly	fixed	3	0	1	2		

Source	DF	SS	MS	F	P
FOW	4	38.45	9.61	1.09	0.362
Tac Dly	2	38582.97	19291.48	2180.79	0.000
Area Dly	2	2708.07	1354.04	153.07	0.000
Comm Dly	2	346.68	173.34	19.60	0.000
FOW*Tac Dly	8	143.36	17.92	2.03	0.041
FOW*Area Dly	8	63.19	7.90	0.89	0.522
FOW*Comm Dly	8	66.80	8.35	0.94	0.479
Tac Dly*Area Dly	4	1041.40	260.35	29.43	0.000
Tac Dly*Comm Dly	4	397.89	99.47	11.24	0.000
Area Dly*Comm Dly	4	192.72	48.18	5.45	0.000
FOW*Tac*Area	16	305.70	19.11	2.16	0.005
FOW*Tac*Comm	16	97.70	6.11	0.69	0.806
FOW*Area*Comm	16	117.16	7.32	0.83	0.654
Tac*Area*Comm	8	148.33	18.54	2.10	0.034
FOW*Tac*Area*Comm	32	281.48	8.80	0.99	0.477

APPENDIX F: T4 PLOTS

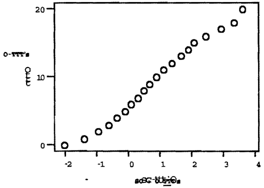

Figure 4 Normal Plot O TTT's

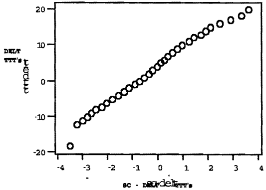

Figure 5 Normal Plot O-X TTT's

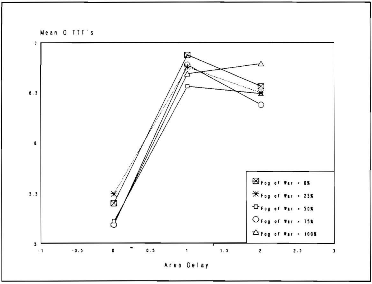

Figure 6 Area Delay vs FOW

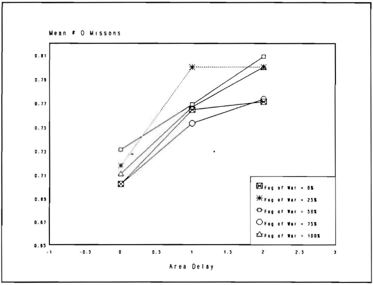

Figure 7 Area Delay vs FOW

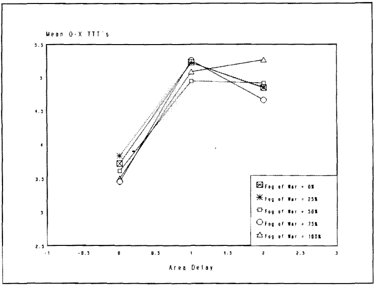

Figure 8 Area Delay vs FOW

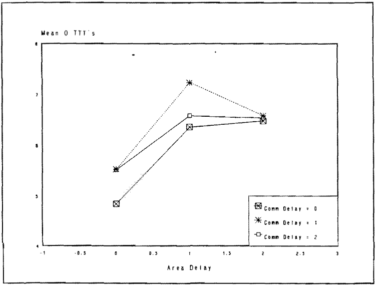

Figure 9 Area Delay vs Comm Delay

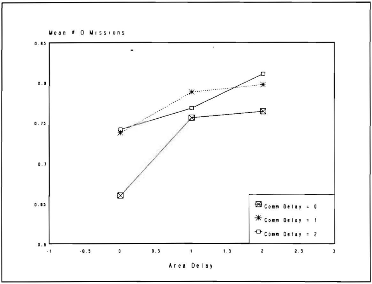

Figure 10 Area Delay vs Comm Delay

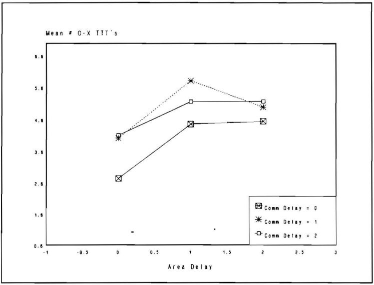

Figure 11 Area Delay vs Comm Delay

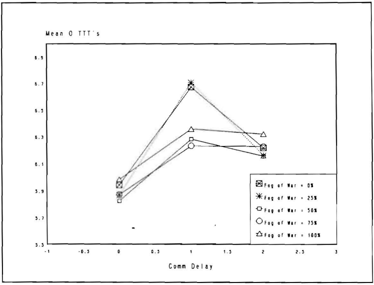

Figure 12 Comm Delay vs FOW

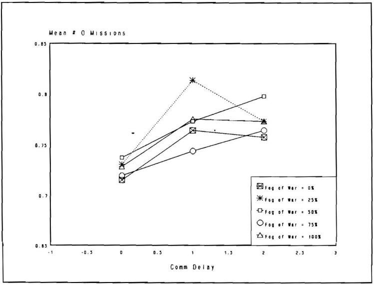

Figure 13 Comm Delay vs FOW

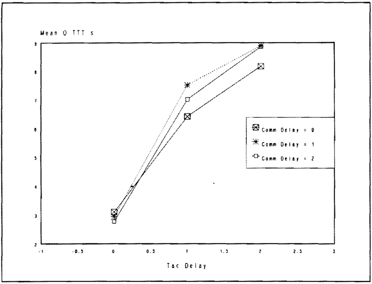

Figure 14 Tac Delay vs Comm Delay

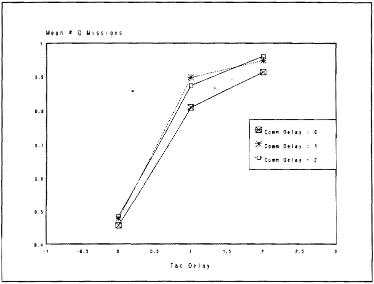

Figure 15 Tac Delay vs Comm Delay

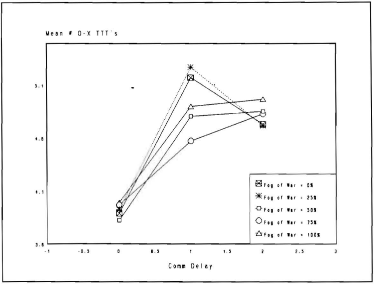

Figure 16 Comm Delay vs FOW

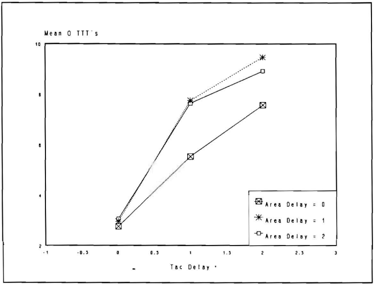

Figure 17 Tac Delay vs Area Delay

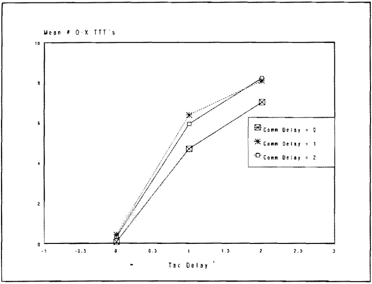

Figure 18 Tac Delay vs Comm Delay

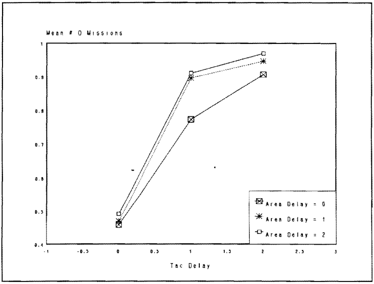

Figure 19 Tac Delay vs Area Delay

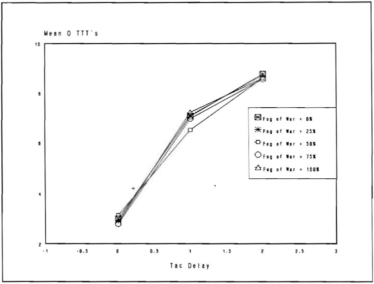

Figure 20 Tac Delay vs FOW

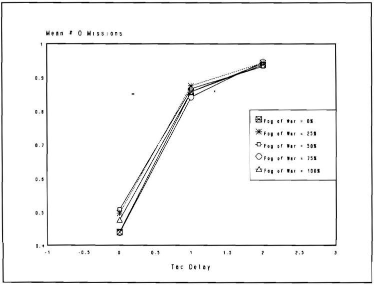

Figure 21 Tac Delay vs FOW

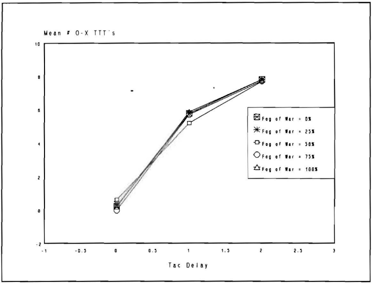

Figure 22 Tac Delay vs FOW

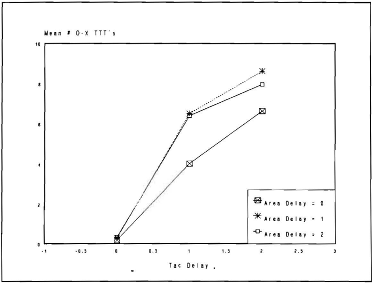

Figure 23 Tac Delay vs Area Delay

```
MTB > DotPlot  'TTT O';
SUBC>   By 'FOW'.    Each dot represents 9 points
              :              .
              : :  : .. .    :   .
           :  : :  : :  :    :    :
 FOW       :  : :  : :  : :  :    :
 0         :  : :  : :  : :  : :  :    :
         . :  : :  : :  : :  : :  : :  : :
         : :  : :  : :  : :  : :  : :  : :    .
         : :  : :  : :  : :  : :  : :  : :  : :  : .
+---------+---------+---------+---------+---------+---------+-------TTT
0        0.0       4.0       8.0      12.0      16.0      20.0

MTB > DotPlot  'Msn Sc O';
SUBC>   By 'FOW'.   Each dot represents 74 points
                                                           .
  FOW 0                                                    :
                                                           :
                                                           :
                                                           :
         .                                                 :
         :                                                 :
         :                                                 :

+---------+---------+---------+---------+---------+---------+-----MsnSc
0                                                          1
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