MODELING THE ADVANCED FIELD ARTILLERY
TACTICAL DATA SYSTEM
(AFATDS)

by

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ABSTRACT

This thesis is a continuation of an analysis of the Advanced Field Artillery Tactical Data System (AFATDS) conducted by students in the Operations Research Program at the Colorado School of Mines. In previous work (Mattes 1995), a problem existed with the processing of some of the messages that are used by the AFATDS model; the time required to pass these messages through the system was unacceptable. In this study, the previous model was verified and five more models were created. The new models had differing message priorities and radio frequency bandwidths, changes intended to fix the problem mentioned above.

During analysis of the previous model, a discrepancy in counting the number of fire missions was uncovered. Some fire mission related messages were counted as part of the total number of fire missions processed resulting in some fire missions being counted two and three times. As a result of our new approach to counting fire missions, we concluded that the AFATDS system, as modeled here, will not fulfill its contractual requirement of processing 720 fire missions per hour.

We ran the six models for 16 iterations each, and conducted statistical analyses on the output. The statistical analyses revealed that the data produced by these models were statistically significant. Therefore, our modifications had significantly improved the model. We solidified this conclusion using a factorial design which verified that our changes did have a significant effect on the model's improvement. The model now more closely mimics reality.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronym	Meaning
AFATDS	Advanced Field Artillery Tactical Data System
AJF	Adjust Fire Mission
ANOVA	Analysis of Variance
BCS	Battery Computer System
BFA	Battlefield Functional Area
COE	Common Operating Environment
DAPNAD	Deterministic Adaptable Priority Network Access Delay
DOD	Department of Defense
EOM	End of Mission
FDC	Fire Direction Center
FFE	Fire for Effect Mission
FIST	Fire Support Team
FO	Forward Observer
FSCM	Fire Support Control Measure(s)
FSO	Fire Support Officer

GLM	General Linear Model
HPFFE	High-Priority Fire for Effect Mission
LCU	Lightweight Computer Unit
MTO	Message to Observer
RISC	Reduced Instruction Set Computer
RTO	Radio-Telephone Operator
TACFIRE	Tactical Fire Direction System
TOEL	Time Ordered Event List
TRADOC	Training and Doctrine Command

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CHAPTER ONE

INTRODUCTION

In an attempt to take full advantage of modern computer technology, the Department of Defense (DOD)[1] has initiated several programs designed to capitalize on this area in defining the battlefield of the future. One problem with this technology, however, is that, with all of the competitiveness of free enterprise, there are many different computer operating standards from which to choose. The leaders of the DOD wisely recognized that if they did not establish and enforce some specific standards, each branch of the nation's defense would come up with its own operating system, and not be able to communicate with the others. By developing and enforcing a common operating environment (COE), the DOD is now better prepared to conduct joint operations as well as joint training exercises (See Figure 1). "Joint" refers to any situation where more than one branch of service (Army, Navy, etc.) is involved. In developing a COE, the DOD established a list of nineteen different areas of software standardization called baseline modules. The COE also provides a set of standardized hardware for use by all services. This hardware standardization will help keep repair costs down and help the services share expertise.

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[1] Please refer to the List of Acronyms on pages x-xi for a list of all acronyms and their meaning.

Similar to the DOD, the Army has a standardization concern for its sub-areas. The Army considers five functions to be critical on the battlefield. These functions are called Battlefield Functional Areas (BFA). The BFA's are (1) maneuver, (2) fire support, (3) intelligence, (4) air defense, and (5) combat service support. Each of these BFA's has been placed under the responsibility of a specific branch of the Army. For example, the Infantry branch is responsible for the development of the maneuver BFA. Each BFA branch is in the process of developing its own digital operating system; these processes are at different levels of completion. The Army has placed a demand on each of the BFA's that their respective systems have interoperability with each other.[2]

The fire support community is one of the leaders in digital communications, and the Field Artillery is the responsible branch for the fire support BFA. In 1978 the branch introduced the Tactical Fire Direction System (TACFIRE) into the Army. This system allowed the digital transmission of fire plans and requests for fire, functions that are collectively called tactical fire control. Tactical fire control also involves the decision analysis that goes into deciding the appropriate projectile and fuze combination, in the proper amount, that will accomplish the maneuver commander's intent for a given target type. Then, in 1983, the battery computer system (BCS) was introduced. The BCS was a major break-through in that, not only was it able to interface digitally with TACFIRE, but it was also able to provide technical fire control. Technical fire control is the process of

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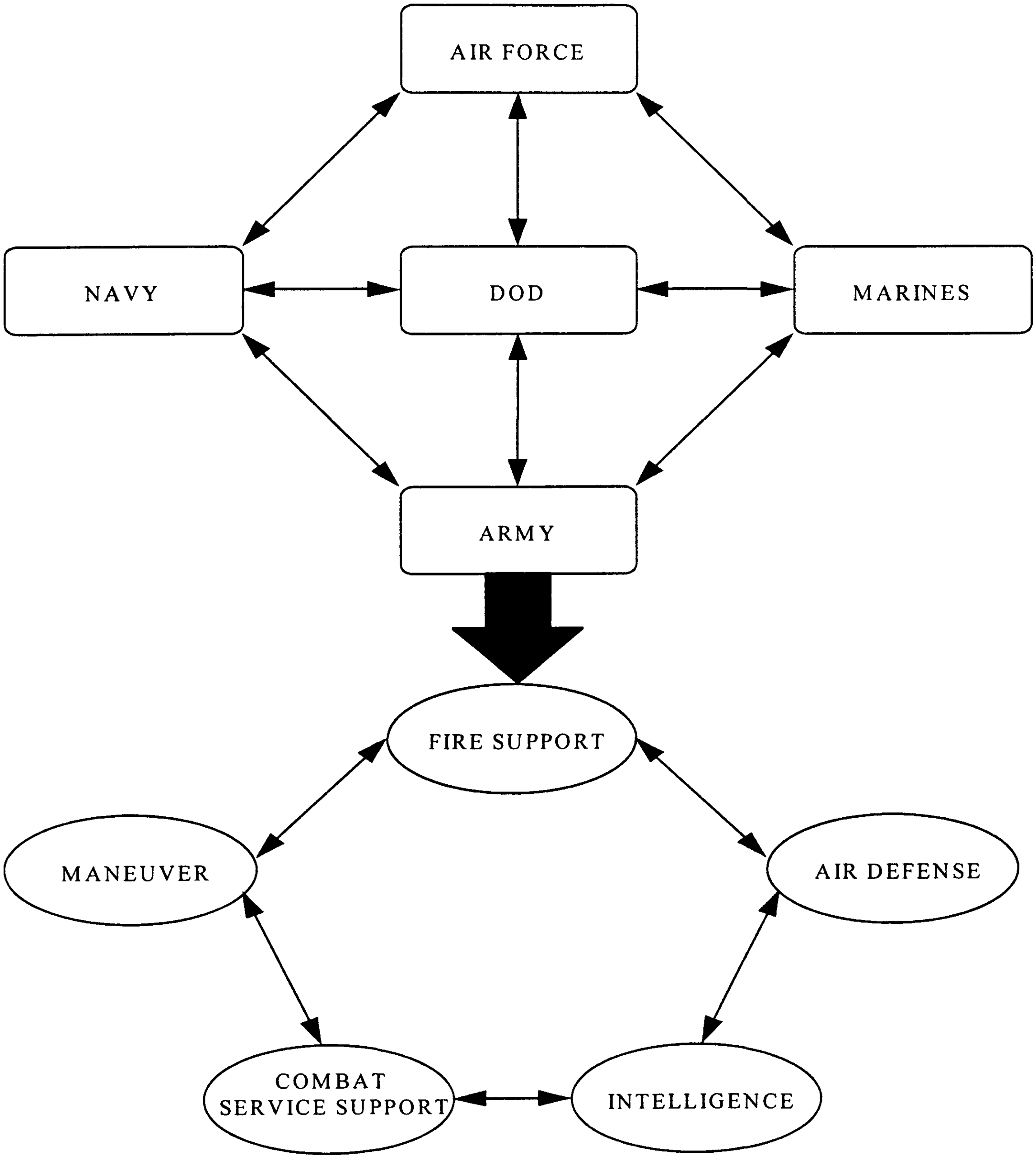
[2] For an overview of the Army's approach to 21st Century warfare, see Appendix A.

Figure 1: Diagram of Inter-relationship of COE and BFA's



determining the firing data that the artillery pieces need to successfully put “steel on target.”

As early as 1981, the Army recognized the need for a digital fire direction system that would take better advantage of improving computer technology. The TACFIRE system is a six ton system that includes a five ton truck. Its power source is a 15kW DC generator that is hauled on a separately towed trailer. With the development of the microprocessor, the Army recognized that it could greatly reduce the transportation and hardware overhead involved with TACFIRE. Therefore, the Army developed a mission elements needs statement that laid out exactly what they would want in future fire direction systems. This needs statement led to the development of the Advanced Field Artillery Tactical Data System (AFATDS).

In 1984, the Army developed the “Redbook.” The Redbook lists all the functions that fire support elements must be able to perform to adequately support maneuver forces. This book consists of 321 tasks. The TACFIRE system only performs 124 of these tasks, which is not surprising considering the fact that TACFIRE existed before the Redbook. The Redbook added additional requirements to the development of AFATDS.

The AFATDS system is being developed by Magnavox®. Even though the name includes the words “field artillery," AFATDS manages all methods of fire support including artillery, close air support, and naval gunfire. The system is being developed in three versions. Version 1 is already being fielded and tested. Version 1 performs 211 of the 321 Redbook tasks. Version 2 will perform an additional 81 tasks, and Version 3 will include the remaining 29 tasks. Another feature of version 3 will be the ability to compute technical firing data. In versions 1 and 2, the AFATDS in the fire direction centers (FDC) will be linked by wire to a lightweight computer unit (LCU), which performs the required technical fire control.

The initial hardware used to run AFATDS had limited hard drive space and too little memory to perform without crashing. The present system is made by Hewlett-Packard®. It uses the technology of a reduced instruction set computer (RISC). This new system has a one gigabyte hard drive, and 144 megabytes of random access memory as a minimum.

The purpose of AFATDS is to provide a digital means of transmitting fire support related information, and to help automate some of the decision-making processes that computers can make more quickly and efficiently than humans. The present fielded version of AFATDS, version 1.0.03, is undergoing a series of tests to ensure it meets the contractual specifications outlined by the Army. In 1994, the program manager for AFATDS approached Dr. Woolsey at the Colorado School of Mines to do analysis on future versions of AFATDS. Three Army officers (Major Greg Hoscheit, Captain Paul Gaasbeck, and Captain Pete Mattes) initially worked on the project. Their work consisted of modeling AFATDS version 3 on a simulation software package called COMNET III, which is specifically designed to model communications networks.[3] The purpose of their work was to determine whether AFATDS was going to achieve its contractual requirement of processing 720 fire missions per hour at the brigade level. A fire mission was considered processed when it reached the Brigade Fire Support Officer (FSO). The results of their work can be found in the theses of Paul Gaasbeck (1995) and Pete Mattes (1995).

One of our first activities was to completely dissect the existing model, and locate any problems. We only found minor errors that required correcting. Since we did make corrections, however, we re-created Pete Mattes's experiment to determine if any changes would result from our corrections.

There is an important issue of definitions that must be addressed here. There are three types of fire missions conducted in this model: fire-for-effect (FFE), high priority fire-for-effect (HPFFE), and adjust fire (AJF). An FFE mission is used in cases where the observer's target location is very good, or if the need for rapid volumes of fire is greater than the need for accuracy. An HPFFE is used for extremely dangerous times when artillery is needed immediately. These missions are obviously given the highest priority. An AJF mission is used when the observer is unsure of the target's location, and accuracy is a must. Within this model, FFE and HPFFE missions are stand-alone, which means

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[3] Hoscheit and Mattes used COMNET III. Gaasbeck built his model using SLAM II.

they are generally fired and ended very quickly. Conversely, AJF missions are very time consuming. In these missions, the original request for fire support and each of up to two adjustments receive one round. When the observer has successfully adjusted the rounds to the target, he receives a volley of rounds from several delivery systems. If these adjustments are counted as part of the total count for “fire missions," then the totals exceed the contractual requirement of 720 fire missions per hour. However, the adjustments could also be viewed as components of existing AJF missions; and to count them would result in double and triple counting some missions. This is obviously the worst-case scenario, and the approach to counting we chose to use to further improve the model. Exactly how we modified the model is explained in Chapter 3. Our method of counting resulted in the contractual requirement of 720 fire missions not being met.

The model modifications we developed were used to evaluate version 3 of AFATDS based on (1) the number of fire missions processed by the direct support (DS) artillery battalion FDC, (2) the speed with which fire for effect missions were passed on to firing units, and (3) the utilization rate of the DS artillery battalion’s operations net. Consideration was also given to the time it takes the messages involved in an AJF mission to process. The adjustments of an AJF mission are triggered by the receipt of certain messages from the firing unit. Obviously, the time it takes to process these messages has a direct impact on both the processing of the individual AJF mission, and the overall quantity of missions fired in an hour.

CHAPTER TWO

LITERATURE REVIEW

Simulating an immense communications network can get very complicated. Although the advent of computer based modeling has made this task much easier to accomplish, a basic understanding of simulation is essential before modeling is begun. Once the basics of modeling are understood, the modeler is ready to apply modern computer simulation software to the project.

In their article from the 1994 Winter Simulation Conference Proceedings, "Simulation of Communications Networks," Averill M. Law and Michael G. McComas discuss the basics of developing valid and credible simulation models (Law and McComas 1994). The authors stress that a credible model should be the basic goal of every model designer. The simulation must be valid enough that any conclusions made from the model should be the same as if they were obtained by physically experimenting with the actual system being simulated. The authors then go on to list techniques for deciding the level of model detail, validating a simulation model, and for developing a highly credible model.

Several authors point to the importance of a simple and understandable model. In his keynote address to the 1993 Winter Simulation Conference, John D. Salt stresses that simplification is the essence of simulation (Salt 1993). The modeling process involves including important factors of a system in the model and throwing out all the rest. He states that simply constructed simulation models not only take less time to write and to run, but also take less time to interpret and apply their results. He explains that smaller models can help the modeling project get off the ground faster. It is easier to make modifications and "spin-offs" to a simple model than to a more complex one. He goes on to explain that it is easy enough to add complexity to a model if that is what is needed. It is, however, very difficult to do away with complexity once it is already incorporated into a model. In an article also presented at the 1993 Winter Simulation Conference, Kenneth J. Musselman reiterates the importance of model simplicity (Musselman 1993). Musselman believes that the outputs of a highly complex model are too difficult to interpret. He advocates building the model in stages. Each stage of the model builds upon the previous stage and, as stages are completed, the modeler can see the impact on the model as a whole.

Simulation is used to design and examine communications networks. In their article, Law and McComas (1994) discuss the application of simulation to improve an existing communications network's performance. They point out that it is often necessary to use a model to evaluate system performance because the network itself is too complicated, not cost effective, or hasn't been built yet. The authors point out that analytic queuing models have several shortcomings when applied to the modeling of communications networks. Only steady-state results are usually possible and it is difficult to obtain performance measures other than mean values. The drawbacks of analytical techniques have led to the advent of several simulation products specifically designed for communications networks.

One of the most basic forms of communications oriented simulators is COMNET III. An article entitled "COMNET III: Object Oriented Network Performance Prediction" was presented at the 1994 Winter Simulation Conference by Dr. Robb Mills and John G. Goble. The authors (both employed by CACI Products, the manufacturers of COMNET III) explain that COMNET III can be used to predict the performance of communications networks using object oriented simulation analysis. They discuss how COMNET III provides a graphical environment for model creation and execution and analysis that allows the designer to interact with the model while it executes. Topology is defined by nodes and links that can be organized hierarchically into subnetworks. Each node can perform processing functions and provide ports for connecting to links. The authors discuss in detail application nodes and communication nodes. Application nodes run applications and can contain storage devices for files. They explain how each application node accepts requests for processing, read, write, and transport. Communications nodes are defined as performing switching and/or routing functions. The authors discuss how COMNET III models are created, executed, and analyzed in an integrated graphical environment. They explain that the Windows version is user friendly because the click of a mouse button expedites the modeling process.

In the Law-McComas article from the 1994 proceedings, it is clear that basic simulation packages, such as COMNET III, have both advantages and disadvantages. One major advantage of a basic simulation package is that the model development time is drastically reduced due to the fact that no knowledge of simulation language is required. This could be important given possible time constraints when dealing with government agencies and academic deadlines. Another advantage is the fast model execution speed, which is necessary to simulate networks with an immense number of messages. A major disadvantage is that modeling is limited only to network configurations that can be constructed with the building blocks provided in any particular package.

In an article entitled "New Technology For Force XXI Artillery," AFATDS is featured. This article appeared in the February 1996 issue of *Army* magazine and explains the current posture of the AFATDS project. As explained in Chapter 1, AFATDS is the automated, command, control and coordination system that provides digitization capabilities for the fire support battlefield functional area of the U.S. Army. AFATDS is an essential link in the digitization of the army of the twentieth-century, and will be an integral part of the Task Force XXI experiment, scheduled to take place in February 1997. The current version of AFATDS software, Version 1, underwent initial operational testing and evaluation in August 1995. As a result, the Army System Acquisition Review Council Milestone III decision authorized the fielding of AFATDS to the total force. The 1st Cavalry Division at Fort Hood, Texas is currently designated as the initial operational test and evaluation unit for AFATDS. The next phase for AFATDS will be to update the software to Version 2.0 and 2.1. Version 2.0 software is designed to satisfy U.S. Marine Corps requirements while Version 2.1 will automate additional processes as contracted with the Army.

There were many textbooks used as research for this thesis. There are two that I want to specifically mention here. Simulation: A Problem Solving Approach was written by Stewart Hoover and Ronald Perry. This book was an invaluable source of information for simulation. It provided excellent discussions of the simulation process. In every stage of the simulation process, this book used very understandable examples to get the point across.

The other very useful book was, Discrete-Event System Simulation written by Jerry Banks, John Carson, and Barry Nelson. I feel its discussions on the simulation process were a little wordy and hard to follow. On the other hand, the sections on output analysis were outstanding. These sections were well written and very organized.

CHAPTER THREE

METHODOLOGY

3.1 Introduction to Simulation Methodology

In Hoover and Perry's text (1989), simulation is defined as, "The process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain, and predict the behavior of the real system." This definition very adequately describes the occurrences of this modeling effort. The model of AFATDS is a model of a real system. As mentioned previously, the AFATDS model replicates version 3, which does not exist to date. Version 1 is in the final test stages, and is undergoing limited fielding as of the writing of this thesis. The modeling effort done here will help identify strengths and weaknesses that can be considered as version 3 is further developed.

3.2 Model Classification

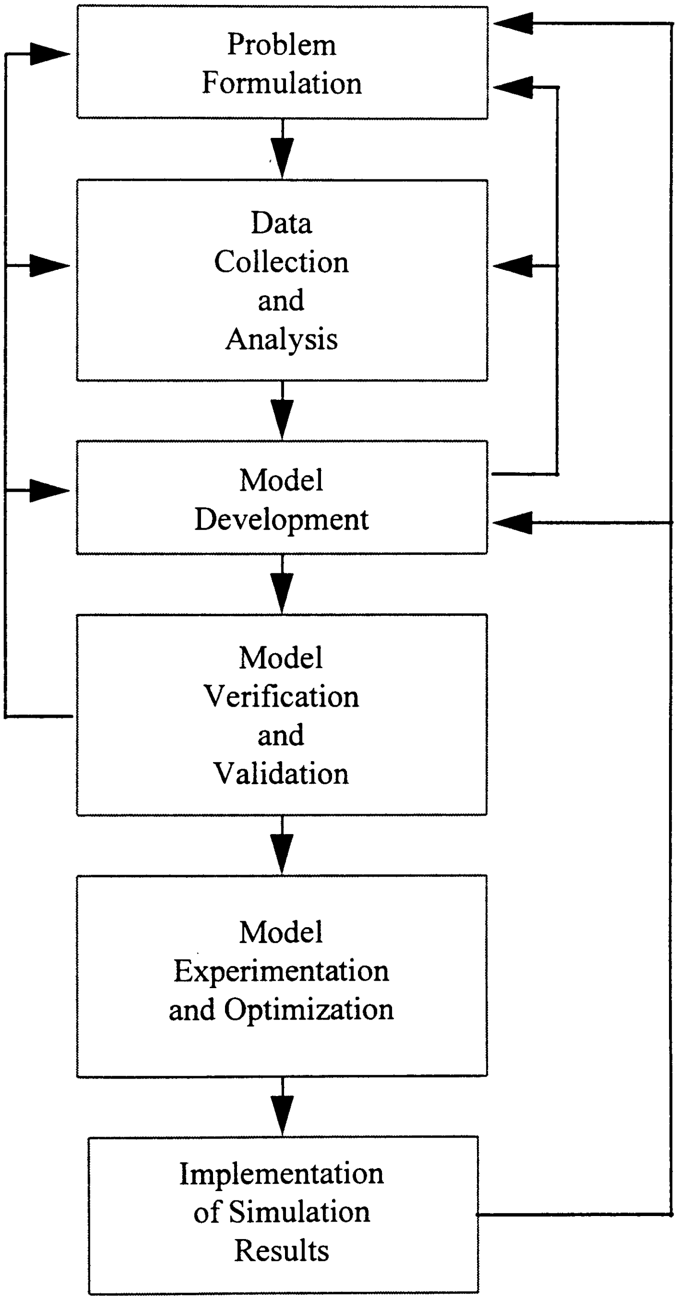
There are five characteristics that describe a model (Hoover and Perry 1989). The first of these is *prescriptive* or *descriptive*. The AFATDS model is descriptive because it describes the system behavior, as opposed to making a recommendation for optimization. Then a model is determined to be either *discrete* or *deterministic*. The AFATDS model is discrete because we are measuring parameters that describe discrete entities (messages). For example, one of our parameters is a measure of how many fire missions are processed at the end of an hour. The AFATDS model's third characteristic is that it is *probabilistic.* It is probabilistic because its messages are created by using random numbers. The random numbers follow an exponential distribution that represents the time between creation of the different messages.

The fourth characteristic of a model is the determination of whether it is *static* or *dynamic.* The AFATDS model is dynamic because the system state is constantly changing. Messages are created while other messages complete their functions. Finally, a model can be an *open loop* or a *closed loop.* In AFATDS, there are no provisions within the model that allow it to correct itself. If there is a better way to do things, the model will not recognize that - it blindly does as it is told. This type of model is useful for measuring the behavior of a model that must have particular design specifications. These qualities make the AFATDS model an open loop model. Therefore, the AFATDS model is a descriptive, discrete, probabilistic, dynamic, open loop model.

3.3 Problem Formulation

Hoover and Perry also provide a sequence of events that should be followed during any modeling effort (See Figure 2). Notice the interaction of all the elements. This is not

Figure 2: The Elements of Simulation Analysis (Hoover and Perry 1989)



a progression that simply flows from one phase to the next without occasionally revisiting a previous phase. Rather, as the progression flows, previous steps are continually updated and/or reevaluated. We worked to follow this outline, but found ourselves revisiting old ground just as depicted in Figure 2.

The first, and most difficult part, of simulation analysis is problem formulation. First of all, the modeler must decide what it is that is to be modeled, and then decide the variables and constraints. There may be many ways to build the model. The modeler can try to model every little detail of the system, but there would be costs to doing so. If the model has too many variables involved, it could run slower and quickly bury the modeler in mountains of paper output. Our output totaled over 4,200 pages! As part of problem formulation, the modeler must decide what parameters the model is to measure. There are two types of variables - exogenous and endogenous. Exogenous variables are input variables. The rate at which the model creates entities in the system is an example of an exogenous variable. The endogenous variables are what the model is measuring. If the modeler doesn't decide the endogenous variables early in the simulation process, the model may be either too difficult, or too general, and may not collect the appropriate data that answers the relevant questions.

As mentioned previously, the purpose of this modeling effort is to modify the existing model to make it more correctly mirror reality. The adjustments to the AJF missions are being held up by the slow moving Shot, Splash, and Message to Observer (MTO)

Messages. When one of the firing platoons receives a request for fire support from one of the forward observers (FO), it generates an MTO that advises the FO what type of projectile will be fired on the target, how many projectiles will be fired, and a target number for the mission. After the firing platoon fires its first round, it sends a Shot message to the FO, so that the FO knows his rounds are coming. One of the pieces of technical data that the firing platoon computes is the time of flight. This is the expected time it takes the projectile from the time it is fired to impact on the target. Approximately five seconds before impact, the FO should receive from the firing platoon a Splash message. This lets the FO know that impact is imminent. The Shot, Splash, and MTO messages were taking too long in the previous model. Another important message in fire mission processing is the end of mission (EOM). Until the firing platoon receives an EOM from the FO, it must keep the mission active in the computer, taking up valuable memory. The computer presently used by the FDC for technical data computation can only keep three active fire missions in its buffer.

The messages discussed above became the center of attention for this modeling effort. The ten endogenous variables for this model are depicted in Table 1. The variable "% AJF's Adjusted" in Table 1 was useful to determine if a faster transmission of Shot, Splash, and MTO messages would increase the ability of AJF's and their adjustments to be processed.

Table 1: Endogenous (Measured) Variables

Variable	Explanation
# of Missions received by the Battalion (Bn) Fire Direction Center (FDC)	How many total fire missions of all types were received by the FDC?
FFE Time in seconds	How long for this mission to get from FO to the firing platoons?
HPFFE Time in seconds	How long for this mission to get from FO to the firing platoons?
% Utilization of the Bn Operations Net	How much of the time was this important radio net (frequency) busy?
Shot Time in seconds	How long for this message to travel from firing platoon to FO?
Splash Time in seconds	How long for this message to travel from firing platoon to FO?
MTO Time in seconds	How long for this message to travel from firing platoon to FO?
EOM Time in seconds	How long for this message to travel from FO to firing platoon?
% AJF's Adjusted	What % of the initiated AJF's received at least one adjustment?
Total # Messages at Brigade	How many total messages (minus acknowledgments) were handled by Brigade?

3.4 Data Collection and Analysis

Once the problem is formulated, data collection and analysis begin. Data collection is very important because it allows choice of the appropriate representation for the model. Data collection does not just include the recording of reams of raw data. This is also the time when the modeler should, if possible, get some hands-on experience with the system. If possible, no modeler should depend on someone else to provide the necessary data. Collecting data is a good way to learn the system. Of course this is not always possible. If the system does not exist yet, the modeler may have to depend on the design specifications of the system.

After the data is collected, the modeler must analyze it. Sometimes some parts of the model may be deterministic. Consider a stamp on an assembly line. Perhaps the stamp comes down every 30 seconds without fail. This would be an example of a deterministic process. (Of course the modeler must keep in mind that the decision to call a process deterministic may be a result of the accuracy with which the modeler is measuring the system!) If a system is not deterministic, it is probabilistic. This means the data is based either on a theoretical probability distribution, or a custom distribution the modeler derived specifically for a particular data set.

One final consideration during this phase is the amount of data to be collected. Obviously, the analysis will be more accurate with larger data sets. Sometimes, however, the data is not easy to collect, or is very expensive to collect. In cases such as these, it might be useful to conduct some confidence interval testing to determine the minimum number of data points needed. The modeler must be prepared to make a trade-off between cost and accuracy.

Data collection and analysis were not particularly difficult in this case. Since we are improving an existing model, we were not required to collect a lot of data. Our main effort during this phase was gaining an understanding of the physical AFATDS system. We visited Fort Hood, Texas where we received several briefings on AFATDS. One briefing was intended to explain where AFATDS fits into the Army's grand scheme. We also received a briefing on how to use AFATDS. The biggest help to us was being allowed to actually work at the keyboard. We spent several hours in front of the AFATDS device going through the motions. Another helpful part of the trip was our visit to a motorpool where we were able to see the system set up in one of the tracked vehicles belonging to the 1st Cavalry Division. During this visit we were able to talk to a couple of the soldiers who regularly use the system.

We verified that the random variables and probability distributions being used by the model were accurate through our liaison officer at Fort Sill, Oklahoma, Major Daniel Hughes. Major Hughes acted as our liaison to all sources of information. He verified the topology of the model, the exponential probability distributions used to replicate the times between creations, and the sizes of the messages.

3.5 Model Development

The next element of simulation analysis is model development. This is probably the most difficult step, after problem formulation. The modeler must have a very good understanding of the physical system in order to model it. This is where the hands-on training mentioned above is useful. While collecting the data, one gains an understanding of the intricacies of the system. Hoover and Perry (1989) discuss two techniques for understanding a system - the physical flow approach and the state change approach. The physical flow approach concentrates on the entities of the system; that is, objects that are serviced by the system. The entities are carried through the system by a series of processes and decision nodes. The modeler tracks the entities through the system and develops a flow chart that portrays the progress.

The state change approach tracks events instead of entities. Hoover and Perry (1989) define an event as "a particular point in time when the status of the system changes." This approach is especially useful for determining the future state of a problem. One derivation of this type of approach is steady-state behavior in which the modeler is interested in the performance of the system under steady-state conditions. Instead of a flow chart of nodes and decisions, as in the physical flow approach, a diagram of the events that occur may be more useful.

After figuring out the physical appearance of the system, the modeler must select a software that will adequately behave as the physical system behaves. Hoover and Perry

(1989) provide several criteria for choosing the best software. The general answer to the question lies in the circumstances of the system and the modeler, as will be seen in the following discussion. The criteria are as follows. (1) Ease of learning. Either pick an easy to learn software, or one that has knowledgeable technical experts readily available. (2) Ease of explanation to nontechnical individuals. Very few people want a "black box" answer to their question. If the clients cannot understand the solution, or how the modeler got it, they might not accept the results. (3) Cost. There is a series of trade-offs between cost and efficiency and accuracy of the results. Sometimes a less expensive software may not be very user friendly, and the results may be suspect. On the other hand, a very expensive software may have a whole lot more "bells and whistles" than are needed. (4) Standard code for all computers. Try to find a package that is executable on several hardware/software platforms. Some newer packages can run on both mainframe and personal computer systems. (5) Scope of problems addressable by the language. Try to find a package that is useful for many types of systems. There are specialized packages for certain types of systems. The software used for this modeling effort is COMNET III which is designed for analyzing communications networks.

Our understanding of the physical system was initiated at Fort Hood, but was strengthened by studying the existing model. We began at the lowest level, the FO, and traced a mission through all portions of the model. At every level, we tried to ensure that things that occurred to the message made sense.

There was not a software decision for us to make. To model AFATDS is to basically model a communications network. The types of questions we are trying to answer deal mainly with throughput - how much stuff can we push through the system without adversely effecting other sub-systems in the model. The software used to model AFATDS, COMNET III, has all the characteristics of a good package as discussed above. One weakness compared to the above guidelines is that it is a very specialized software; it can only model communications networks.

An additional weakness that we discovered is that the software doesn't allow the design of different communications protocols. The package has a few internal protocols, but if the model requires a non-standard protocol, the only option is to pick the existing one that best fits the situation. Magnavox has developed a protocol called deterministic adaptable priority network access delay, or DAPNAD. The closest thing to this in COMNET III is the token passing ring. The token passing ring works on the "take a number, take a seat" principle. Earlier prototypes of AFATDS allowed the message with the highest priority first passage. The problem is that this logic quickly allowed the system to become overwhelmed with high priority messages and allowed no lower priority messages to be passed. The idea of a token ring is that every entity has the chance to pass messages. Messages waiting to be passed are concatenated, or grouped together, until the entity receives its turn to transmit; then all the gathered messages are sent in one burst of digital traffic.

3.6 Model Verification and Validation

Model verification and validation are very important for model acceptance. Verification is the assurance that, internally, the model is behaving appropriately. If the modeler tells a node to do something to another node, the model must carry this out as told. Even though we were not creating a brand new model, we still spent a lot of time in the verification process. As mentioned above we traced the path of a message through its entire existence. Verification was very complicated. If an FO generated a message, we went to the respective FIST to ensure that not only did he receive the message, but that he took the necessary action on that message. Some messages were scheduled by iteration time, which means they are created at random using some sort of probabilistic means of creation. Other messages are triggered by the receipt of another message. It is important during verification to ensure that messages that trigger other messages go to the right place.

The verification process is made easier with COMNET III. There is an available verification function that checks all these things for the modeler. However, care must be taken when using this function. When a message is generated, COMNET III can ensure that there is a destination for that message; it cannot verify that the destination is the correct one. That is why we went through the existing model with a fine-tooth comb and checked all these things.

Validation is extremely important if the modeler is to receive any acceptance of the model's results by the client. If the model is going to be used to predict future behavior, it is imperative that it accurately reflect the present. If the real system has data available, that data should be used to validate the model's estimates of the same parameters. If the model appears to accurately reflect reality, then its predictions for the future will more readily be accepted. Validity not only pertains to the output variables, but also to the input variables. For example, the time between creations of the model must be accurate. The modeler must ensure that the model does not "pad" the output with unrealistic input.

Another important part of the validation process is the acceptance of the modeler's assumptions. Not every single characteristic of the model may allow representation. As mentioned above, Magnavox's DAPNAD algorithm was unable to be modeled exactly in COMNET III. In cases such as these, assumptions must be used to complete the work. The major assumptions used in this model, and approved by Major Hughes, are in Table 2.

There are times when the model results cannot be compared to the real system. For example, if modeling a system of the future that is still on the drawing board, there is no data with which to compare the results. The AFATDS system falls under these circumstances. Since we are modeling version 3, and the Army is currently testing version 1, we have no data from version 3 to use for validation. In this case we chose to let our liaison, Major Hughes, decide if our results were valid. A document containing the measurements of the parameters in Figure 3 was sent to him. Major Hughes validated our

Table 2: Major Assumptions

	Assumption
1	The model represents a Pure Infantry Brigade with 3 Infantry Battalions
2	All levels of the model are equipped with AFATDS devices with either 1200, 9600, or 16000 bits per second bandwidth
3	All HPFFE missions are fired by the Direct Support Artillery Battalion; 60% of the regular priority FFE missions are fired by the Reinforcing Artillery Battalion
4	At all levels perfect communications exist
5	The time for processing missions on the howitzers is a constant 35 seconds
6	The time of flight for the projectile is a uniform probability distribution with a minimum value of 11 seconds and a maximum value of 50 seconds
7	The firing platoons are equipped with 155mm self-propelled howitzers

results based on his familiarity with the results in version 1 testing, and his knowledge of the version 3 developments. A copy of the validation memorandum he provided is in Appendix B.

3.7 Model Experimentation and Optimization

It is at this stage that the modeler begins to answer the questions posed by the client. One thing the modeler must decide is whether the model is of a terminating or nonterminating system. A terminating system runs for a certain time duration, or until a certain event or sequence of events occurs (Banks et al. 1996). An example of this type of system would be a bank or grocery store that is not open 24 hours a day.

A nonterminating system is one that would, theoretically, run infinitely. There is no inherent stopping criterion. The AFATDS system is an example of a nonterminating system. Normally, the intent of the study of such a system is to measure system performance for the long-run, or at steady-state conditions (Banks et al. 1996). In this situation the modeler must decide how to long to let the system run. An important consideration in how long to let the model run is initialization bias. When a model begins to run, all its statistical arrays are probably zeroed out. Whether or not this is true is based on the software package being used, and on any user preferences the modeler designated in the package. If the model begins running with empty arrays and no entities (messages), this situation could greatly skew the results. A warm-up time must be established that allows the system to get going and reduce the effect of early moments of the run. In the case of the AFATDS model, a 15 minute warm-up precedes the actual run. The COMNET III system does not collect any data during this time period. At the end of the warm-up period, the simulation keeps running without initializing, but the software begins collecting data. This warm-up period allows messages to be created and to start flowing.

Experimentation is one of the beauties of simulation. The model can be used to answer an endless number of "what ifs". As mentioned earlier, there was a concern that AFATDS was not pushing Shot, Splash, and MTO messages through the system quickly enough. There was not an obvious fix for this situation. If too many "remedies" are utilized at once, the modeler may not be able to determine which remedy, or combination of remedies, improved the system or which made the situation worse. We determined that there were a couple of things that could cause the delay in transmitting the important messages - bandwidth and priorities. There are three bandwidths used in AFATDS. If the FOs talk to the FISTs on special dedicated radio nets, their bandwidth is 1200 bits per second (bps). If no dedicated nets are present, they have the same bandwidth as everyone else. The system basically uses 9600 or 16000 bps. In COMNET III, these bandwidths are rounded to the nearest 1000 bps. Therefore, the only models that have the true bandwidth represented are those using 16000 bps.

The priority system used in COMNET III is relational. Assume one message has a priority of 25, and another has a priority of 50; this does not imply that the higher priority will be passed twice as fast as the lower one. It simply means that the higher priority message will get passed first. Based on the system of priorities and the available bandwidths, six experiments (models) were developed, each modifying the system in a different way (See Figure 3). The first model is the corrected version of the existing model referred to in Chapter 1. Model 2 simply changes the priorities on some key messages. Models 3 through 6 all have dedicated FO nets. Models 3 and 4 use 9600 bps for their bandwidth. Models 5 and 6 use 16000 bps for bandwidth. A more complete discussion of the use of message priorities in these models can be found in Chapter 4.

Figure 3: Experiments (Models) Tested

Model 1

➔ All nets at 9600 bps
➔ Corrected version of previous model

Model 2

➔ All nets at 9600 bps
➔ HPFFE priority set to 99
➔ Shot, Splash, MTO, EOM set to higher priorities

Model 3

➔ FO - FIST links at 1200 bps
➔ All other nets at 9600 bps
➔ Original priorities

Model 4

➔ FO - FIST links at 1200 bps
➔ All other nets at 9600 bps
➔ Higher priorities

Model 5

➔ FO - FIST links at 1200 bps
➔ All other nets at 16000 bps
➔ Higher priorities

Model 6

➔ FO - FIST links at 1200 bps
➔ All other nets at 16000 bps
➔ Original priorities

3.8 Implementation of Simulation Results

The successful implementation of a simulation is greatly dependent on successful completion of all the above mentioned steps. The most important of these is validation and acceptance by the client. The Army is using the results of this modeling effort as a secondary check on the contractual requirements with Magnavox, and to help determine future policy regarding the use of AFATDS. One way to avoid a lack of acceptance is to keep the client involved and informed during all phases of the simulation process. Keeping the client abreast of all activities throughout the study works to the benefit of both parties. The modeler will benefit from the client's expertise and understanding of the physical system, simultaneously, the client may develop a sense of "ownership" in the project. The client will benefit by being involved in the whole process because the results will be revealed a little at a time instead of all at once at the end of the study. Too much data at once could overwhelm the client.

CHAPTER FOUR

MODEL ANALYSIS

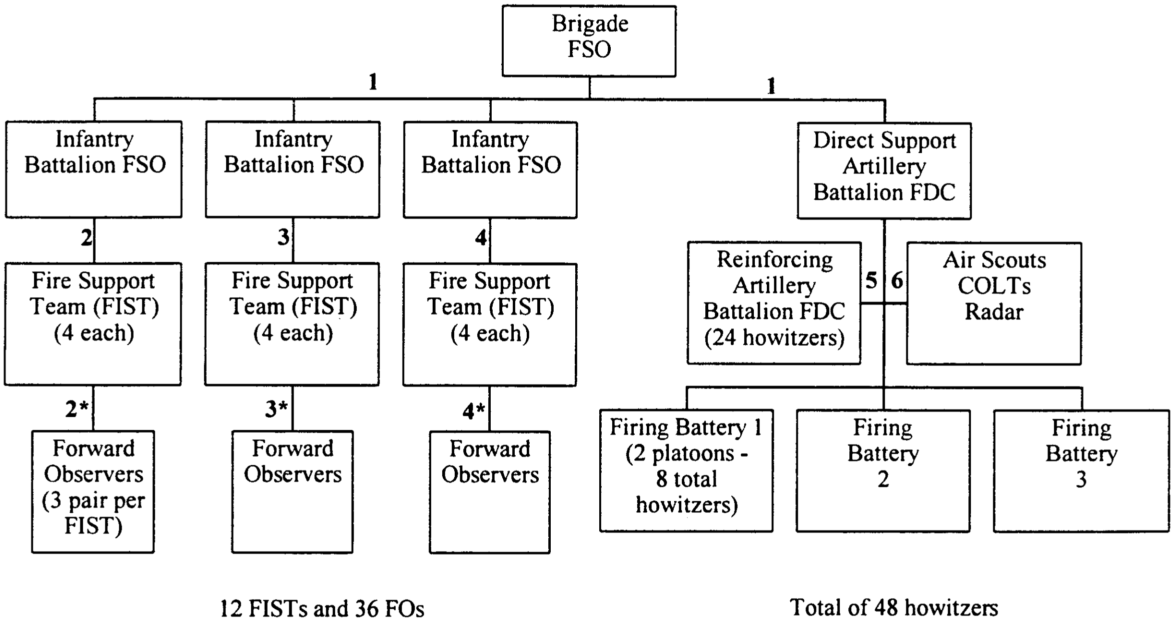
The intent of this chapter is to explain the AFATDS model itself, and how it mimics the real system. The last chapter included a brief discussion of the fire mission process; this chapter will get into more detail.

4.1 The Physical System

The AFATDS system includes a great number of messages. To have modeled every message that AFATDS has in its menu would have been both time consuming and unnecessary. Earlier we mentioned that a model can be too involved, and not even collect relevant data. The questions being answered with this model do not require that every message, many of which are administrative messages, be modeled. The fire mission messages are passed over one radio frequency, while administrative messages are passed over a frequency established for support purposes.

The unit depicted in the model is a pure infantry brigade (See Figure 4). This means that all the maneuver forces are infantry, as opposed to being a mix of infantry and armor. The pure infantry approach was chosen because this is more of a worst case scenario. In this situation “worst case” refers to the number of users in the system. An infantry

Figure 4: Infantry Brigade Fire Support Assets



Legend

Net Number	Use/Definition
1	DS battalion operations net used by brigade/battalion FSOs and FDC
2	Battalion #1 mortar net (* indicates FO may be on different net)
3	Battalion #2 mortar net (* indicates FO may be on different net)
4	Battalion #3 mortar net (* indicates FO may be on different net)
5	Reinforcing battalion operates on FD3
6	These assets will operate on the division operations net
	The 6 platoons in the DS battalion will split evenly between FD1 and FD2

brigade is made up of infantry battalions, in this case three. Every battalion has, as part of the battalion staff, a fire support officer (FSO) responsible for advising the battalion commander on fire support matters. The battalion FSO works for his supported maneuver commander, but also answers to the FSO at brigade. Each battalion is divided into four companies. Each company has a fire support team (FIST) consisting of a command team and three FO teams who have working relationships with each of the three platoons of the company. The FO team consists of an FO and a radio-telephone operator (RTO), who is also trained to observe indirect fires. All the personnel mentioned above are trained field artillerymen - not infantrymen or tankers assuming an extra duty.

The difference between an infantry unit and an armor unit, as far as fire support is concerned, is that armor platoons do not have FO teams. That is why the depicting of an infantry brigade puts more strain on the system than if one of the battalions were an armor battalion. Notice in Figure 4 that there are two battalions of artillery. The direct support (DS) battalion is part of a larger group called the division artillery. Each battalion of the division artillery is “farmed out," one to a brigade. The reinforcing artillery is another battalion that may have been provided by the division or corps commander. The reinforcing battalion basically augments the DS battalion.

The system in place for providing fire support is not complicated. Either the FO or FIST can generate a request for fire. In some rare cases, the battalion FSO may generate a fire mission. Those instances are so rare that they were not depicted in this model. When the request for fire is generated, it is subsequently reviewed by each next higher level of command before the request is granted. The AFATDS system has made improvements to this system of checks and balances. Prior to AFATDS, the FSO at each level was responsible for ensuring that the target did not violate any fire support control measures (FSCM). An example of an FSCM would be a no-fire area that might have been imposed to protect a friendly town or city. The FSOs at higher levels not only verified the safety aspects of the target, but also ensured multiple missions were not unintentionally fired at the same target. They also had to ensure that, if a certain unit was designated to receive the priority of fire support, it did so. Another part of the decision making process was what type of munition to use, and which firing unit not only had that munition, but had it on hand and was able to shoot. The AFATDS system, given all the correct inputs, can make all these decisions instantaneously. At each level, the operator can tell the AFATDS machine to pass all messages through the system, or can request that it stop certain or all messages for that FSO's review. The model we are using assumes that all AFATDS devices, at every level, are on "automatic."

If the FO or FIST initiates a request for fire that makes it through all the gates to the fire direction center (FDC), the FDC will forward it to one of the firing platoons. The firing platoon will send the FO or FIST an MTO. When the first round is fired, the firing platoon sends a Shot message. Five seconds prior to impact, the FO should receive a Splash message. If the initial request for fire was for FFE, there will be a number of impacts. If the request for fire was an adjust fire mission, there will only be one round fired initially. The FO then adjusts the round onto the target. When the FO is satisfied that the round is properly adjusted, he changes the mission to fire for effect. When the FO has achieved the desired effects on the target, an EOM is sent through the system.

An important part of the fire support system is the use of radio nets (frequencies). Obviously, if all the activity above occurred on the same net, overload would quickly be achieved. Different levels of authority have dedicated nets for their own use (See Figure 4). The brigade FSO communicates with all the battalion FSOs and the battalion FDC on the artillery battalion's operations net. The FISTs talk to the battalion FSOs on the infantry battalion's mortar net. The DS artillery battalion has three digital fire direction nets (FD1, FD2, and FD3) for communicating with the firing platoons and reinforcing battalion. In the six AFATDS models we developed and analyzed, the battalion FDC communicates with three of its organic platoons on FD1, the other three platoons use FD2, and the reinforcing battalion communicates on FD3. In models one and two, the FOs communicate with the FISTs on the battalion mortar net. In models three through six, the FOs have dedicated nets for communicating with their respective FISTs. These dedicated nets are operating at 1200 bps as indicated in Figure 3.

The AFATDS model uses other messages as mentioned above. The main messages used in this model and their meanings are in Table 3.

Table 3: Messages Used in Model

Message	**Meaning**
Ack	Used by every element at all levels to acknowledge receipt of a message
Adjust1	Makes the 1st adjustment to an AJF mission
Adjust2	Makes the 2nd adjustment to an AJF mission
AJF	Initiates an AJF mission
ATI	Provides intelligence on a target or potential future target
EOM	Ends a fire mission
FFE	Initiates an FFE mission
Geom	Advises all elements in the system of the originator's new location
HPFFE	Initiates an HPFFE mission
MTO	Advises the FO of the unit firing, the target number, the munition to be fired, and the number of rounds
Shot	Advises the FO that artillery rounds are on the way
Splash	Advises the FO that impact is imminent (within 5 seconds)

4.2 COMNET III Building Blocks

The COMNET III software package uses a number of building blocks to help build a model. The visible portion of the model is known as the topology. The modeler may run several experiments that use the same topology and only change internal characteristics. In the six models we used (Figure 3), the first two models had the same topology, and the last four shared a different topology. There are numerous tools COMNET III uses to build the topology of the model; the following discussion addresses those used in the AFATDS model.

Two of the basic things seen when viewing a COMNET III topology are nodes. There are two nodes used in our model - computer and communications (C&C) nodes and computer group nodes. Nodes are used to represent end systems. If the topology of the model were thought of as a skeleton, nodes would be the bones. All the players in the AFATDS system are portrayed using nodes. The C&C node represents one entity, such as a FIST or battalion FSO. The computer group nodes represent groups of nodes that all behave the same.

Nodes are more than just “place-holders”. Nodes describe all the physical characteristics of the represented entity. They also have a list of all the capabilities of the entity. Within each node is a repertoire of available commands that the node can execute. These commands range from processing time to acknowledgments. The functionality of the computer group node is identical to that of the C&C node except for the computer group node's ability to represent more than one entity.

The next most noticeable object of the topology is the sources. Sources are the objects that make things happen. Referring back to the skeleton analogy, sources would be comparable to muscle. As mentioned above, nodes contain the commands and how they are to be done. The sources tell the nodes *when* to execute the commands. The AFATDS model makes use of two types of sources - message sources and application sources. Message sources are instigators; they create a message as scheduled by the modeler. There are two ways to cause a message source to function; they can be scheduled by time or by receipt of another message. For example, to simulate an FO generating an FFE mission, the message source that triggers the creation is scheduled by an exponential probability distribution. An FO's Adjust1 message source, however, is triggered by a received message - the receipt of a splash message from the firing platoon. Since message sources can only do one thing, create messages, they are primarily used in the AFATDS model at the FO and FIST levels for generating fire missions.

The application source is useful for executing series of commands. For example, when a FIST node receives an FFE mission from one of the FOs, it must allow some process time, acknowledge receipt of the mission, and forward it to the battalion FSO. Most of the nodes in the AFATDS model have similar series of commands to execute, which accounts for the majority of the sources being application sources.

The last element of topology is the link. As mentioned earlier, we are using the token passing ring to represent the DAPNAD algorithm. The token passing ring is one of the choices for links in COMNET III. It connects all the nodes together. The sources are attached to the nodes, and the nodes are attached to each other by links. Referring to the skeleton analogy one last time, the links would act as the nervous system carrying the impulses to the appropriate places.

The next series of figures attempt to give the reader a brief look at different levels of the topology of the AFATDS model. Figure 5 shows the typical FO to FIST connection. Notice that the message sources are indicated by a piece of paper slanted to the right. The application sources look like a computer diskette. The FO (computer group node) looks like a computer monitor. The C&C node is simply a square box with several horizontal lines. Figure 6 shows the communications link between a battalion FSO and the brigade FSO. Figure 7 shows the FDC setup. Then Figure 8 shows the firing platoon cluster. The reinforcing battalion is not depicted because it is almost identical to the firing platoon node. Finally, Figure 9 attempts to give the reader a birds-eye view of the entire model. This representation is not presented for study, but only to provide a glimpse of the scope of the model.

Figure 5: The FO to FIST Link

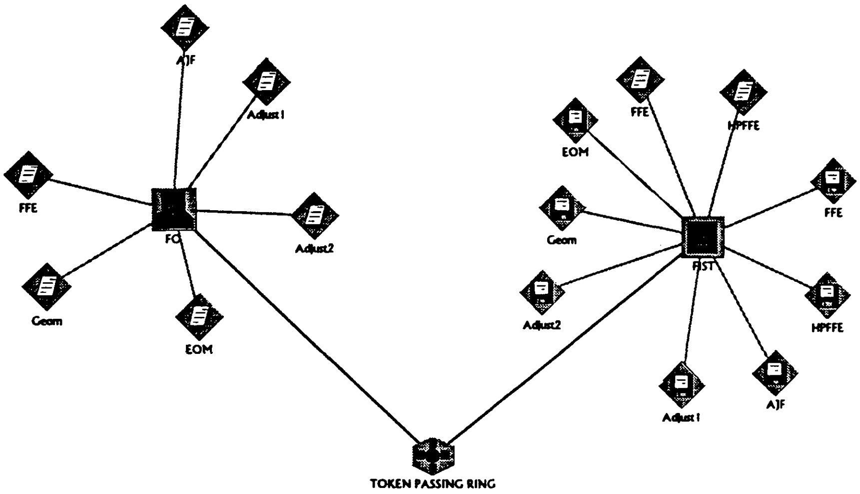


Figure 6: Battalion & Brigade FSO Communications Link

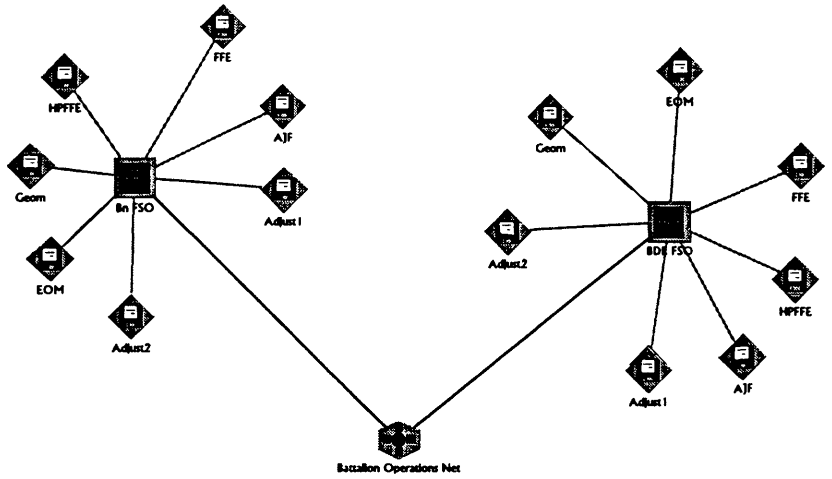


Figure 7: The DS Battalion FDC Node

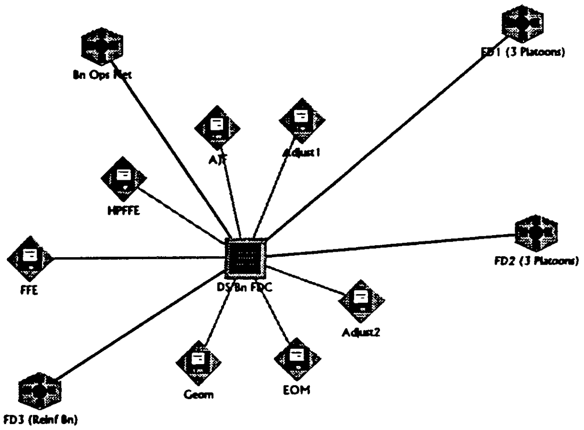


Figure 8: The Firing Platoon Node

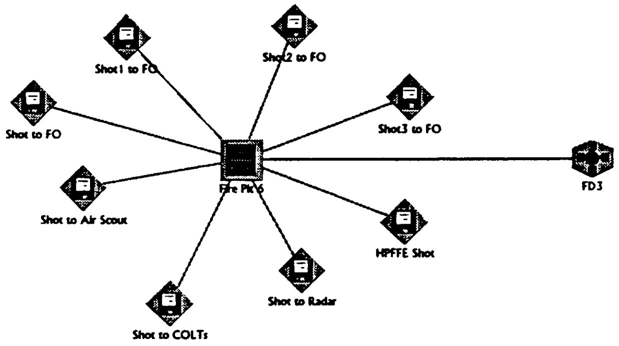
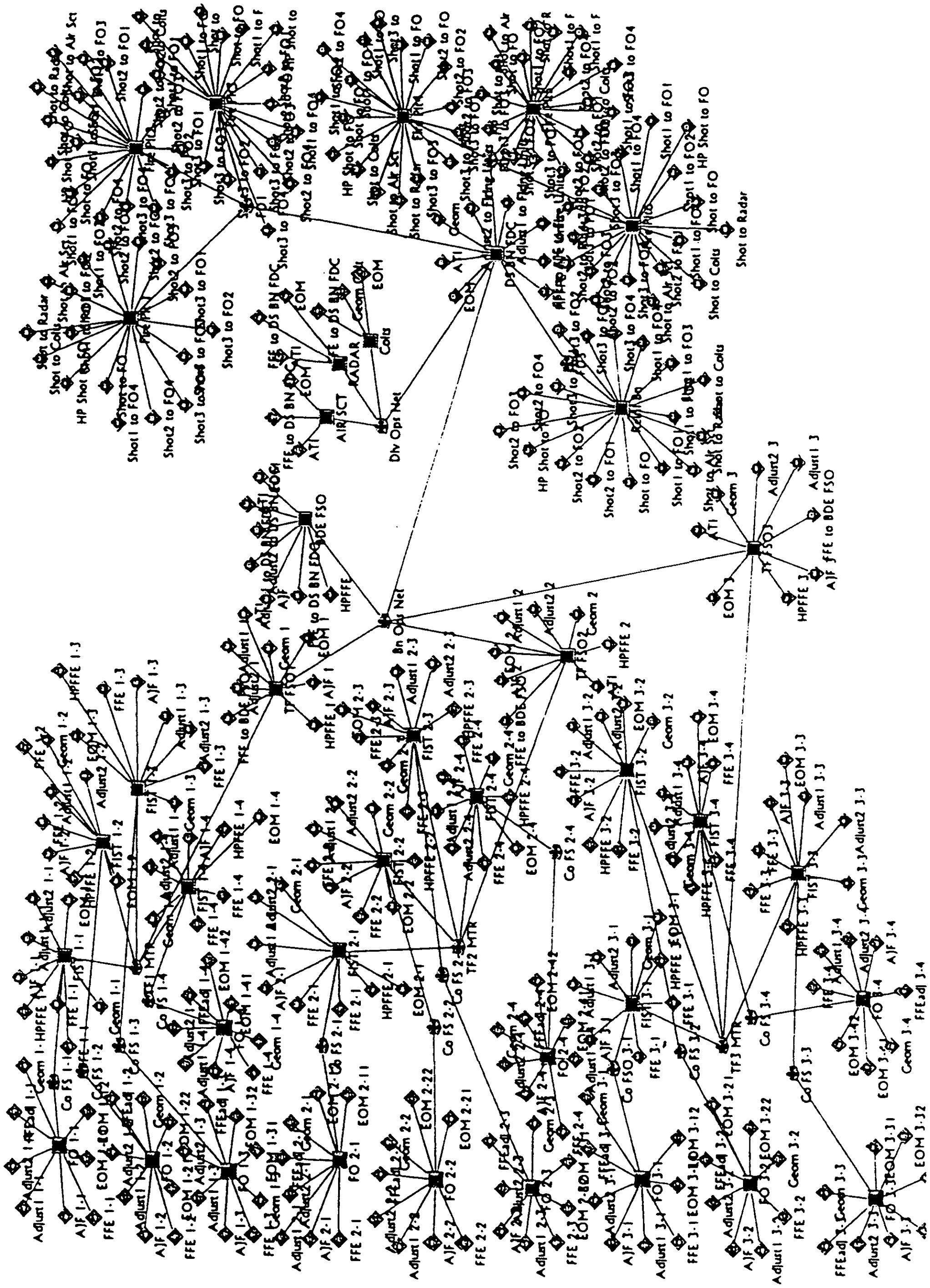


Figure 9: Full Model with Dedicated FO - FIST Nets



4.3 Internal Characteristics

The external topology of the model is only the beginning. Once the model is constructed, all the internal characteristics must be developed. The commands are developed for this purpose. As mentioned previously, the nodes contain a command repertoire that lists all the commands that the node can recognize and perform. Those commands must be described to the software package. The three types of commands used in the AFATDS model are process commands, answer commands, and transport commands.

All commands in COMNET III have an accessible Windows dialogue box. The dialogue box for the process command is the easiest of all. The modeler must provide a name for the command and a length of the process. In the AFATDS model, there are three process commands. The "process time" command is used by entities at all levels. It has, for its length, a uniform probability distribution ranging from 2.5 to 4.5 seconds. This represents the amount of time it takes an AFATDS machine to cycle in reaction to a stimulus such as a received message. The "time of flight" command is used by the firing platoons to determine when to send Splash messages. The time of flight is a uniform probability distribution ranging from 11 to 50 seconds. This range was determined by using tabular firing data for an M109A3 howitzer at its minimum and maximum ranges. The "time on guns" command is also used by the firing platoons to simulate the time it takes a gun crew to prepare a round and fire it. This time is a constant 35 seconds. This is the maximum amount of time allowed the crew by the Army's testing manuals. Since the gun crews are trained to meet or beat this time, and since it is only humanly possible to decrease this time by a very small amount, this parameter was left as a constant.

Answer commands are used by all entities to acknowledge receipt of a message. Unlike process commands, answer commands allow the use of a priority. Priorities will be discussed later in the chapter. The answer commands in the AFATDS models have varying priorities; they are coupled with the parent message. The size of each answer command is 100 bytes.

The rest of the extensive assortment of commands are transport commands. The name transport says it all; these commands act as relays for the commands that are generated by the message and application sources. These commands ensure the proper flow of all messages. The development of the transport command is similar to the answer command, except that the transport command must have a destination. The destination can be a specified entity or a weighted list in which the modeler assigns the probability of a message going to a particular member of the list. The only place the latter capability is used in this model is with the firing platoons. Since there are six firing platoons, each has a probability of one-sixth, or .167, of being chosen to fire a mission by the FDC.

One final very important issue with internal characteristics is message priorities. Referring back to Figure 3, it is quickly obvious that priorities are one of the main differences between the six models used in this project. As mentioned previously, priorities in COMNET III are used in a relative sense. Most of the messages in the AFATDS model are in the 70 to 80 priority range, which corresponds to similar modeling efforts conducted by Magnavox. Since one of the goals of this modeling effort was to reduce the passage time of Shot, Splash, MTO, and EOM messages, these were the priorities with which we experimented. The expressions “original priorities," or “higher priorities” as used in Figure 3, refer to the priorities of these messages and the HPFFE messages. The original priorities were those used by Mattes (Mattes 1995). The higher priority values were arbitrarily chosen by us to attempt to get messages passed faster. The HPFFE mission must by definition remain the most important message in the system. All other messages are secondary to these messages when the model is using higher priorities. Messages in COMNET III can have a priority from 1 to 99. Table 4 contains these messages and both their original priorities and their respective higher priorities.

Table 4: Priorities

	Priorities	
Message	**“Original”**	**“Higher”**
Shot	75	95
Splash	75	95
MTO	75	95
EOM	75	95
HPFFE	90	99

4.4 Running the Model

As mentioned previously, our initial effort was a thorough verification of the previous model. After we verified and corrected the old model, we decided to recreate the experiment of Pete Mattes (1995). We ran the model using a 15 minute warm-up to eliminate the effects of initialization bias. Since the main parameters we are measuring are in hours, the model was run for one hour. The total of 75 minutes counted as one replication. We decided to forgo some of the intermediate steps taken in Mattes's work. He ran the model for five initial iterations, and then computed the number of iterations that should have been run. The final outcome of his calculations was that he should run 15 iterations. We decided not to recreate this part of his work because his process and documentation were sound. Therefore, Model 1 was run for 15 iterations. It was during the compilation of the results of the 15 iterations that we discovered the double and triple counting of missions mentioned in Chapter 1 of this thesis. This discovery led to the development of the remaining five models. All models were subsequently run for 15 iterations. The results are discussed in Chapter 5.

One very important term in simulation is randomness. Painstaking efforts were taken throughout this project to ensure that everything was random. The FFE, HPFFE, and AJF messages are all generated according to an exponential probability distribution. In COMNET III, any time a probability distribution is used, a random number stream is associated with it. The stream is identified by one or two digits ranging from zero to 99.

When all 15 iterations are run at once, there will be no repetition in the output reports. However, if the iterations would have been run one right after another (manually initiated by the modeler), they would have all repeated. We ran the iterations all at once (automatically) to solve this problem. We wanted each model to be completely random and independent of each other. To ensure this, we changed the streams in all 48 places that generated the fire missions before running each model's iterations.

In the output, we quickly noticed that all FOs and FISTs were having similar results in all parameters. Instead of going through the 47 page report for each iteration and trying to average all the numbers, we randomly chose one FO for each iteration. To do this, we assigned equal probabilities to selecting any FO. We then used a random number generator to determine which FO's data would be tallied in each iteration. In this phase we tallied the results of 90 total iterations. An example of how the FOs were chosen for Model 1 can be found in Table 5. The choices were made in the same manner for the other five models.

Now that a certain level of understanding of the fire mission process and of how COMNET III was used to model the process has been established, Chapter 5 will discuss the results and the statistical analyses applied.

Table 5: FO Selection

FO #	Probability	Cumulative Probability	Random Number Assignment
1-1	.083	.083	.001 - .083
1-2	.083	.166	.084 - .166
1-3	.083	.249	.167 - .249
1-4	.083	.332	.250 - .332
2-1	.083	.415	.333 - .415
2-2	.083	.498	.416 - .498
2-3	.083	.581	.499 - .581
2-4	.083	.664	.582 - .664
3-1	.083	.747	.665 - .747
3-2	.083	.830	.748 - .830
3-3	.083	.913	.831 - .913
3-4	.083	1	.914 - .000

Run #	Random Number	FO #
1	.618	2-4
2	.984	3-4
3	.724	3-1
4	.301	1-4
5	.249	1-3
6	.946	3-4
7	.925	3-4
8	.042	1-1
9	.113	1-2
10	.696	3-1
11	.985	3-4
12	.632	2-4
13	.312	1-4
14	.085	1-2
15	.997	3-4

CHAPTER FIVE

OUTPUT ANALYSIS

One of the quickest ways to lose credibility with the project's client is to conduct an incorrect output analysis. Careful attention must be given to correct statistical procedures and the assumptions that accompany them. As mentioned earlier, we are analyzing the steady-state conditions of a nonterminating system.

5.1 Determining the Number of Replications

After we ran all six models and compiled the measurements of our endogenous variables (Table 1), our first concern was whether enough replications had been conducted.

Before we could test for the number of replications, we had to decide the parameter we would use for the analysis. Since the number one concern of this modeling effort has always been throughput, we decided that the number of fire missions processed would be the test parameter for determining the number of runs. This led to another fork in the road. We collected data on the number of fire missions at both brigade and at the battalion FDC. Since our approach throughout this project had been to use the worst case scenario, we decided to stick with that idea. The fire missions processed at the FDC had gone through one additional another link in the chain (the Brigade FSO), so the FDC would potentially have a lower number of processed fire missions. Evaluating the data averages, no significant difference appeared between the number of missions processed at brigade and at the FDC. We were unable to calculate the statistically significant difference between the two means because an important rule of hypothesis testing would have been broken. Two means can only be compared if the samples come from independent, identically distributed populations (Montgomery and Runger 1994). Our means were identically distributed, but they were not independent. The number of missions processed at the FDC is directly related to how many missions are processed at brigade. However, we did calculate the percentage of missions that were processed at brigade and subsequently processed by the FDC. The lowest percentage among the six models was 99.61%. With this result we pursued our testing using the number of missions processed at the FDC.

The first decision necessary prior to estimating the number of replications is the choice of the level of significance. The level of significance, α, is the probability of rejecting the null hypothesis when the null hypothesis is true (Type I error). In other words, this is the chance that the test will make a false rejection. In all tests of output analysis, we used an α of .05.

The other parameter that must be chosen is the degree of error, ε. With this parameter, the modeler is able to indicate how much deviation from the desired result is allowed. The contractual requirement for the number of fire missions processed by brigade in an hour is 720. We chose to use an ε of ± 2%, or ± 14.4 missions.

Since the population standard deviation, σ, is unknown, the t-distribution is used. The sample standard deviation, *S*, is used in place of σ; *S* is computed using the number of missions processed during each iteration, and is computed for all six models. The "t" statistic comes from a t-distribution using $\alpha/2$ and R_0-1 degrees of freedom, which can be found in any basic statistics book. The reason $\alpha/2$ is used is because we have a two-tailed rejection region; that is, the rejection region could lie on either side of 720. The variable R_0 is the number of replications of the model that have already been executed. All these variables are used in the following equation:

$$R \geq \left(\frac{t_{.025,\,R_0-1}S}{\varepsilon}\right)^2 \tag{5.1}$$

The results of the computations using Equation 5.1 can be found in Table 6. Note that

Table 6: Number of Replications

Model #	R_0	S_0	R_1	S_1	R_2
1	15	24.96	13.8	24.19	12.8
2	15	21.35	10.1	20.65	9.3
3	15	27.24	***16.5***	26.94	15.9
4	15	14.37	4.6	13.89	4.2
5	15	23.77	12.5	22.97	11.6
6	15	25.34	14.2	24.54	13.2

all models were run for 15 initial replications (R_0). The second column contains the S_0 for the initial set of runs. The results of the initial computations using Equation 5.1 are in the fourth column (R_1). Note that model 3 exceeded 15 runs. It was decided to run the model for only one more iteration because (1) there is a great deal of time involved in running the model and compiling output, and (2) the value of the t-statistic would decrease thereby helping to decrease the value for R. To ensure that the results were random and independent of previous runs, all random number streams were changed as explained in Chapter 4. Statistical analyses are easier to understand and explain when dealing with equal sample sizes. For this reason, the random number streams were changed in all the models, and one more run of each was conducted. Therefore, the S_1 column in Table 6 is based on 16 runs per model. Equation 5.1 was used again, yielding the results in column 6 (R_2) where all R values were less than 16.

5.2 Initial Results

Now that the number of replications is carefully decided, we begin to look at the data. Table 7 contains comparisons of the 6 models in terms of our established endogenous variables. The entries in each cell of the top table are the averages for all 16 iterations of the respective model for the given parameter; **bold** type indicates which model was best for each parameter. In the bottom table, each cell contains the percentage improvement, or performance decrease, for each parameter and model. The percentages in **bold** indicate

Table 7: Model Results

Model #	#Msns processed by FDC	Total Messages Processed	FFE (sec)	HPFFE (sec)	% Utiliz Ops Net	Shot (sec)	Splash (sec)	MTO (sec)	EOM (sec)	% AJFs adjusted
1	659.1	2036.3	90.3	95.4	69.8	950.6	957.4	937.4	140.5	56.7
2	669.2	2139.6	233.9	99.3	70.5	637.5	627.9	638.1	119.7	61.8
3	657.5	1980.8	58.8	66.0	69.6	951.2	951.1	966.3	178.6	53.5
4	667.2	2135.9	231.2	68.0	70.5	661.2	664.0	649.2	73.0	59.1
5	**683.6**	**2467.8**	66.1	46.9	57.4	**177.2**	**176.5**	**175.4**	**57.9**	**72.7**
6	682.6	2282.9	**52.7**	**45.4**	**55.0**	263.6	267.5	266.5	62.5	62.5

1 2 3 4 5 6 7 8 9 10

Model #	#Msns processed by FDC	Total Messages Processed	FFE (sec)	HPFFE (sec)	% Utiliz Opns Net	Shot (sec)	Splash (sec)	MTO (sec)	EOM (sec)	% AJFs adjusted
1	659.1	2036.3	90.3	95.4	69.8	950.6	957.4	937.4	140.5	56.7
2	**+1.5%**	**+5.1%**	+159%	+4.1%	+1%	**-32.9%**	**-34.4%**	**-31.9%**	**-14.8%**	**+9%**
3	-.24%	-2.7%	**-34.8%**	**-30.8%**	**-.26%**	+.06%	**-.66%**	+3.1%	+27.1%	-5.6%
4	**+1.2%**	**+4.9%**	+156%	**-28.8%**	+1%	**-30.4%**	**-30.6%**	**-30.8%**	**-48.1%**	**+4.2%**
5	**+3.7%**	**+21.2%**	**-26.7%**	**-50.8%**	**-17.8%**	**-81.4%**	**-81.6%**	**-81.3%**	**-58.8%**	**+28.2%**
6	**+3.6%**	**+12.1%**	**-41.6%**	**-52.4%**	**-21.2%**	**-72.5%**	**-72.1%**	**-71.6%**	**-55.5%**	**+10.2%**

an improvement. The bottom table indicates that nine times out of ten the parameters improved. However, the top table clearly indicates that every parameter is most improved by either model 5 or model 6; and seven out of ten parameters favor model 5.

5.3 Equality of Means

The previous discussion provided a good initial evaluation of the models. We were able to determine if improvements were made across the models, and which models made the most improvements. None of the previous observations, however, is statistically sound. Statistical tests must be run to determine whether model improvements are significant. In the rest of the chapter, we will provide statistical answers to three questions:

(1) For each measured parameter, are the means of the six models equal?

(2) If the answer to question (1) is no, which models are significantly different?

(3) Which changes, or interaction of changes, made to the model significantly effected the results?

Since we are comparing multiple model designs, simple hypothesis testing for the equality of six averages (means) is not feasible. Besides, testing every pairwise comparison would result in six combinations of two, or 15 hypothesis tests. A line of testing designed for this situation is analysis of variance (ANOVA).

The first ANOVA tests we considered are single-factor ANOVA tests on each of the parameters. Single-factor indicates how many treatments we are considering. Initially, we are only concerned with the effect of changing the model on the parameters, so we have six treatments. For each parameter, we are concerned with the following hypothesis test:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$$

$$H_a: \mu_i \neq \mu_j \text{ [for at least one pair (i,j)]} \tag{5.2}$$

In other words, are all the average parameter measurements equal, or is at least one statistically different from the others?

The ANOVA process is based on a model:

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \tag{5.3}$$

This model says that every observation (y_{ij}) consists of three components - the mean of the entire set of data (μ or grand mean) plus the effect of the different treatments (τ_i) and the effect of error (ε_{ij}). The treatment effects must be evaluated as random or fixed. Random effects are those that are randomly chosen from a larger set of possible treatments. The AFATDS data would be evaluated as fixed effects because we developed the different models with very specific differences in mind.

The primary evaluation tool for ANOVA testing is the F statistic. One of the products of an ANOVA analysis is the ANOVA table. The F statistic is computed using elements of the ANOVA table:

$$F_0 = \frac{MS_{\text{Treatments}}}{MS_E} \tag{5.4}$$

The MS in both numerator and denominator stands for mean squares. These terms are derived from the sums of squares. Analysis of variance is a partitioning of total variability into its component parts (Montgomery 1991). The total sums of squares can be broken into two component parts - the sum of squares for treatments and the sum of squares for error.

$$\sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij}-\bar{y}_{..})^2 = n\sum_{i=1}^{a}(y_{i.}-\bar{y}_{..})^2 + \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij}-\bar{y}_{i.})^2 \tag{5.5}$$

In Equation 5.5, a is the number of treatments (in our case six). The letter n is size of the sample corresponding to a. The expressions $\bar{y}_{i.}$ and $\bar{y}_{..}$ refer to the treatment mean and the grand mean respectively. The first term after the equality is the formula for the sum of squares for treatment, and the second term is the sum of squares for error. Each term divided by its corresponding degrees of freedom gives the mean square for each term.

The degrees of freedom for treatments is the number of treatments minus one (in our case 5). The degrees of freedom for error is the total sample size across all treatments minus the number of treatments (in our case 90). Finally, substitution into Equation 5.4 yields the test statistic F_0.

A spin-off of F_0 is the p-value. The p-value "is the smallest level of significance that would lead to rejection of the null hypothesis H_0" (Montgomery and Runger 1994). Simply stated, if the p-value of the test is less than the chosen α, then the null hypothesis is rejected. The advantage of the p-value is that a change in α does not require a recomputation of the p-value, so the p-value can be used to test the hypothesis at a given α or to determine what level of α would render a rejection.

With ANOVA there are assumptions. First of all, the data must fit the data in Equation 5.3. The error terms (ε_{ij}) are normally distributed and have equal variance. The software package Minitab (version 10) can perform all the tasks just described. The operator simply enters all the data in one column, and the subscript that indicates the treatment for that point in another column. Minitab will provide an ANOVA table, and, upon request, graphs and tests that can be used to verify the error term assumptions.

If instructed, Minitab will compute and store the error terms while computing the ANOVA table. The errors can subsequently be plotted on a normal probability graph to determine normality. If the errors are normally distributed, then the plots are in a straight line. Minitab can also run Bartlett's Test to determine the equality of variance. Bartlett's Test will yield a p-value to be used for determination of rejection of the null hypothesis. The hypothesis test for equality of variance is:

$$H_0: \sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2 = \sigma_5^2 = \sigma_6^2$$

$$H_a: \sigma_i^2 \neq \sigma_j^2 \text{ [for at least one pair (i,j)]} \qquad (5.6)$$

The following figures provide sample output from Minitab that was used in the analysis of the AFATDS model. The first parameter tested was the number of fire missions processed by the FDC. Figure 10 shows the ANOVA table and the normal probability plot. Figure 11 contains the sample output from the Bartlett's test. From Figure 10, one can see that the p-value in the ANOVA table is .003, which indicates that at least one of the fire mission means is different from the others. The p-value on the normal probability plot is .223, which indicates that the error terms are normally distributed. Finally, in Figure 11, the p-value for Bartlett's Test is .240, which indicates that the background variances are equal (a condition called homoscedasticity) (Neter et al. 1990).

The rest of the parameters were evaluated with Minitab. All parameters had p-values less than our α value of .05, so all parameters had at least one mean that was different from the others. There was a problem with the normality and homoscedasticity assumptions. The only two models that met all the model assumptions were the number of fire missions processed, and the percentage of AJFs that received at least one adjustment. Bartlett's Test, however, is known to be very sensitive to the normality assumption (Montgomery 1991), so the two tests could be swayed by this fact. Due to the fact that we had a large sample size for each parameter, and the fact that the normality tests and homoscedasticity tests could be interfering with each other, we decided to proceed with our testing. All test results, however, should be looked at carefully for reasonability since the test assumptions weren't explicitly met.

Figure 10: ANOVA Table and Normal Probability Plot (provided by Minitab)

```
     One-Way Analysis of Variance

Analysis of Variance on no. msns
Source       DF         SS          MS          F        p
model         5      10048        2010       3.94    0.003
Error        90      45894         510
Total        95      55942
                                         Individual 95% CIs For Mean
                                         Based on Pooled StDev
 Level        N       Mean       StDev   ---------+---------+---------+------
     1       16     659.13       24.19     (------*-------)
     2       16     669.19       20.65           (------*-------)
     3       16     657.50       26.94    (------*-------)
     4       16     667.19       13.89          (-------*------)
     5       16     683.62       22.97                   (-------*------)
     6       16     682.63       24.54                   (------*-------)
                                         ---------+---------+---------+------
Pooled StDev =        22.58                     660       675       690
```

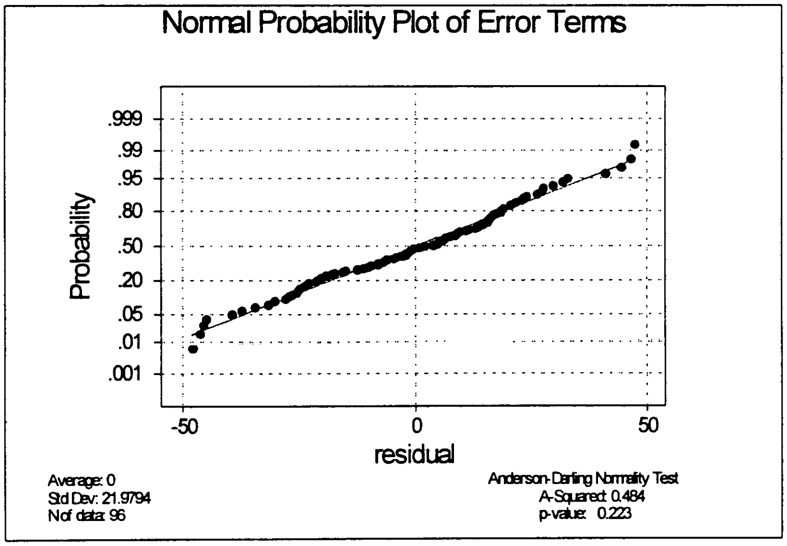
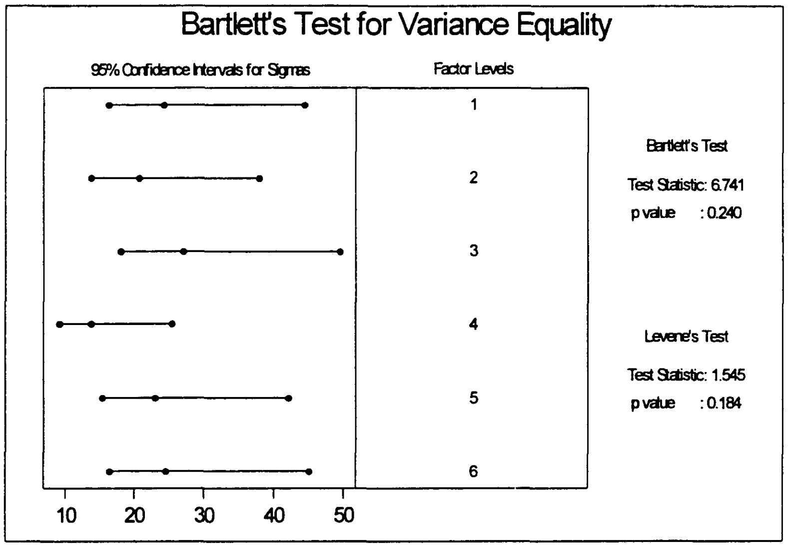


Figure 11: Bartlett's Test (provided by Minitab)



5.4 Differences in Means

Since we established in the previous section that there is statistical evidence that at least one of the means in each parameter is different from the others, the next step was to determine which of the means were different. We chose Fisher's Test for pairwise comparisons. Fisher's Test was chosen because our tests for equality of means were all significant at $\alpha = .05$. Under these conditions, Fisher's Test, which is a modification of the least significant difference (LSD) method, is a powerful test (Montgomery 1991). The LSD method incorporates the following equation and relationship:

$$LSD = t_{\alpha/2,\, N-a} \sqrt{\frac{2\, MS_E}{n}} \tag{5.7}$$

and

$$|\bar{y}_{i\cdot} - \bar{y}_{j\cdot}| > LSD \tag{5.8}$$

The relationship (Equation 5.8) compares the difference in the means of two different treatments (models) to the calculated value for *LSD*. Fisher's Test in Minitab makes this comparison for every pair of means in the study. An example of the Minitab output for Fisher's Test can be found in Figure 12. Note the triangular matrix. Minitab summarizes the output with a series of confidence intervals corresponding to each pairwise comparison of the six models. If the number zero does not fall in the interval, then the model numbers corresponding to the column number and row number for that interval are

Figure 12: Fisher's Test (provided by Minitab)

```
Fisher's pairwise comparisons

    Family error rate = 0.0497
Individual error rate = 0.00450

Critical value = 2.914

Intervals for (column level mean) - (row level mean)

                1         2         3         4         5

     2     -33.33
            13.20

     3     -21.64    -11.58
            24.89     34.95

     4     -31.33    -21.26    -32.95
            15.20     25.26     13.58

     5     -47.76    -37.70    -49.39    -39.70
            -1.24      8.83     -2.86      6.83

     6     -46.76    -36.70    -48.39    -38.70    -22.26
            -0.24      9.83     -1.86      7.83     24.26
```

significantly different. In this example, models 1 and 3 are both significantly different from models 5 and 6. Note, however, that models 5 and 6 are not different from each other. Referring back to Table 7, these results seem reasonable. These are the types of conclusions we drew from the Fisher's Test output for all the parameters.

Table 8 contains the results of all the Fisher's Tests. As mentioned previously, the raw data indicates that in every parameter, the most improvement was seen with either model 5 or model 6. Since a table that included all results would have 150 comparisons, a simpler table was developed. The first two columns of numbers include those of models 1 through 4 for which model 5 or 6 was significantly different. The third column indicates any significant difference between 5 and 6. The fifth column indicates, statistically speaking, which model was best. If no model is specified, it is because 5 and 6 were not better than all other models. For example, in the first row, model 5 was better than 1 and 3; model 6 was better than 1 and 3; models 5 and 6 were not significantly different, so no conclusion can be drawn for which model is best. The second row, however, allows a conclusion to be drawn that model 5 is the best statistically for that parameter. The last column of Table 8 compares the results of looking at the raw data against the results of the formal statistical testing. The results are very similar!

5.5 Effects of Model Changes

Now that the differences in the measures of the model parameters have been evaluated

Table 8: Results of Fisher's Testing (computed with Minitab)

	Comparisons				
Parameter	**"5" differences**	**"6" differences**	**"5" vs. "6" different?**	**Best Statistically**	**Best with Raw Data**
# Missions	1,3	1,3	No	Inconclusive	5
Total Messages	1,2,3,4	1,2,3,4	Yes	5	5
FFE (sec)	2,4	2,4	No	Inconclusive	6
HPFFE (sec)	1,2,3,4	1,2,3,4	No	5 or 6	6
% Util Ops Net	1,2,3,4	1,2,3,4	Yes	6	6
Shot (sec)	1,2,3,4	1,2,3,4	Yes	5	5
Splash (sec)	1,2,3,4	1,2,3,4	Yes	5	5
MTO (sec)	1,2,3,4	1,2,3,4	Yes	5	5
EOM (sec)	1,3	1,3	No	Inconclusive	5
% AJFs Adjusted	1,2,3,4	1,3	Yes	5	5

statistically, the final step is to measure the effect each of the changes had on the model. Three changes were made either one or two at a time in each model (See Figure 3). The priorities were set to either the original or the higher ones. The bandwidths were set to either 9600 bps or 16000 bps. The FOs either had dedicated nets with their FISTs, or they didn't. Normally this analysis would be conducted using 2^k factorial model design. Factorial designs are used in cases when the effects of the individual factors, or their interactions, need to be determined. The model must have k factors with two levels each. In the case of this analysis, there are three factors (k=3) that have two levels each. This type of design is known as a 2^3 factorial design (Montgomery 1991). We were unable to do the full design, however, because this design requires eight models, and our study only has six. The factorial design will continue to be explained because our alternative to answering the question stems from the discussion.

We assigned each factor a letter. Factor A is the change of priorities, factor B refers to the bandwidth, and factor C ascertains the existence of dedicated FO to FIST nets. The priorities receive a 1 for original or a 2 for higher; the bandwidths receive a 1 for 9600 bps or a 2 for 16000 bps; and the FO nets receive a 1 if they exist or a 2 if they don't. Table 9 contains the layout of the design. The treatment combinations are listed in "standard order" (Montgomery 1991). For every combination of three digits, the corresponding treatment combination contains the factor letters that have a value of 2. For example, if factor A is 1, factor B is 2, and factor 3 is 1, then the treatment combination is b. The rest of the combinations are in Table 9.

Table 9: 2^3 Factorial Design

Treatment Combination	Level of Factor A (Priorities)	Level of Factor B (Bandwidths)	Level of Factor C (FO Nets)	Corresponding Model
(1)	1	1	1	Model 3
a	2	1	1	Model 4
b	1	2	1	Model 6
ab	2	2	1	Model 5
c	1	1	2	Model 1
ac	2	1	2	Model 2
bc	1	2	2	N/A
abc	2	2	2	N/A

As seen in the table, the last two combinations do not have a corresponding model. Since this is an incomplete design, we used the general linear model (GLM) to finish the analysis. The GLM is a tool used within Minitab to derive ANOVA tables for incomplete or unbalanced data. The GLM uses regression tools to fit the model specified by the user (Minitab Help 1995). Since the "bc" and "abc" interactions were missing from our study, we ran the GLM on the full model minus these two interactions. The output generated by Minitab is an ANOVA table similar to the one shown in Figure 10. The factors are listed both singly and as interactions as indicated in Table 9.

Care must be taken in the interpretation of the results in the ANOVA table. The p-values are compared to our α value of .05. Just because a single factor has a p-value less than α does not mean that it alone had a significant effect on the model. That factor also will appear as part of an interaction term. If the interaction term(s) containing that single factor also has a p-value less than α, then the single factor cannot be singled out as a significantly contributing factor. However, if the interaction term is not significant, then conclusions can be drawn on the single factor. We ran the GLM on each of our measured parameters, and received the results shown in Table 10.

From Table 10, it is obvious that factors of A and B, singly or interactively, affected most of the parameters. Therefore, it appears that simply increasing the bandwidth of the system will not have as much effect on the parameters of the model as will an additional changing of the priorities. The converse is also true.

This analysis has answered all the questions posed earlier in the chapter; more general conclusions can be found in Chapter 6.

Table 10: Results of GLM on Model Factors (computed with Minitab)

Parameter	Statistically Significant Factors
# Missions	B
Total Messages	A and B
FFE (sec)	AB Interaction
HPFFE (sec)	B and C
% Util Ops Net	AB Interaction
Shot (sec)	A and B
Splash (sec)	A and B
MTO (sec)	A and B
EOM (sec)	AB Interaction; C
% AJFs Adjusted	AB Interaction; C

Legend

Factor	Meaning
A	Priorities (Low or High)
B	Bandwidth (9600 or 16000 bps)
C	FO Nets (Present or not)

CHAPTER SIX

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Conclusions

The changes made to the model have enabled it to more closely mimic reality. As seen in Major Hughes's memorandum (Appendix B), the results were as expected based on the performance of version 1. The statistical analyses confirm that the changes made to the model (Figure 3) created significant improvements in its operation.

In Chapter 1, three AFATDS evaluation criteria were established: (1) the number of fire missions processed by the direct support (DS) artillery battalion FDC, (2) the speed with which fire for effect missions were passed on to firing units, and (3) the utilization rate of the DS artillery battalion's operations net. All three of these criteria were evaluated as part of our ten endogenous variables (Table 1). Table 11 contains the final results of these criteria, as well as of the other seven variables in Table 1. The results are in the form of 95% confidence intervals. The intervals were developed using the t-distribution since the population standard deviation is unknown. Furthermore, each interval was developed using the mean and standard deviation of the model that had the best performance for the given parameter. Due to the fact that our point estimates are based on averages, the use of intervals is more appropriate. The intervals give the client a

Table 11: 95% Confidence Intervals

Parameter	Interval	Model Used
# Missions Processed by FDC	(671.4, 695.8)	5
Total Messages Processed	(2401.4, 2534.2)	5
FFE (sec)	(51.5, 53.9)	6
HPFFE (sec)	(42.2, 48.6)	6
% Utilization Ops Net	(54.6, 55.4)	6
Shot (sec)	(115.1, 239.3)	5
Splash (sec)	(116.9, 236.1)	5
MTO (sec)	(116.1, 234.7)	5
EOM (sec)	(55.5, 60.3)	5
% AJFs Adjusted	(70.7, 74.7)	5

feel for how much fluctuation exists in the data. A wider interval indicates a lot of deviation (see Shot in Table 11 for example). A narrower interval indicates that the point estimate (Table 7) was probably pretty good.

Evaluating the three criteria described above, AFATDS, as modeled here, is not presently meeting its contractual requirement of processing 720 fire missions per hour. The other two criteria were satisfied at an even better level than in the previous study.

In Chapter 5, we established that, for each measured parameter, the different model means were significantly different. We also established the fact that both the changes in priorities and the changes in bandwidth had significant effects on the model (Table 10).

Finally, Figures 13a-d provide a graphical portrayal of the improvements made in each of our ten endogenous variables. Each graph compares the output of Model 1 to whichever model had the best improvement (Models 5 or 6). These bar-charts make visualizing the improvements easier.

Figure 13a: Comparison of Model 1 to Best Model (by parameter)

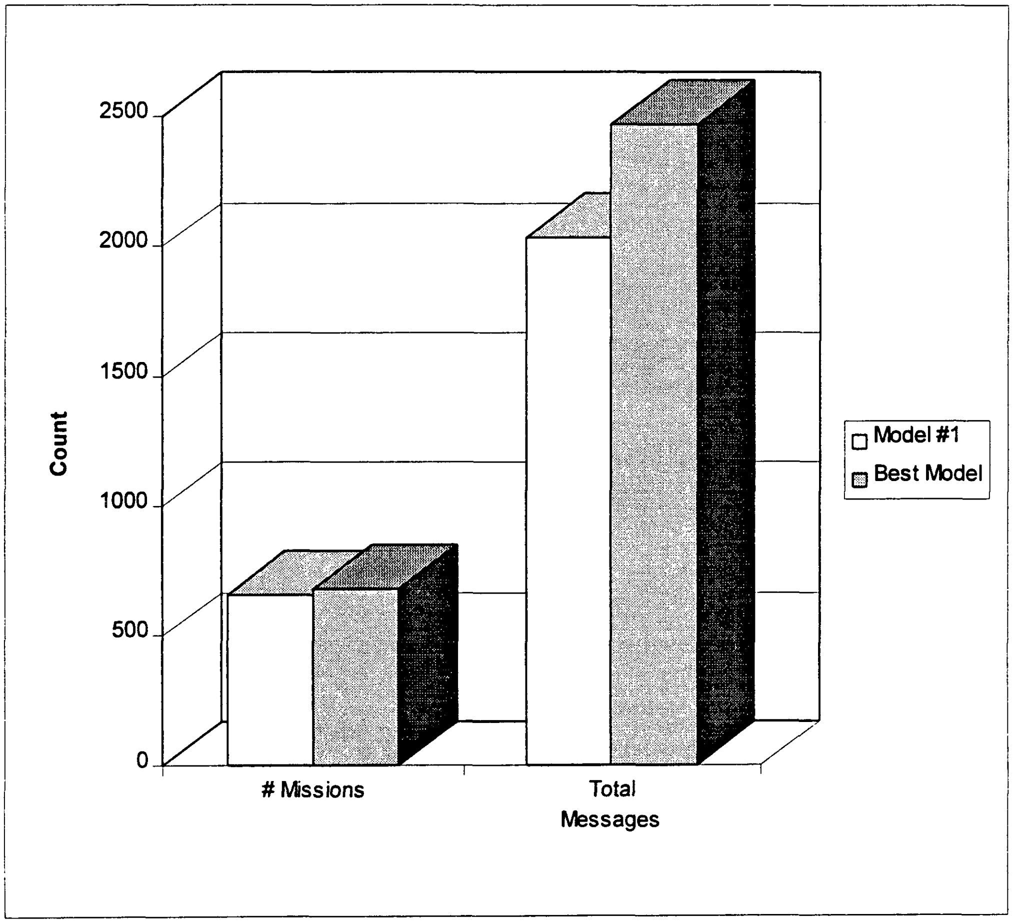


Figure 13b: Comparison of Model 1 to Best Model
(by parameter)

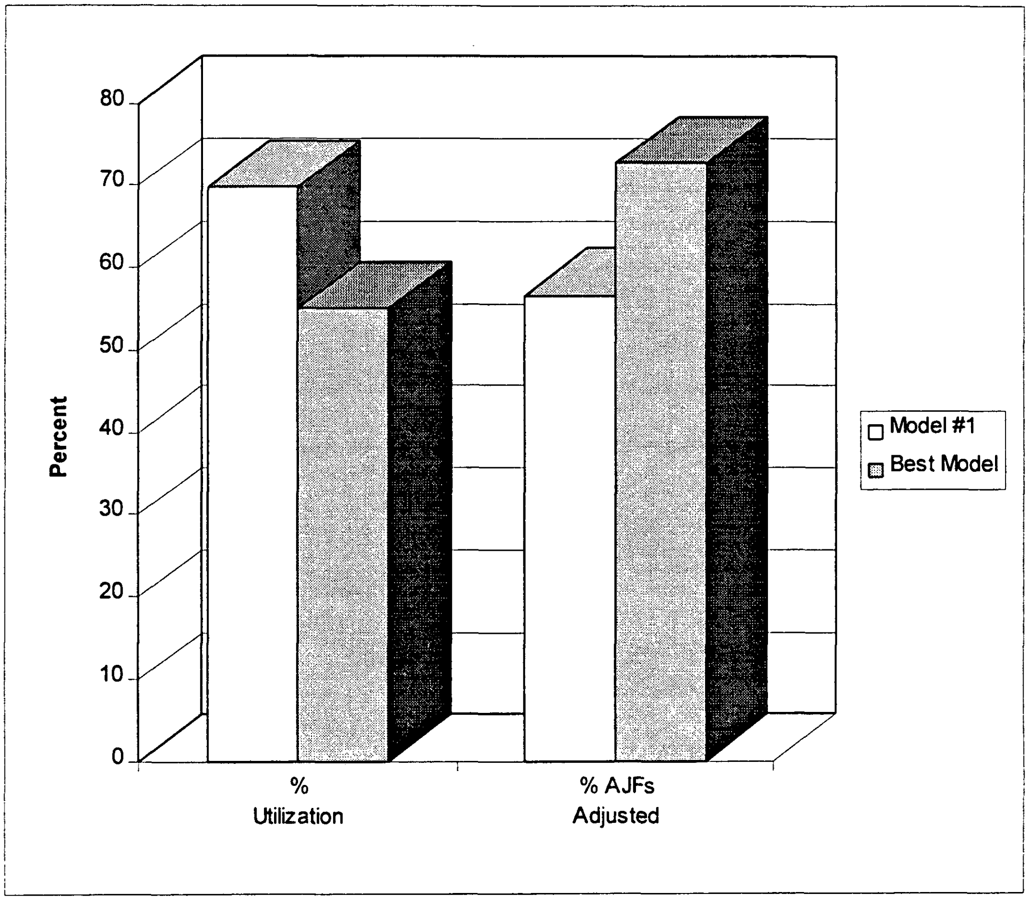


Figure 13c: Comparison of Model 1 to Best Model (by parameter)

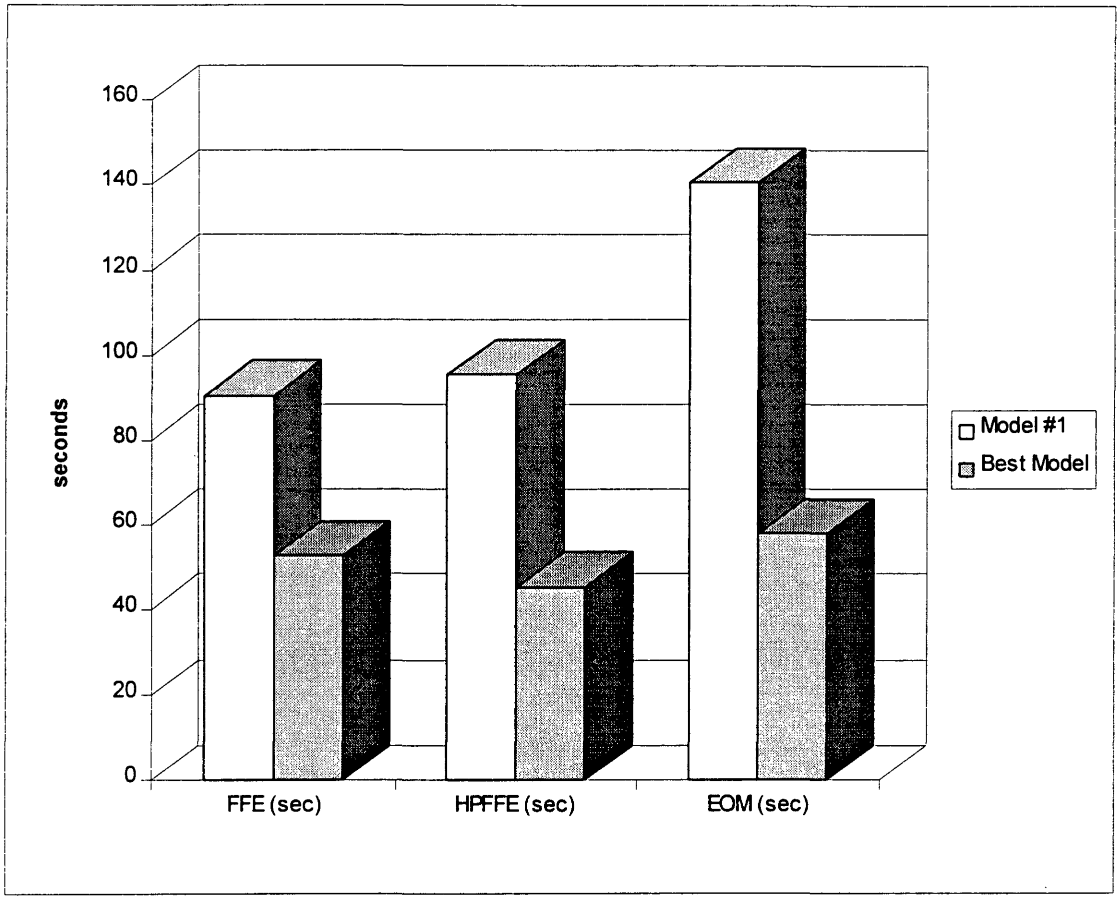
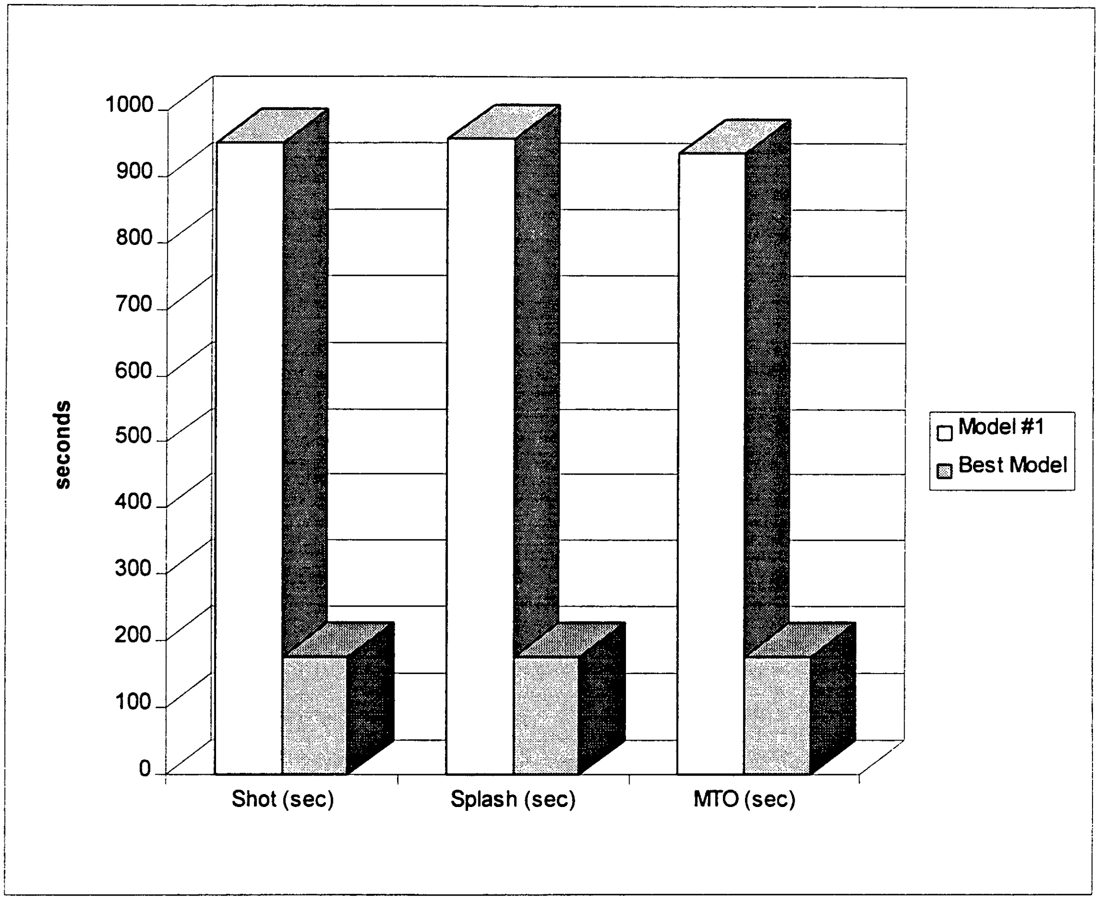


Figure 13d: Comparison of Model 1 to Best Model (by parameter)



6.2 Areas for Future Research

There are a number of areas for future research. One input to the model that was not formally tested was increasing the frequency with which the FOs and FISTs generate fire missions. If the inputs could come faster, what would the impact be on the system? As mentioned in Chapter 1, one of our concerns was that FOs were being hindered by the slow adjust fire missions. We created a seventh model, derived from model 6, in which we shut down the entire adjust fire process. Then we changed the frequency of generation of FFE and HPFFE missions. FOs create FFE missions every two minutes; FISTs generate FFE missions every three minutes and HPFFE missions every four minutes. We changed all the random number streams and ran only one iteration. Previously, the highest average number of fire missions processed by the FDC was 683. With this new model, the FDC processed 1,461 fire missions! There was a trade-off, however. The Shot, Splash, and MTO messages that had so greatly improved now took an average of over 25 minutes each to reach their destination. An unexpected result was that the FFE time only increased approximately ten seconds, and the HPFFE time increased approximately seven seconds. These data alone should not be used as the basis for further improvements to the model. This was only one iteration. More iterations should be conducted to get more robust, statistically sound results. Perhaps a future modeler can determine a mission generation threshold that, once surpassed, might lead to degraded performance of AFATDS.

The COMNET III software package has the ability to make C&C nodes "fail" occasionally. The modeler can establish failure criteria based on a constant or probabilistic time schedule. Some benefit could be achieved by knowing how certain nodes failing in the battlefield would impact on the system. This modification would serve to relax the assumption of perfect communications (Table 2). This procedure could also be used on the firing platoons to allow them to move. Not all the platoons will be in position and ready to fire at all times.

Another modification similar to the one mentioned above would be to develop an alternative routing of messages for FOs if their respective FIST fails. If the FO is not on a dedicated net, as in models 1 and 2, then the battalion FSO should be able to receive the FO's request for fire support. When the FOs are on dedicated nets, there isn't a work-around in the present model. In real life, the FO would probably change frequencies to get the message passed. Perhaps a more sophisticated means of backup could be determined.

Another area for research is to make the changes necessary to create two more models to fill out the factorial design discussed in section 5.5. One model would have to have the original priorities, 16000 bps, and no dedicated FO nets. The second model would have the higher priorities, 16000 bps bandwidth, and no dedicated FO nets. The use of a full 2^3 factorial model would give more statistically sound results on the impact of factor effects.

All these ideas are based on continued use of COMNET III. Since COMNET III presently does not allow user designed communications protocols, perhaps a software that does allow this kind of change could be used for future work. The modeler would have to have a very good understanding of communications protocol and layering. We learned this first-hand during our visit to Magnavox headquarters.

A final important suggestion for future improvement to the model is improved validation. The Army conducted a series of tests on AFATDS Version 1 during the Summer of 1995. These test data were unavailable to us at the time of this study. A future modeler could pursue retrieving these data through Major Hughes (see Appendix B for contact information). These data would provide a more acceptable means of validating the model. Another interesting comparison would be the times for FFE and HPFFE from this model versus these same times during Operation Desert Storm. This comparison could strengthen the justification for developing AFATDS.

6.3 Epilogue

The AFATDS system is a good system that will help carry the Army into the Twenty First Century. From our analysis, however, it appears that improvement is not only possible, but needed to meet the criteria specified for the system. There also appears to be a threshold of change that, if crossed, could improve some areas of the system while simultaneously worsening other areas. With human reluctance to change, the main challenge for the AFATDS developers will be acceptance by the users. If the system is to truly succeed, it must be trusted and used properly.

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APPENDIX A

AN OVERVIEW OF THE ARMY'S APPROACH TO 21st CENTURY WARFARE

by

Captain David K. Grimm

A.1 Background

The Advanced Field Artillery Tactical Data System is merely one small link in the Army's progressive "technology chain" as it enters into the dawn of a new century. Developing a concept for warfare in the 21st century is a daunting prospect, but one that is nevertheless being met head-on by the Army. Having enjoyed a smashing military success in the Gulf War on both an operational and technological level, those at the highest echelons of leadership in the Army are pushing the envelope in their quest for a more projectable and audacious combat force. While the Army has been no stranger to technological advancement in the past,[4] today's revolution of progress with respect to information systems and technology is unparalleled in the course of human history.

A.2 A Military Revolution

In the post-Vietnam Cold War era of the mid-70's to late 80's, the Army primarily prepared itself for warfare by matching weapons systems and tactics with the Soviet threat. In fact, the military literature and doctrine spawned in this era simply referred to the USSR's military as "The Threat." This approach is now obsolete as the US's next foe on the battlefield is an unknown commodity. This lack of knowledge about the enemy and the Army's own firepower capabilities against it has stimulated an all out

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[4] A comprehensive analysis of technological change in warfare is the major facet of Lt. Col. Richard Dunn's Dissertation work, "From Gettysburg To The Gulf and Beyond: Coping With Revolutionary Change In Land Warfare," National Defense University Archives, Ft. McNair, Md. July 17, 1991.

effort to develop advanced warfighting technologies that go hand-in-glove with operational tactics to defeat any threat on any battlefield (Kiernan 1994).

The Army's awareness of its direction and needs can be seen as the beginnings of a new military revolution. Defined as "... what occurs when the application of new technologies into a significant number of military systems combines with innovative operational concepts and organizational adaptation in a way that fundamentally alters the character and conduct of conflict..." (Krepinevich 1994), this new military revolution differs from "evolution" due to the Army's perception of a need for dynamic change. Specifically, the Army recognizes that "... the character of conflict has changed dramatically, requiring equally dramatic - if not radical - changes in military doctrine and organizations." (Krepinevich, 1994) What further sets apart the current revolution is the goal it has spawned within the American defense community. Admiral William Owens, Vice-Chairman of the Joint Chiefs of Staff, sees the goal of the military revolution as providing dominance of the information battlespace - a volume hundreds of kilometers wide and 10 trillion wavelengths deep (Unknown Author, The Economist, 1995).

A.3 Digital Technology: The Combat Multiplier of the Future

As the landscape of modern warfare changes, the Army[5] has focused its modernization efforts on five objectives: win the information war; conduct precision strikes; project and sustain combat power; dominate maneuvers; and protect the force. (Force XXI Pamphlet, 1995) Supporting these objectives is the introduction of digital technology into the Army's existing and projected combat systems. Key to the implementation of digital technology is that it be "holistic" or distributed on a peer to peer basis, allowing "situational awareness" to permeate all echelons of the force across the entire battlefield (Bernstein 1995). Situational awareness, as facilitated by new digital systems, involves the dissemination of complete updated information on all aspects of the battlefield environment to all elements of a fighting force. As Retired Army General Gordon R. Sullivan, former Chief of Staff of the U.S. Army states, ".. operational and tactical forces will know where their enemies are and are not ... enemy and friendly information will be distributed among all forces - land, sea, air, and space - to create a common perception of the battlefield among the commanders and staffs of information age armies." (Sullivan and Dubik 1994) Increased situational awareness is not the only improvement to battlefield operating systems brought on by digitization enhancements. A second, extremely critical aspect is the synchronization of unit movements throughout

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[5] This essay limits its discussion to the Army. This limitation should not be taken to mean that the overall argument of the paper does not equally apply to the Navy and Air Force - it does. Applying the argument to these services, however, lies beyond the scope of this paper.

the battle zone. This synchronization, known as "enhanced battle command," enables commanders to pass on orders and instructions to subordinate units by digitally sent and enhanced visual and graphical computer displays. The ultimate effect of digitization will be the reduced impact of the "fog of war" on strategic and tactical decisionmakers. Since information will be received in real time with commanders actually seeing (as opposed to hearing) the situation at hand, quick response decisions can be made and transmitted almost instantaneously. This responsiveness translates to a more effective allocation of combat power at the critical junctures of battle, thereby enabling a swift defeat of the enemy and increased protection to the friendly forces committed. As the Army's Enterprise Strategy Mission Document, The Vision, states, "Commanders will be able to see what the enemy is doing almost instantaneously and decide on the best use of whatever forces they have." (The Vision, 1993)

A.4 Force XXI: The Army's Digital Future Design

The Army of the 21st century has been not inauspiciously titled Force XXI. As General Sullivan describes, " Force XXI is the reconceptualization and redesign of the force at all echelons, from the foxhole to the industrial base, to meet the needs of a volatile and ever changing world." (Force XXI Pamphlet, 1995) The goal is a fighting force that is totally (digitally) integrated and versatile to react immediately to the changing conditions of the battlefield environment.

The plan of attack for outfitting and preparing Force XXI centers on three base architectures. The objective of these architectures is to facilitate total interoperability across systems (and forces) and give contractors a baseline for developing products that can be integrated into seamless information systems. These architectures and their functions are:

Technical (Information Architectures): The laws governing arrangement, interaction, and interdependence of elements forming information systems.

Operational Architecture: The Army's Training and Doctrine Command (TRADOC) plan for interconnecting diverse units and the types and volume of digital communications to be sent and received.

System Architecture: The actual technical connections of an information system, to include nodes, locations, and circuit bandwidth requirement. (Bernstein, 1995)

A.5 Digitizing the Force: Four Thrusts

Revamping and reshaping the Army on a digital level requires a plan of "attack" that both creates and integrates systems that have future sustainability as well as horizontal and vertical implementation applications. To accomplish this diverse task, the Army has identified four “thrusts” designed to implement digital systems into Force XXI’s existing and projected platforms (Bernstein 1995).

Thrust I: Acquisition

The awarding of contracts by the Army to digital systems vendors will be predicated on the ability of the products to be used equally by platform-unique systems. Essentially, this means developing software that will adapt to several different current hardware systems and has a degree of longevity with regards to future hardware systems procurement. Care must be taken to ensure that new software being developed is not outmoded before it is even implemented . As one member of the National Academy of Sciences, Dr. Alan Ward, advises, “The Army should not worry yet about digital hardware. Rather, it should focus on designing the communications software that will bind the digital battlefield together.” (Kiernan 1994) AFATDS is but one of the new systems that fits into this category.

Thrust II: Creation of Network XXI, “The Tactical Internet.”

Translator “gateways,” known in military circles as “Tactical Multinet Gateways” (TMGs) or “Internet Controllers” (INCs) are the keys to linking the Army’s major communications and information systems together. The objective here is to develop the aforementioned common software environment amongst hardware systems. This will enable Force XXI to operate under the previously described "situational awareness" and "enhanced battle command" environment.

Thrust III: Integration

Interoperability amongst systems designed for specific vertical battlefield functions is the challenge facing integration efforts. As explained in Chapter 1 of this thesis, the major task is to cross-link the five major Battlefield Functional Areas (BFAs): maneuver, fire support, intelligence, air defense, and combat service support. Eventually, this concept will expand to link BFAs across Joint lines, and ultimately, multi-national systems.

Thrust IV: Future Digital Radio

The future of radio technology will be digital/voice applications that operate on multiple bands and replicate various signal waveforms in one portable package. Additionally, the quest for enhanced imaging technology is paramount among Army leadership. Instant access to high resolution pictures and graphics enabling accurate command visualization of battlespace is the unquestionable priority for future information systems (Bernstein 1995).

A.6 Putting The Digital Force To the Test: Ultimate High-Tech Training

A prototype Task Force, outfitted with all the current digital systems in the Army inventory today, was deployed to the National Training Center at Fort Irwin, California (the Army's mechanized warfare combat training proving grounds) to face the highly regarded Opposing Force (OPFOR) in April of 1994. The Opposing Force is an active unit which is stationed at Ft. Irwin and serves as the Army's enemy replication force. Having the advantage of knowing the terrain and fighting similar battle scenarios year in and year out, the OPFOR routinely defeated the digital force in training battles.[6] However, the digital task force was thrown together shortly before the exercise, and had a limited opportunity to learn their new system's capabilities. Also, the systems themselves had many operational shortcomings and bugs that were not anticipated. This exercise may be the best thing to happen to the Army, however, in that it demonstrated the need for both proper soldier training, and for future software systems versions to be compatible with hardware prior to fielding. In essence, the most technologically advanced system is only as good as the soldier who uses it. To this end, the Army has planned a second full blown exercise at the NTC in February 1997. Hopes are high that

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[6] Author's Note: This comment is in no way meant to denigrate or rationalize the professionalism and expertise of the OPFOR units. The fact is, the OPFOR at Ft. Irwin is by all regards the most capable mechanized (training) fighting force in the Army today. Their high level of tactical prowess is unquestioned, and they more than capably serve to literally "whip" rotating units into shape on the training battlefield. Augmenting the OPFOR at Ft. Irwin are the Observer Controllers (OC's), whose mission it is to assist visiting units in analyzing and assessing their performance after each battle at the NTC, in an effort to facilitate the learning process from a planning and operating perspective.

the test unit from the 2nd Armored Division, with ample train-up time, will perform at a higher level then the ad-hoc Task Force did previously. Additionally on the horizon is a concerted effort by the Army to conduct increased simulations battle training. Both virtual battle simulation and constructive ("wargame") simulation efforts are currently being conducted by active and reserve units as a means to test and incorporate the newest digital technology without the costs associated with full scale "maneuver" exercises. The advantage to simulation warfare is, unequivocally, the fact that mistakes imbedded in new systems won't cost soldiers their lives. With virtual imaging technology advancing at such a fast pace, training will take on most of the conditions of warfare without the costs associated with maintenance breakdowns, training ammunition expenditure costs, and so on. The ultimate effort the Army is pursuing on the simulation training front is the creation of "synthetic theatres of war." (Unknown Author, The Economist,1995) The Army's objective here is to incorporate a combination of both real and virtual exercises, interconnected worldwide via computer networks, thereby allowing commanders to control their forces without any discernible differences between real and imaginary forces.

A.7 Technological Advancement in The Army -- A Shift to a New Paradigm

Technology alone does not win wars; however, the effective use of new technology combined with innovations in doctrine, strategy, and tactics can make the difference on the battlefield. (Unknown Author, The Economist 1995) As we have seen, AFATDS and the other new products comprising the next generation of digitally enhanced systems are the links in the chain of technological progression. This blend of revolutionary change in technologically advanced systems and the operational art of war is evidence of a military shift to a new paradigm. The army that embraces this shift, as the U.S. Army is, will enjoy an immense advantage when the next battle is joined (Dunn 1991).

In the final analysis, the linchpin in the entire spectrum of information age warfare is no different than in combat waged during the Middle Ages; the soldier makes the difference. Learning to handle and control technology will emerge increasingly important as the information age progresses, but the bloody battlefield environment will never change. And the effect on armies and nations, as the grim realities of war remain constant, will be measured in the blood that is shed from their sons and daughters. Hence, as the Army moves into the 21st Century, embracing new technology, combined with teaching our soldiers how to use it, is paramount to the effectiveness of our force on the next battlefield.

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APPENDIX B

A MEMORANDUM FOR RECORD PROVIDED BY MAJOR DANIEL HUGHES THAT SERVES AS VALIDATION FOR THE AFATDS MODEL

9 February 1996

MEMORANDUM FOR RECORD

SUBJECT: Validation of AFATDS Communications Model

1. This memorandum will serve as validation of the AFATDS Data Model that Captain (CPT) Rodney Roederer has used for his thesis preparation.

2. The modeling for AFATDS communications networking presents a realistic portrayal of Army systems architecture for the near term future (5 to 10 years). It identifies fire support processing throughput in certain constrained environments.

3. This modeling is consistent with projections from "best guess" scenarios from the TRADOC Systems Manager for Fire Support Command and Control Systems (TSM-FSC3). The AFATDS Version 3 functionality objective is 720 fire missions an hour based on the same networks that CPT Roederer modeled. CPT Roederer's model results are within the range expected.

4. This thesis and modeling effort will contribute to the design of the Army's Force XXI.

5. Questions should be addressed to Major D.P. Hughes, 405-442-3410 or INTERNET at hughesd@doim6.monmouth.army.mil.

Daniel P. Hughes
Major, U.S. Army
PM FATDS LNO- Fort Sill

APPENDIX C

RAW DATA

Table 12a: Message Counts for Model 1

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	677	147	675	147	2065
2	612	168	611	168	1953
3	692	165	692	164	2061
4	675	155	675	155	1932
5	668	150	668	150	2062
6	644	123	644	123	2022
7	631	168	631	168	1973
8	682	157	682	157	2017
9	700	166	700	166	2057
10	669	163	668	160	2022
11	651	128	651	128	2028
12	636	160	636	160	1973
13	654	137	652	136	2140
14	674	182	674	182	2047
15	635	135	635	135	2188
16	652	151	652	151	2040
Mean	659.5	153.4	659.1	153.1	2036.3
s	24.14	16.17	24.19	16.10	64.86

Table 12b: Times/Utilization for Model 1

Run #	FFE (sec)	HPFFE (sec)	% Util. Ops Net	"Shot" (sec)	"Splash" (sec)	"MTO" (sec)	"EOM" (sec)	%AJFs Adjusted
1	75.21	114.46	69.97	1020.54	993.28	1037.98	250.4	53.1
2	91.14	103.24	69.14	851.47	927.61	901.57	382.57	63.9
3	92.64	97.03	70.01	939.71	957.71	1016.16	433.11	61.1
4	85.09	91.62	69.78	914.56	864.73	920.34	192.37	61.4
5	95.51	72.96	70	1088.21	1070.35	1078.15	298.26	55.2
6	91.14	69.64	69.64	958.31	955.82	916.76	203.36	47.6
7	88.64	100.47	69.17	701.18	634.25	697.7	171.13	62
8	95.4	90.27	69.86	1024.42	1090.26	1060.15	492.61	54.4
9	98.71	98.98	70	1127.51	1033.55	920.91	583.28	55.2
10	93.78	97.78	69.87	1096.37	1106.29	1061.13	491.94	57.9
11	84.98	103.45	69.6	978.15	1002.6	994.66	204.99	56.3
12	90.45	100.82	69.28	793.28	781.92	740.97	149.37	60.9
13	95.47	101.86	70.2	1006.94	971.03	914.34	157.71	48.4
14	92.62	101.03	69.75	920.3	941.46	877.06	216.08	59.1
15	87.04	93.38	70.36	811.51	880.58	894.04	160.78	55.9
16	87.28	90.09	69.91	977.88	1107.21	966.68	291.69	55.4
Mean	90.3	95.4	69.8	950.6	957.4	937.4	292.5	56.7
s	5.66	11.19	0.35	116.91	125.22	108.02	140.54	4.64

Table 13a: Message Counts for Model 2

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	642	131	642	131	2142
2	624	195	624	195	2137
3	667	160	667	160	2154
4	684	177	683	176	2160
5	701	168	701	165	1914
6	679	180	674	180	2173
7	673	200	673	193	2187
8	686	176	686	176	2152
9	644	176	644	176	2122
10	682	197	682	197	2146
11	699	166	699	158	2202
12	675	194	675	194	2137
13	668	191	668	191	2136
14	664	175	651	170	2171
15	665	171	665	171	2151
16	673	182	673	182	2149
Mean	670.4	177.4	669.2	175.9	2139.6
s	20.28	17.16	20.65	17.28	63.52

Table 13b: Times/Utilization for Model 2

Run #	FFE (sec)	HPFFE (sec)	% Util. Ops Net	"Shot" (sec)	"Splash" (sec)	"MTO" (sec)	"EOM" (sec)	% AJFs Adjusted
1	338.37	97.43	70.46	795.07	653.55	753.41	147.96	53.3
2	139.63	92.55	70.28	486.75	523.72	490.65	106.33	68.2
3	108.31	101.73	70.52	630.82	575.11	567.21	271.65	61.5
4	217.66	100.61	70.51	566.21	568.94	576.34	104.89	59.2
5	554.12	102.63	70.53	654.98	686.47	698.34	106.93	56.7
6	266.09	95.56	70.58	610.12	613.91	622.47	107.13	58.9
7	213.73	101.36	70.61	631.94	586.6	682.56	108.21	75.8
8	175.15	110.03	70.56	618.56	623.03	636.24	106.86	62.4
9	225.84	96.74	70.39	606.84	603.78	585.51	107.87	64
10	334.6	96.84	70.47	613.46	628.88	609.08	106.47	64.9
11	319.98	95.13	70.64	625.12	573.3	617.39	111.58	52.6
12	171.63	95.76	70.42	700.79	681.13	668.68	109.41	63.4
13	172.4	103.28	70.47	636.67	694.02	692.81	107.29	60.8
14	161.24	102.66	70.53	645.98	645.95	659.9	106.1	62.7
15	166.36	103.93	70.49	720.39	696.22	723.87	104.63	60.2
16	176.79	92.65	70.5	656.86	692.46	625.39	101.53	64.9
Mean	233.9	99.3	70.5	637.5	627.9	638.1	119.7	61.8
s	110.05	4.74	0.09	66.89	53.58	66.18	41.86	5.58

Table 14a: Message Counts for Model 3

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	667	125	667	125	2021
2	704	181	704	181	2022
3	685	131	685	131	2041
4	678	158	678	158	2029
5	678	150	678	150	2012
6	676	144	676	144	2064
7	666	162	666	162	2019
8	638	134	638	142	1983
9	629	142	627	142	1968
10	615	145	611	144	1771
11	638	155	636	155	2021
12	645	144	645	144	1731
13	673	144	673	144	2034
14	637	172	637	172	1968
15	620	131	620	131	2003
16	680	157	679	156	2005
Mean	658.06	148.44	657.50	148.81	1980.75
s	26.29	15.25	26.94	14.86	93.41

Table 14b: Times/Utilization for Model 3

Run #	FFE (sec)	HPFFE (sec)	% Util. Ops Net	"Shot" (sec)	"Splash" (sec)	"MTO" (sec)	"EOM" (sec)	% AJFs Adjusted
1	51.94	65.19	69.86	1051.16	1135.14	1091.5	136.86	43.6
2	48.79	50.22	69.83	913.73	906.74	844.42	197.34	59.7
3	61.94	99.84	69.96	1096.44	953.14	1018.64	371.79	48.4
4	60	64	69.92	1006.23	1022.31	1086.49	315.64	51.3
5	60.09	73.48	69.84	902.3	954.19	904.74	185.62	51.6
6	60.25	63.64	69.86	924.48	992.49	1014.47	164.05	51
7	61.6	60.93	69.69	1078.56	1009.71	1052.87	146.44	60.2
8	61.09	64.3	69.41	757.56	684.83	777.53	111.77	54.1
9	56.95	64.06	69.22	881.47	926.18	947.41	107.75	53.6
10	58.95	64.91	69.19	983.59	985.18	957.04	119.66	54.1
11	57.93	68.62	69.28	970.56	902.45	911.36	108.22	57.7
12	57.26	57.86	69.56	902.31	920.25	937.14	163.07	52.6
13	62.78	62.65	69.86	1034.66	996.26	1022.19	139.77	49.5
14	60.55	65.4	69.13	756.86	742.94	743.02	99.93	59.1
15	62.1	66.1	69.42	915.42	1009.78	1101.91	119.43	51.6
16	59.28	64.62	69.86	1043.57	1076.18	1049.87	369.41	58.3
Mean	58.84	65.99	69.62	951.18	951.11	966.29	178.55	53.53
s	3.76	10.26	0.30	101.84	111.51	109.43	91.38	4.58

Table 15a: Message Counts for Model 4

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	669	170	669	170	1889
2	642	177	642	177	2107
3	686	120	686	120	2167
4	699	140	673	138	2188
5	674	167	661	167	2181
6	657	172	657	172	2163
7	671	160	668	160	2149
8	686	194	686	189	2152
9	646	192	646	192	2125
10	678	150	678	150	2180
11	664	167	664	167	2176
12	659	188	659	188	2134
13	673	152	673	152	2131
14	656	197	656	197	2133
15	691	166	691	166	2138
16	666	169	666	169	2161
Mean	669.81	167.56	667.19	167.13	2135.88
s	15.88	20.54	13.89	20.33	69.77

Table 15b: Times/Utilization for Model 4

Run #	FFE (sec)	HPFFE (sec)	% Util. Ops Net	"Shot" (sec)	"Splash" (sec)	"MTO" (sec)	"EOM" (sec)	% AJFs Adjusted
1	253.85	65.19	70.45	666.98	720.19	654.97	54.78	61.1
2	128.04	67.31	70.37	581.37	589	584.6	73.04	63.3
3	614.05	68.1	70.69	779.86	740.21	616.25	74.6	57.4
4	183.07	68.65	70.67	655.97	663.44	635.65	74.14	51.8
5	183.02	68.18	70.58	655.21	639.41	628.59	74.77	65.2
6	257.71	66.02	70.47	652.01	700.11	617.23	74	57.7
7	181.8	70.22	70.58	657.41	612.03	680.06	77.67	56.4
8	283	70.83	70.52	735.72	720.24	732.05	72.93	57.8
9	151.98	80.51	70.32	582.83	621.56	598.21	72.91	65.8
10	265.75	66.53	70.64	799.37	757.22	763.92	76.66	52.9
11	135.09	64.65	70.45	642.63	599.13	629.58	74.3	55.8
12	214.56	66.53	70.41	641.52	640.09	617.14	74.33	65
13	124.7	64.6	70.43	611.03	631.66	651.2	72.92	53.1
14	127.83	74.03	70.39	584.82	660.51	646.57	72.43	63.8
15	231.43	62.5	70.51	587.87	615.04	594.47	72.65	61.7
16	362.81	63.58	70.47	744.36	714.31	736.23	75.18	56.1
Mean	231.17	67.96	70.50	661.19	664.01	649.17	72.96	59.06
s	122.35	4.44	0.11	69.67	53.93	53.22	5.06	4.68

Table 16a: Message Counts for Model 5

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	674	257	674	255	2542
2	666	227	666	227	2468
3	650	227	649	227	2367
4	684	219	681	218	2428
5	658	207	658	207	2424
6	711	256	710	254	2526
7	728	222	728	222	2535
8	691	228	691	228	2465
9	657	219	657	219	2481
10	700	243	700	243	2485
11	654	209	652	209	2535
12	707	265	707	265	2516
13	688	206	688	205	2517
14	699	244	698	242	2600
15	703	227	697	227	2052
16	682	208	682	208	2543
Mean	684.5	229.0	683.6	228.5	2467.8
s	23.07	18.88	22.97	18.51	124.59

Table 16b: Times/Utilization for Model 5

Run #	FFE (sec)	HPFFE (sec)	% Util. Ops Net	"Shot" (sec)	"Splash" (sec)	"MTO" (sec)	"EOM" (sec)	% AJFs Adjusted
1	72.02	49.13	57.87	269.83	291.29	279.93	59.7	76.3
2	64.87	48.2	57.36	155.55	156.05	163.41	58.52	68.7
3	60.34	39.01	56.04	104.88	104.72	98.8	47.27	76.3
4	58.46	49.36	56.83	55.27	52.41	50.25	58.92	77.4
5	59.99	49.16	56.58	127.76	139.74	133.01	58.4	70.2
6	70.25	39.51	57.84	166.68	186.1	139.72	60.73	75.5
7	56.11	50.34	57.94	176.86	171.46	183.63	60.29	70.8
8	64.68	47.33	57.18	59.21	61.16	65.23	58.48	69.8
9	72.11	41.41	57.22	187.7	191.83	197.24	62.38	68.5
10	64.18	47.88	57.28	116.86	109	96.6	57.79	77.2
11	65.95	56.13	57.68	58.96	58.17	65.75	59.01	77
12	73.45	38.29	58	506.97	474.43	463.84	61	74.4
13	66.82	46.8	57.84	186.39	187.36	201.71	59.5	68.8
14	71.58	50.71	58.39	351.71	346.59	360.03	45.76	74
15	65.7	47.85	57.08	161.04	159.56	170.49	59.11	66.7
16	70.74	48.55	57.78	148.84	133.62	137.32	59.27	70.8
Mean	66.1	46.9	57.4	177.2	176.5	175.4	57.9	72.7
s	5.36	4.87	0.61	116.54	111.85	111.37	4.59	3.70

Table 17a: Message Counts for Model 6

	Missions at Bde		Missions at FDC		Total
Run #	FFE/ADJ	Adjustments	FFE/ADJ	Adjustments	Messages
1	701	182	701	172	2360
2	694	203	694	202	2284
3	643	181	643	181	2293
4	659	187	659	187	2280
5	683	191	681	191	2288
6	638	174	637	174	2273
7	681	201	678	200	2230
8	700	173	699	172	2056
9	662	194	662	194	2279
10	700	151	700	151	2344
11	667	202	667	202	2291
12	682	215	682	215	2302
13	690	174	690	173	2260
14	710	199	710	199	2340
15	734	185	730	184	2321
16	689	191	689	191	2326
Mean	683.3	187.7	682.6	186.8	2282.9
s	24.95	15.43	24.54	15.88	69.15

Table 17b: Times/Utilization for Model 6

	FFE	HPFFE	% Util.	"Shot"	"Splash"	"MTO"	"EOM"	% AJFs
Run #	(sec)	(sec)	Ops Net	(sec)	(sec)	(sec)	(sec)	Adjusted
1	53.59	34.92	55.75	286.86	272.06	292.45	64.71	56.7
2	54.81	46.94	55.12	685.59	716.46	672.29	64.24	63.3
3	51.07	46.36	55.23	210.88	210	215.31	61.79	64.9
4	51.03	48.07	53.95	565.42	519.26	472.35	61.07	66.9
5	53.52	47.27	55.21	217.74	225	214.55	63.87	65.8
6	54.71	36.93	53.59	176.57	185.11	194.92	60.03	60.1
7	56.8	49.46	53.38	243.19	232.75	271.39	59.63	65.1
8	50.65	50.5	55.57	692.16	756.65	745.55	61.21	61.6
9	51.03	36.21	54.94	569.08	561.95	577.11	61.55	68
10	53.79	47.7	55.82	667.61	637.18	656.31	64.18	58.2
11	49.18	54.94	54.81	180.74	179.02	169.37	62.19	65.3
12	50.46	46.17	54.88	728.9	730.02	702.19	68.78	67.5
13	51.75	36.59	54.91	111.04	117.7	109.5	60.55	58.7
14	54.91	45.28	55.69	740.79	717.65	719.09	65.5	62.4
15	54.69	49.2	55.72	724.37	748.31	772.72	63.86	56.5
16	51.15	49.63	55.53	883.34	887.16	916.45	56.19	58.7
Mean	52.7	45.4	55.0	480.3	481.0	481.3	62.5	62.5
s	2.16	5.94	0.76	263.62	267.49	266.46	2.90	3.92