NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN INITIAL STUDY EXAMINING THE FEASIBILITY OF EXPERT SYSTEM TECHNOLOGY FOR COMMAND AND CONTROL OF SUPPORTING ARMS IN THE UNITED STATES MARINE CORPS

by

Michael C. Albano
and
Robert A. Gearhart, Jr.

March 1988

Thesis Advisor: James G. Taylor

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) 74	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification) AN INITIAL STUDY EXAMINING THE FEASIBILITY OF EXPERT SYSTEM TECHNOLOGY FOR COMMAND AND CONTROL OF SUPPORTING ARMS IN THE UNITED STATES MARINE CORPS

12 PERSONAL AUTHOR(S)
Albano, Michael C. and Gearhart, Robert A., Jr.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1988 March	

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Artificial Intelligence, Expert Systems, System Design, Human Factors Engineering, Fire Support Coordination, Marine Air Ground Task Force

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL James G. Taylor	22b TELEPHONE (Include Area Code) (408) 646-2683 22c OFFICE SYMBOL 55Tw

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Block 18 (continued)

Distributed Systems, Man-Machine interface, System Design, Knowledge Base, Knowledge Engineering

Block 19 (continued)

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Approved for public release; distribution is unlimited.

An Initial Study Examining the Feasibility of Expert System Technology for Command and Control of Supporting Arms in the United States Marine Corps

by

Michael C. Albano
Major, United States Marine Corps
B.S., United States Naval Academy, 1974

Robert A. Gearhart, Jr.
Captain, United States Marine Corps
B.A., Virginia Military Institute, 1980

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(Command, Control and Communications)

from the

NAVAL POSTGRADUATE SCHOOL
March 1988

ABSTRACT

The authors of this thesis propose the use of knowledge based expert system technology to automate Marine Corps fire support command and control. It investigates the need for such support for the control of supporting arms and the ways to achieve it. The authors provide general information about artificial intelligence (specifically, expert system technology) and its potential use for automating command and control functions for Marine Corps combat functions. In particular, they examine the complexities of system design (especially critical man-machine interfaces) within the context of basic command, control, communication, and intelligence (C3I) architecture. Finally, the authors investigate the potential use of expert system technology for improving the effectiveness of command and control of various combat and combat support activities, but focus on fire support coordination: they illustrate the feasibility of using a so-called "expert system" to aid a Marine Air Ground Task Force (MAGTF) commander in the employment of supporting arms.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENT

We would like to express appreciation to our advisor, Professor James G. Taylor, and second reader, Lt. Col. Linda K. Crumback, for their comments and guidance during preparation of this thesis and our gratitude to Kathy Fargo for her administrative support. Finally, we would like to acknowledge the constant support and understanding of our wives, Linda and Ginger, which contributed significantly to the completion of this thesis.

I. INTRODUCTION

Unprecedented advancements in science and technology over the past three decades have culminated in a world which is increasingly dependent upon automation. Even our homes have been invaded by coffee pots, toasters, microwave ovens, video cassette recorders, and a myriad of other devices which, in one way or another, rely on a central processing unit: a computer. And so, we have become accustomed to, and now readily accept, automation as part of our daily routine.

The presence of computers has been even more significant in other applications. Consider the impact which automation has had on the medical profession. The important role that automated systems have played in medical research is common knowledge, but equally important has been the application of computer technology to the diagnosis and treatment of complex diseases. These developments have literally revolutionized the medical profession.

Unfortunately, as much as mankind has benefitted from automation, so has our mere existence been threatened by it. Micro-miniaturization of integrated circuits has resulted in development of weapons and weapon systems with unparalleled lethality. The advent of ballistic missiles with multiple warheads, lasers, anti-air missiles, and many other sophisticated weapon systems owe their existence to automation. Now we are on the verge of developing sophisticated weapons for deployment in space.

Even with the vast improvements in war fighting capabilities, one aspect of war remains relatively unchanged. Victory in combat eventually requires an infantryman to occupy the conquered territory. Thus, the concepts of land warfare have not endured the significant changes that have permeated other types of combat. In fact, with the sophistication of strategic and, to a lesser degree, tactical weapon systems; combat at the battalion and regimental levels stands out like an anachronism. Yet, the availability of sophisticated weapons at the tactical level is beginning to have an impact. In order to meet this threat, the United States Marine Corps must modernize the command and control systems which are fundamental to its operational doctrine.

Command and Control is the "linch-pin" which holds Marine combat organizations together. Without an effective command and control system, the Marine Corps would be incapable of responding to the rigors of combat. Planners at the service headquarters have recognized the need to modernize or replace current command and control systems and have sponsored several acquisition initiatives to accomplish this goal. With the termination of the Marine Integrated Fire and Support System, the Marine Corps must search for alternate means to improve the Marine commanders' ability to employ supporting arms.

Marine Corps operational doctrine stresses the requirement for timely, coordinated supporting arms to achieve success on the battlefield. Current force levels indicate the significant advantage that Soviet bloc countries have in sheer numbers of personnel and equipment. Efficient use of supporting arms will be a crucial factor for survivability in the future.

Achieving the efficiency which will be required of our supporting arms will soon exceed the capability of our current approach to fire support coordination. Marines, regardless how proficient and dedicated, will simply be physically incapable of performing to the extent required during routine combat operations. As fatigue, emotion, confusion, and combat tempo increase; command and control of supporting arms will become increasingly ineffective.

The authors are not suggesting replacing Marines with machines. Instead, they propose to extend his capability by having routine, repetitive functions (that in the past have usually consumed much time and sometimes even created bottlenecks) automated. Provided that required inputs are correctly entered (i.e. development of a reliable man-machine input interface), such automated processing will be more reliable (as long as the equipment functions), since it is not prone to systematic degradation over time that manual processing was due to fatigue, boredom, stress, etc.

Decision aids may be categorized in various ways depending upon the role which they have in the decision process and the algorithm used to achieve the solutions. Having investigated several approaches to the man-machine interface problem, the relatively new concept of "expert system technology" might be the most appropriate for application to command and control of fire support coordination.

The feasibility of using expert system technology in the United States Marine Corps command and control structure to assist in fire support coordination is investigated. An initial assumption that the reader would possess minimal knowledge of United States Marine Corps fire support coordination and the previously unrelated concept of expert system technology was used as a baseline for discussion.

Therefore, artificial intelligence and expert system are defined in Chapter II. A thorough understanding of artificial intelligence and expert system technology is essential in understanding the proposed application to the complex problem of fire support coordination.

In Chapter III the authors provide a discussion of the man-machine interface. They not only provide a discussion of the design approach and delineation of tasks between man and machine, but also provides insight into the advantages and disadvantages of using both man and machine in similar roles. While providing significant capabilities when used in an appropriate role, system designers must be aware that expert system technology is not the panacea for all problems.

Chapter IV continues with an appraisal of general applications of expert system technology to various tasks in the Marine Corps command and control structure. the authors' intention is to identify possible applications of expert systems while demonstrating the characteristics of each function performed which favor their use.

In order to fully understand the proposed application of expert systems in the Marine Corps, the reader must have more than a casual knowledge of Marine Corps functioning in time of war. Therefore, Chapter V presents a brief description of the Marine Corps combat organization.

Chapter VI amplifies the previous chapter by providing detailed information on the Marine Corps command and control structure. Included in this chapter is a detailed discussion of staff functioning with emphasis on fire support coordination.

Through Chapter VI, the reader was provided information on expert systems and Marine Corps fire support coordination. In Chapter VII the two subjects are merged to demonstrate conclusively that the application of expert system technology is not only feasible, but extremely desirable.

While this thesis is intended to be an organized and logical discussion of the feasibility of applying expert system technology to fire support coordination, it is not intended to be an exhaustive, all encompassing investigation. The discussions of various topics, such as Marine Corps organization and staff functioning, have been limited to the extent deemed necessary for understanding the proposed application of expert system technology.

Subsequent to completion of this thesis, a change was disseminated by Headquarters, United States Marine Corps which renamed the three MAGTF organizations discussed in Chapters V and VI. The word "amphibious" has been replaced by "expeditionary" in all three titles. Thus, the three MAGTF organizations are now called: Marine Expeditionary Unit, Marine Expeditionary Brigade, and Marine Expeditionary Force. To the authors' knowledge, all other facts remain unchanged.

II. ARTIFICIAL INTELLIGENCE/EXPERT SYSTEM OVERVIEW

A. BACKGROUND

The following discussion of artificial intelligence and expert systems is written with the intention of providing readers with various technical/nontechnical backgrounds, a broadbrush explanation of this rapidly growing and important field in computer science. A detailed examination concerning the various aspects and subfields of artificial intelligence is beyond the scope of this thesis. Therefore, this chapter will initially review several fundamental concepts germane to artificial intelligence and then shift focus towards that portion of the artificial intelligence field possessing the highest degree of military application: expert systems. The field of artificial intelligence continues to gain increased military interest and acceptance. Indeed, the military's dependance on highly technical, complex systems, coupled with the grim prospects of future Defense Department budget reductions could rapidly expand the role of artificial intelligence within the Armed Forces of America.

B. DEFINITION OF ARTIFICIAL INTELLIGENCE

Not surprisingly, the computer science world has experienced great difficulty and differences of opinion while attempting to describe the concept of artificial intelligence in words. A great deal of semantics have been expended in attempts to mold an ethically, technically and logically acceptable description of artificial intelligence. At present, there is no single universally accepted definition of artificial intelligence. However, there are various different definitions that have gained acceptability within different schools of thought in computer science. Here we state three of the most widely accepted such definitions.

- Artificial Intelligence technology is intended to design and to produce intelligent computer systems, that is, computers that can imitate the human thought process, yet attain more accurate results. [Ref. 1:p. 21]

- Artificial Intelligence is not the study of computers, but of intelligence in thought and action. Computers are its tools, because it's theories are expressed as computer programs that enable machines to do things that would require intelligence if done by people. [Ref. 2:p. xi]

- Artificial intelligence will be considered the branch of computer science dealing with the development of methods that solve problems previously considered solvable only by humans. These problems include reasoning, understanding, natural language, planning and problem solving, learning, visual processing and manipulation of the physical world. [Ref. 3:p. 29]

C. SUBFIELDS OF ARTIFICIAL INTELLIGENCE

Being broad in definition by nature, artificial intelligence contains the following major subfields: expert or knowledge based systems, natural language processing, artificial or computer vision, sound sensing/understanding and robotics. To the imaginative mind, each of these subdivisions would appear to possess significant military potential and while this bears true, the expert system emerges as the most useful. Accordingly, a brief discussion of each subfield is included followed by a separate, in depth examination of expert systems.

1. Natural Language Processing

The emphasis within this derivative of artificial intelligence is to develop a system where man can control computer operations through the medium of natural language (for example, either spoken or typed English). The implications of this, as not yet fully developed capability, are far-reaching. Theoretically, anyone with the ability to speak a natural language would become a potential computer programmer, or at least able to interact in some respect with a computer system. Obviously, a system operable through natural language processing would represent the ultimate in "user friendly" computing. As mentioned above, a viable, realistic system utilizing natural language processing does not exist at the present time. Problems causing this center around the huge memory and knowledge requirements necessary to interpret sentence structure, word meaning, word morphology and conversation rules. [Ref. 4:pp. 107-108]

2. Artificial Vision

With the exception of expert systems, this subfield of artificial intelligence possesses the greatest potential degree of military applicability. Artificial vision or computer vision consists of programming into computer systems the ability to see, draw, describe and categorize objects based upon visual sensory input. This still represents an evolving field of artificial intelligence with many recent developments being quite functional. However, to date, no computer vision system exists which can match the visual discrimination and accuracy of the human eye. Areas of interest being presently examined include, imagery interpretation, cartography, fault inspection of detailed electronic equipment and target acquisition. [Ref. 4:pp. 82-83]

3. <u>Sound Sensing and Understanding</u>

Likewise, this area within the realm of artificial intelligence holds great promise for military utilization. Sound sensing and understanding, or as it is more commonly referred: speech recognition, concerns the interaction of computer systems with the human voice. Not surprisingly this subfield is closely related to that of natural language processing. In speech recognition, the computer system must possess the ability to receive human voice commands, correctly interpret meaning, and then take further necessary actions to completely accomplish the assigned task. Proponents of speech recognition are quick to point out that speech is the fastest means of communication, and does not require visual contact or physical proximity. Additionally, when interacting with computer systems by voice commands, an individual remains mobile and free to utilize his hands for alternate tasks. A complication the user must understand revolves around the point that speech recognition systems today are segregated as either speaker dependent or speaker independent. One can immediately foresee the disadvantages and advantages relevant to each. Current military applications center around utilizing speech recognition within areas of equipment operation (i.e. aircraft, tanks and ships), fire support agencies, and command centers. [Ref. 4:pp. 128-129]

4. Robotics

The final broad subfield of artificial intelligence worthy of examination is the discipline of robotics. Succinctly stated, "Robotics is the intelligent connection of perception to action." [Ref. 5:p. 137] Until recently, the area of robotics focused on programming robotic arms to perform repetitive functions, mainly limited to assembly line manufacturing applications in areas such as automotive plants. Inside the realm of artificial intelligence, man is attempting to create robots possessing human attributes such as reasoning and creativity. Actually this subfield usually requires utilization of computer vision and speech recognition for successful implementation. Specific applications for robotics include area protection, ordinance disposal, search and rescue, and reconnaissance capability within hostile territory. Thus, the continued developments within robotics signal potential reductions in the number of dangerous jobs presently required to be performed by man. [Ref. 5:pp. 137-140]

D. APPLICATIONS OF ARTIFICIAL INTELLIGENCE

Perhaps the most interesting and controversial aspects of artificial intelligence stem from the various applications associated with the field. In order to gain a significant appreciation of the potential for artificial intelligence within an organization, one should be exposed to several current applications.

1. Training/Learning

The field of artificial intelligence presents many interesting options when applied to training and learning. Interactive artificial intelligence training programs are designed primarily for personnel instruction. During such sessions they can be expected to provide advice and issue specific guidance to students over a broad range of subjects. Additionally, the ability for a student to review or see an "experts" approach toward the solution of difficult problems often proves invaluable. This application allows students to harmlessly test either standard or innovative approaches to a variety of problems. For example, when applied to a nuclear propulsion plant operating scenario, a wrong move merely results in the student seeing the disaster unfold on a screen. Consequently, the student receives a detailed review of what procedures lead to the unfortunate occurrence, followed by a demonstration of how it could have been avoided. Undeniably, valuable experience would have been acquired without a disastrous results. Pragmatic supervisors quickly perceive the inexpensive value of such training, which finds purpose within a broad spectrum of military occupational specialties. Significant implications include reduction of training cycle time as well as gaining valuable training benefits without disabling expensive equipment. [Ref. 3:p. 29]

2. Simplifying Man-Machine Interface

This application calls for the utilization of artificial intelligence programs to create a more "user friendly" environment at locations of man-machine interface within command, control, communications and intelligence computer systems. The main point being reduction of the amount of expertise necessary for a user to generate input, and receive/understand output from a system. This simplification of man-machine interaction requirements is necessary in today's environment of high information and data influxes. Simply stated, in a given situation one only has a certain amount of time available, and the less time spent sorting through raw data, the better. An organization would be best served by individuals able to devote the maximum amount of their allocated time evaluating information and reaching a decision. Time spent interacting with machines to acquire requisite information for reaching a decision is simply wasted time. Artificial intelligence programs which simplify such interfaces grant their practitioners a precious commodity in today's rapidly developing military situations: time. [Ref. 6:p. 51]

3. Database Update

The area of database update gains increased significance in these times of rapidly changing situations and capabilities throughout the world. Informed decision making depends upon an accurate and current database. Artificial intelligence techniques applied within this realm involve the development of an embedded machine database administrator. Being administered by artificial intelligence methods, the system would perform more efficient information retrievals by utilizing improved search techniques, while at the same time allowing for more rapid database updates. [Ref. 7:p. 53]

4. Situation Assessment

Given all the variables confronting commanders on today's modern battlefield, the capability for obtaining rapid and accurate situation assessment becomes extremely important. There exist two primary distractions preventing the commander from obtaining an accurate and timely situation assessment. These are information overload and information processing speed. Indeed,

> Among the most difficult problems facing todays military command centers are the escalating requirements placed on Command, Control, Communications and Intelligence (C3I) systems. These centers are inundated with a continuing

> flood of information and data from highly sophisticated sensors - information that must be processed, analyzed, correlated, and disseminated to military field commanders in the form of situation and threat analyses, status reports, and targeting information. [Ref. 8:p. 27]

Utilization of expert systems to process, analyze and correlate information followed by dissemination of polished situation assessments etc., portrays an excellent application of artificial intelligence technology. The critical area of situation assessment warrants such technology, for time saved in this process cascades down throughout the entire command structure, benefitting all.

E. CHECKLIST FOR ARTIFICIAL INTELLIGENCE APPLICABILITY

This section presents several critical questions which an organization may utilize to ascertain if the application of artificial intelligence techniques would prove beneficial in solving particular problems. The following questions were presented by David C. Walden, president of BBN Laboratories, Inc. in the article "Successful Applications of Artificial Intelligence" featured in <u>Signal Magazine</u>, May, 1987. [Ref. 9:p. 258]

- Is the problem difficult or unsolvable with conventional software methodologies?

- Is the problem big enough to prove the concept?

- Is the problem narrowly defined? (Does not imply that it lacks complexity)

- Have human experts mastered and agreed upon how to solve the problem, and is a cooperative human expert available to participate in knowledge engineering?

- Is there sufficient return on investment for the finished application to justify the development effort?

- Does the problem solution replace experts, act as their assistants or raise the competence level of nonexperts?

A point made above which warrants further emphasis is that artificial intelligence methods function best when applied to narrowly defined problems. Reasons for this will become apparent upon reading the upcoming section on expert systems. For now it will suffice to say that the probability of successful application of artificial intelligence to a specific problem is inversely related to the problems dimensions. [Ref. 10:p. 121]

F. EXPERT SYSTEM COMPOSITION/FUNCTIONING

1. Definition of Expert Systems

The artificial intelligence community appears in almost total agreement when defining expert systems. The following two definitions lend the most appropriate justice to the topic:

- A knowledge-based system or expert system is a computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a high level, plus the inference procedures used, can be thought of as a model of the abilities of the best practitioners in that field. [Ref. 8:p. 28]

- Expert systems are software programs that support and extend the problem solving ability of humans. These programs model the problem solving thought processes of one or more human experts and then mimic the reasoning abilities of those experts. [Ref. 11:p. 65]

2. <u>Expert System Basics</u>

All expert systems contain four basic functional parts: a knowledge base, an inference engine, a language processor and a knowledge engineer. This relationship is depicted in Figure 2-1. [Ref. 1:p. 22]

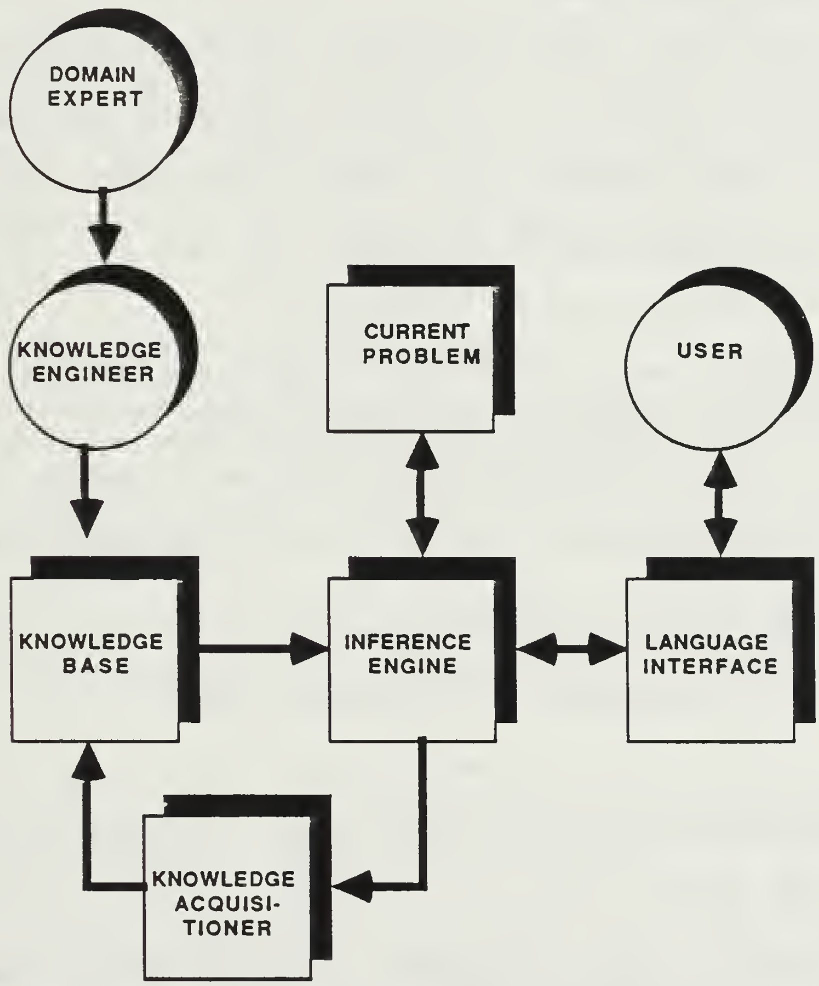


Figure 2-1. Components of an Expert System

The next excerpt is a concise, simplistic explanation of the process occurring in Figure 2-1. After which a detailed examination of the intricate expert system relationships will be presented.

> A Knowledge Engineer captures a domain expert's knowledge and builds a knowledge base. This knowledge base is then used by the inference engine to make decisions and to present solutions to the user. A current problem area (commonly called a blackboard) is used as a work space in building the present situation. The person who performs knowledge acquisition continually is adjusting the knowledge base when new or more definitive data becomes available. [Ref. 1:p. 21]

3. Knowledge Base

The first, and many argue the most integral portion of any expert system, is the knowledge base. However, before exploring the knowledge base, one should review the definition of the term knowledge.

a. Definition of Knowledge

> ...Knowledge can be defined as the store of information or the models used by a person or machine to interpret, predict and appropriately respond to the outside world....Thus the specific structures by which knowledge is characterized and its encoded form can have a significant effect on its use in solving problems. [Ref. 12:p. 44]

b. Knowledge Base Composition

Feigenbaum, a respected pioneer in the realm of expert systems, feels rather strongly that within the knowledge base resides the key (heart and soul) to any expert system. He states,

> ...to enhance the performance of Artificial Intelligence programs knowledge is power. The power does not reside in the inference procedure. The power resides in the specific knowledge of the problem domain. The most powerful systems will be those which contain the most knowledge. [Ref. 13:p. 38]

The knowledge base of an expert system contains both facts and heuristic rules concerning a relatively focused domain. These are obtained and maintained by knowledge engineers from proclaimed human experts within the specified domain. Probably the easiest to understand explanation of a knowledge base was offered by Gevater in his book, Intelligent Machines. He states that the knowledge base of an expert system consists

> ...of facts and heuristics. The 'facts' constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The 'heuristics' are mostly private, little discussed rules of good judgement (rules of plausible reasoning, rules of good guessing) that characterize expert level decision making in the field. The performance level of an Expert System is primarily a function of the size and quality of the knowledge base that it possesses. [Ref. 4:p. 47]

c. Knowledge Representation

In previous discussions, a point made worth reiterating is that the power, and therefore the key, to all expert systems resides within the knowledge base. Therefore, proper organization of this knowledge, or knowledge representation, assumes an increased level of performance. Indeed,

> The purpose of knowledge representation is to organize required information into a form such that the artificial intelligence program can readily access it for making decisions, planning, recognizing objects and situations, analyzing scenes, drawing conclusions, and other cognitive functions. Thus, knowledge representation is especially central to expert systems....[Ref. 4:p. 30]

Knowledge representation, like many areas within the field of artificial intelligence, has several associated problems. The prudent individual should take note of these, understanding both why they occur and how to avoid them. The considerations shown below were presented by G. L. Simmons in his book, Introducing Artificial Intelligence, and must be addressed early in the system design process or lack thereof will become embarrassingly evident shortly after fielding. [Ref. 14:p. 107]

- How to build a representational system that avoids the ambiguity that tends to characterize human symbol systems.

- How to preserve flexibility so that currently unresolved details can be accommodated at a later time.

- How to recognize relevant knowledge (new knowledge may become relevant during the process).

- How to accumulate new knowledge and to displace old knowledge that may be superseded.

- How to accept new knowledge when it is presented at an unexpected time or in an unexpected way.

d. Rules

By their nature, rules are rather formalized and structured within a knowledge base. They should simply be considered as strict guides located throughout the knowledge base pointing towards some logical ending. The rules are logically designed to rapidly focus the search for a conclusion by directing the search to necessary factual storage areas within the knowledge base. [Ref. 11:p. 65] One should be cognizant of the fact that associated probabilities of occurrence may be attached to rules. This feature allows organizations to assess situations where some degree of uncertainty exists.

(1) Meta-rules. Within the knowledge base the majority of rules apply to conditions surrounding facts. However, a different type of rule, the meta-rule, also resides within the knowledge base. Simply stated, a meta-rule is not concerned with facts, but rather with the relationships which exist between specific rules. Meta-rules govern the utilization of rules existing within the knowledge base and contribute significantly to knowledge base search efficiency. [Ref. 3:p. 48]

(2) Self-generating Rules. An area within expert systems currently creating a great deal of debate is that of self-generating rules. A solid capability for expert systems to generate their own rules does not presently exist. An expert system possessing a self-generation rule capability would be able to produce its own rules upon encountering unprecedented situations or queries, independent of outside assistance. Proponents argue this capability is required if expert systems are to participate in the rapidly changing environments of modern warfare or in areas where human expertise is not readily attainable. Detractors point to the enormous potential and consequences of faulty or incorrect self-generated rules. Regardless of the outcome, one should be aware of the controversy surrounding self-generating rules and continue to monitor future developments. [Ref. 15:p. 119]

4. Inference Engine

Once an acceptable knowledge base has been created for a particular expert system, an ability to sort through the facts and rules, leading toward an eventual and meaningful solution must be developed. The specific portion of an expert system devoted toward accomplishing this complicated task is commonly referred to as the inference engine.

a. Definition

Often misunderstood, the inference engine represents a critical portion of any expert system. Specifically, an inference engine is "the part of an expert system that controls the selection of rules and their application to data in searching for a solution to the problem." [Ref. 3:p. 48] In fact, the principal purpose of the inference engine resides in managing the expert system's reasoning functions. [Ref. 11:p. 65]

b. Heuristic Search

Often, in extremely detailed problems there exist many paths, of varying lengths (measured in both time and complexity) which lead to problem solution. This problem forces systems designers to discover an approach which would both limit and focus the knowledge base search. The heuristic search method employed by an expert system's inference engine strives to achieve the most efficient rule search possible in quest of a problem solution. Heuristics are often referred to as empirical rules or rules of thumb, successfully utilized by human experts. Knowledge engineers obtain these heuristics from domain experts while extracting their problem solving methodologies and incorporate them into the expert system's inference engine. [Ref. 4:pp. 30-5]

c. Rule Search Methodology

These heuristics are embodied within each of three basic rule search methodologies: forward chaining, backward chaining and a combination of forward/backward chaining employed by the expert system's inference engine. Rules within the expert system are written with an IF-THEN structure. Simply, this means that if a certain condition is satisfied, then a particular conclusion may be assumed. Additionally, rules may be accompanied with probability of occurrence assessments. This provides users with the capability of utilizing the power of expert system's under conditions of uncertainty. The inference engine will, employing heuristics, begin chaining the IF-THEN rules together forming a progression of logical reasoning, converging toward a solution. This progression or rule search methodology activates necessary rules, which allow access to pertinent portions of the knowledge base, while at the same time ignoring irrelevant rules, thus preventing access to unnecessary portions of the data base. [Ref. 4:pp. 48-49]

(1) Forward Chaining. The forward chaining rule methodology consists of a top-down, data driven style that progresses through facts toward a conclusion. By design, this methodology examines the IF portion of the rules first and ensures compliance prior to committal down a certain path within the knowledge base. [Ref. 16:p. 47]

(2) Backward Chaining. The backward chaining rule methodology consists of a bottom-up, goal driven style that begins with conclusions and works in reverse through the facts. By design, this methodology examines the THEN portion of rules first and ensures compliance prior to committal back up a particular path. [Ref. 16:p. 47] To provide further explanation, Richard Forsyth, a noted author in the artificial intelligence field, states, "Backward chaining works from hypothesis to evidence. The system picks a hypothesis and looks for data to support or refute it." [Ref. 17:p. 191]

(3) Combination Search/Chaining. Some system designers dislike a purely forward or backward chaining inference engine search process. Aside from forward chaining and backward chaining an expert system designer has the option of employing a "...combination of the two that uses a relaxation-like convergence process to join these opposite lines of reasoning together at some intermediate point to yield a problem solution." [Ref. 18:p. 195]

d. Rule Repair

To date, the field of artificial intelligence has not produced an expert system with a demonstrated capability to learn. However, systems exist which have the ability to locate and then correct or fix faulty rules. In the event an expert system responds with an incorrect answer, the user provides the system with the correct response. The expert system then examines internal rules simultaneously with the path chosen which lead to the incorrect answer. At the conclusion of this examination, the system presents a listing of rules which possibly caused an incorrect response, and thus warrant appropriate alteration. This is a reiterative process and after each rule change, the system re-evaluates the problem until the desired solution is finally obtained. A point worth mentioning here is that the computer system in this application does not internally generate rules, but rather serves to enhance man's capability in the area of rule composition. [Ref. 16:p. 48]

e. Basic Inference Engine Capabilities

Regardless of which expert system is chosen to accomplish a specific task, an organization should demand that the inference engine, at a minimum, possess the following characteristics, which appeared in the article "Selecting a Shell" by R. Citrenbaum, J. Geissman and R. Shultz in <u>AI EXPERT</u>, September, 1987. [Ref. 19:p. 34]

- Support multiple paradigms and search strategies. A flexible inference engine should be able to deal with a given knowledge representation in more than one way.

- Allow user modifications to modify or tune the basic control mechanisms.

- Allow dynamic user influence of hypothesis generation and search strategy; for example, by assigning priorities to rules or intermediate states.

- Allow variables as well as literals within rules.

- Provide belief maintenance, updating all related knowledge, conclusions, and reasoning strategies as individual facts become known or change.

- Support uncertain reasoning, dealing with less-than-certain conclusions and a multiplicity of possible reasoning paths. This should be done while maintaining knowledge of how certain each conclusion is, without irrevocably pruning off alternatives if their probabilities might later be improved.

- Provide explanation and audit trail. This involves giving a clear account of the path followed to arrive at conclusions and hypothesis in terms the user can understand. Exactly what the user wants to know in this regard and how much he or she can understand may vary widely.

5. Language Processor

The language processor is that portion of the expert system which interacts with the outside world. This includes receiving and interpreting queries from the system user. The language processor correctly formats and submits user commands or questions to the inference engine which activates the search for a solution/response. Once the inference engine obtains a result, the language processor must format the response for display to the system user. [Ref. 1:p. 22] Thus, the language processor comprises an integral part of any expert system by serving as the critical man-machine interface point. To facilitate performance, common sense dictates that the two most important considerations in language processor construction are speed and degree of user friendliness.

6. Knowledge Engineering

Up to this point there has been a great deal of discussion concerning the various aspects, functioning and components of an expert systems knowledge base with no mention as to how this knowledge base is acquired and assembled. These points, considered knowledge engineering, are the responsibility of an individual appropriately referred to as a knowledge engineer or a knowledge acquisitioner.

a. Definition

Probably the best definition of knowledge engineering was presented by H. Penny Nii, a respected author in the field. She states,

> Knowledge Engineering is the art of designing and building computer programs that perform specific tasks by combining methods of symbolic reasoning with knowledge of the task domain....The knowledge of the problem domain is held by experts of the domain. This knowledge consists of both formal, textbook knowledge and experimental knowledge - the 'expertise' of experts. The task of integrating artificial intelligence methods with knowledge of the problem domain to build Expert Systems falls to the Knowledge Engineers. [Ref. 20:p. 215]

b. Knowledge Engineer/Acquisitioner

The knowledge engineer is the ultimate key to the expert system, for if he misrepresents how human experts reach conclusions, the resulting expert system will be faulty. Thus, the knowledge engineer must observe and extract from a human expert the intricate process associated with how a human expert's mind flows though the course of problem solution. The knowledge engineer must pay particular attention to the human expert's problem solving process, carefully noting influential factors and points considered crucial to the decision. He must then give structure to the human experts reasoning process so that a specific list of rules may be developed which parallel the human expert's reasoning process. These rules, combined with factual databases give birth to the expert system's knowledge base and inference engine procedures. [Ref. 21:pp. 59-61] Additionally, the knowledge engineers responsibilities include designing within the expert system a capability for update. This covers a current update of factual information as well as rule adjustment necessitated by new, improved human expert problem solving methodologies.

c. Automated Knowledge Engineering/Acquisition

This area within knowledge engineering remains in an evolutionary stage. However, a great deal of effort is being expended to produce an expert system which is not dependant upon a human knowledge engineer. Proponents of this approach desire to produce an expert system which possesses the ability to acquire requisite knowledge or update rules to improve its own performance in terms of accuracy and timeliness. Thus, an expert system demonstrating this capability must be able to learn from prior experiences and utilize this newly acquired information or reasoning processes to more effectively and efficiently solve problems. This capability is considered essential for expert systems deployed on modern battlefields. [Ref. 22:p. 81]

d. Problems with Knowledge Engineering/Acquisition

The ability to extract meaningful information from human experts concerning their problem solving methodologies is an essential process conducted early in the construction of an expert system. The following points, associated with the knowledge engineering process, can produce significant problems within expert systems if not properly understood.

- No person can envision, at a systems inception, all the information requirements which will be necessary for problem solution. Thus, the knowledge acquisitioner must create a versatile system, capable of accepting additions as well as deletions. [Ref. 23:pp. 47-48]

- Knowledge engineers experience problems when attempting to filter/mix information gleaned from several experts, possibly of varying skill levels. [Ref. 23:pp. 47-48]

- The knowledge engineer must ensure that the basic system design prevents all but authorized personnel from changing any of the expert system's parameters. [Ref. 23:pp. 47-48]

- Due to the infancy of the field, no standardized rules or methods exist to guide knowledge engineers in the performance of their duties.

- The time required for the knowledge engineer to extract the required information from a human expert for use in an expert system cannot be reliably estimated.

The final point is an extremely important consideration for,

> Experts are notoriously bad at saying how they reach their conclusions, not because they wish to preserve trade secrets but because much of the 'intuition' lies buried beneath the level consciousness. It has to be laboriously quarried out of the unyielding rockface of the human skull. So knowledge acquisition has come to be regarded as the main bottleneck in expert system development. [Ref. 17:p. 194]

G. EXPERT SYSTEM OVERVIEW

1. Why Expert Systems?

A perfectly legitimate question at this juncture would be, why do we need expert systems? There exist several reasons, some practical and some technical. However, most boil down to the fact that today, a human within a system finds his mental abilities severely taxed by the sheer volume and complexity of the tasks confronting him. Expert systems carefully designed to support and enhance human performance can dramatically improve productivity by making the problem solving techniques of acknowledged domain experts along with the speed of modern computer systems available to benefit man.

Another legitimate concern is

> ...the trouble with human experts is that they are scarce, they are not always reliable, they require payment, and in the long run, they die-taking much of their expertise with them. Many people, therefore, are interested in the idea of encoding expert knowledge in computer programs, to get the benefits without the drawbacks. [Ref. 17:p. 186]

2. Expert System Prerequisites

The following points should be considered and incorporated within expert system's in order to render them practical for man's utilization.

- There must be at least one respected and acceptable human expert from a given domain. [Ref. 18:p. 203]

- The main origins of the expert's extraordinary abilities must be experience and special knowledge along with the reasoning methodology utilized to apply these effectively to specific areas requiring solution. [Ref. 18:p. 203]

- The task to which an expert system is being applied must have a well defined and bounded domain. [Ref. 18:p. 203]

- A definite segregation between the knowledge base and inference methods is required. [Ref. 20:p. 215]

- The expert system must be able to provide the user, through the language processor interface, an explanation of it's problem solving approach. [Ref. 20:p. 215]

- The knowledge base should be created such that update and refinement can be conducted, as required, from the point of system inception. [Ref. 20:p. 215]

3. Limitations of Expert Systems

Expert systems possess several limitations which constrain their degree of problem solving applicability. The following list, developed entirely by Andrew Basden, a respected authority on artificial intelligence, covers instances where as a rule of thumb, it would be difficult to apply the present day capabilities of expert systems. [Ref. 24:pp. 68-69]

- Problems which are too simple (under 10 rules) since the human brain can ordinarily handle them very adequately.

- Problems which are too complex (over 10,000 rules) since construction and search times become too long and current hardware has difficulty coping with anything larger.

- Problems which require none of the advantages of expert systems, such as well structured numerical problems.

- Problems involving visual/pattern recognition since human capabilities in this regard remain far superior.

4. Roles for Expert Systems

The following list was compiled from multiple sources and represents specific areas where expert systems have proved a viable alternative for problem solution. This list is by no means all encompassing. Indeed, nearly everyday individuals and organizations discover new roles or applications for expert systems.

- Situation Assessment
- Multisensor Integration
- Data Fusion
- Weapon to Target Assignment
- Instruction
- Conceptualization
- Diagnostics
- Monitoring
- Interpreting
- Assignments
- Analysis
- Maintenance
- Checklist
- Planning

- Refining Expertise
- Increased Reliability
- Scheduling
- Consultation
- Designing
- Training
- Explanation
- Increased Consistency
- Increased Computational Speed

The following three examples were selected to represent the flexibility of expert system roles and demonstrate their potential benefits.

a. Consultancy

An important role an expert system can perform for an organization is that of a trusted consultant. Here, non-experts or non-specialists within an organization obtain the benefits of advice and problem solving approaches, when operating an expert system, that a real live expert would utilize. The expert system would thus significantly elevate the non-experts abilities within a given area. Virtually any member within an organization could improve their performance by utilizing the expert system. Additionally, the expert system will be available around the clock and cost much less than full time human experts. [Ref. 24:pp. 66-69]

b. Checklist

The expert systems ability to provide a checklist function intertwines somewhat with the consultancy role. Man, being less than perfect, is subject to occasional lapses of memory. Unfortunately, and according to Murphy's Law, the most crucial information and procedures will be forgotten at the most critical time. Stress, exhaustion, etc., only serve to further deteriorate man's ability to think rapidly and rationally. Herein lies one beauty of the expert system, by consistently querying the user on all aspects of a particular problem it will serve as a dependable checklist, ensuring that the user examines all the aspects of a particular problem necessary to arrive at a solution. [Ref. 24:pp. 66-69]

c. Refining Expertise

In this area, expert systems prove an acceptable, cost-effective method. Within a specific domain some experts or specialists possess certain weaknesses and gaps in their knowledge. Through interaction with an expert system, these individuals can identify troublesome areas and take appropriate corrective action. Another point worth mentioning, is that over a period of time, a particular expert system can accumulate input from a variety of experts, thus refining its internal expertise and providing system users with an increased capability. [Ref. 24:pp. 66-69]

H. DISTRIBUTED EXPERT SYSTEMS

One method currently under examination which would dramatically expand the scope of expert system applicability is that of distributed expert systems. Proponents envision these distributed systems possessing the ability to integrate information from a wide variety of sources, interpret and assess the inputs, and then assume an advising role. To accomplish this requires several expert systems operating in tandem. The critical point being that each expert system undertakes a specific portion of the overall problem and make results available to other expert systems within the distributed network. The various expert systems throughout the distributed network share information and data through use of a "blackboard". The blackboard is essentially a common database which can be updated, changed and accessed by all expert systems within the distributed network. The blackboard allows utilization and sharing of data between multiple expert systems without attempting to integrate widely varying subject areas (problem domains) inside a single expert system, which as discussed before, is presently infeasible. Therefore, the distributed expert system network remains the only current solution allowing expansion of the expert systems limited problem solving dimensions. [Ref. 3:p. 46]

I. ADVANTAGES OF EXPERT SYSTEMS

The following list was compiled to concisely portray the various advantages afforded to an organization through utilization of expert systems.

- An expert system can enable individuals of varying skill levels in a particular area to perform comparable to an expert within that field. [Ref. 16:p. 47]

- Utilization of expert systems can drastically decrease the number of personnel required, to perform various functions, by an organization. [Ref. 25:p. 96]

- Increased invariability, especially in stressful or time dependent environments. [Ref. 24:pp. 61-64]

- Increased availability of expert's knowledge. Often, human experts, for whatever reason, are simply not available. [Ref. 24:pp. 61-64]

- Increased ability to either quickly arrive at an answer, or try a large number of alternatives within a specified time during situation assessment. [Ref. 24:pp. 61-64]

- Programming expert system rules utilizes a format which closely approximates the English language. [Ref. 24:pp. 61-64]

- Uncertainty/probability assessments can be programmed into the rules. [Ref. 24:pp. 61-64]

- Expert systems may be employed in remote areas where it is impossible, either financially or physically to have live human experts. [Ref. 23:p. 47]

- Expert systems can significantly reduce an organizations maintenance costs. [Ref. 23:p. 47]

- Expert systems "provide quick responses during rapidly changing situations with minimal reliance on highly trained technicians/specialists." [Ref. 6:pp. 51-52]

- Expert systems provide organizations with an instant corporate memory, independent of human frailty. [Ref. 6:pp. 51-52]

- Expert systems are not subject to fatigue, stress or emotions.

- Expert systems are very user friendly, only a minimal learning curve is involved.

- Expert systems decrease training times required, along with associated expenses.

- Expert systems can assess situations where varying degrees of uncertainty exist.

J. DISADVANTAGES OF EXPERT SYSTEMS

In spite of all the capabilities and potential demonstrated by expert systems, there exist several, often significant, disadvantages. One should be cognizant of and fully understand all expert system shortcomings in order to make an informed assessment as to the applicability of them within any organization. The following list presents several disadvantages and limitations of expert systems.

- "Expert system rule maintenance presents a great challenge." [Ref. 15:p. 118]

- Time required by a knowledge engineer to extract knowledge from a human expert is not measurable, thus creating a potentially costly and timely bottleneck in expert system development. [Ref. 15:p. 115]

- To date, expert systems contain no "common sense" whatsoever, therefore individuals are required to separate meaningful statements from absurd advice. [Ref. 16:p. 47]

- Human knowledge, no matter how refined, is usually deficient in some respects. "Even human experts do not know everything, so their rules and problem solving methodologies will not cover all cases." [Ref. 16:p. 48]

- Solutions presented by expert systems "... may be reasonable to one human, and unsatisfactory to another, more sophisticated and better informed human. The sufficiency of the system is inextricably bound to the characteristics of the user." [Ref. 26:p. 12]

- Expert systems expertise is currently limited to a narrow domain.

- Difficulty in maintaining a current and accurate knowledge base.

- Lack of demonstrated learning capability.

- Lack of standardized methods and rules utilized by knowledge engineers.

- Use of expert systems increase an organization's dependence on machines.

- Deterioration of personnel skills, experience and knowledge through overdependence on expert systems.

- Time required for users to gain confidence in expert systems abilities/recommendations.

K. SUMMARY

Throughout this chapter, the area of computer science known as artificial intelligence has been broken down into various subfields and examined. Hopefully, the reader has gained an increased appreciation of this relatively new and evolutionary field. Indeed, one must understand how expert systems function, along with their capabilities and disadvantages, in order to effectively plan for and utilize them within any organization. Proper planning for an expert system's interface within an organization during the design phase is paramount.

III. MAN-MACHINE INTERFACE WITHIN SYSTEM DESIGN

A. INTRODUCTION

In this chapter the complexities surrounding system design and the division of labor between man and machine within basic command, control, communications and intelligence (C3I) architecture are explored. Additionally, this section provides guidelines and information relevant to individuals considering, designing or evaluating man-machine systems. The "machines" considered herein are computer systems and expert systems. The purpose being to evaluate the system design process by indicating which portions within C3I design architecture appear better suited for man or machine. Additionally, machine utilization of expert systems will be developed and examined. Likewise, the physical, mental and ethical aspects of human factors engineering will undergo consideration. Finally, a detailed, indepth comparison of the advantages and disadvantages of man versus machine within C3I architecture, seeking the appropriate mix of man and machine within system design, concludes the chapter. It is not the authors' intent to investigate every aspect of man-machine interaction within the framework of C3I architecture and system design, which is beyond the scope of this paper, but rather to explore selected portions perceived to be pertinent and worthy of examination.

The computerization of society, and particularly the military, advances today at virtually breakneck speed, with some systems even being declared obsolete prior to fielding. As Americans, we experience almost daily some of the most advanced technological breakthroughs known to man, yet increasingly dismiss them as being almost commonplace. Meanwhile, the computer and more importantly, computer systems, become more firmly entrenched within society and military organizations alike. These evolutionary trends are in and of themselves not bad, for computers and computer systems offer significant potential and continually demonstrate great promise in various military applications. The underlying danger, often oblivious to "technology drunk" individuals, lies in misunderstanding what computer systems can and cannot accomplish. Accordingly, grave dangers exist for organizations which misinterpret or misuse the computers capabilities, while significant benefits await those who understand the correct balance of man and machine within the basic design of C3I systems.

B. SYSTEM DESIGN CONSIDERATIONS

1. System Definition

Countless definitions of the word system abound today and the majority boil down to stating that a system consists of various elements which focus toward goal attainment or mission accomplishment. The following formal definitions of the word system appear to have gained the most widespread acceptance.

- "We may define a system as a group of components-at least some of which are pieces of equipment-designed to work together for some common purpose." [Ref. 27:pp. 13-14]

- "We will define a system as an entity that exists to carry out some purpose. It consists of people, machines and other components that interact to produce a result that these same components could not produce independently." [Ref. 28:p. 192]

2. Basic System Design Overview

By nature, some systems are relatively simple, while others are frighteningly complex. Therefore, the design of systems becomes extremely important, particularly those aspects concerning the interface of technology and man. Simply stated, common sense coupled with a pragmatic approach should be the norm and not the exception throughout the entire system design process. Accordingly, a relatively simple system, requiring low levels of maintenance and training, which works, should be preferred to the latest "high tech", intricate system which requires more time for repair than solving algorithms. The military application arena of such systems demands and requires nothing less.

a. Stating Requirements

This brings attention to perhaps the largest problem in system design: the user's inability to properly describe system requirements to the contractor. The requesting organization must first examine it's goals/users and then properly state all specific requirements to the contractor. Also, the system should be designed specifically for the organization which will utilize it for goal attainment. To most individuals, the above seems almost too trite to even mention, however, the millions of dollars and time lost by the military and private industry every year for abandoning common sense and forgetting the basics of system design appears almost criminal.

b. Technology Ignorance

Another snag surfaces when Americans, by their nature, seek purely technological solutions to the majority of their problems. An inherent danger in the C3I system design architecture occurs when one allows technology to significantly influence or overinfluence system design. Modern technology per se (or it's influence) is clearly not bad. It is only when too much focus on technology causes one to lose sight of system design considerations or goals that technology becomes a problem.

c. Information Considerations

An additonal, important aspect of system design is that the architecture must pass the right information to the right people at the right time. Implicit in the above lies the premise of not overloading decision makers with sheer mountains of data. Rather, the system design should ensure the decision maker receives the requisite quantity of quality information, at the correct time, to make an informed decision. (A distinction is probably well advised at this point, information should be considered as a filtered, finished product while data consists of raw, unprocessed intelligence.)

d. Redundancy

Astute system designers will ensure their C3I architectures afford the user some degree of redundancy. This gives the future user several options to continue operating when a portion of the system crashes. The current "buzzword" for the benefits of redundancy is: "graceful degradation". Most catastrophic system failures can be prevented by designing a self-diagnostic capability into the system. Proper system design should also address the means to minimize uncertainty when encountered.

e. Design Approach

The systems design approach should address the system as a whole rather than separate fragments. The peril here being, that if a system is carefully designed, yet constructed in pieces, then the individual portions probably function fine, however when merged together, the system becomes dysfunctional. Common sense should dictate that this not occur. However, the push for project completion may well blind even competent systems designers, wasting millions of dollars, while still leaving using organizations without a required system.

f. Functional Component Tasking

Once the user adequately states the organizations requirements, the system designer must consider functional component tasking. Actually, the designer faces two separate dilemmas, first he must decide which functions within the system will be done by man and which will be accomplished by automation. Secondly, the designer should strive for a functional interface between man and machine. The science of Human Factors Engineering, or Ergonomics, attempts to simplify transition points within a system where man meets machine. Thus, system designers must assess each area within the system architecture and appropriately assign responsibility to either man or machine based upon the respective strengths and weaknesses of each. At the outset, such assignments appear rather straight forward, however, the many tradeoffs in performance usually require detailed examination in the assessment process. This determination process should also address ethical questions, which are critical to system design and should not be dismissed as trivial. Improper tasking of man-machine functions can lead to disastrous consequences for C3I architecture. Therefore, a thorough comparison of the advantages and disadvantages concerning assignment of responsibility within a system to man or machine proves essential to successful C3I system design.

3. Specific Military System Design Considerations

Within the confines of military applications there exist several unique systems design considerations which must be confronted and compensated for by system designers in order to produce an acceptable or operational system. First of all, the majority of functional commercial expert systems correctly examine narrow problem domains with well-defined knowledge bases. Conversely, the majority of military related expert system applications must tackle broad, ill-defined problem domains with often speculative or at best poorly constructed knowledge bases. Secondly, most commercial expert systems are utilized by a small, well educated and non-diverse user base. Unfortunately, the inevitable personnel turbulence found within the military infrastructure presents the system designer with a broad user base of greatly varying experience and educational levels. Therefore, the demographics of military personnel utilizing such systems force system designers to create more universal, user friendly systems. Finally, the unique aspects of the military's Planning, Programming and Budgeting System often sends mixed signals to civilian contractors designing systems for the military. This sometimes creates a feast or famine atmosphere to contractors vying for government contracts. Often, in their frantic bids to procure lucrative government contracts, these firms forget the basic principles of good system design and consequently deliver substandard systems. [Ref. 29:p. 6]

4. Decision Making System Design Considerations

Another aspect which system designers must take into consideration concerns designing a system able to accommodate the diverse decision making characteristics and styles present within the user population. Failure to consider these varying decision making styles may result in a system unable to properly support a diverse user clientele. According to R. W. Bailey in Human Performance Engineering, there are basically four decision making characteristics, listed below, which the designer must consider during system development. [Ref. 28:p. 144]

- Users usually wait longer to decide than needed (over-accumulate information)
- Users tend not to use all available information
- Users tend to be hesitant in revising original opinions, even if new information warrants revision
- Users usually consider too few alternatives.

5. Penalties of Poor System Design

Quite often, a pressing operational need or requirement of tactical forces in the military requires the creation of a new system. At times, rapid fielding of this system takes precedence or priority over common sense procurement evolution and system design. A corporation which successfully underbids the competition for a particular system may have financially overextended themselves and, in the inevitable cost cutting measures, siphon money from the important system design effort, eventually producing a flawed system. Unfortunately, practices such as these have occurred in the past and will probably continue in the future. There are many factors including incompetent, poorly motivated and ignored system designers which can lead to the creation of poorly designed systems. Managerial personnel should be well aware of the penalties for allowing poor system design. Corrective actions generally result costing organizations several times more in manpower, time and money than would have been incurred in adhering to the widely accepted proper system design format. In his book, New Horizons for Human Factors in Design, R. Dale Huchingson presents the following sobering consequences of poor system design: [Ref. 30:p. 19]

- Underestimating costs (manufacture, utilization, repair)
- Inefficient use of human resources
- Duplicated efforts
- Insufficient definition of requirements
- Unrealistic scheduling
- Work slippages
- Late delivery of end items
- Increased probability of accidents, misuse.

C. STEPS IN THE SYSTEM DESIGN PROCESS

Over the years many knowledgeable individuals interested in the discipline of system design have attempted to perfect a logically developing process of system design--generically applicable to the development of any system. Remarkably, the majority of the results are quite similar. Purists in the system design field will argue that "cookbook checklists" cannot apply to system design. However, the most respected authors on the subject agree that judicious application of the system design process steps, coupled with common sense, will in the end produce an acceptable system. Figure 3-1, [Ref. 31:p. 522], illustrates the significant stages contained in the system design process, each of which warrants further comment.

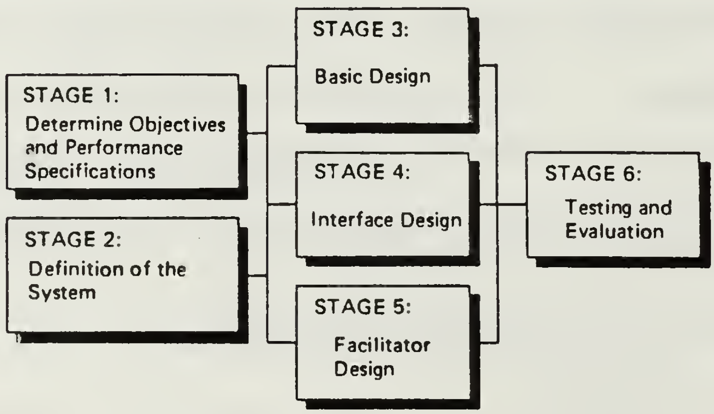


Figure 3-1. Major Steps in the System Design Process

1. <u>Stage One</u>

Stage 1 consists of determining objectives and performance specifications. Basically, during this stage the systems purpose and performance parameters (in the form of requirements and constraints) are stated in somewhat general terms. This stage, though general in nature, should not be taken lightly for performance requirements will often exert significant influence over later stages in the system design process. Probably two important points to consider at this juncture would be the identification of the probable user community and the environment, both physical and social, where the system will be employed. [Ref. 28:pp. 195-198]

2. Stage Two

The definition of the system is presented during the second stage of system development. The major effort consists of delineating functions that the system must accomplish in order to satisfy performance specifications and objectives outlined in Stage 1. Functional flow diagrams are often employed at this time to aid in understanding general relations within the system. At this stage, system designers talk in general terms of what functions will be required to accomplish stated objectives and are not concerned with the specifics of how such functions will be accomplished. [Ref. 31:pp. 523-524]

3. Stage Three

Stage 3 examines the system's basic design. The following four major factors are determined at this point: allocation of tasks to man or machine, expected human performance requirements, task analysis, and job design. The allocation of functions to man or machine requires the system designers to consider the advantages/disadvantages of man and machine relative to the required task and make a decision as to which will perform a given assignment. A detailed examination of this intricate process occurs later in this chapter. Likewise, human performance parameters in the form of specifications must be detailed for each function to be satisfactorily completed. Task analysis covers design of human-machine interface points, writing instruction manuals, examining personnel requirements and producing training and evaluation methods. [Ref. 31:pp. 525-531]

4. Stage Four

Stage 4 consists of interface design and is where human factors engineers should exert a great deal of influence. Specific equipment and software designs for all areas of man-machine interaction throughout the system undergo scrutiny and are finalized. The human factors engineers most significant contributions during this stage are to ensure that designs at all man-machine interface points conform to human capabilities and limitations. [Ref. 28:p. 207]

5. Stage Five

At this juncture in the system design process, personnel begin to develop facilitator designs. These consist of creating aids which will help personnel to understand the system's functioning and most importantly, their specific man-machine interface role. Thus, the inherent purpose of facilitators is to enhance human performance within the system. These facilitators take the form of written instructions, performance aids and selected training classes. [Ref. 28:pp. 207-208]

6. Stage Six

The final stage in the system design process consists of developing adequate testing and evaluation procedures. The key in this final step involves pertinent testing coupled with realistic measures of performance or effectiveness which will produce valuable feedback information concerning system operation and design. Evaluation concerns how the system performs as well as how the human factors engineering at man-machine interface points has faired. Adequate feedback, provided by sound testing and evaluation methods, allows system designers to first identify and then correct flaws within the system during this iterative process. [Ref. 31:p. 538]

D. HUMAN FACTORS ENGINEERING/ERGONOMICS

One important aspect within the system design process which possesses significant ramifications, depending upon employment methodology, is human factors engineering or ergonomics. Adequate human factors engineering concerns, correctly applied throughout the system design process, greatly enhance the probability of successful system design. Conversely, downplaying the significance of human factors engineering throughout the system design process will certainly produce flawed designs, sub-par systems and their associated costs. Therefore, it is extremely important that managers understand the important contributions of human factors engineering to the overall system design process. Indeed,

> Not considering human performance in the human/computer interface frequently results in large numbers of errors, requires huge amounts of training time, and causes user frustration and dissatisfaction. [Ref. 28: p. 293]

1. Definition of Human Factors Engineering/Ergonomics

Human factors engineering or ergonomics have existed in some way shape or form for several centuries, mostly under the guise of common sense. However, it has only been within the last century, that this discipline has emerged, gaining both acceptance and recognition. Prior to proceeding further, a formal definition of the terms human factors engineering and ergonomics are in order.

First a minor distinction, human factors engineering and ergonomics are considered throughout the profession to be synonymous in meaning and context. However, human factors engineering is the term used within the geographical confines of America, while the remainder of the world and especially Europe, favor the term ergonomics. [Ref. 31:p. 4]

Thus, human factors engineering or ergonomics, depending upon your geographic distribution

> ...focuses on human beings and their interaction with products, equipment, facilities, procedures, and environments used in work and everyday living. The emphasis is on human beings (as opposed to engineering, where the emphasis is more on strictly technical engineering considerations) and how the design of things influences

people. Human factors, then, seeks to change the things people use and the environments in which they use these things to better match the capabilities, limitations, and needs of people. [Ref. 31:p. 4]

Therefore, the main theme of human factors engineering concerns the "...application of relevant information about human capabilities and behavior to the design of objects, facilities, procedures and environments that people use." [Ref. 31:p.4] This leads to the conclusion that human factors engineering "...efforts are directed toward designing things people use in order to enhance performance and minimize errors." [Ref. 31:p. 606]

2. Objectives of Human Factors Engineering

The majority of human factors engineering objectives focus upon decreasing the probability of human error and increasing human performance potential. When glancing through the list of human factors engineering objectives, one can rapidly surmise the significant impact human factors engineering has within the system design process. The following objectives of human factors engineering were presented by Balbir S. Dhillon in his book, Human Reliability with Human Factors. [Ref 32:p. 197]

- To reduce losses from accidents and misuse
- To improve user acceptance
- To improve human performance and manpower utilization
- To reduce the costs of training
- To improve the economy of maintenance
- To improve human reliability.

3. Human Factors Engineering Doctrine/Guidelines

As in any field or discipline, those working in the area of human factors engineering have created an accepted basic doctrine. Mark Saunders and Ernest McCormick in their book, Human Factors in Engineering and Design, imply that the majority of human factors engineers practice and live by the following guidelines. [Ref. 31:p. 5]

- Commitment to the idea that things, machines, etc. are built to serve humans and must be designed always with the user in mind.

- Recognition of individual differences in human capabilities and limitations and an appreciation for their design implications.

- Conviction that the design of things, procedures, etc. influences human behavior and well-being.

- Emphasis on empirical data and evaluation in the design process.

- Reliance on the scientific method and the use of objective data to test hypotheses and generate basic data about human behavior.

- Commitment to a systems orientation and a recognition that things, procedures, environments, and people do not exist in isolation.

4. Human Factors Engineering Considerations

There are many human factors engineering considerations involved in the system design process. It is essential that all human factors engineering considerations are examined, understood and resolved as soon as possible in the system design process, so as to allow the system design process to proceed in a logical and orderly manner. In his book, New Horizons for Human Factors in Design, R. Dale

Huchingson, a noted professor of human factors, lists the following human factors engineering considerations. [Ref. 30:pp. 6-7]

- Do we need the human at all? Can the human, as a systems component, contribute something to the functioning of the system that is going to be designed and built?

- If needed, what functions should the human perform as the primary controller; which functions should be automated; which functions should one only monitor and serve as a backup element to override automatic control in the event this system should fail?

- Accomplishment of each human function requires a series of tasks. How should these tasks be organized into jobs so that the task demands are not too great for any single operator? Who does what and how?

- What human-machine equipment is required? How should it be designed and arranged to facilitate performance?

- How can the operator be best protected from the ambient environment during the operational mission? What is required to sustain the operator in terms of air pressure and oxygen, food and water, and other life-support provisions.

- What kind of person is needed for the various jobs? The tasks defined earlier must be broken down into the skills and knowledge required to effectively perform each task.

- After selection of personnel, the practical problem remains: How can we best teach the system user? Where and how should this teaching be accomplished? Again, the task descriptions may serve as the groundwork for a training syllabus. But the user will need also special training equipment, job aids, technical manuals, and checklists.

- Finally, throughout the development of a personnel subsystem, it is important to know how valid were the decisions that were made to each of the above questions. The questions imply a test program to evaluate the system under development.

5. Advantages of Human Factors Engineering Within Systems Design

By now, one should begin to envision the immense significance and ramifications of human factors engineering within the system design process. Managers must comprehend the enormous advantages associated with the proper employment of human factors engineering considerations within the system design process. The following list, presented by Balbir S. Dhillon, in his book, Human Reliability with Human Factors, portrays in a concise and convincing manner the many advantages of utilizing human factors engineering considerations within the system design process. [Ref. 32:p. 207]

- It helps reduce potential human errors.
- It can increase system safety.
- It helps to reduce difficulties in learning equipment operation.
- It can increase productivity.
- It helps to reduce difficulties in learning system maintenance.
- It helps to reduce the cost of personnel training and selection.
- It helps to reduce equipment downtime.
- It can reduce operator fatigue.
- It can provide greater comfort to operators.
- It is useful for reducing the occurrence of accidents and injuries.
- It helps to improve user acceptance.

6. Human Factors Engineering Within Military Systems

The increasing recognition of the significant advantages obtained by including human factors engineering considerations within the system design process has led to a whole-hearted endorsement by the military for utilization of human factors engineering by contractors in the design of military systems. Probably one of the primary reasons concerns the unpredictable yearly military budget and funding problems inherent in the Planning, Programming and Budgeting System. A properly designed and engineered system, political considerations excluded, possesses the greatest probability of being actually fielded. Systems which are delayed by design flaws attributed to poor human factors engineering practices prolong their exposure to the PPBS, thus increasing their probability of being cancelled. This result benefits none concerned, and continues to deprive operational forces of a needed system. Therefore, one can rapidly surmise why the military decided to push human factors engineering. In fact, Balbir S. Dhillon, in one of his books, Human Reliability with Human Factors, describes how military specification MIL-H-46855B (Human Engineering Requirements for Military Systems, Equipment and Facilities) aides the military establishment. [Ref. 32:p. 223]

- It defines the human factors needs applicable at the time when contractors respond to requests for proposals by the military.

- It helps the military procurement agency to have effective control of the human factors engineering effort.

- It defines the human factors needs during the research design and development, test and evaluation phases.

- It helps in the assessment (with the aid of information provided by the contractor) of the contractor's capability with respect to human factors engineering.

- It defines the nature and scope of work to be performed by the contractor with respect to human factors.

E. MAN-MACHINE SYSTEMS

1. Definition of Man-Machine Systems

In spite of man's continued technological advances, no system presently exists totally free of dependence upon man in some manner. This caused the emergence of human factors engineering as discussed previously and also created considerable controversy over what has grown to be called man-machine systems. In the most basic sense, a man-machine system is a system wherein interaction of man and machine occurs, producing a desirable result. Alphonse Chapanis, a noted human factors pioneer, defines a man-machine system simply as

> ...an equipment system in which at least one of the components is a human being who interacts with or intervenes in the operation of the machine components of the system from time to time. [Ref 27:p. 16]

Ronald Erickson feels that,

> A man-machine system is a set of interacting components composed of humans and machines (including software) directed toward performing a function or number of functions and operating within the constraints of time and specified environments. [Ref. 33:p. 6]

2. Classes of Man-Machine Systems

There exists a means by which man-machine systems are classified. The characterization criteria concerns the level of man versus machine control and consists of the following three classes: manual systems, mechanical systems and automated systems. Figure 3-2 illustrates manual, semiautomatic and automatic types of man-machine systems. [Ref. 31:p. 13]

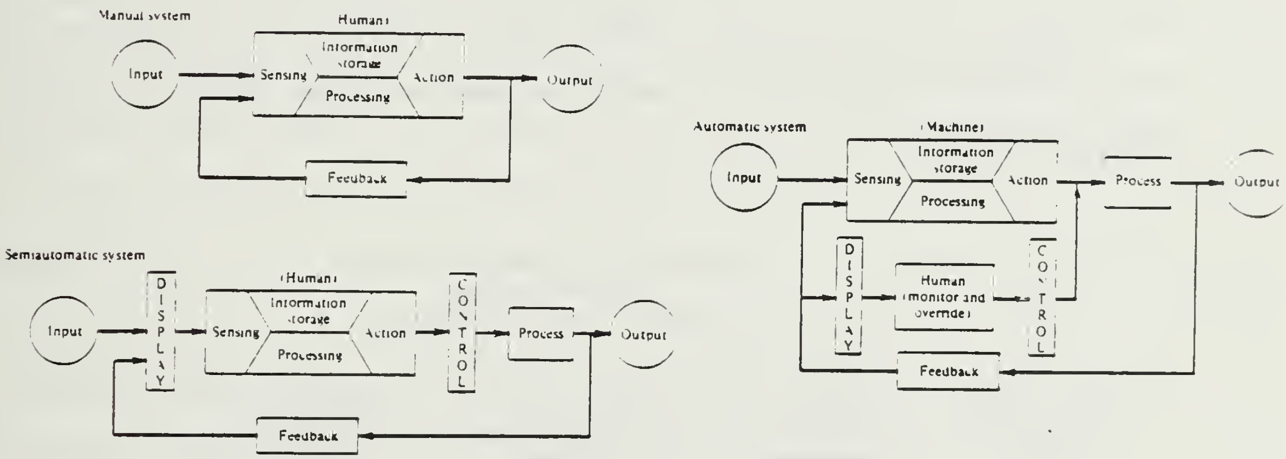


Figure 3-2. Types of Man-Machine Systems.

Basically, a manual system consists of a combination of simple tools and man, with man providing the control and muscle power for operation. Mechanical systems are also commonly referred to as semiautomatic systems. These consist of more complex machines functioning under their own power while directed and controlled by a human operator. Automated systems are those systems where the machine provides it's own power and direction. One should be cautioned that even automated systems require human intervention for installation, maintenance, programming, monitoring, and override capability. [Ref. 31:pp. 13-14]

3. Basic Man-Machine Functions

Within any man-machine system the various components working toward goal fulfillment are either man or machine. These components, or a combination thereof, are responsible for performing the four basic functions of a man-machine system: sensing, information storage, information processing and decision, and action functions. Figure 3-3 diagrams the basic functions within a generic man-machine system. [Ref. 31:pp. 15-16]

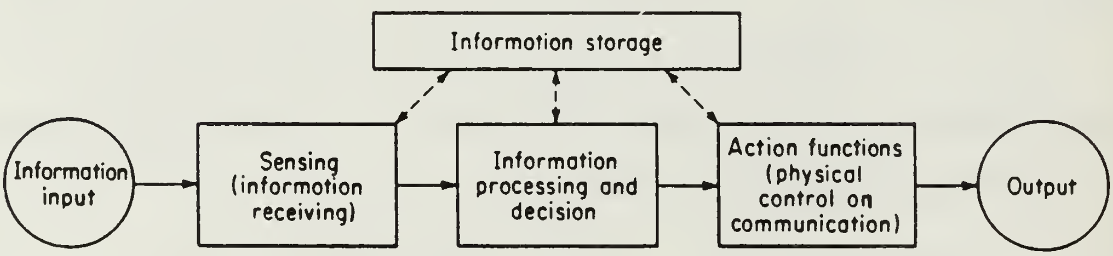


Figure 3-3. Functions Within Man-Machine Systems

F. ADVANTAGES OF AUTOMATION

The utilization of computers within the realm of C3I system architecture continues to increase at an alarming rate. To the uninformed, it appears that "computers do it all"; however, this is not, and should never be the case. System designers should be intimately aware of the advantages/disadvantages associated with automation and accordingly position machines within areas of the system from which man can take advantage of the computer's positive aspects. Indeed,

> ...the increase in battlefield information rate brought about by modern weapons, sensors and tactics requires selective but extensive application of automation to assist commanders and their staffs in reaching timely and appropriate decisions. [Ref. 34:p. 618]

1. Computational Ability

First of all, no sane man would disagree with the statement that the computers "number crunching" ability to rapidly perform complex mathematical computations vastly exceeds that of man. Likewise, the computer can rapidly and reliably execute well-defined and, therefore, routine operations, while man monitors the tasking and setting of goals. Thus, in areas throughout the system where sheer computational rapidity of well-defined, routine operations is desired, system designers would be well advised to employ computers.

2. Software Compatibility

Unlike man, if several computers within a distributed system, utilizing the same software packages are given the same input, the output will be the same. Thus, discrepancies such as differing levels of intelligence and training (commonplace among man) would not enter into the process causing varying degrees of output. This advantage of automation would be an extremely desirable characteristic for deployed and scattered units, for when given similar input data packages, the resulting output would be the same.

3. Time Reduction

Undoubtedly, one of the key contributions made by the computer, and one recognized by the Soviets and Americans alike, is that the computer's power returns valuable time back to the commander or decision maker. When properly programmed, computers evaluate given options (provided the task has been well-defined) in a fraction of the time required by man. This allows the commander or decision maker the option of placing more time into making the decision, or to rapidly make the decision, which then cascades more time to subordinates. Either way, this aspect of automation, if properly factored into system design, lends increased flexibility to the commander. [Ref. 35:p. 3]

4. Expert Systems

One of the most controversial areas within automation today resides within the realm of expert systems and artificial intelligence. This area contains great potential for C3I systems. However, if not properly understood, expert systems can create a multitude of problems. Expert systems function quite well, within a narrow problem domain while having access to an adequate knowledge base. The specific advantages of expert systems were covered in Chapter II. System designers must remember that expert systems follow only programmed rules and quite rigidly. With this in mind, the following two examples portray areas where expert systems could provide exceptional service.

When given enemy targets, expert systems within a Fire Support Coordination Center could provide rapid targeting options and recommend a prioritized listing of engagement systems and munitions. In this operational mode, the expert system matches the best employment systems with the most effective munitions for the noted target.

A rule based expert system will assess human generated courses of action against a given threat in a fraction of the time required by a normal staff. An expert system employed in this fashion provides agencies with additional planning, decision and execution time. One should be cautioned that such models are a valuable means to gain knowledge, but should not be interpreted as a definitive, absolute answer. Man must carefully review the expert system recommendations before making a decision. Likewise, man must also be aware upon what "rules" the decision is based.

5. Automation Advantages Checklist

The following list appeared in Sander's and McCormick's Human Factors in Engineering and Design, and is intended to provide the reader with a ready reference showing the advantages of machines in the performance of tasks. [Ref. 31:pp. 526-527]

Machines are generally better in their abilities to:

- Sense stimuli outside the normal range of human sensitivity, such as x-rays, radar wavelengths, and ultrasonic vibrations

- Apply deductive reasoning, such as recognizing stimuli as belonging to a general class (when the characteristics of the class need to be specified)

- Monitor for prespecified events, especially infrequent ones (but machines cannot improvise in case of unanticipated types of events)

- Store coded information quickly and in substantial quantity (for example, large sets of numerical values can be stored very quickly)

- Retrieve coded information quickly and accurately when specifically requested (although specific instructions need to be provided on the type of information to be recalled)

- Process quantative information following specified programs

- Make rapid and consistent responses to input signals

- Perform repetitive activities reliably

- Exert considerable physical force in a highly controlled manner

- Maintain performance over extended periods (machines typically do not "fatigue" as rapidly as humans)

- Count or measure physical quantities

- Perform several programmed activities simultaneously

- Maintain efficient operations under conditions of heavy load (humans have relatively limited channel capacity)

- Maintain efficient operations under distractions

6. Summary

When properly understood, the future uses of computers and expert systems within any man-machine system are limited only by man's imagination, for these systems, when properly understood and appreciated, are adaptable to most situations. Thus, system designers and managers should recognize the enormous capabilities of computer/expert systems and judiciously capitalize upon their strengths within the design of C3I systems

G. WEAKNESSES WITHIN AUTOMATION

Automation, like just about everything else in the world, presents many unique problems to man and in particular to system designers. The challenge is for system designers to recognize computer/automation shortcomings and then work around them within the C3I architecture by utilizing effective human interfaces. The following areas continually challenge and frustrate system designers.

1. Power Requirements

Computers require a constant, unswerving electrical power source. Even minor power fluctuations can abort running programs as well as sabotage information stored in databases. Therefore, when depending upon computer systems for important organizational requirements, a reliable primary power source, along with a ready back-up power system should be in place.

2. Environmental Dependency

Even with all the modern technological advances in the field, computer performance remains highly dependent upon the environment. Today's high speed computers generate elevated levels of heat, thus requiring temperature and humidity controlled spaces to properly function. Providing such amenities for systems under mobile combat conditions may prove difficult.

3. EMP Vulnerability

Modern computer and automation systems, being "chip dependent" are extremely vulnerable to the effects of Electro Magnetic Pulse (EMP) generation. Thus, system designers are confronted with answering the question, "What level of survivability does the system require?" Adequate EMP hardening escalates cost and usually requires a fixed site, which fails to support mobile operations required in modern combat, thus providing the enemy with relatively simple targeting options.

4. Human Overreliance

Commanders, as well as system designers, who utilize and design expert systems and decision aides should recognize that if personnel are "...continually relying on a decision system to make decisions for them, through observation by the enemy, our actions could become very predictable." [Ref. 36:p. 46] Repercussions of this practice could be disastrous, especially if commanders inadvertently telegraph every future movement and decision to the enemy thru constant reliance on expert systems and decision aids. This overreliance could cause disruption of human creativity and spontaneity, thus leading to total predictability.

5. Programming Requirements

Several inherent weaknesses reside within the basic framework of the expert system itself. First, the expert system relies upon a set of rules programmed into the system. Any inputs to the expert system flow through those rules and those rules only. System designers should be very cognizant of the above, for by it's nature, the expert system is extremely inflexible and thus unable to adequately respond or interpret data which it cannot process through preprogrammed rules. Thus, the expert system performs poorly upon encountering situations not accounted for within the rules.

6. Constant Database Update

In today's world, technology, equipment, strategy, tactics, etc., undergo frequent change. System designers must grasp this point and understand that expert system rules and databases require constant updating as change occurs in order to remain current and reliable. Ease of database and rule update should be a primary consideration of system designers. An expert system's inability to respond in situations for which programmed directions or rules do not exist can cause enormous problems, which magnifies the importance for a rapid database and rule update capability.

7. Inflexible Rules

Probably the greatest weakness of any expert system lies within the rules. The computer always follows the programmed rules, never deviating from them. These rules are supposed to be written by "human experts" within the discipline that the particular expert system supports. Rules should be proven or accepted formulas and doctrine, intertwined with the "experts" personal problem solving insights. Thus, if the "expert" writing the rules is not very good or thorough, the resulting expert system won't be either. Quality output of an expert system is a function of the quality of rules input. The old adage "garbage in results in garbage out" applies.

8. Lack of Judgment

Because human judgment and intuition cannot be transcribed into a rule based system, an expert system experiences difficulty in interpreting the intent or initiation of certain critical events (i.e., political, social, economic, and military). Therefore, expert systems may not properly detect or interpret early warning signs of potentially escalatory situations. In today's world, even a slight lag in classifying a potential adversary's intent could prove very costly.

9. Machine Error

Another weakness in automation that one must not totally discount is the realistic probability of computer or expert system error. Although the frequency of computer error is extremely low, the repercussions may be extremely high, particularly in national defense and early warning systems. Indeed,

> On rare occasions a machine may give a wrong answer to the tune of several magnitudes. A human operator when asked the same question may get a wrong answer more often, but seldom with as spectacular an error as that liable to be produced by a machine. [Ref. 37:p. 63]

10. Summary

One does not have to look far within the world of automation to notice a variety of shortcomings in computer and expert systems. The challenge becomes that of not becoming overwhelmed by what appears to some to be an "end all, cure all" solution. The astute system designer should recognize the constraints/weaknesses of computer and expert systems and keep them out of areas within C3I architecture where they could cause significant problems.

H. THE ARGUMENT FOR MAN

The following section examines the usefulness of man within the C3I architecture. Regardless of what the world's "technocrats" would have one believe, man stands head and shoulders above machine in many significant mental, physical and ethical aspects.

1. Flexibility

First of all, humans possess several intangible abilities, which psychologists refer to as "higher mental processes". Thus, man has purpose and can teach himself what he needs to know in order to achieve his goals. Possession of these "higher mental processes" affords man the

> ...ability to remember, to compare what he learned during training, or to coordinate what he perceives with the strategies he may have formed for handling similar events. He is not necessarily aware that he is doing these things. [Ref. 27:pp. 18-19]

This innate natural flexibility should be recognized by system designers and influence C3I architecture accordingly. The key point being that because of his ability to rapidly adapt to changing situations, man should closely monitor computer and expert systems to prevent possible conflicts. Therefore, man must have the ability to stop or override the computer or expert system at any point.

2. <u>Sensing</u>

One physical attribute possessed by man which a computer cannot come close to matching is the eye. The human eye far exceeds the computer's capacity to detect items when only given partial or incomplete information. In fact,

> Few of us appreciate, for example, what a marvelous transducer we have in the human eye. With this instrument, a normal human being can, under good conditions, see a wire 1/16 inch in diameter at a distance of half a mile. It is so sensitive that when fully dark adapted, the average person can see the flare of a match 50 miles away on a clear dark night....The average person, moreover, can discriminate several hundred thousand different colors. There is no single physical instrument that even begins to approach the flexibility and sensitivity of the human eye. [Ref. 27:pp. 36-37]

3. <u>Maintenance</u>

In spite of all the speed and computational abilities possessed by computer and expert systems, they remain completely dependent upon man for programming, maintenance and rule composition. Without man, these impressive machines have no guidance or ability to physically function. Human experts from particular disciplines are required to transfer their decision making processes and knowledge to machines in the form of rules, so that expert systems can properly function.

4. Common Sense

In fact, "Humans appear to surpass machines in detection, pattern recognition, flexibility, long term memory, inductive reasoning and judgement." [Ref. 37:p. 61] Perhaps an easier way to describe the above quotation would be to say that most humans possess that intangible trait, often referred to as "common sense". Common sense prevails when all else fails. This trait allows man to successfully solve unpredictable and unexpected problems under changing conditions. Because of man's flexibility and ability to respond to stochastic situations, he should remain the final decision maker at critical points within an C3I architecture.

5. Ethical Considerations

Major ethical questions should arise anytime a system designer creates a system where a machine is given the authority to make a final decision. Machines, not being human, cannot be held accountable for their action, much less their decisions. K. G. Corkindale, a noted human factors engineer, states that,

> It is generally accepted that responsibility can be assigned to men only, which means that in many situations the task allocation will be to man rather than to a machine as the consequences of an inappropriate response may be extremely serious. [Ref. 37:p. 64]

6. Human Advantage Checklist

The following list appeared in Sander's and McCormick's Human Factors in Engineering and Design, and is intended to provide the reader with a ready reference showing the advantages of humans vis-a-vis machines in the performance of tasks. [Ref. 31:p. 526]

- Sense very low levels of certain kinds of stimuli: visual, auditory, tactual, olfactory, and taste
- Detect stimuli against high-noise background, such blips on CRT displays with poor reception
- Recognize patterns of complex stimuli which may vary from situation to situation, such as objects in aerial photographs and speech sounds
- Sense unusual and unexpected events in the environment
- Store (remember) large amounts of information over long periods (better for remembering principles and strategies than masses of detailed information)
- Retrieve pertinent information from storage (recall), frequently retrieving many related items of information (but reliability of recall is low)
- Draw upon varied experience in making decisions; adapt decisions to situational requirements; act in emergencies (do not require previous "programming" for all situations)
- Select alternative modes of operation if certain modes fail

- Reason inductively, generalizing from observations
- Apply principles to solutions of varied problems
- Make subjective estimates and evaluations
- Develop entirely new solutions
- Concentrate on most important activities when overload conditions require
- Adapt physical response (within reason) to variations in operational requirements

7. Summary

Man does possess many characteristics which computer or expert systems never will, his adeptness and knack to react to the fluid nature of combat operations should impress upon system designers that in man-machine systems, man must always remain in control (or have the ability to take control) at all times.

I. SHORTCOMINGS OF MAN

All men are different. Such a short statement, but to system designers the implications are enormous and often insurmountable. In spite of all the positive attributes possessed by man, there exist many shortcomings within this creature that system designers must both comprehend and address.

1. Bounded Rationality

One of man's most glaring shortcomings lies in his inability to consider more than a few factors simultaneously. Thus, unlike machines, man approaches information overload or "bounded rationality" rather quickly. D. Whitfield, an expert within the field of computer science, feels that

> ...in allocating specific functions to human operations...one...must ensure their distinctive qualities are fully exploited, but he must also guard against overloading operators. [Ref. 38:p. 54]

This point should not go unnoticed by system designers, and throughout C3I architecture, the number of tasks allocated to human operators must be carefully examined to ensure certain nodes of the system are not subjected to information overload. Such points would become bottlenecks or chokepoints, eventually degrading the entire systems performance.

2. Biological/Physical Requirements

Being human, man requires several physical necessities not needed by machine such as: sleep, food, water and air. This means that while computers can function effectively around the clock, man cannot. In addition, fluctuations both above and below certain environmental thresholds, such as temperature and humidity, cannot be tolerated by man. This restricts man's usefulness within a system, for while one machine can perform the same task 24 hours a day, it will require 3-4 men to perform supervisory duties during the same time period.

3. Variance

Other difficulties associated with the physical and mental variances of man are his limited attention span, motivational problems, size and age differences, boredom, emotions, and most importantly, stress. Even when machines and computers are run around the clock, they experience none of the above, not even stress. These faults, in and of themselves are not crippling, however when one realizes that each individual human within the system exhibits varying levels of reaction to the above, the inevitable question of consistency arises.

4. Inconsistency

Every human being possesses differing levels of intelligence, comprehension and reasoning abilities, while machines or computers demonstrate steady and constant performance. Such inconsistency forces system designers to be extremely careful in areas of man-machine interface where congruity is the primary, overriding consideration. The nature of rapid personnel turnover within the military only serves to exacerbate the predicament. Man-machine interfaces must then be devised such that humans, possessing varying mentalities and sizes, can quickly master all tasks within their areas of responsibility.

5. Information Retention

Beyond the basic factor of widely disparate human intelligence variations lies the foggy realm of information retention ability. It is widely accepted that the "normal" human being can remember no more than seven discrete "chunks" of information given to them unless time is available for them to satisfactorily store the information in long term memory. This drawback relates quite obviously to the relatively low information overload threshold attributed to man. On the other hand, a computer or expert systems memory capability is enormous and constantly expanding with technology, which unfortunately, cannot solve man's memory retention problems. [Ref. 39:p. 16]

J. SUMMARY

In retrospect, the question of man or machine within the confines of system design is not quite as "cut and dry" as one might have originally envisioned. In the final analysis, both possess numerous, irrefutable strengths and weaknesses. The key challenge for system designers is to recognize these and accordingly assign responsibility to either man or machine throughout all levels of C3I architecture, allowing both to function in a coordinated manner, striving to achieve overall system goals. Of particular concern remains an effective and efficient man-machine interface within the system. Without a doubt, ultimate and positive control of any C3I system must rest solely with man due to his superior judgement, flexibility and creativity. Although, one should not lose sight of the enormous support and computational power embodied in computer and expert systems available to assist man in reaching decisions.

> ...man and computer should be regarded as a system, with man as the main focus of the design process. The computer should be regarded as subservant to human needs "emancipating" the user by extending his memory and reasoning power. [Ref. 40:p. 3]

IV. ARTIFICIAL INTELLIGENCE APPLICATIONS WITHIN THE MARINE CORPS

A. INTRODUCTION

There exists no time like the present for the United States Marine Corps to carefully examine the application of artificial intelligence technology, particularly expert systems, to enhance the operational and administrative performance of Marines throughout the broad spectrum of military occupational specialties within the Corps. As mentioned previously, artificial intelligence contains the following subfields: expert or knowledge based systems, natural language processing, artificial or computer vision, sound sensing/understanding, and robotics. Each of these subfields of artificial intelligence shows great promise in various areas of military application. This thesis will continue to concentrate singularly on the merits of expert system technology applications in the Marine Corps, eventually focusing on fire support coordination. The value of expert systems has been validated in civilian and industrial communities. Through increased research, application, technological progress and attention, problems experienced while implementing expert system technology should be surmounted. Our sister services and the Soviet Union recognize the current capabilities and future potential embodied in application of artificial intelligence, particularly expert systems, to military organizations in general.

The main obstacle confronting the implementation of artificial intelligence and expert system technology into the United States Marine Corps appears to be a lack of exposure throughout the hierarchy of command. Without a doubt, the operational requirement for expert system technology exists and can be validated. The challenges of modern combat facing the Marine Corps demand that upper echelons of command recognize the value of bringing the vast potential associated with artificial intelligence and expert systems into the Marine Corps community. The intricacies of acquiring new military systems contained within the Planning, Programming, and Budgeting System, demand decisive action now in order to place artificial intelligence and expert system technology into the hands of Fleet Marine Force Marines within a reasonable timeframe.

Acknowledging that cost will be an initial primary consideration, the Marine Corps must judiciously examine applications of expert system technology throughout the entire organization, focusing developmental efforts on areas where the benefits of expert systems could return the greatest results. Governmental funding of significant research and development efforts in the realm of artificial intelligence and expert systems, most notably within the

Defense Advanced Research Programs Agency (DARPA), combined with advances made in private industry, will soon trigger reduction of the high costs currently associated with artificial intelligence and expert systems. This would be similar to the history of computer technology, where over a relatively short time period, computational abilities have increased drastically, while prices have dramatically declined. The principles of economics should, with the aid of time, solve artificial intelligence's initial cost problem.

However, excellence should not be dismissed or delayed simply on the basis of expense. Certainly, to place the enormous capabilities of artificial intelligence and expert systems into the hands of Fleet Marine Force Marines will be expensive and necessitate a hardline review of the allocation of future Marine Corps budget dollars. However, to excessively ponder the question from the sidelines might cost the Marine Corps dearly in future conflicts and simply does not demonstrate the evolutionary and forward thinking attitudes which have established the proud heritage and stature enjoyed by Marines today. Therefore, the Marine Corps must thoroughly examine applications of expert system technology throughout the entire organization, concentrating efforts on those applications deemed most appropriate.

B. SPECIFIC APPLICATIONS

The following sections examine the application of expert system technology in several selected military occupational specialties within the Marine Corps, demonstrating the need, while simultaneously showcasing the expert system's ability to improve overall performance within the respective communities. It is not within the scope of this thesis to examine the applicability of all facets of artificial intelligence technology to every military occupational specialty within the Marine Corps. Rather, we will explore how expert system technology can increase the performance of Marines within a few specific military disciplines to demonstrate to the reader the flexibility and potential embodied in expert systems. This will allow readers to draw comparisons and perhaps envision how the application of expert system technology would assist various military occupational specialties or units. Readers should remember and perhaps review the advantages and disadvantages, covered in Chapter II, concerning expert systems when considering possible applications. A detailed examination of the application of expert system technology to the fire support coordination problem follows in later chapters.

1. <u>Intelligence</u>

a. Applicability to Expert System Technology

Many of the advantages embodied within expert systems can find expression within the intelligence community. The expert systems ability to provide rapid problem assessment and evaluation could increase both the speed and accuracy with which volumes of raw sensor data are processed. Since uncertainty, to some degree, is always present in intelligence evaluations, the expert system's ability to factor varying degrees of uncertainty into problem assessment could be extensively utilized. During protracted combat operations, operational exercises, or deployments, the unit intelligence section would function more effectively due to the elevated levels of performance over extended periods of time offered by the expert system. Within intelligence manuals, key indicators for the following opposing force options: delay, defend, withdraw, reinforce, and attack; are well defined and, therefore, readily adaptable within expert systems. The expert system "corporate memory" retention ability prevents the loss of senior intelligence officers or highly trained assistants, either through combat or transfer, from seriously degrading the quality of the intelligence section's products. Finally, intelligence related training often consists of lengthy and intensive courses. Expert systems utilized for instruction purposes could decrease the time intelligence personnel must spend separated from their primary units while receiving instruction.

b. Specific Occupational Utilizations

The Marine Corps intelligence community stands to gain a great deal of assistance through the application of expert system technology. The majority of Marine intelligence centers, and thus intelligence staffs, find themselves rapidly overwhelmed by the unmanageable quantities of raw, unprocessed sensor data converging upon them. Current attempts to sift through and transform this raw sensor data, from ground, air and space based platforms, into a usable, finished intelligence product often become exercises in frustration. The intelligence staff must sort through reams of raw sensor input data, extracting items perceived to be of relevance and then present the commanders staff with information concerning the current location, size, disposition, intent and capabilities of the opposing force, while at the same time postulating a hypothesis as to future enemy actions. This information is extremely time sensitive and important, since the entire commander's staff will utilize it for recommendation of possible courses of action. Quite expectedly, for even large intelligence staffs to provide accurate summaries in a timely fashion proves extremely difficult.

Utilization of an expert system could substantially increase both the timeliness and accuracy of the intelligence summaries produced by the intelligence staff. First, the expert system could rapidly sort through incoming raw sensor reports, obtaining pertinent intelligence information, while quickly dismissing irrelevant reports. The expert system's knowledge base would receive "real-time" input, maintaining current locations, size, disposition, capabilities and intentions of opposing forces. The value of such time critical information to the commander's staff, particularly in the areas of operations and fire support coordination, would be immeasurable. Real-time processing of enemy locations and dispositions would significantly enhance the fire support coordinator's targeting ability, along with the operations officer's scheme of maneuver. Through use of distributed expert system networks, units throughout the chain of command would have immediate access to critical intelligence, much in contrast to today's slow filtering of intelligence information both up and down the hierarchy of command.

Additionally, with a rule base containing the key intelligence indicators for enemy courses of action (attack, defend, delay, reinforce, and withdraw), the expert system could, based upon sensor input, provide up to the minute information concerning probably future enemy intentions. The expert system could link to sensors, directing them to more closely examine suspicious activities or reposition them along perceived enemy avenues of approach. This timely control of sensors could include ground based, air breathing and space based platforms. Such a capability is especially crucial to the intelligence community, where the value of accurate information is extremely critical and time sensitive. Without timely and accurate intelligence input, neither a commander or his staff can properly prepare to successfully engage an opponent in combat.

Furthermore, an interservice distributed expert system, functioning within the intelligence environment, would allow services conducting joint or combined operations to share time critical information rapidly and efficiently. Naturally this would reduce the amount of valuable equipment resources and personnel involved with duplication of effort, thus affording the various intelligence staffs greater flexibility. The same argument, in certain situations, could be made for a distributed expert system which includes allied nations. Application of expert system technology to the intelligence community would significantly expand and enhance their ability to support the commander and his staff.

2. <u>Logistics/Maintenance/Supply</u>

a. Applicability to Expert System Technology

Within the areas of maintenance and supply, the directives governing procedures are well documented and relatively straightforward. This makes the application of expert systems technology for monitoring or directing supply and maintenance functions very feasible. Often, specialty areas within the discipline of logistics require lengthy training packages. Expert system technology can decrease required training time, along with associated expenses. The user friendliness embodied within expert system programs allows incoming unit personnel to become productive and contribute more rapidly. The expert system's ability to provide rapid problem assessment and evaluation can aid decision making at maintenance management facilities in addition to supporting logistical decisions required throughout the conduct of unit operations or deployments.

b. Specific Occupational Utilizations

Expert system technology possesses the ability to drastically increase Marine Corps performance in the logistics area, which includes the military occupational specialties of supply and maintenance. A distributed expert system, connecting the logistics, supply and maintenance sections of a unit would afford Marines the capability to instantly order required repair parts for deadlined or operationally degraded equipment from the closest source offering the most rapid delivery time. In an attempt to minimize the equipment deadline list, the expert system could send deadlined gear to the repair facility which could provide the quickest repair turnaround time, since as a result of operational requirements, work loads may not be evenly distributed, resulting in significant differences in turnaround times at the various facilities.

Additionally, the expert system could monitor supply levels of repair items, and automatically reorder spare parts when on-hand supplies reach reorder levels. Due to the expert system's real-time update ability, the probability of exhausting repair part bins at maintenance facilities would be measurably reduced. On a similar note, the expert system could monitor the frequency of repair statistics on major end items and order replacement parts based upon operationally validated "mean time between failure" data. Each unit commanding officer could, based on the unit's mission, assign priority of repair requirements to the expert systems rule base, which would then schedule repair efforts to coincide with the unit's desires.

Even today, unit commander's maintenance management reports are inaccurate simply because they are not real-time. A distributed expert system, located within the unit's various logistical nodes, could provide the unit commander with accurate information relative to the status of equipment within his command. This would prove extremely desirable when planning for future operations, exercises, inspections and deployments. The distributed expert system could even be expanded up the chain of command, allowing higher headquarters immediate access to subordinate units' equipment and maintenance status, again aiding management and planning efforts. This would significantly reduce the volumes of paperwork and man hours spent preparing unit equipment status reports required by higher headquarters.

As for the operational logistics picture, the distributed expert system could maintain a real-time count on consumable utilization rates (i.e., fuel, ammunition, equipment, repair parts, medical supplies, food and water) for each subordinate unit, directing resupply via the most rapid conduit. Simultaneously, the expert system could reorder consumables experiencing high usage rates, thus ensuring a constant, uninterrupted flow of needed supplies to front line units. Priority of resupply would be prearranged in the expert systems rule base by the logistics officer, as per the unit commanders desires. Tracking real-time unit consumption levels allows logistics personnel to anticipate reorders, thus facilitating resupply efforts.

Through a distributed expert system, logistics personnel could interact with the supporting Marine air group by screening the daily aircraft frag orders, and piggy-backing logistical packs on available helicopter missions for rapid resupply. Traditionally, the logistics, supply and maintenance military occupational specialties, because of their many associated intricacies, present steeper learning curves to incoming personnel. The expert system would permit retention of valuable corporate knowledge, while at the same time, allow newly arrived personnel to reach full potential within a reduced timeframe. The uses of expert system technology within the realm of logistics are many and varied. Previously suggested applications barely begin to scratch the surface of the problem solving benefits available through such technology.

3. Operations and Training

a. Applicability to Expert System Technology

There exists one section, common to all Marine units, the operations and training section, which bears responsibility for the proper training of unit personnel along with overall management of unit operations. Expert system technology can significantly enhance the operations and training section's effectiveness, thus contributing greatly to overall unit preparation and readiness. Expert systems, not being subject to fatigue, stress or emotions will allow personnel within the operations and training section to operate at elevated levels of performance for extended periods of time. Scheme of maneuver and fire support coordination measures are rather well documented and defined, thereby allowing expert system application. The instant "corporate memory" ability contained within expert systems prevents the loss of critical operations and training personnel from paralyzing unit operations. Decreased training lengths and costs associated with the utilization of expert systems significantly increases the operations and training section's flexibility. Being able to rapidly conduct assessments, the expert system can enhance the section's ability to quickly evaluate numerous proposed staff courses of action present in the unit commander's staff planning process.

b. Specific Occupational Utilizations

With a distributed expert system functioning throughout the unit, utilizing administrative and training databases, school quotas could be filled with the most qualified personnel. Furthermore, the expert system would allow rapid update of individual's training accomplishments and levels which could aid the commander in scheduling various types of military occupational specialty and essential subjects training so as not to interfere with other unit requirements. Through the timely update of personnel training records, unit commander's have instant access to review actual levels of training obtained by unit personnel and adjust instruction, as necessary.

The expert system's low cost, realistic training ability will provide interactive and beneficial training, encompassing a broad spectrum of subjects including pertinent military occupational specialty training, essential subjects training and appropriate level school instruction, all done on the local unit's terminals. In this environment, students can, through the expert system, attack realistic problems with innovative approaches, without fear of damaging operational equipment. Additionally, the expert system could show personnel where they went astray and what an acceptable approach would look like. This approach to training appears to be less costly than normal "lock-step" training methods, concludes sooner and actually improves student information retention levels. Moreover, once back on the job, personnel would continue to have access to all course training manuals allowing continuing education through reinforcement or refreshment of knowledge.

The expert system's "corporate knowledge" capability will enable new personnel within the operations and training section to perform at an elevated level from the beginning. The operations section plays a significant role with assisting the commander in evaluating courses of action for a myriad of scenarios involved with deployments, exercises and contingencies. In assessing courses of action, the expert system would examine a unit's administrative, intelligence, scheme of maneuver, fire support, air support, logistics, supply, motor transport, communications, medical, and nuclear, biological and chemical plans, et al. The expert system could examine and provide recommendations concerning all aspects of the various courses of action in a fraction of the time presently required by the commander's staff, allowing additional time for decision or providing subordinates with greatly appreciated extra preparation time.

At higher headquarters, expert system technology could support deployments, contingency packages or operation plans by generating unit activation messages and coordinating the timing and routing of unit movement in response to orders. This would preclude confusion, traffic jams and overcommitment of transportation assets. Additionally, the expert system could initiate recall of personnel, to include ready reserve forces.

As in other applications, a distributed expert system operating throughout the hierarchy of command, would reduce the manpower required to prepare training schedules and summaries of operational readiness. Higher headquarters could have immediate access to such information through a distributed database. Additionally, an interservice distributed expert system, functioning within the realm of operations, would allow forces conducting joint or combined operations to coordinate plans, contingencies, and deployments on a real-time basis, reducing confusion and duplication of effort. Similar arguments could be utilized, based upon the situation, to include U.S. allies in the distributed expert system architecture. The application of expert system technology to operations and training appears limited only by ones imagination.

4. Air Defense

a. Applicability to Expert System Technology

With the increasing speed and lethality of weapons systems in modern combat, detection and reaction time gain increased significance. Perhaps nowhere is this premise more understood and appreciated than within the air defense community. Therefore, expert system technology, with it's high-speed, real-time processing capabilities appears well suited for air defense applications. Rules of engagement, firing battery characteristics and operational parameters, air threat condition levels, and the air defense target engagement process are all relatively well defined and documented, exhibiting narrow problem domains. Such structure enables expert systems to perform at high levels. Expert systems are user friendly, with only minimal learning curves involved, which becomes important in reducing the time required for air defense personnel to gain proficiency within their designated areas of responsibility. Expert systems, not being subject to fatigue, stress, or emotion can compliment the decision making of air defense personnel during periods of extended operations.

b. Specific Occupational Utilizations

The expert system, with human override options, could simultaneously control both target acquisition radars and firing batteries, while screening all contacts for friend or foe status. Upon confirmed enemy contact, the expert system would then assign the best weapons system, i.e., Hawk, Stinger, or combat air patrols to confront and destroy the existing threat. Distributed expert systems would ensure coordination with adjacent units on areas of responsibility, leaving no gaps in the overall air defense umbrella. Resupply of firing batteries, in addition to repositioning both launchers and radars in support of mission parameters, could be accomplished and coordinated through expert system applications. Of utmost importance, would be the expert system's value in untangling complex interservice air defense issues present during the conduct of amphibious operations. An interservice distributed expert system would allow interoperability between Marine Corps, Navy, Army and Air Force air defense systems covering the Amphibious Objective Area, assuring judicious allocation of combined air defense assets. This would prevent the often confusing and costly duplication of air defense efforts and provide both the Amphibious Task Force and the Landing Force with the best air defense coverage possible. Once firmly ashore, and if still conducting joint operations, Marine air defense systems could work effectively in concert with Army or Air Force units once again through utilization of interservice distributed expert systems, providing maximum air defense protection through efficient economy of force. This line of thinking could also be expanded to include allied air defense systems. Undoubtedly, there exists both purpose and merit in the application of expert system technology to air defense.

5. <u>Communications</u>

a. Applicability to Expert System Technology

The communications military occupational specialty stands to reap enhanced operational capabilities with the aid of expert system technology. The expert system's ability to conduct rapid problem assessment allows communication personnel to evaluate the feasibility of communication plans which support unit operations and incorporate necessary changes within a relatively short time period. The expert system's "corporate memory" retention ability prevents the loss of senior communication personnel, either through combat or routine transfer, from seriously degrading the communications section's performance. Frequency settings, output power levels, equipment parameters, antenna configurations, and power requirements, in addition to the mathematical calculations required to determine the Maximum Usable Frequency, Lowest Usable Frequency and Frequency of Optimum Transmission, are all fairly well-defined, lending themselves to the strengths of expert systems.

b. Specific Occupational Utilizations

First of all, the increased percentage of operational communication equipment, obtained through the application of distributed expert system technology within the areas of logistics, supply and maintenance (as discussed earlier), immediately provides the communicator with greater flexibility, possibly including the luxury of redundant circuits. Furthermore, expert system technology could evaluate the communicator's proposed courses of action to support outlined schemes of maneuver with extreme rapidity, pointing out the strengths and weaknesses of each, and providing enhancement recommendations. This tool would allow the communicator to provide the commander with optimum communications support for a given operation. During operations, expert system technology could constantly evaluate the LUF, MUF and FOT, adjusting frequency changes within parameters of published Communications-Electronics Operating Instructions, to maintain reliable communications. Assessment of the probability of opposing force electronic warfare units intercepting friendly communications could be conducted, resulting in changes of frequencies, locations, output power and antenna sites or configurations to reduce friendly vulnerability.

Probably the most significant contribution expert system technology could make to the communications military occupational specialty would be within the System Control (SYSCON) and Technical Control (TECHON) facilities. In this regard, the expert system would be assigned the responsibility of optimizing the organization's communication links. Through real-time control of SYSCON and TECHON facilities, the expert system could continually monitor overall system status, instantly assessing the affects of degraded communication links, shifting assets to restore high priority circuits, while directing the efforts of repair teams on degraded links.

Additionally, the expert system would determine optimal paths for message routing throughout the organizational hierarchy. An expert system, employed in this fashion provides agencies additional planning and decision time, while greatly improving the probability that all organizations throughout the command receive their message traffic in the most expeditious manner. Thus, when communication related problems occur, the expert system would ensure proper alternate routing paths for messages, maintain service, and, if necessary, provide the guidance and direction necessary to achieve graceful system degradation. With minimal human oversight required, the expert system could provide reliable 24 hour SYSCON and TECHON control, thereby easing personnel requirements. As in other applications, the expert system could be part of a joint-service distributed expert system, easing interservice communications planning, interoperability and operational concerns. Once again, only the mere surface has been scratched in regard to the applications of expert system technology to communications. The remaining possibilities appear almost limitless.

6. <u>Administration</u>

a. Applicability to Expert System Technology

The numerous rules, regulations and directives governing the military occupational specialty of administration are rather structured and well-defined, providing an excellent base from which an expert system can operate. The expert system, being able to provide continuous operation at elevated levels of expertise for extended periods of time, allows reduction in the number of personnel required to operate the administrative section. The expert system's user friendliness also enhances personnel performance and significantly reduces the time required to train incoming administrative personnel. Rapid problem assessment permits the expert system to assist in the real-time update of unit administrative files and records.

b. Specific Occupational Utilizations

A distributed expert system operating throughout the chain of command could streamline and enhance administrative and personnel related activities within the Marine Corps. The expert system would provide real-time monitoring of various military occupational specialty manpower levels, flagging critical manpower shortages. This would alert recruiting stations as to which particular military occupational specialties required personnel influx. Simultaneously, the expert system could screen personnel databases, initiating orders transferring qualified Marines into critically short units. The expert system could ensure that a Marine's personnel records are an accurate reflection of reality. Thus, computation of composite scores, which determine lower level enlisted promotions, would be fair and timely. Likewise, the expert system could follow promotion windows, ensuring the timely and proper promotion of Marines. In concert with this, necessitated changes in pay status would be instantly adjusted and properly reflected on the following payday. In addition to streamlining the awards process, a distributed expert system could provide an instant and accurate worldwide personnel locator. Once again, the applications of expert system technology within administration, as in other military occupational specialties, are limited only by the imagination.

7. Summary

In conclusion, one can quickly surmise the almost limitless applications of expert system technology available to enhance performance within the wide spectrum of Marine Corps military occupational specialties. As with almost any new system, all applications cannot be anticipated or conceived prior to introduction to FMF units. Once expert system technology reaches the hands of eager, innovative Marines in the field, additional new applications and methods, not even previously considered will be conceived. Some applications are more practical than others, some are nice to have but not required, and some are simply unrealistic. The rational evaluator will surely recognize each of these. However, within each military occupational specialty, there exist valid requirements and needs for application of expert system technology. An interesting employment of expert system technology which warrants further study concerns the utilization of distributed expert systems to improve interservice joint/combined operations and during operations with allied nations. Future procurement of expert systems to increase the Marine Corps potential and combat effectiveness depends upon the visionary abilities of present day high level officials. To dismiss or delay such capability without fair evaluation or study could prove extremely costly to the Marine Corps in future conflicts. The increased tempo of future combat conditions will overwhelm even the best humans, therefore relegating the ultimate determination of victory to the best performing man-machine systems. Innovation and foresightedness have enabled the Marine Corps to survive and flourish over two hundred years and must be continually employed to secure a successful future.

V. UNITED STATES MARINE CORPS ORGANIZATION

A. INTRODUCTION

The next two chapters are devoted to readers who are not familiar with the organization or functioning of the United States Marine Corps. The authors believe that a limited understanding of the manner by which the United States Marine Corps organizes for combat and performs fire support coordination is essential for understanding the application of either artificial intelligence or expert systems to the fire support coordination problem.

The organization of the Marine Corps includes three basic elements: ground combat, aviation, and combat service support. Although this appears to be a conventional approach, when preparing for combat the Marine Corps task organizes into commands specifically designed to meet the perceived threat. The resulting organizations, comprised of a conglomeration of units from the three basic elements of the Marine Corps, create a Marine Air Ground Task Force (MAGTF). Therefore, in reality, the Marine Corps has two very distinct organizations: an administrative organization and a combat organization.

B. ADMINISTRATIVE ORGANIZATION

1. General

The administrative organization is the more conventional and structured of the two organizations. While differences do exist between like units, they generally contain the same table of organization and table of equipment which culminate in approximately the same operational capabilities, as opposed to the flexible structuring common to the MAGTF.

2. Ground Combat Structure

Within the ground combat structure there are currently three active Marine Divisions and one reserve division in existence. Historically, the Marine Corps has had as many as six active divisions. The important point, however, is that all of the divisions are similarly structured. Each has three infantry regiments, one artillery regiment, one headquarters battalion, and five separate battalions. Figure 5-1 provides a block diagram of the structure of the Marine division [Ref. 41:p. A-1].

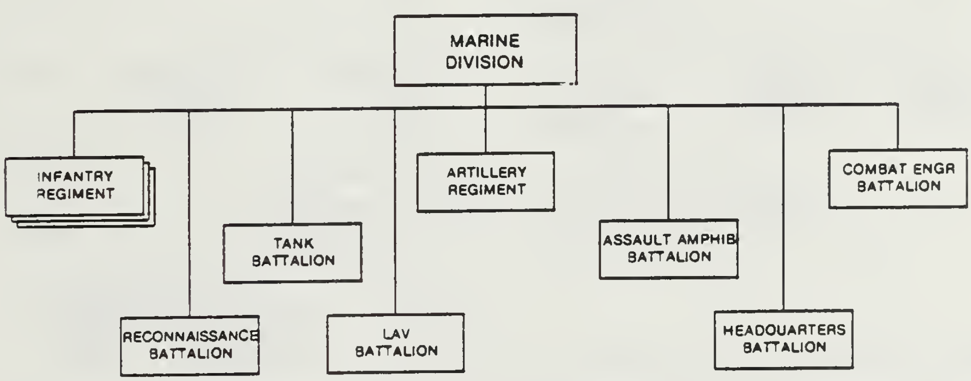


Figure 5-1. Marine Infantry Division

Each infantry regiment further breaks down into battalions, companies, platoons, squads, and fire teams. The structure of the infantry regiment is contained in Figure 5-2 [Ref. 42:p. 177].

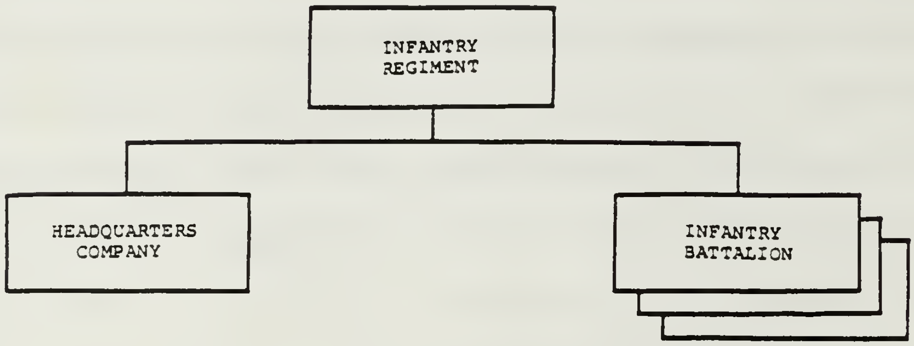


Figure 5-2. Marine Infantry Regiment

However, coordination of supporting fire does not extend below the infantry battalion headquarters level. Figure 5-3 provides a graphic representation of the artillery regiment [Ref. 41:p. A-4]. Normal employment of the artillery regiment provides for one regiment to support one infantry division, one artillery battalion to support one infantry regiment, and so on.

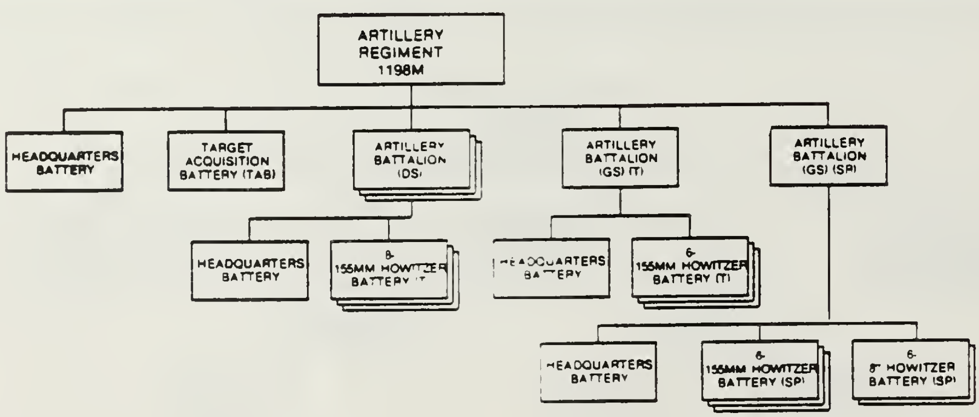


Figure 5-3. Marine Artillery Regiment

3. Aviation Structure

The administrative organization for Marine aviation contains three active and one reserve Marine Air Wings. The Marine Air Wing is further broken down into groups/ battalions, squadrons/batteries, and sections as indicated in Figure 5-4 [Ref. 43:p. 5-14]. The Marine Air Groups contain all of the fixed wing and rotary wing aircraft which provide the bulk of air support to the infantry units. Within the Marine Air Control Group (MACG) exist the command and control agencies which are critical in fire support coordination.

4. Service Support Structure

The third, and most diversified, of the three organizations is the Combat Service Support Element. There are three active Force Service Support Groups (FSSG) and elements of a reserve FSSG in the Marine Corps. Eight separate battalions comprise the FSSG. The functions of the eight battalions are generally unrelated to one another, but all contribute to the overall support of the ground elements and aviation elements. Because of the mission performed by the battalions of the FSSG, minimal direct involvement exists in fire support coordination. Figure 5-5 depicts the structure of the FSSG [Ref. 44:p. 112].

C. COMBAT STRUCTURE

1. General

The preceding discussion provided a limited overview of the administrative organization of the United States

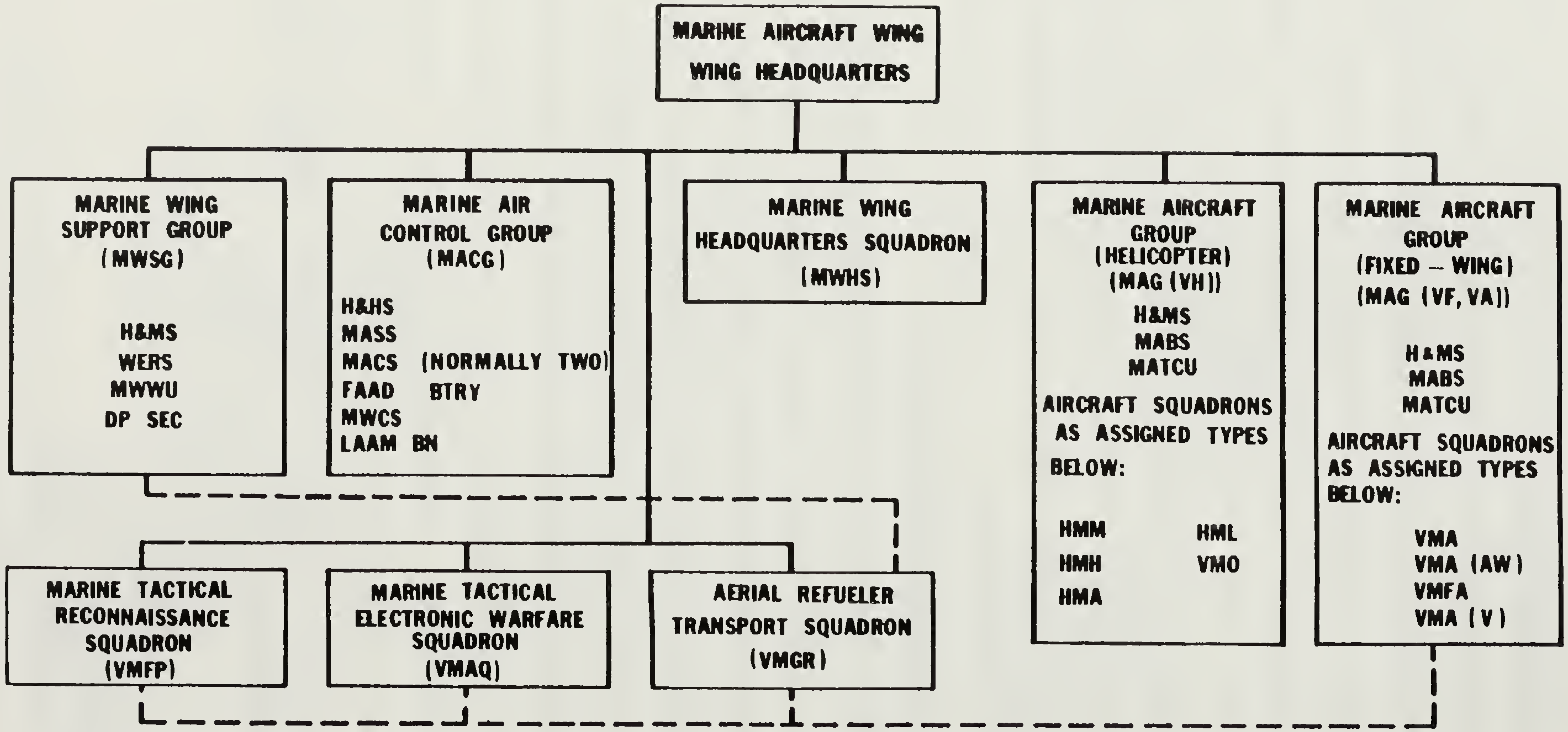


Figure 5-4. Marine Aviation Organization

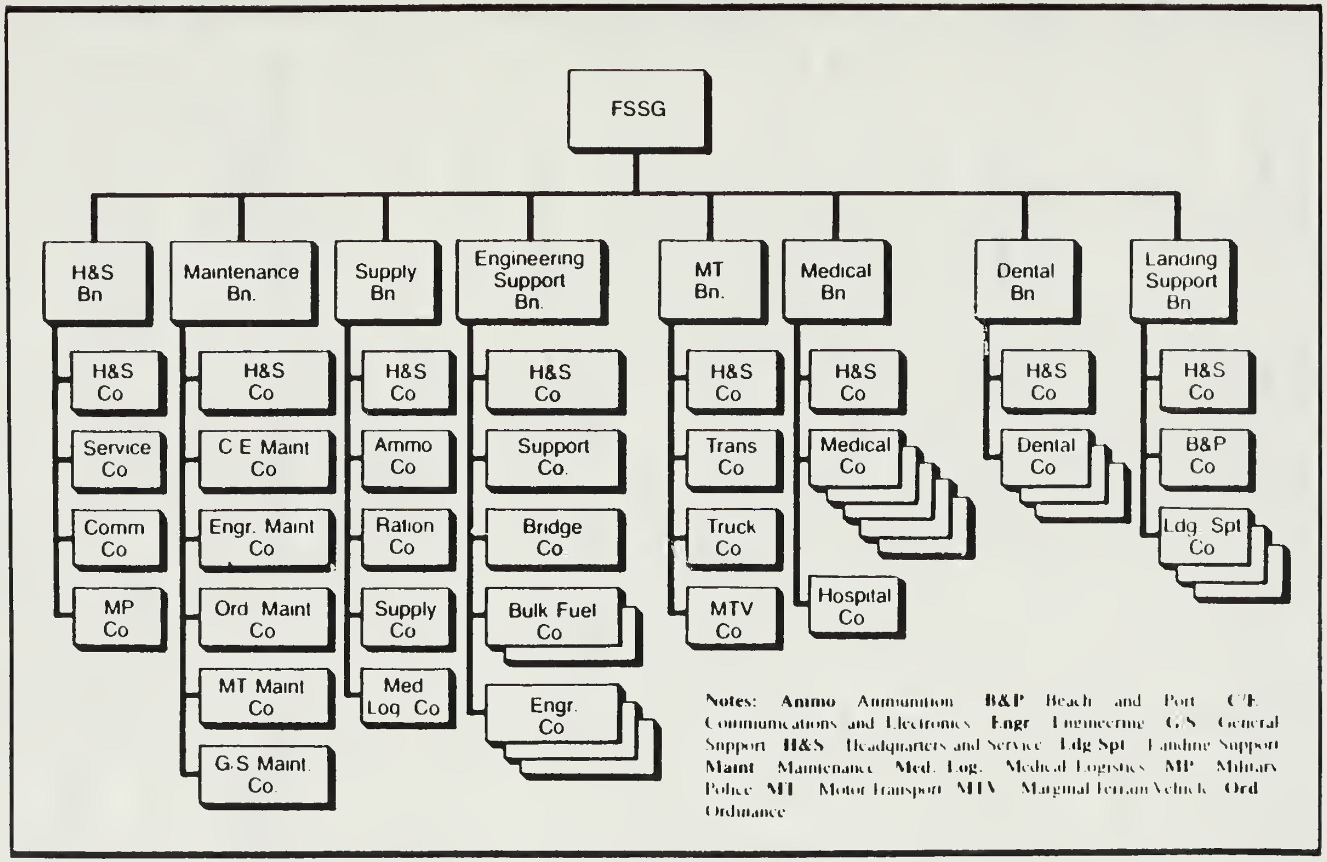


Figure 5-5. Marine FSSG Organization

Marine Corps. However, for the purpose of this thesis, the Marine Corps organization for combat exceeds the administrative organization in importance.

> Marine forces are most effective in battle when employed as a strategic mobile combined arms air-ground combat force possessing its own combat service support, all under a single commander. [Ref. 45:p. 1-1]

Marine Corps policy indicates that Marine forces will be employed as integrated air-ground teams.

> MAGTF's comprised of combat, combat support, and combat service support units, are routinely task organized from the Fleet Marine Force. [Ref. 45:p. 1-1]

Therefore, the preponderance of fire support coordination occurs within MAGTF organizations. The MAGTF contains four principle elements: command element, ground combat element, aviation combat element, and combat service support element. Figure 5-6 depicts the relationship of the elements within the MAGTF [Ref. 45:p. 2-2].

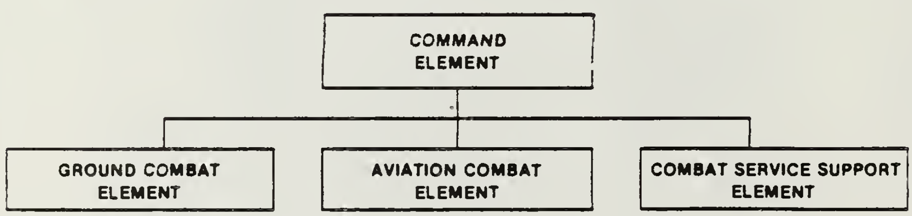


Figure 5-6. MAGTF Elements

a. Command Element

As the name implies, the command element of the MAGTF contains the commander, commander's staff, headquarter's section, communications, and service support facilities. This element provides the command and control for the MAGTF. [Ref. 45:p. 2-2]

b. Ground Combat Element

The ground combat element (GCE) is task organized around an infantry unit varying in size between a reinforced battalion and a reinforced division. As the name implies, the purpose of the GCE is to conduct the ground combat operations. [Ref. 45:p. 2-2]

c. Aviation Combat Element

The aviation combat element (ACE) is task organized to perform necessary missions in air reconnaissance, antiair warfare, assault support, offensive air support, electronic warfare, and control of aircraft and missiles. The ACE varies in size from one "composite" squadron to one or more Marine Air Wings. [Ref. 45:p. 2-2]

d. Combat Service Support Element

Dependent upon the size and composition of both the GCE and ACE, the combat service support element (CSSE) is also task organized to fully provide the combat service support necessary for accomplishment of the assigned mission. Services which may be provided include: supply, maintenance, transportation, engineer, health, postal, disbursing prisoner of war, automated information systems, exchange utilities, legal, and graves registration. [Ref. 45:p. 2-2]

2. <u>Marine Air Ground Task Forces</u>

a. Marine Amphibious Unit

Three distinct sizes of MAGTF's have been pre-planned to meet varying threats: Marine Amphibious Unit, Marine Amphibious Brigade, and Marine Amphibious Force.

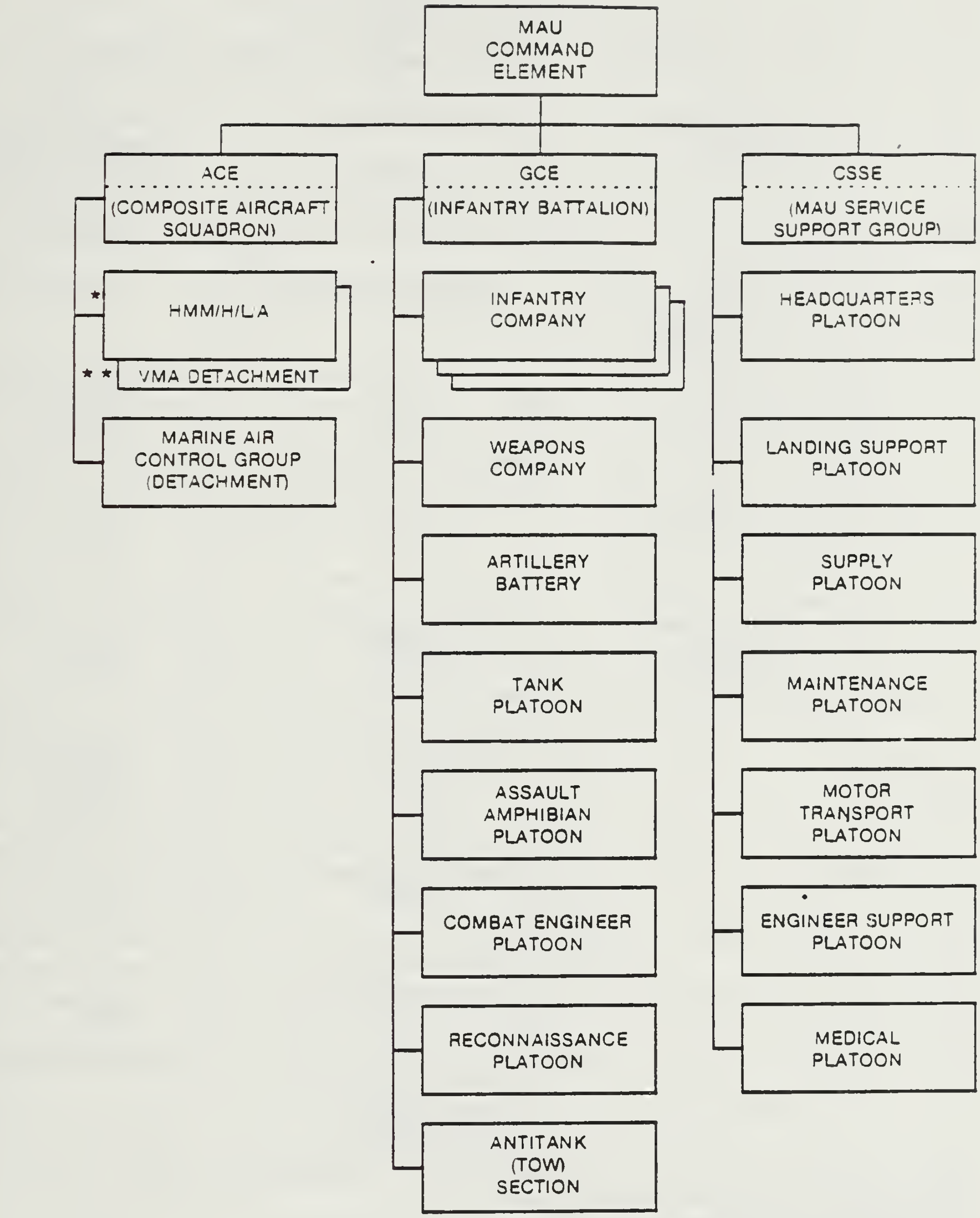
The Marine Amphibious Unit (MAU) is the smallest of the three MAGTF's. A reinforced infantry battalion, composite aircraft squadron, and MAU service support group comprise the core around which the MAU is built. Organization and training enable the MAU to conduct a variety of amphibious operations, but size and structure limit the scope and duration of missions which may be undertaken. [Ref. 45:p. 2-3] Figure 5-7 illustrates the organization of a notional MAU [Ref. 45:p. 9-3].

b. Marine Amphibious Brigade

The Marine Amphibious Brigade (MAB) represents the next largest MAGTF. The MAB is also task organized and normally built around a reinforced infantry regiment, a composite Marine aircraft group, and a brigade service support group. The MAB can conduct a wider range of amphibious operations, but cannot perform sustained operations ashore. [Ref. 45:p. 2-3] The organization of the MAB is depicted by Figure 5-8 [Ref. 45:p. 8-3].

c. Marine Amphibious Force

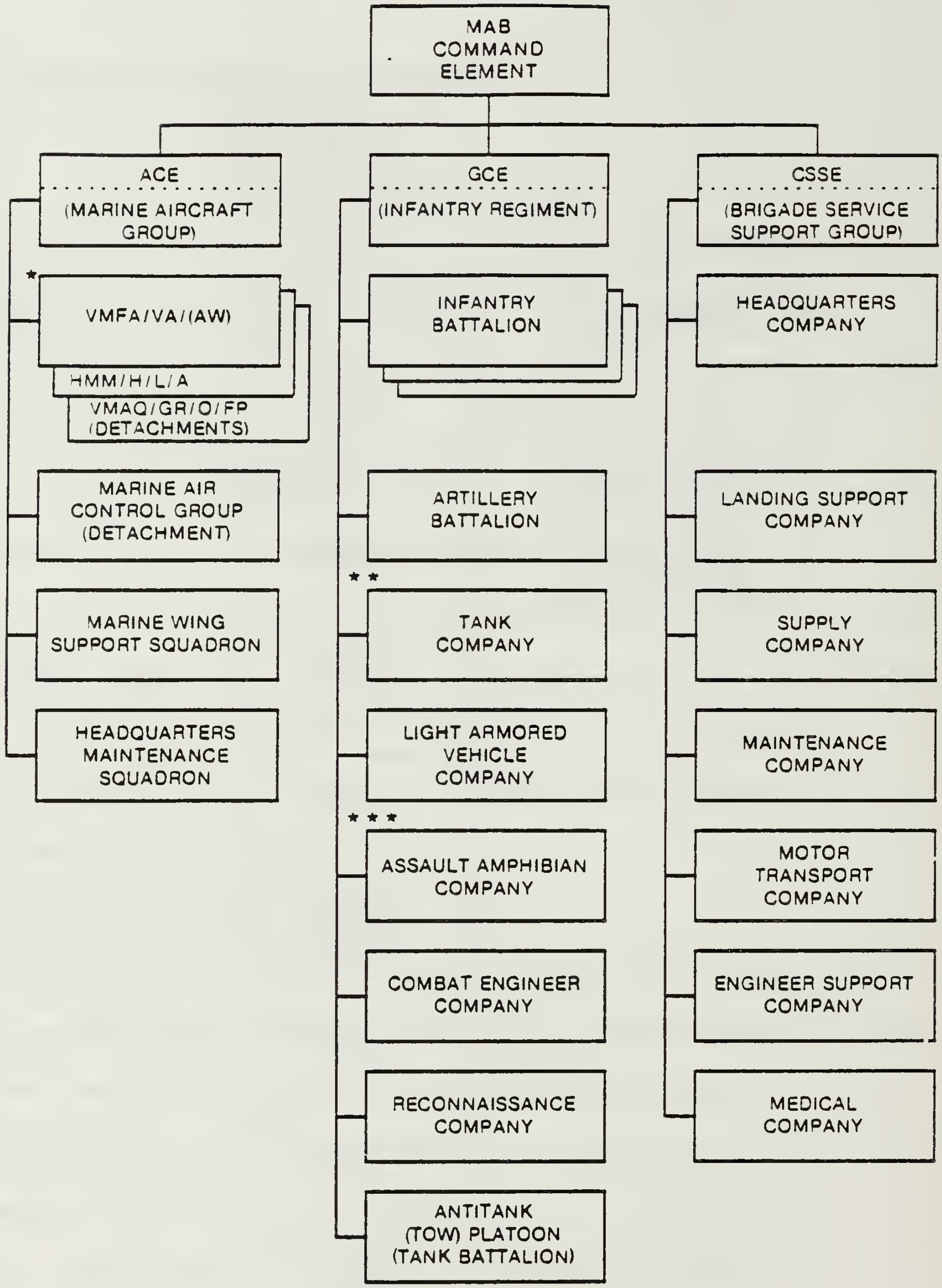
The Marine Amphibious Force (MAF) is indicative of the largest MAGTF organization. Normal composition of the



* HMM/H/L/A: Marine Helicopter Medium/Heavy/Light/Attack Aircraft

** VMA DETACHMENT: Marine Fixed-Wing Attack AV8 Aircraft (not always deployed)

Figure 5-7. Notional MAU Organization



* VMFA: Marine Fixed-Wing Fighter/Attack Squadron
VMA: Marine Fixed-Wing Attack Squadron
VMA/(AW): Marine Fixed-Wing Attack Squadron/(All-Weather)
FMAQ/GR/O/FP (DETACHMENTS): Marine Fixed-Wing Tactical Electronic Warfare/Aerial Refueling Transport/ Observation/Tactical Reconnaissance Squadrons Detachments
HMM/H/L/A: Marine Helicopter Medium/Heavy/Light/Attack Squadron

** In MPF MAB, Tank Battalion vice Tank Company

*** In MPF MAB, Assault Amphibian Battalion (—) vice Assault Amphibian Company

Figure 5-8. Notional MAB Organization

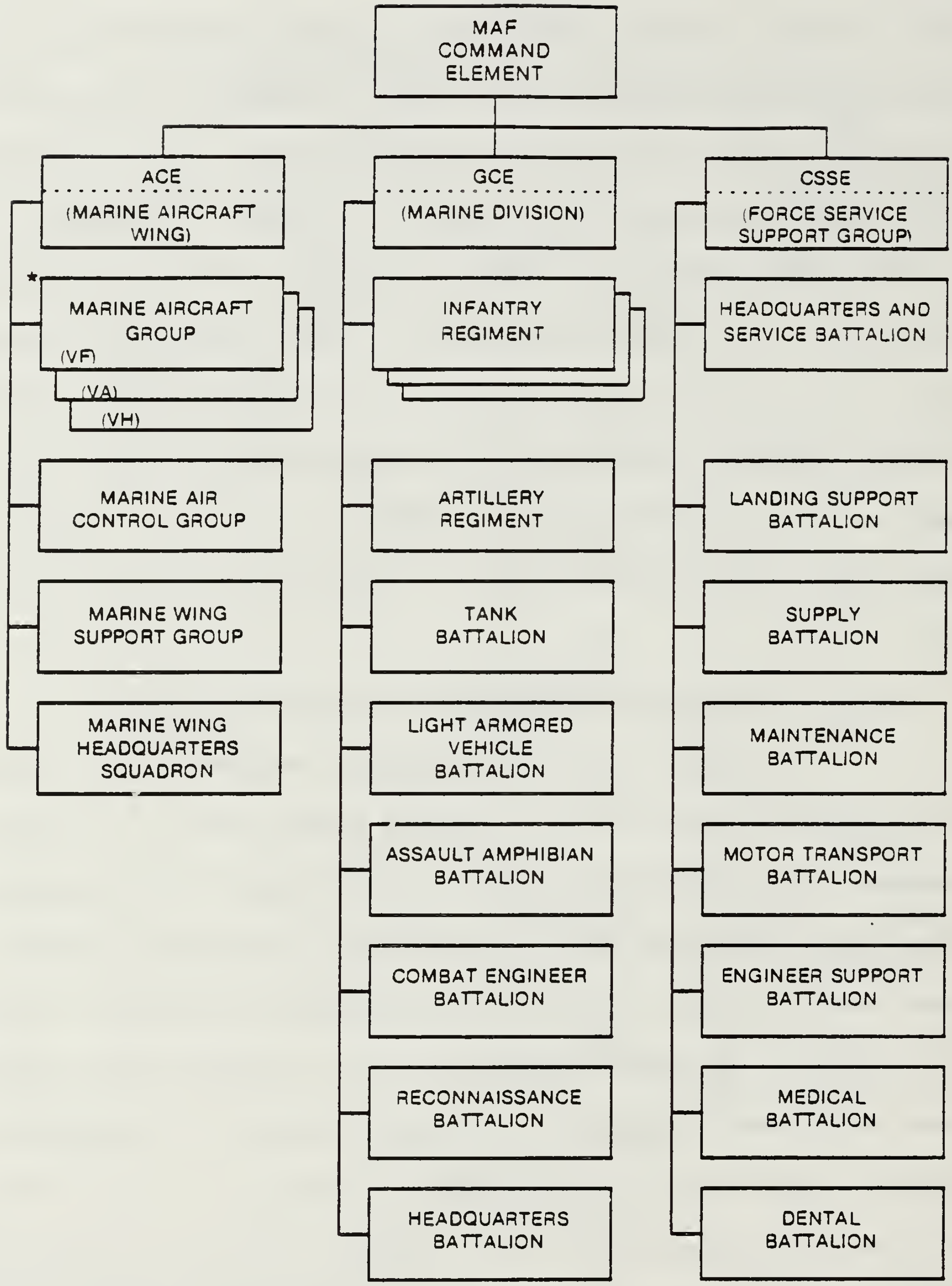
MAF includes a Marine division, Marine aircraft wing, and a force service support group (FSSG). However, the MAF may be composed of multiple divisions and/or wings and a suitable force service support group as the mission dictates. Without a doubt, the MAF represents the greatest diversity in mission assignment. The MAF can conduct a wide range of amphibious operations in various geographic environments and, unlike the smaller MAGTF's, contains the combat power to conduct sustained operations ashore. [Ref. 45:p. 2-3] Figure 5-9 represents the organization of a notional MAF [Ref. 45:p. 7-3].

d. Concurrent MAGTF Employment

Within the United States Marine Corps, there exists the capability to organize three MAF's, six MAB's, and six MAU's depending on location and scope of the engagement. Figure 5-10 depicts the distribution of current MAGTF's [Ref. 45:p. 2-13]. It remains extremely important to note that not all of these MAGTF's can be fielded simultaneously. There has been significant debate relative to determining the maximum number and size of MAGTF's which the Marine Corps can activate simultaneously. The debate will not be continued here since it is not germane to the topic of this thesis.

D. SUMMARY

The discussion presented in this chapter provided limited insight into the organization of the Marine Corps. An understanding of Marine Corps organization is deemed



* VF: Marine Fixed-Wing Fighter Aircraft
VA: Marine Fixed-Wing Attack Aircraft
VH: Marine Helicopter Aircraft

Figure 5-9. Notional MAF Organization

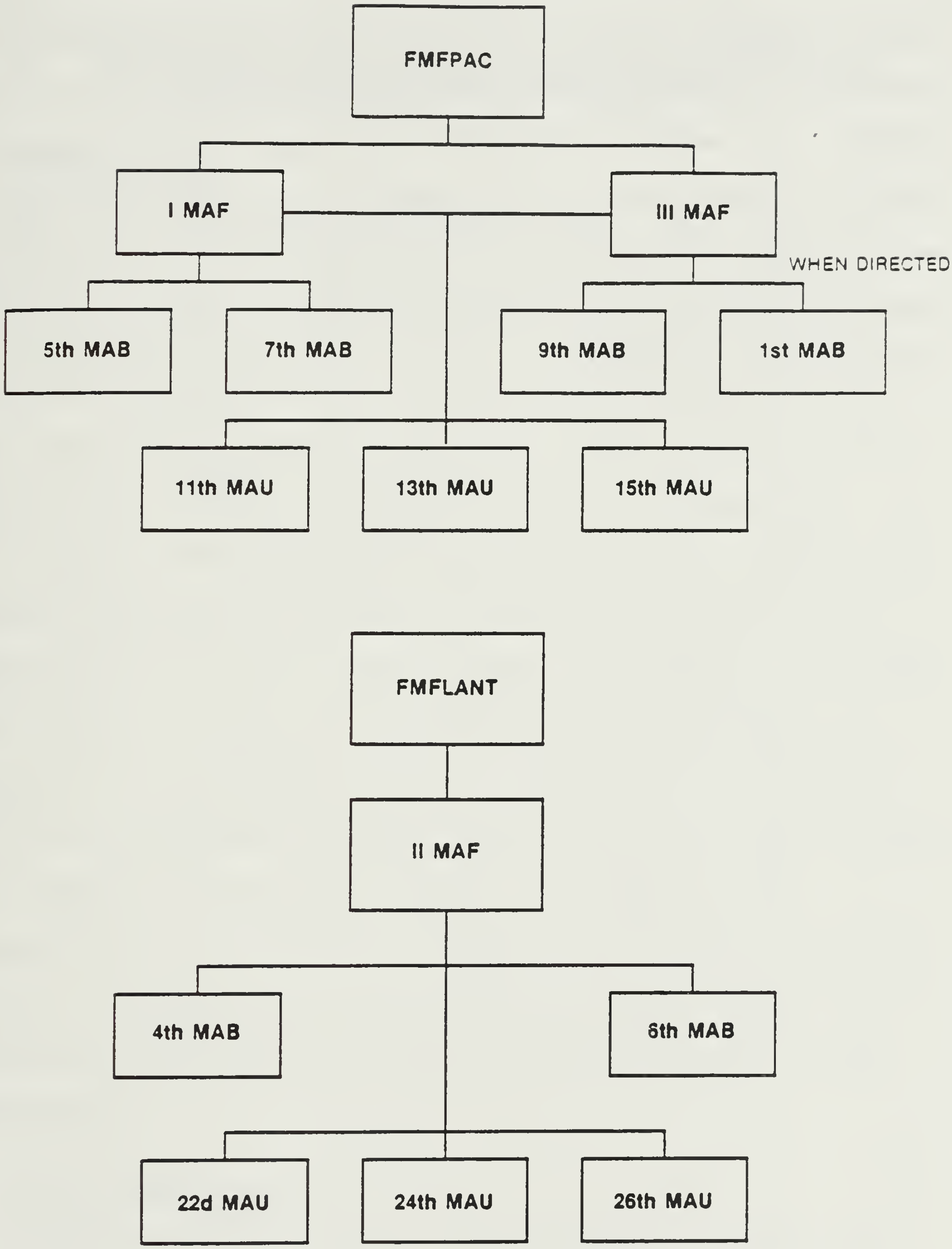


Figure 5-10. Distribution of MAGTF's

essential for comprehending the more detailed discussion of staff organization and fire support coordination which will continue in the following chapters. Upon completion of this chapter, the reader should not only understand the manner by which the Marine Corps task organizes for combat from the more conventional administrative organizations, but also begin to recognize the command and control structure for fire support coordination.

VI. COMMAND AND CONTROL OF FIRE SUPPORT COORDINATION IN THE UNITED STATES MARINE CORPS

A. INTRODUCTION

The previous chapter presented a brief overview of the manner by which the United States Marine Corps organizes, both administratively and tactically. However, to fully understand the application of expert system technology to fire support coordination, additional understanding of the Marine Corps command and control structure is essential. This chapter, therefore, provides a general overview of the command and control structure, with further detail as it specifically pertains to fire support coordination. As one might expect, a thorough investigation of the topics presented in this chapter would be voluminous. Therefore, the following discussions describing command and control, and fire support coordination, are not intended to be all encompassing, but limited to concise representations of the physical structures and procedures considered essential in considering the application of the proposed expert system technology.

B. STAFF COMPOSITION

Although responsible for everything that his/her unit does or fails to do, a commanding officer cannot possibly personally supervise all functions which are undertaken by the command. In fact, to perform effectively, an individual's span of control must be sufficiently limited to allow effective leadership. As in most other modern military forces, the United States Marine Corps has solved this problem through the establishment of general and executive staffs at all command levels to assist the commander in performing vital command and control functions. The concept of staff functioning is quite simple to understand, but difficult to properly implement. A staff might simplistically be described as a group of officers to whom the commander has delegated his authority to oversee specific functional areas. These staff officers are then directly responsible to the commander for the functions to which they have been assigned. Through delegation of authority, the commanding officer can sufficiently reduce the span of control within his unit to a manageable level. The staff officers may then further subdivide their tasks among their subordinates until the command structure develops into a pyramidical shape.

The United States Marine Corps has defined the six principal staff functional areas to be: personnel, intelligence, operations and training, logistics, civil affairs, and financial management [Ref. 46:p. 4]. Collectively this group of staff officers is called either a general staff (when serving a general officer) or an executive staff (when serving all other commanding officers) and individually labeled the G/S-1, G/S-2, G/S-3, G/S-4, G/S-5, and comptroller, respectively. Employment of a general staff will normally be associated with a MAF, MAB, division, MAW, or FSSG headquarters. The executive staff is utilized at all other echelons of command. The relationship of the commander to his staff and subordinate commanders is illustrated in Figure 6-1 [Ref. 46:p. 3].

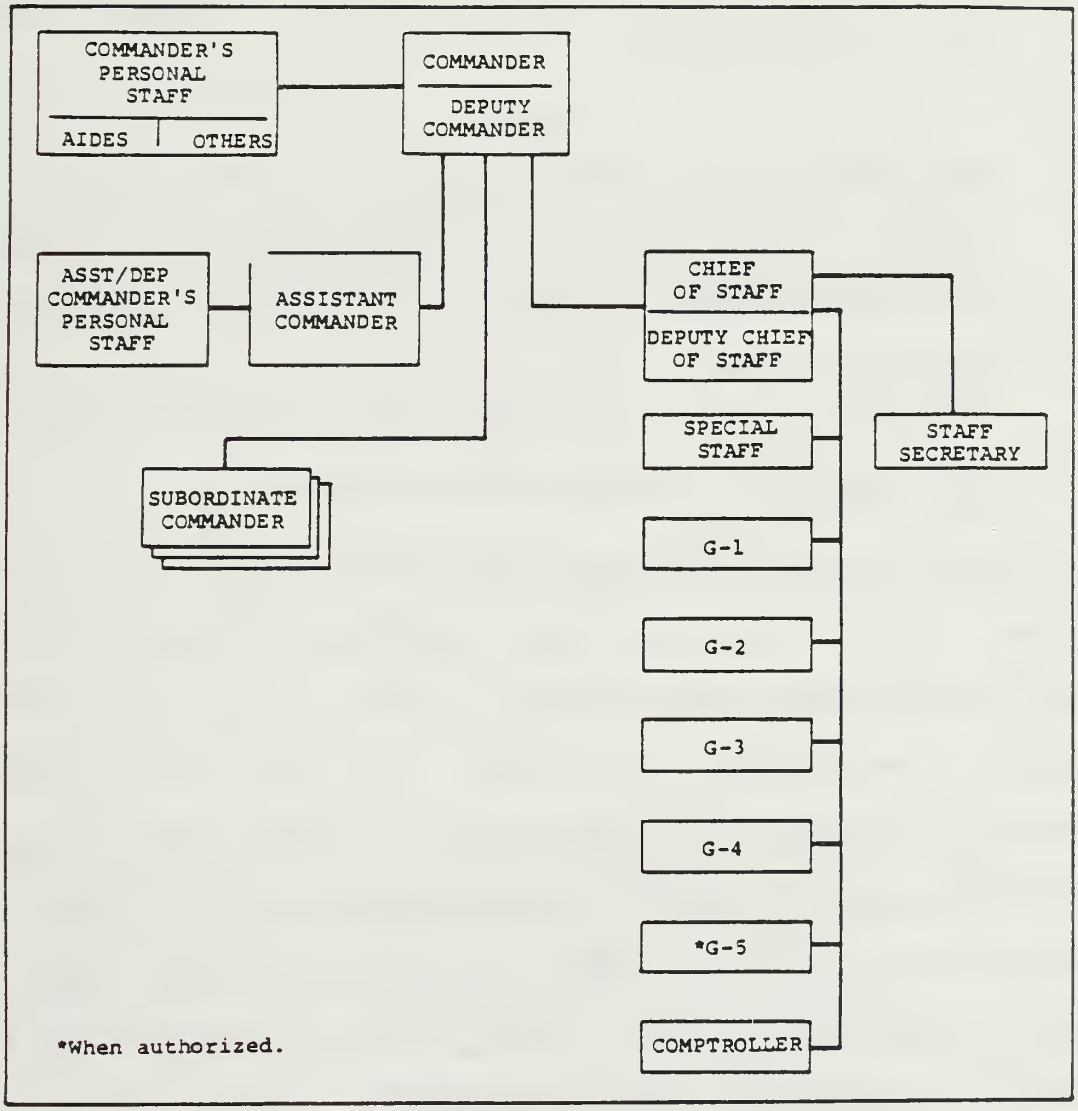


Figure 6-1. Marine Corps Staff Organization

Of particular interest to our discussion of fire support coordination is the G/S-3. The G/S-3 is the principal staff assistant in matters pertaining to organization, training, and tactical operations [Ref. 46:p. 13]. A partial list of the G/S-3 responsibilities, as contained in Marine Corps doctrinal publications, follows:

1. Planning, coordinating, supervising the tactical employment of units.

2. Evaluating the tactical situation and preparing the operation estimate.

3. Integrating fire and maneuver.

4. Preparing or reviewing plans such as fire support to include nuclear fires, chemical agents, barrier denial, communications, tactical cover and deception, tactical engineer operations, and psychological operations which are required to support operations.

5. Determining priorities for allocation of personnel, weapons, equipment, and ammunition in short supply.

6. Developing contingency plans as required. [Ref. 46:p. 15]

In addition to the general/executive staff, there exists another group of staff officers whose activities pertain to other duties which are not specifically encompassed by the principal general/executive staff. This additional group of officers is called the special staff. [Ref. 46:p. 4] A particular special staff officer becomes crucial in our proposed application of expert system technology: the Fire Support Coordinator (FSC). Under the cognizance of the G-3, the FSC performs the following tasks:

1. Supervises the organization, training, and operation of the fire support coordination center.

2. Determines fire support requirements.

3. Assists in the preparation of fire support plans.

4. Supervises the collection and dissemination of target data to include formulating the target list and promulgating target bulletins.

5. Coordinates and integrates support fires.

6. Institutes control and limiting measures as required.

7. Maintains special fire plans for the coordinated employment of supporting arms to meet special situations. [Ref. 46:p. 30]

C. STAFF FUNCTIONING

The stated purpose of this overview is to relate the application of expert system technology to fire support coordination. In an effort to reduce the confusion in the ensuing discussions pertaining to fire support coordination, comments and examples will specifically related to the executive staff. Unless otherwise stated, statements regarding the functioning of the executive staff are equally valid for the general staff.

The function of a staff is summarized in the following paragraph:

> The principle function of the staff is to assist the commander to arrive at the best course of action when confronted with a specific set of circumstances. This is done by preparing and analyzing alternatives from each staff officer's point of view so that the commander can weigh advantages and disadvantages associated with the total scheme of things being considered. Within the framework of the overall decision process and command, management, and leadership relationships, the sequence of command and staff action falls into an orderly pattern. [Ref. 46:p. 46]

Figure 6-2 [Ref. 46:p. 47] provides a graphic representation of the formal staff planing sequence. While the process depicted in this figure accurately portrays the internal process, it does not depict the interaction between commanders, staffs, and command and control agencies throughout the command hierarchy. To develop a more accurate mental image of the process, one must imagine the existence of a staff, similar to Figure 6-1, at each level of command from the battalion/ squadron to the MAF headquarters. Each staff passes information up and down the chain of command, as well as, laterally should the situation dictate. Each staff officer works principally with his/her counterpart on the other staff. For example, the S-3 on one staff generally conducts business with the S-3 on the other staff, and so on. However, frequently the need arises for a staff member to work with someone other than his principal counterpart. For example, the S-3 at the regiment might need to coordinate with the S-2 at a subordinate battalion. Thus, the relations within and among staffs become rather complex.

By now, the reader should have developed an image of the composition and relationship of the Marine Corps staffs and a cursory view of the levels at which they are employed, as well as, an understanding of the complexity of information flow within a MAGTF organization, such as a MAF.

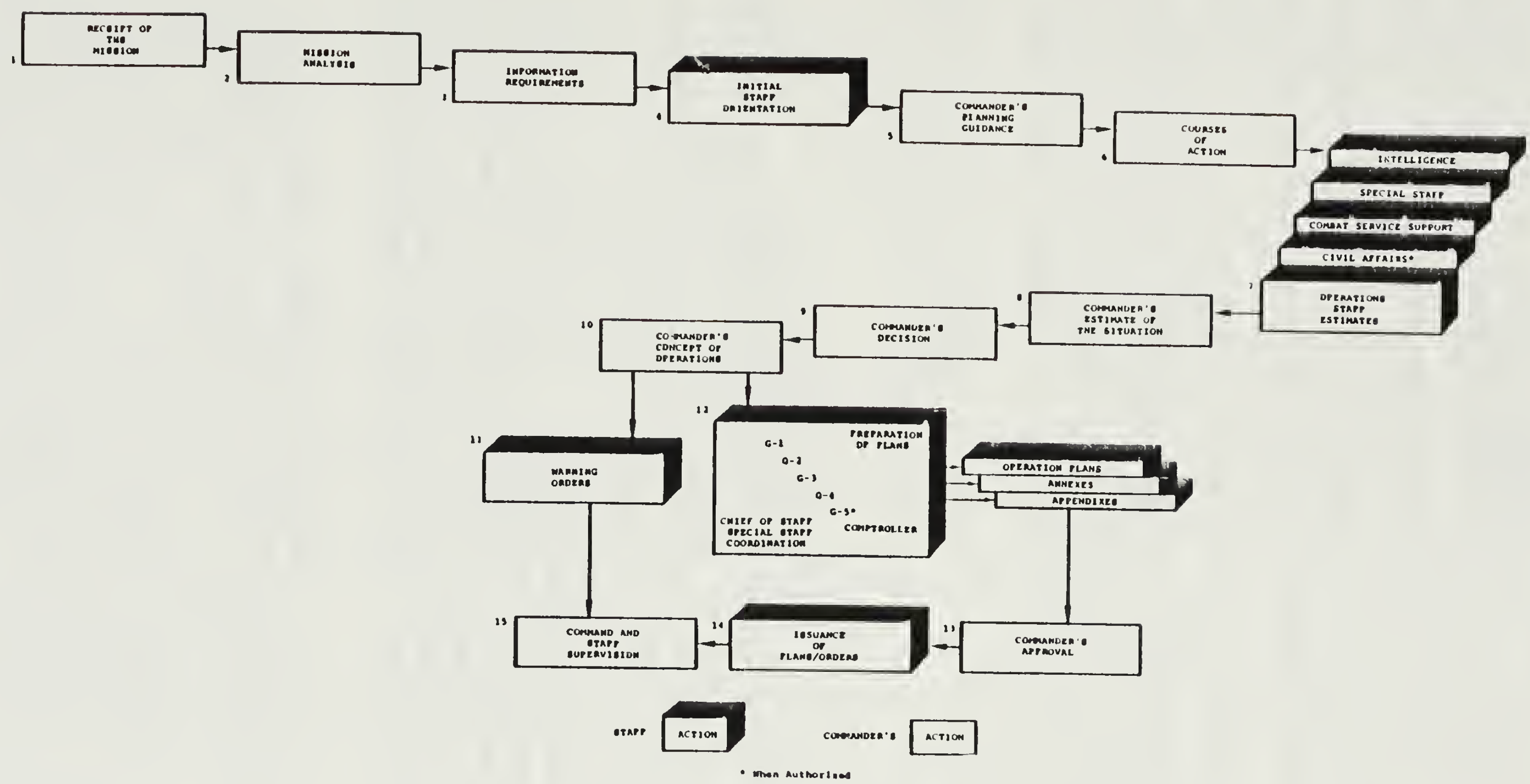


Figure 6-2. Staff Planning Sequence

D. COMMAND AND CONTROL AGENCIES

Another aspect of command and control within the Marine Corps, which further complicates the discussion, involves the use of command and control agencies at various locations. Command and control agencies can be described as dedicated personnel, equipment, facilities, procedures, and processes which are joined under a single commander to accomplish a specified mission. Once again, discussion of each agency employed within the Marine Corps for command and control is beyond the scope of this thesis. However, several agencies, considered crucial in the fire support coordination process, will be briefly described.

1. FIRE SUPPORT COORDINATION CENTER (FSCC). The FSCC is the agency through which the commander exercises the required planning, coordination, and control of supporting arms. An FSCC exists at each echelon of the landing force down to the infantry battalion headquarters. [Ref. 47:pp. 1-4, 1-5]

2. FIRE DIRECTION CENTER (FDC). The element of a command post, consisting of gunnery and communication personnel and equipment, by means of which the commander exercises fire direction and/or fire control. The fire direction center receives target intelligence and requests for fire and translates them into appropriate fire direction. [Ref. 48:p. 7-3]

3. SUPPORTING ARMS COORDINATION CENTER (SACC). The agency through which the commander of the amphibious task force exercises overall coordination of supporting arms in the delivery of fire support. [Ref. 49:p. 4-3]

4. DIRECT AIR SUPPORT CENTER (DASC). A subordinate operational component of a tactical air control system designed for control and direction of close air support and other tactical air support operations, and normally collocated with fire-support coordination elements. [Ref. 48:p. 7-3]

5. TACTICAL AIR COMMAND CENTER (TACC). The principal United States Marine Corps air operation installation from which aircraft and air warning functions of tactical air operations are directed. It is the senior agency of the Marine Corps Air Command and Control System from which the Marine Corps tactical air commander can direct and control tactical air operations and coordinate such air operations with other services. [Ref. 48:p. 7-3]

6. TACTICAL AIR DIRECTION CENTER (TADC). The air operations installation under the overall control of the tactical air command center from which aircraft and air warning service functions of tactical air operations in an area of responsibility are directed. [Ref. 50:p. 3-3]

E. FIRE SUPPORT COORDINATION

1. Definition

The final topic to be addressed in this chapter is fire support coordination. Current Marine Corps doctrinal publications define fire support coordination as:

> ...the continuing process of evaluating fire support needs or missions, analyzing the situation, and planning for and employing air, artillery, mortars or naval gunfire so that the targets are attacked with an appropriate volume of fire by the most suitable weapon(s). This process spans both planning and execution of fire support and provides the means by which the commander uses his available firepower to influence the action while ensuring the safety of his troops. [Ref. 47:p. 1-1]

2. Supporting Arms Availability

There are essentially three types of supporting arms available to the MAGTF commander: naval gunfire, air support, and field artillery. However, within this seemingly limited list of supporting arms there exists an extensive arsenal of weapons and ammunition. The list of ammunition types includes a wide spectrum of capabilities including conventional, chemical and nuclear munitions. [Ref. 47:p. 2-4]

3. Coordination and Planning

At all command levels, fire support coordination is planned and updated to support the tactical operations of the unit supported. Planned fires (developed during the formal staff planning sequence) are monitored to insure that the scheme of maneuver is supported and that requirements have not changed. In addition to planned fires, targets of opportunity are engaged with available supporting arms. [Ref. 47:p. 4-20]

The following sections paragraphs, taken directly from the Marine Corps doctrinal publication pertaining to fire support coordination, outline the procedures for engaging targets of opportunity:

a. FIELD ARTILLERY

> An assigned air observer or artillery forward observer locates a target in the zone of action of the supported unit and, with the approval of the company commander, initiates a fire request direct to the appropriate FDC. Necessary coordination is accomplished by the infantry battalion FSCC which is monitoring the mission. Clearance to fire a mission will be based upon the commander's policy. It can be positive clearance or silence. If coordination is required, the FSCC delays firing as necessary, while appropriate coordination is accomplished. If the FSCC is unable to monitor the mission, the artillery FDC will clear the mission with the FSCC over other channels as may be required. When reinforcing or general support artillery units are required for effective attack of targets short of the coordinated fire line, responsibility for requesting and controlling the fire rests with the forward observer and the artillery battalion. Responsibility for fire

support coordination always rests with the infantry commander and is accomplished in his FSCC. A report of the firing, when required, is sent to the SACC and landing force FSCC.

b. NAVAL GUNFIRE

Naval gunfire spotters with the committed infantry battalions send fire requests directly to the combat information center of the direct support gunfire ships for attack of targets of opportunity. The naval gunfire representatives at the battalion FSCC's do not interrupt or interfere except in emergencies, when additional coordination may be necessary, or when troop safety is involved. Attach of targets of opportunity short of the coordinated firing line must be coordinated by the battalion within whose zone the target is located. Attack of targets of opportunity beyond the coordinated fire line by naval gunfire ships does not require action by the FSCC, except when conflicts between supporting arms must be resolved. The FSCC is kept informed of all direct and general support naval gunfire missions executed on targets of opportunity in the supported unit's zone of action. A report of the firing, when required, is sent to the SACC and the landing force FSCC.

c. CLOSE AIR SUPPORT

(1) FAC CONTROLLED

Forward air controllers with the frontline battalions generally require scheduled or on-call airstrikes for attack on targets of opportunity. Often, unless such arrangements have been made, the transitory nature of targets of opportunity may preclude their attack by air. This is due to the time required for obtaining air support when airborne aircraft are not available. Attack of targets of opportunity beyond the fire support coordination line is accomplished by scheduled or on-call air strikes, or search and attack missions assigned directly to the aircraft by an air control agency (DASC, TADC, or TACC). The air representative in the FSCC is kept advised of all airstrikes forward of and within the zone of action of the command of which he is a part. Close air support requests from the FAC's are monitored by the air representatives at each FSCC. These air support requests are not interrupted except to cancel the mission due to an emergency involving tactical operations, troop safety, limitations imposed by higher headquarters, or when other supporting arms have been requested and approved for the same targets.

(2) BEYOND THE FIRE SUPPORT COORDINATION LINE

Attack of targets of opportunity beyond the fire support coordination line is made at the discretion of the pilot or air control agency and no coordination other than that between pilot and air control agency is required. While no formal coordination requirements exist, the potential for artillery or naval gunfire firing in this area is real, and information coordination between the FSCC and DASC should be accomplished prior to missions being conducted in this area.

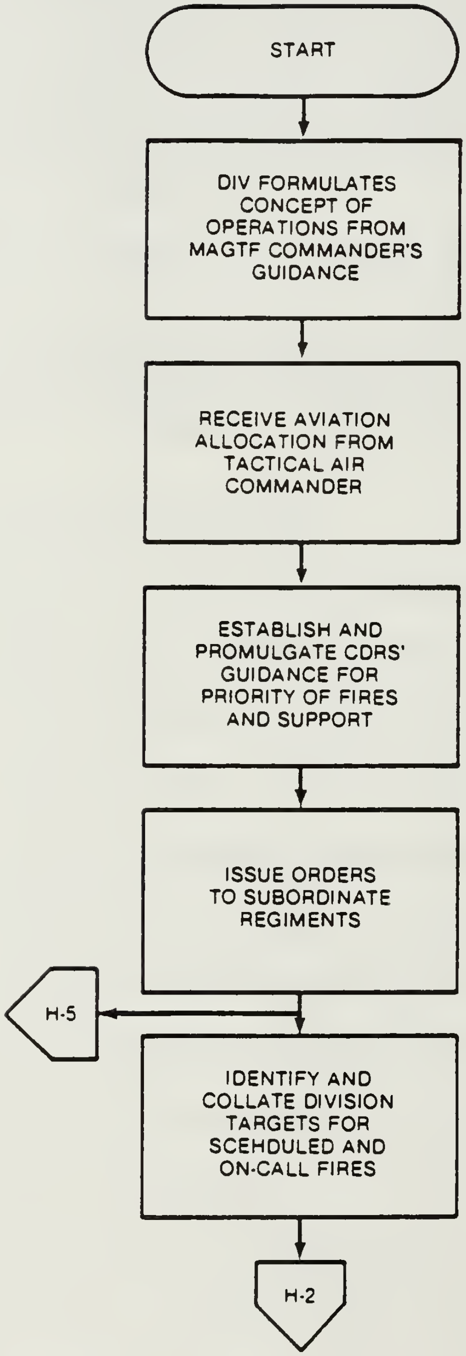
(3) SUPPRESSION OF ENEMY AIR DEFENSE COORDINATION

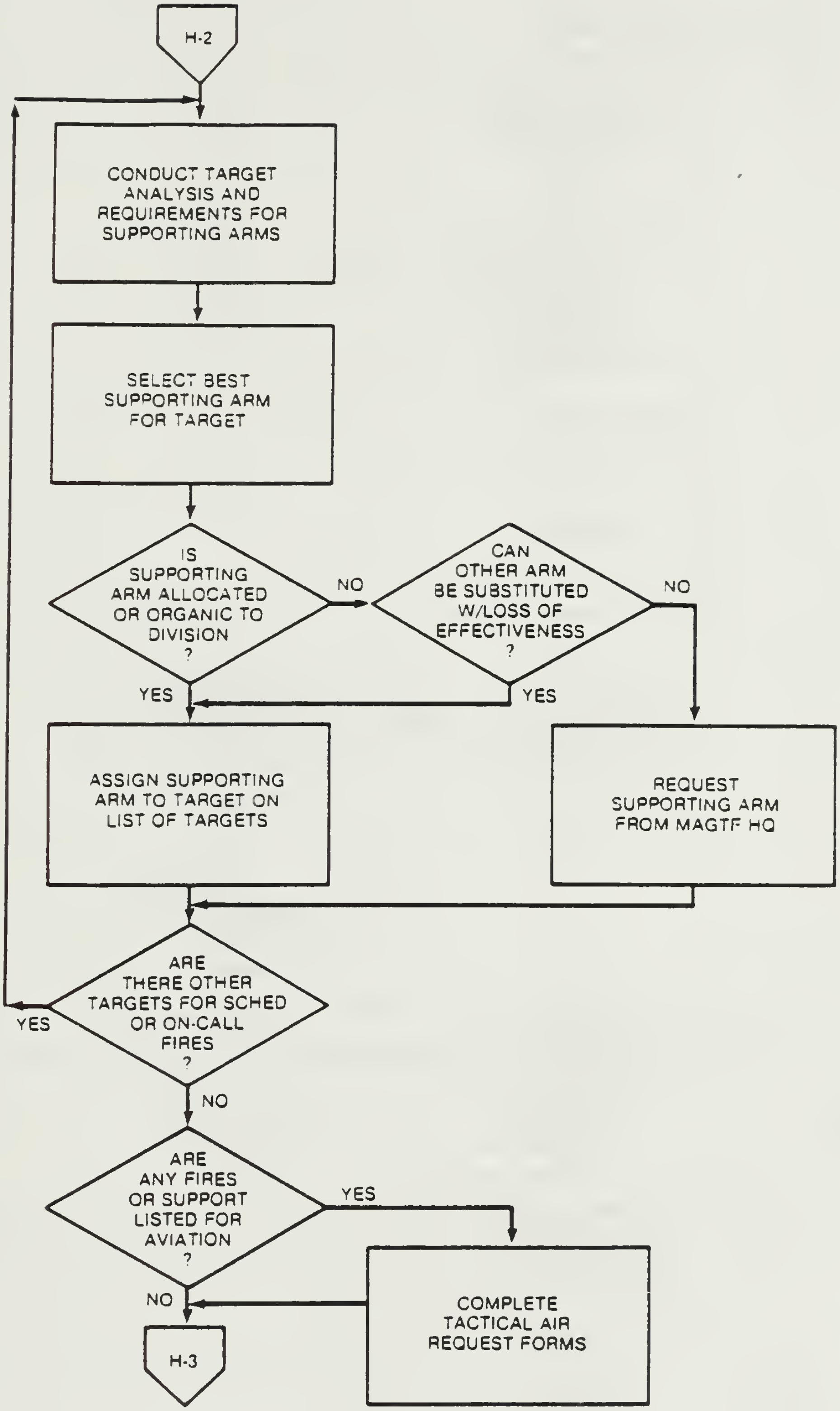
The FSCC coordinates suppression of enemy air defenses and institutes airspace coordination areas of trajectory limitations to enhance aircraft safety and its effective attack of targets. [Ref. 47:p. 4-21]

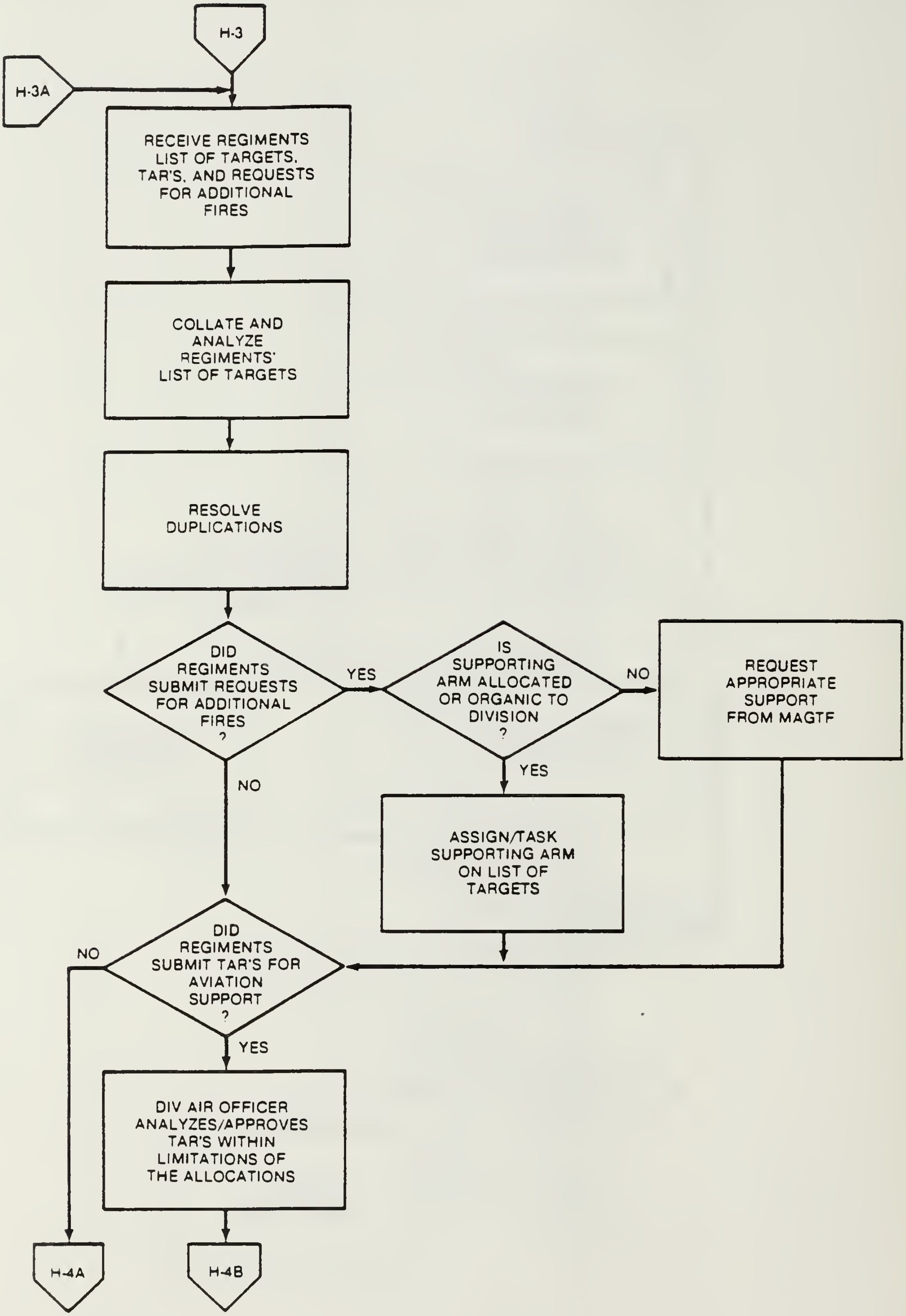
F. FIRE SUPPORT PLANNING PROCESS

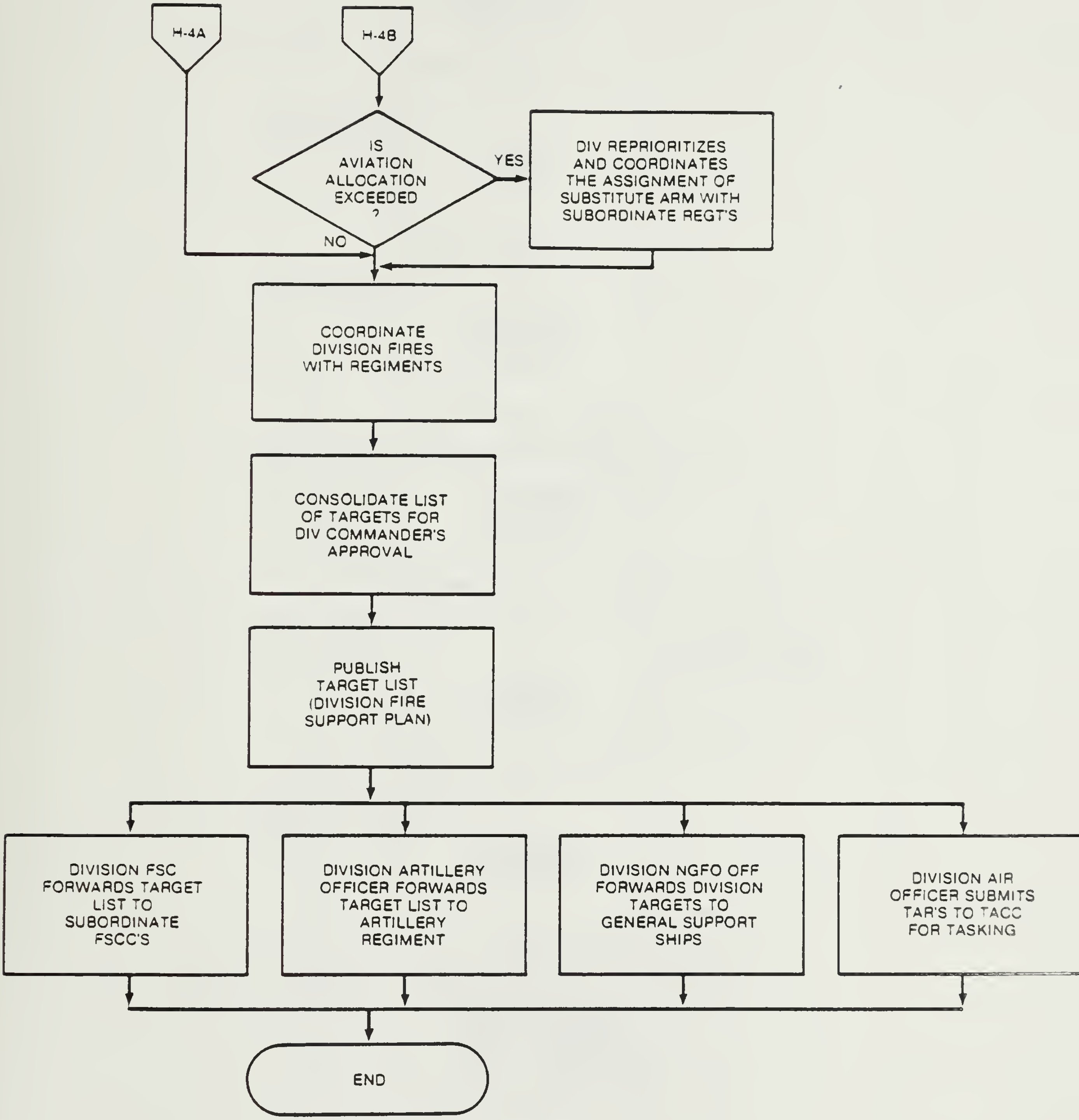
The following pages illustrate the formal fire support planning process through a series of flow charts which were provided by the Marine Corps doctrinal publication pertaining to fire support coordination. [Ref. 47:p. H-2 to H-12] In addition to providing a concise representation of the process, the flow chart is offered as proof that the process may be automated in the manner suggested by the flow charts. Automation of the fire support process is crucial in the proposed application of fire support systems and will be pursued in a subsequent chapter.

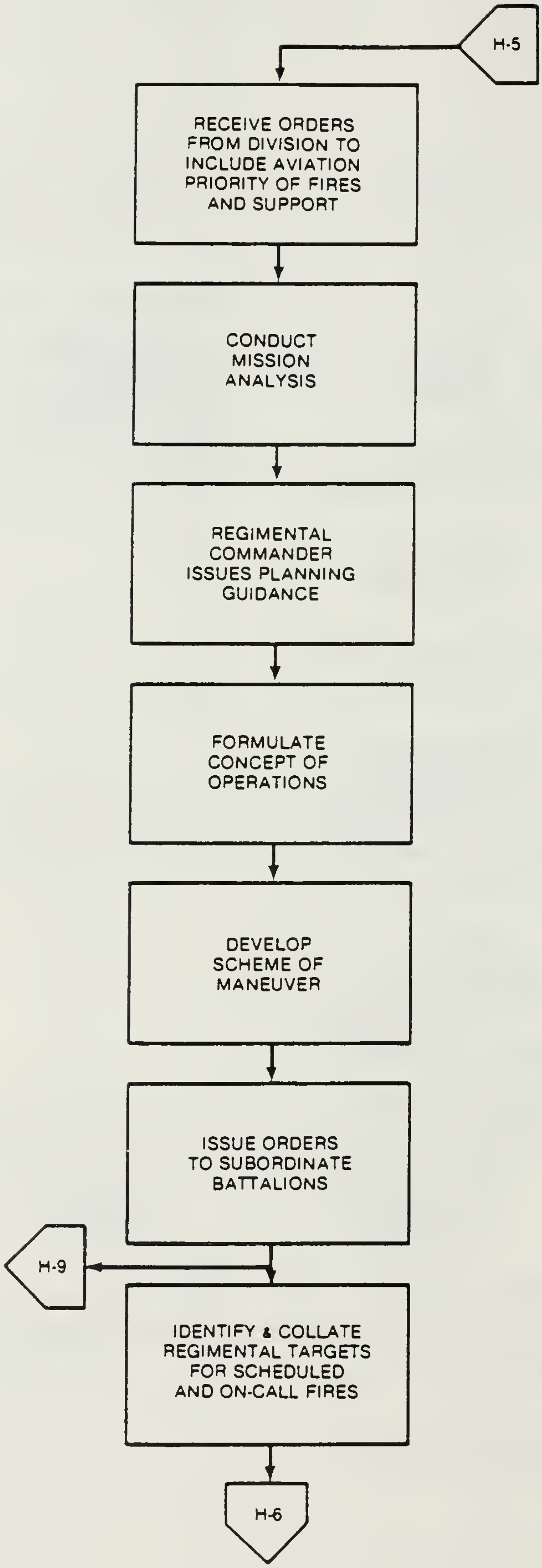
The flow chart allows the reader to follow the fire support planning process step-by-step, from formulation of the Commander's concept of operations to development of the target lists. Also illustrated are the decisions and processes which are accomplished at various levels within the "chain of command" from the Marine Division Headquarters down to the tactical Fire Support Coordinators and liaison officers. This flow chart illustrates a basis for automating the entire process.

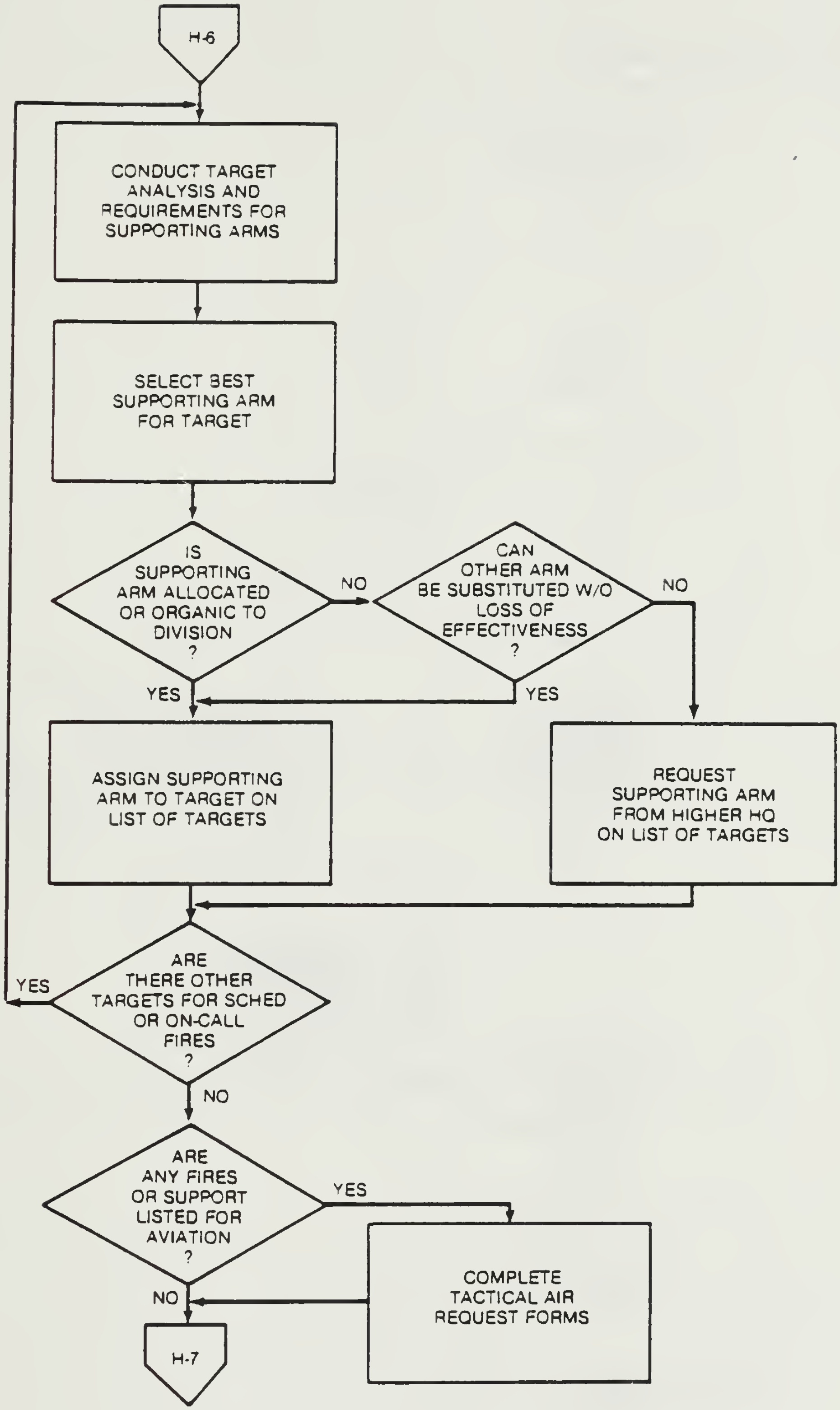

START
DIV FORMULATES CONCEPT OF OPERATIONS FROM MAGTF COMMANDER'S GUIDANCE
RECEIVE AVIATION ALLOCATION FROM TACTICAL AIR COMMANDER
ESTABLISH AND PROMULGATE CDRS' GUIDANCE FOR PRIORITY OF FIRES AND SUPPORT
ISSUE ORDERS TO SUBORDINATE REGIMENTS
H-5
IDENTIFY AND COLLATE DIVISION TARGETS FOR SCEHDULED AND ON-CALL FIRES
H-2

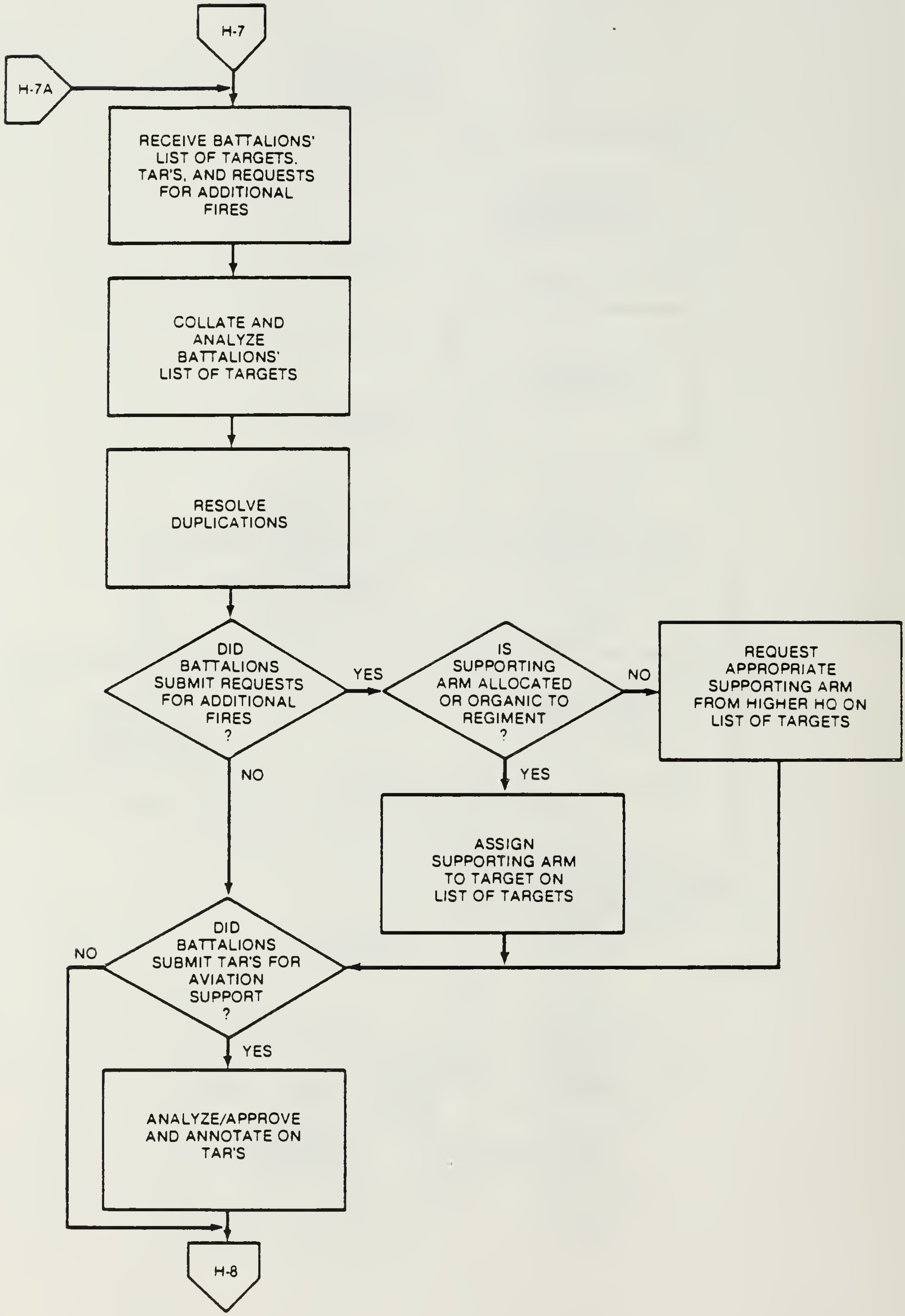

H-2
CONDUCT TARGET ANALYSIS AND REQUIREMENTS FOR SUPPORTING ARMS
SELECT BEST SUPPORTING ARM FOR TARGET
IS SUPPORTING ARM ALLOCATED OR ORGANIC TO DIVISION ?
NO
CAN OTHER ARM BE SUBSTITUTED W/LOSS OF EFFECTIVENESS ?
NO
YES
YES
ASSIGN SUPPORTING ARM TO TARGET ON LIST OF TARGETS
REQUEST SUPPORTING ARM FROM MAGTF HQ
ARE THERE OTHER TARGETS FOR SCHED OR ON-CALL FIRES ?
YES
NO
ARE ANY FIRES OR SUPPORT LISTED FOR AVIATION ?
YES
NO
COMPLETE TACTICAL AIR REQUEST FORMS
H-3

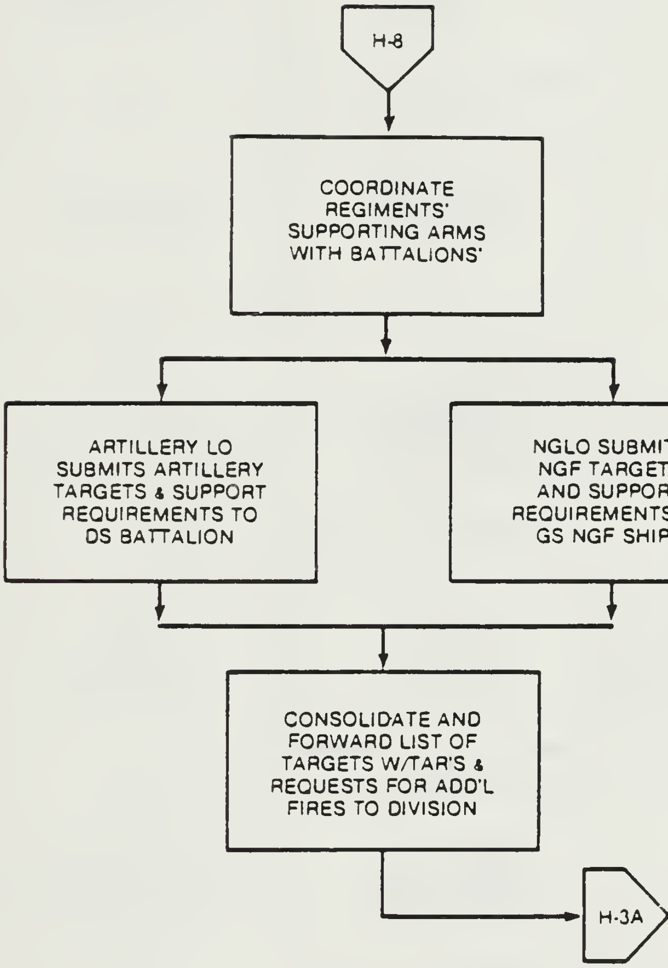

H-3
H-3A
RECEIVE REGIMENTS LIST OF TARGETS, TAR'S, AND REQUESTS FOR ADDITIONAL FIRES
COLLATE AND ANALYZE REGIMENTS' LIST OF TARGETS
RESOLVE DUPLICATIONS
DID REGIMENTS SUBMIT REQUESTS FOR ADDITIONAL FIRES ?
YES
IS SUPPORTING ARM ALLOCATED OR ORGANIC TO DIVISION ?
NO
REQUEST APPROPRIATE SUPPORT FROM MAGTF
YES
ASSIGN/TASK SUPPORTING ARM ON LIST OF TARGETS
NO
DID REGIMENTS SUBMIT TAR'S FOR AVIATION SUPPORT ?
NO
YES
DIV AIR OFFICER ANALYZES/APPROVES TAR'S WITHIN LIMITATIONS OF THE ALLOCATIONS
H-4A
H-4B

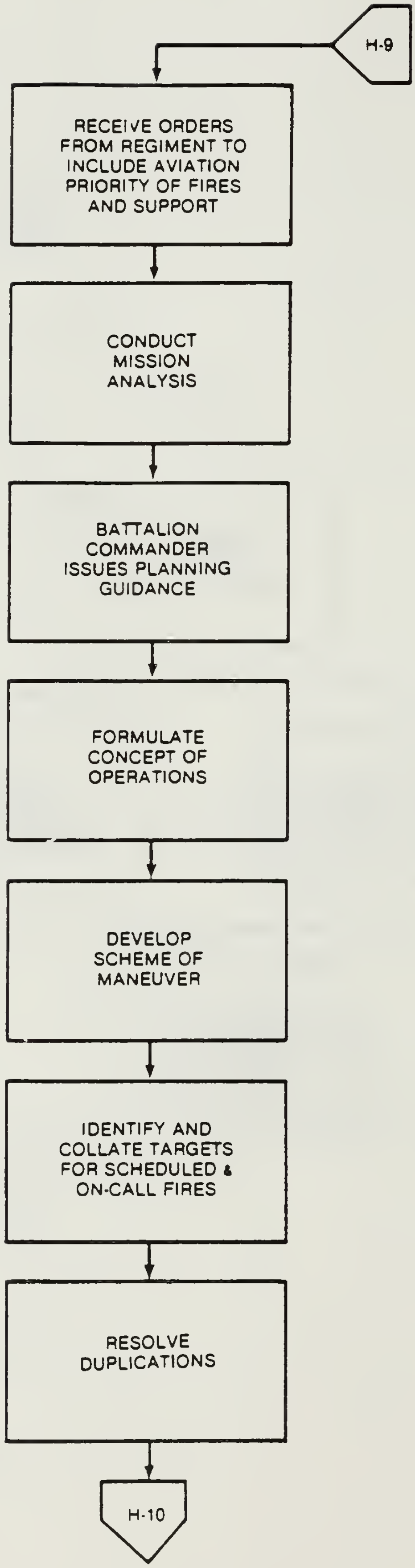

H-4A
H-4B
IS AVIATION ALLOCATION EXCEEDED ?
YES
NO
DIV REPRIORITIZES AND COORDINATES THE ASSIGNMENT OF SUBSTITUTE ARM WITH SUBORDINATE REGT'S
COORDINATE DIVISION FIRES WITH REGIMENTS
CONSOLIDATE LIST OF TARGETS FOR DIV COMMANDER'S APPROVAL
PUBLISH TARGET LIST (DIVISION FIRE SUPPORT PLAN)
DIVISION FSC FORWARDS TARGET LIST TO SUBORDINATE FSCC'S
DIVISION ARTILLERY OFFICER FORWARDS TARGET LIST TO ARTILLERY REGIMENT
DIVISION NGFO OFF FORWARDS DIVISION TARGETS TO GENERAL SUPPORT SHIPS
DIVISION AIR OFFICER SUBMITS TAR'S TO TACC FOR TASKING
END

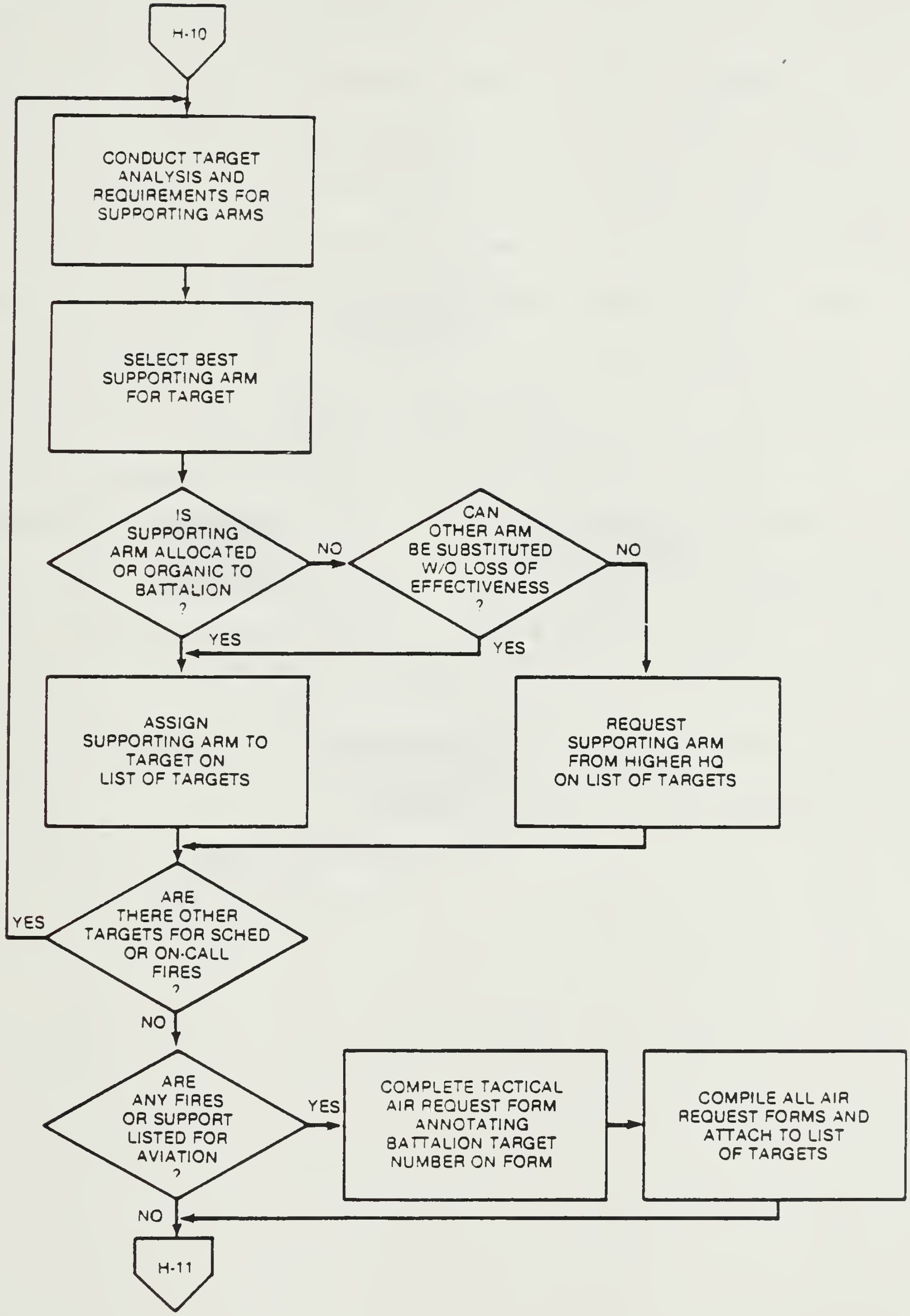

H-5
RECEIVE ORDERS FROM DIVISION TO INCLUDE AVIATION PRIORITY OF FIRES AND SUPPORT
CONDUCT MISSION ANALYSIS
REGIMENTAL COMMANDER ISSUES PLANNING GUIDANCE
FORMULATE CONCEPT OF OPERATIONS
DEVELOP SCHEME OF MANEUVER
ISSUE ORDERS TO SUBORDINATE BATTALIONS
H-9
IDENTIFY & COLLATE REGIMENTAL TARGETS FOR SCHEDULED AND ON-CALL FIRES
H-6

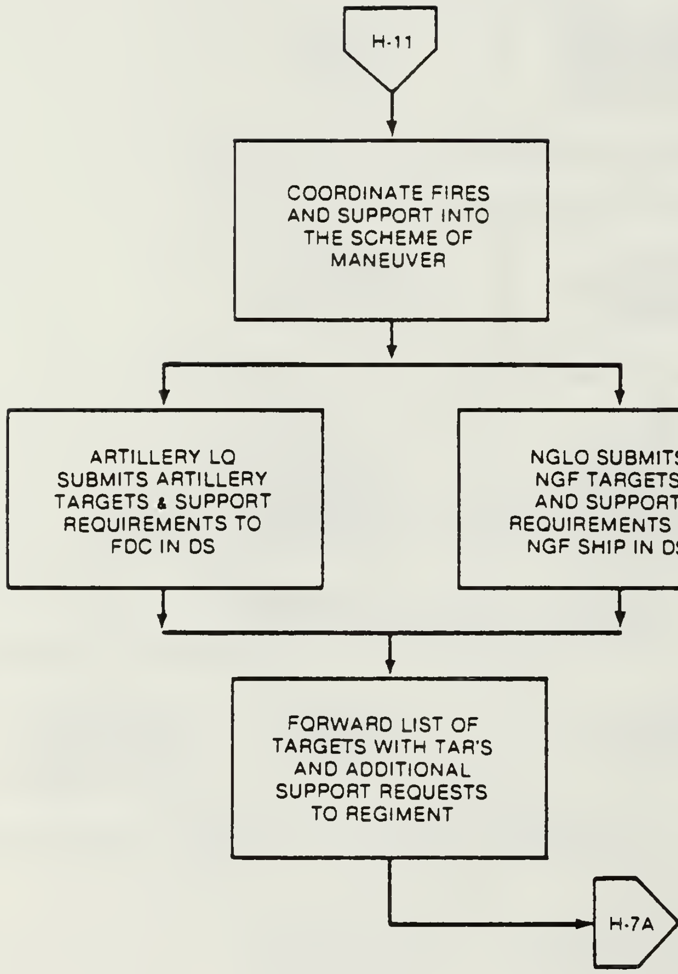

H-6
CONDUCT TARGET ANALYSIS AND REQUIREMENTS FOR SUPPORTING ARMS
SELECT BEST SUPPORTING ARM FOR TARGET
IS SUPPORTING ARM ALLOCATED OR ORGANIC TO DIVISION ?
NO
CAN OTHER ARM BE SUBSTITUTED W/O LOSS OF EFFECTIVENESS ?
NO
YES
YES
ASSIGN SUPPORTING ARM TO TARGET ON LIST OF TARGETS
REQUEST SUPPORTING ARM FROM HIGHER HQ ON LIST OF TARGETS
YES
ARE THERE OTHER TARGETS FOR SCHED OR ON-CALL FIRES ?
NO
ARE ANY FIRES OR SUPPORT LISTED FOR AVIATION ?
YES
COMPLETE TACTICAL AIR REQUEST FORMS
NO
H-7


H-7
H-7A
RECEIVE BATTALIONS' LIST OF TARGETS, TAR'S, AND REQUESTS FOR ADDITIONAL FIRES
COLLATE AND ANALYZE BATTALIONS' LIST OF TARGETS
RESOLVE DUPLICATIONS
DID BATTALIONS SUBMIT REQUESTS FOR ADDITIONAL FIRES ?
YES
IS SUPPORTING ARM ALLOCATED OR ORGANIC TO REGIMENT ?
NO
REQUEST APPROPRIATE SUPPORTING ARM FROM HIGHER HQ ON LIST OF TARGETS
YES
ASSIGN SUPPORTING ARM TO TARGET ON LIST OF TARGETS
NO
DID BATTALIONS SUBMIT TAR'S FOR AVIATION SUPPORT ?
NO
YES
ANALYZE/APPROVE AND ANNOTATE ON TAR'S
H-8


H-8
COORDINATE REGIMENTS' SUPPORTING ARMS WITH BATTALIONS'
ARTILLERY LO SUBMITS ARTILLERY TARGETS & SUPPORT REQUIREMENTS TO DS BATTALION
NGLO SUBMITS NGF TARGETS AND SUPPORT REQUIREMENTS TO GS NGF SHIPS
CONSOLIDATE AND FORWARD LIST OF TARGETS W/TAR'S & REQUESTS FOR ADD'L FIRES TO DIVISION
H-3A

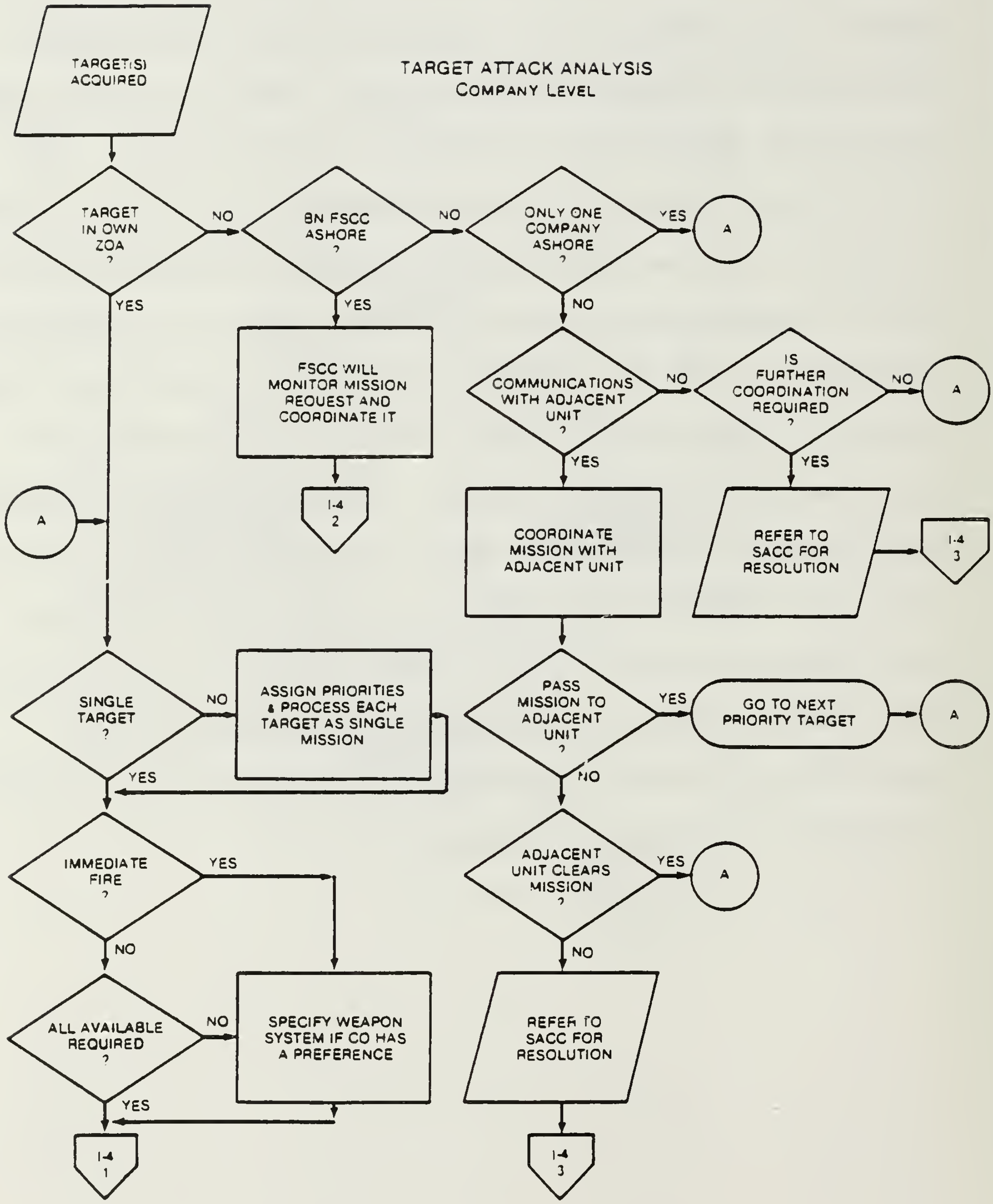

H-9
RECEIVE ORDERS FROM REGIMENT TO INCLUDE AVIATION PRIORITY OF FIRES AND SUPPORT
CONDUCT MISSION ANALYSIS
BATTALION COMMANDER ISSUES PLANNING GUIDANCE
FORMULATE CONCEPT OF OPERATIONS
DEVELOP SCHEME OF MANEUVER
IDENTIFY AND COLLATE TARGETS FOR SCHEDULED & ON-CALL FIRES
RESOLVE DUPLICATIONS
H-10

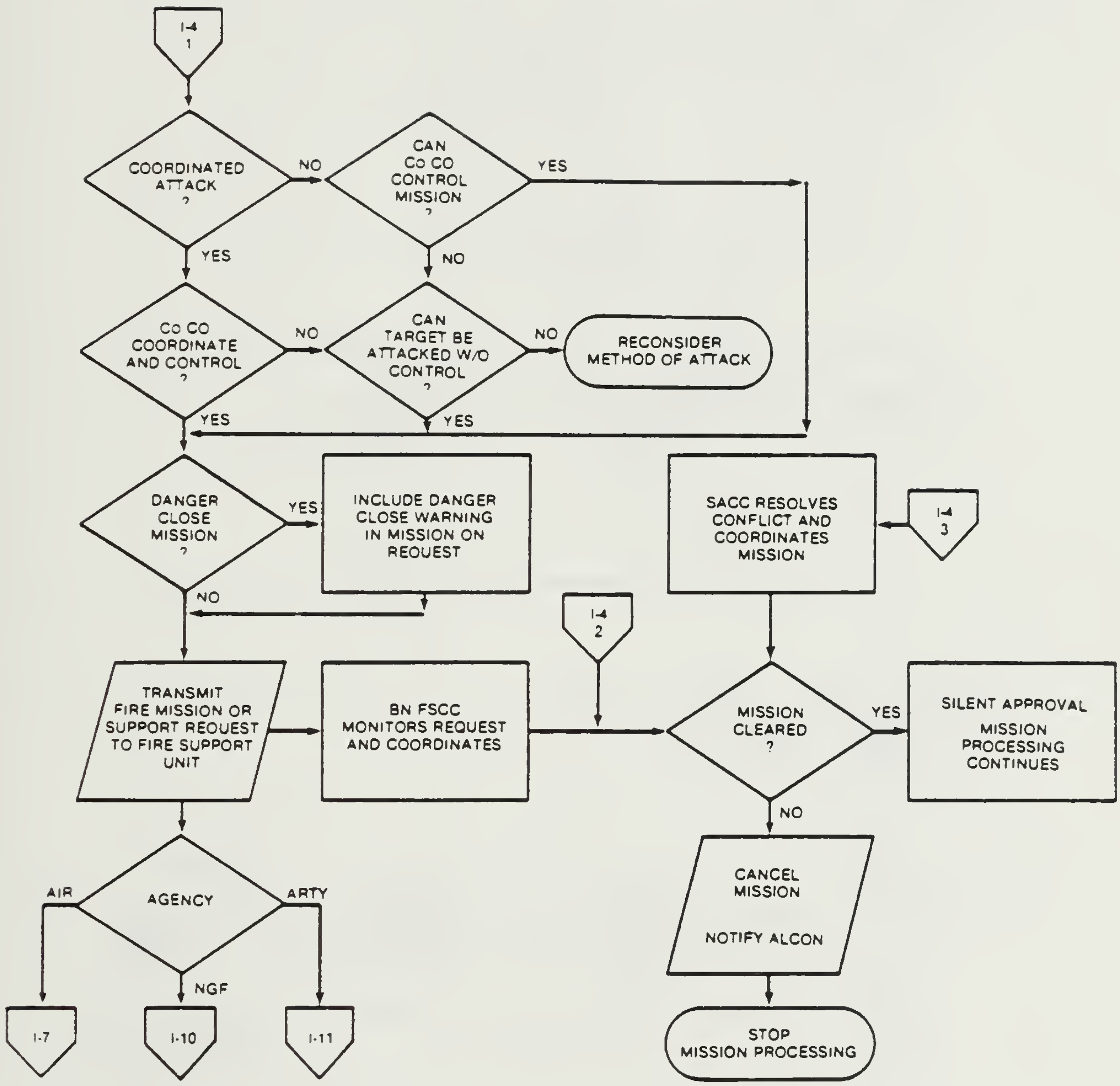

H-10
CONDUCT TARGET ANALYSIS AND REQUIREMENTS FOR SUPPORTING ARMS
SELECT BEST SUPPORTING ARM FOR TARGET
IS SUPPORTING ARM ALLOCATED OR ORGANIC TO BATTALION ?
NO
CAN OTHER ARM BE SUBSTITUTED W/O LOSS OF EFFECTIVENESS ?
NO
YES
YES
ASSIGN SUPPORTING ARM TO TARGET ON LIST OF TARGETS
REQUEST SUPPORTING ARM FROM HIGHER HQ ON LIST OF TARGETS
YES
ARE THERE OTHER TARGETS FOR SCHED OR ON-CALL FIRES ?
NO
ARE ANY FIRES OR SUPPORT LISTED FOR AVIATION ?
YES
COMPLETE TACTICAL AIR REQUEST FORM ANNOTATING BATTALION TARGET NUMBER ON FORM
COMPILE ALL AIR REQUEST FORMS AND ATTACH TO LIST OF TARGETS
NO
H-11


H-11
COORDINATE FIRES AND SUPPORT INTO THE SCHEME OF MANEUVER
ARTILLERY LO SUBMITS ARTILLERY TARGETS & SUPPORT REQUIREMENTS TO FDC IN DS
NGLO SUBMITS NGF TARGETS AND SUPPORT REQUIREMENTS TO NGF SHIP IN DS
FORWARD LIST OF TARGETS WITH TAR'S AND ADDITIONAL SUPPORT REQUESTS TO REGIMENT
H-7A

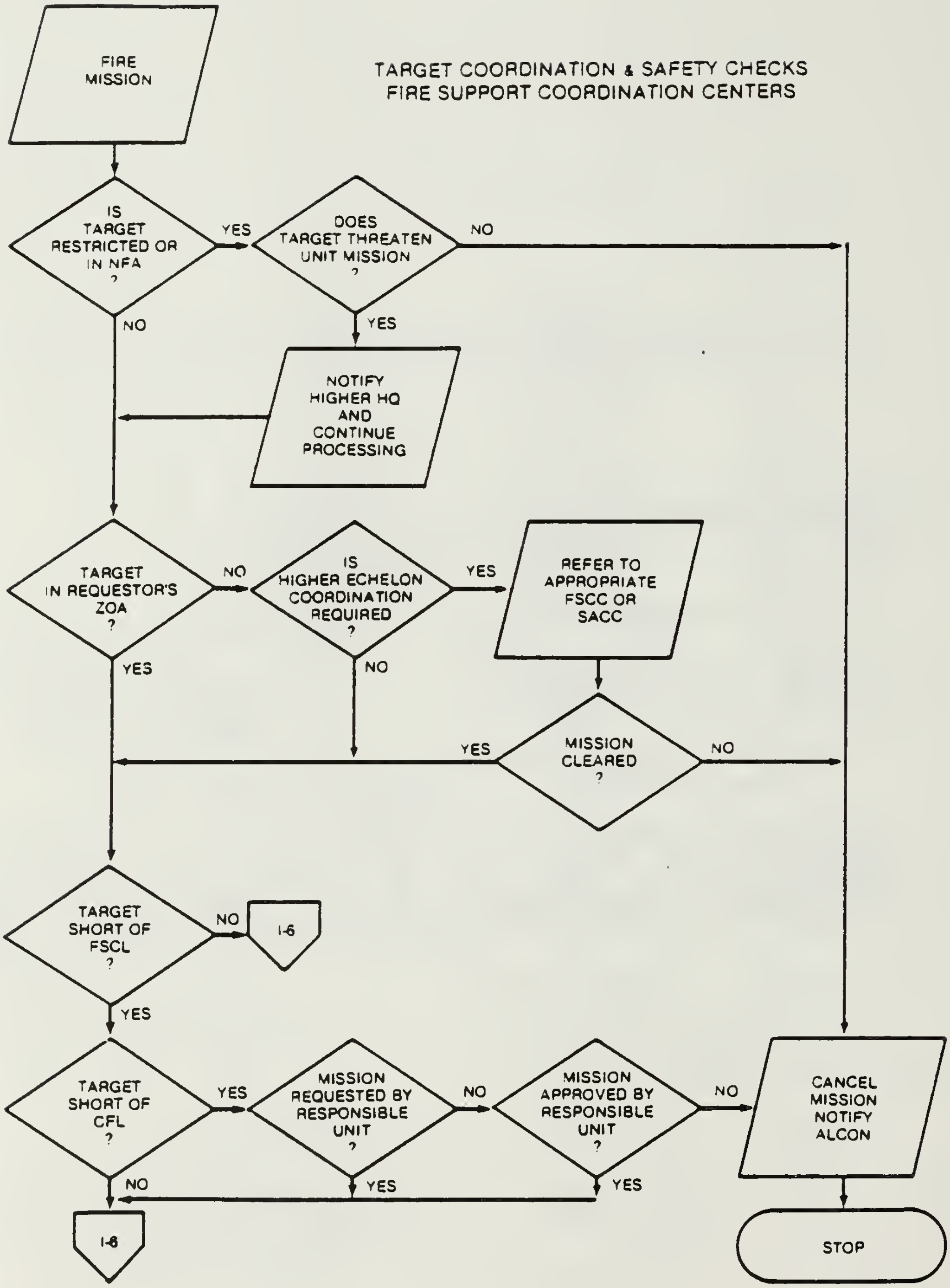
G. FIRE SUPPORT COORDINATION PROCESS

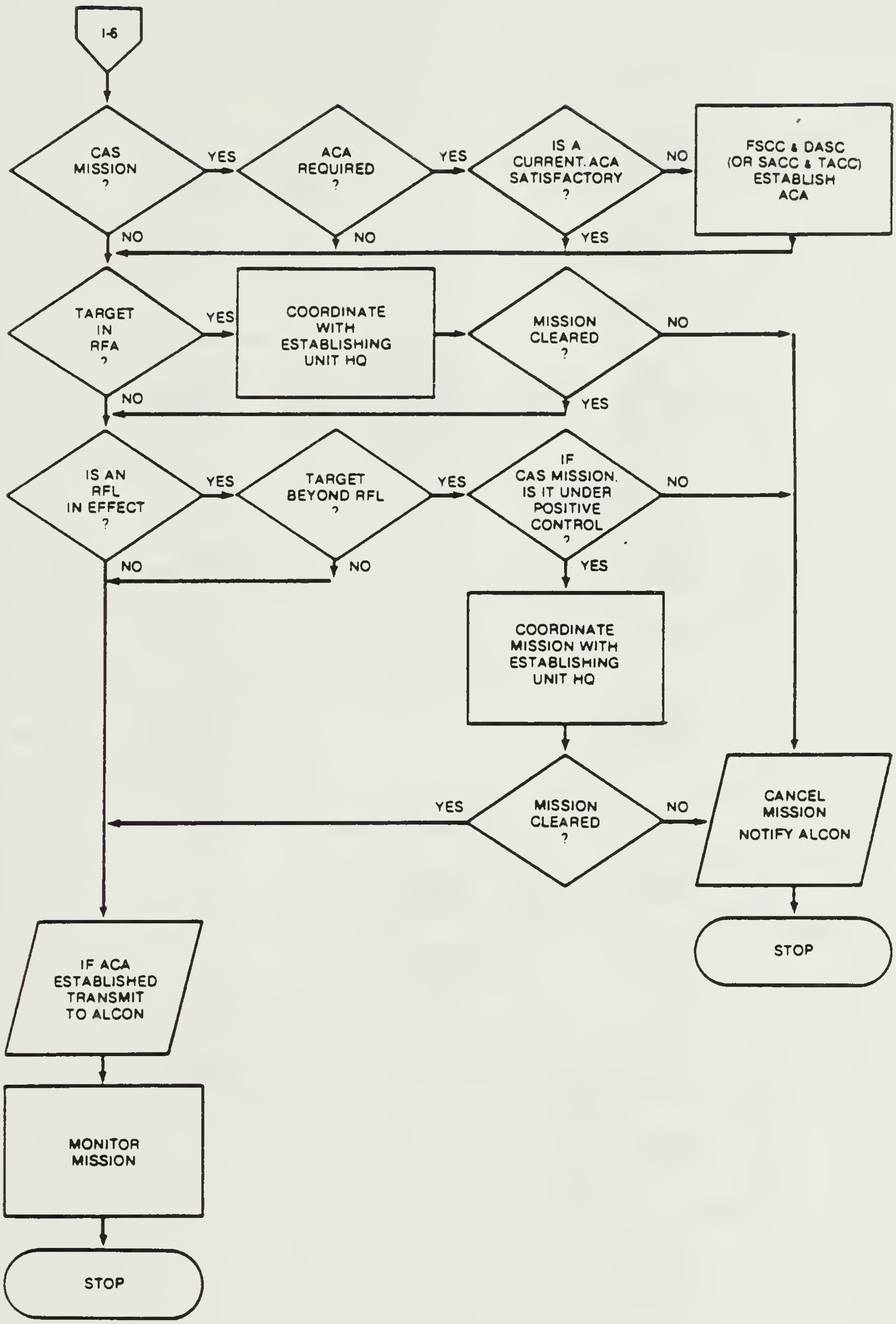
Just as the previous section demonstrated the fire support planning process through the use of a series of flow charts, this section will demonstrate the fire support coordination process through another series of flow charts provided by Marine Corps doctrinal publications. [Ref. 47:p. I-3 to I-13] Once again, the purpose is not only to provide a graphic representation of fire support coordination, but also to demonstrate that the process could be automated as indicated by the flow charts. Included in the flow charted process is the initial target attack analysis, target coordination and safety checks, and the mission processes for coordination of the three types of supporting arms available: close air support, naval gunfire, and field artillery. The flow charts provided in this chapter will also serve as a basis for the detailed discussions pertaining to the application of expert systems technology to fire support coordination provided in Chapter VII.


TARGET ATTACK ANALYSIS
COMPANY LEVEL
TARGET(S) ACQUIRED
TARGET IN OWN ZOA ?
NO
YES
BN FSCC ASHORE ?
NO
YES
ONLY ONE COMPANY ASHORE ?
YES
A
NO
FSCC WILL MONITOR MISSION REQUEST AND COORDINATE IT
1-4 2
COMMUNICATIONS WITH ADJACENT UNIT ?
NO
IS FURTHER COORDINATION REQUIRED ?
NO
A
YES
YES
A
COORDINATE MISSION WITH ADJACENT UNIT
REFER TO SACC FOR RESOLUTION
1-4 3
SINGLE TARGET ?
NO
ASSIGN PRIORITIES & PROCESS EACH TARGET AS SINGLE MISSION
YES
PASS MISSION TO ADJACENT UNIT ?
YES
GO TO NEXT PRIORITY TARGET
A
NO
IMMEDIATE FIRE ?
YES
NO
ADJACENT UNIT CLEARS MISSION ?
YES
A
NO
ALL AVAILABLE REQUIRED ?
NO
SPECIFY WEAPON SYSTEM IF CO HAS A PREFERENCE
YES
REFER TO SACC FOR RESOLUTION
1-4 1
1-4 3

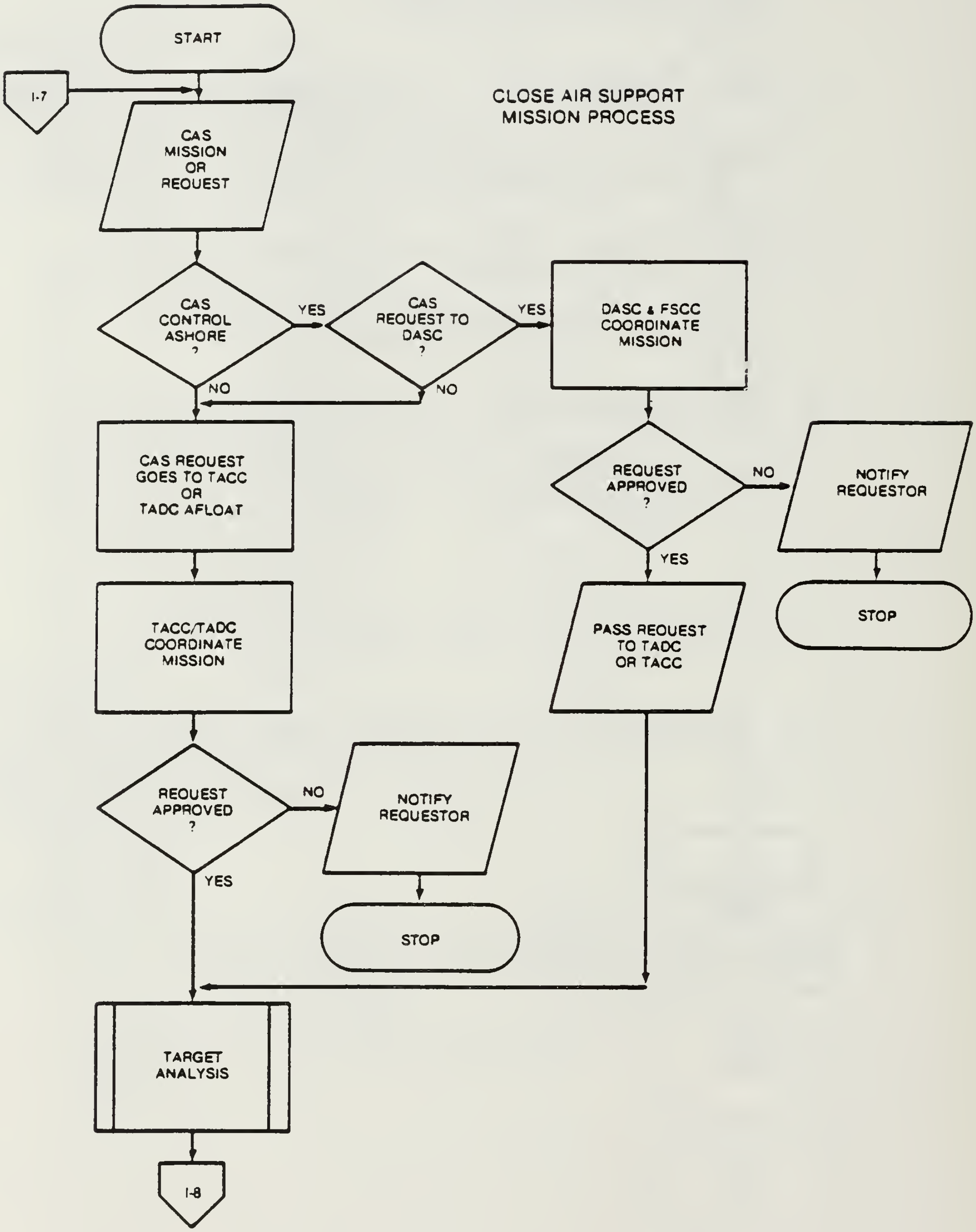

I-4
1
COORDINATED ATTACK ?
NO
CAN Co CO CONTROL MISSION ?
YES
YES
NO
Co CO COORDINATE AND CONTROL ?
NO
CAN TARGET BE ATTACKED W/O CONTROL ?
NO
RECONSIDER METHOD OF ATTACK
YES
YES
DANGER CLOSE MISSION ?
YES
INCLUDE DANGER CLOSE WARNING IN MISSION ON REQUEST
SACC RESOLVES CONFLICT AND COORDINATES MISSION
I-4
3
NO
I-4
2
TRANSMIT FIRE MISSION OR SUPPORT REQUEST TO FIRE SUPPORT UNIT
BN FSCC MONITORS REQUEST AND COORDINATES
MISSION CLEARED ?
YES
SILENT APPROVAL
MISSION PROCESSING CONTINUES
NO
AGENCY
AIR
ARTY
NGF
CANCEL MISSION
NOTIFY ALCON
I-7
I-10
I-11
STOP MISSION PROCESSING

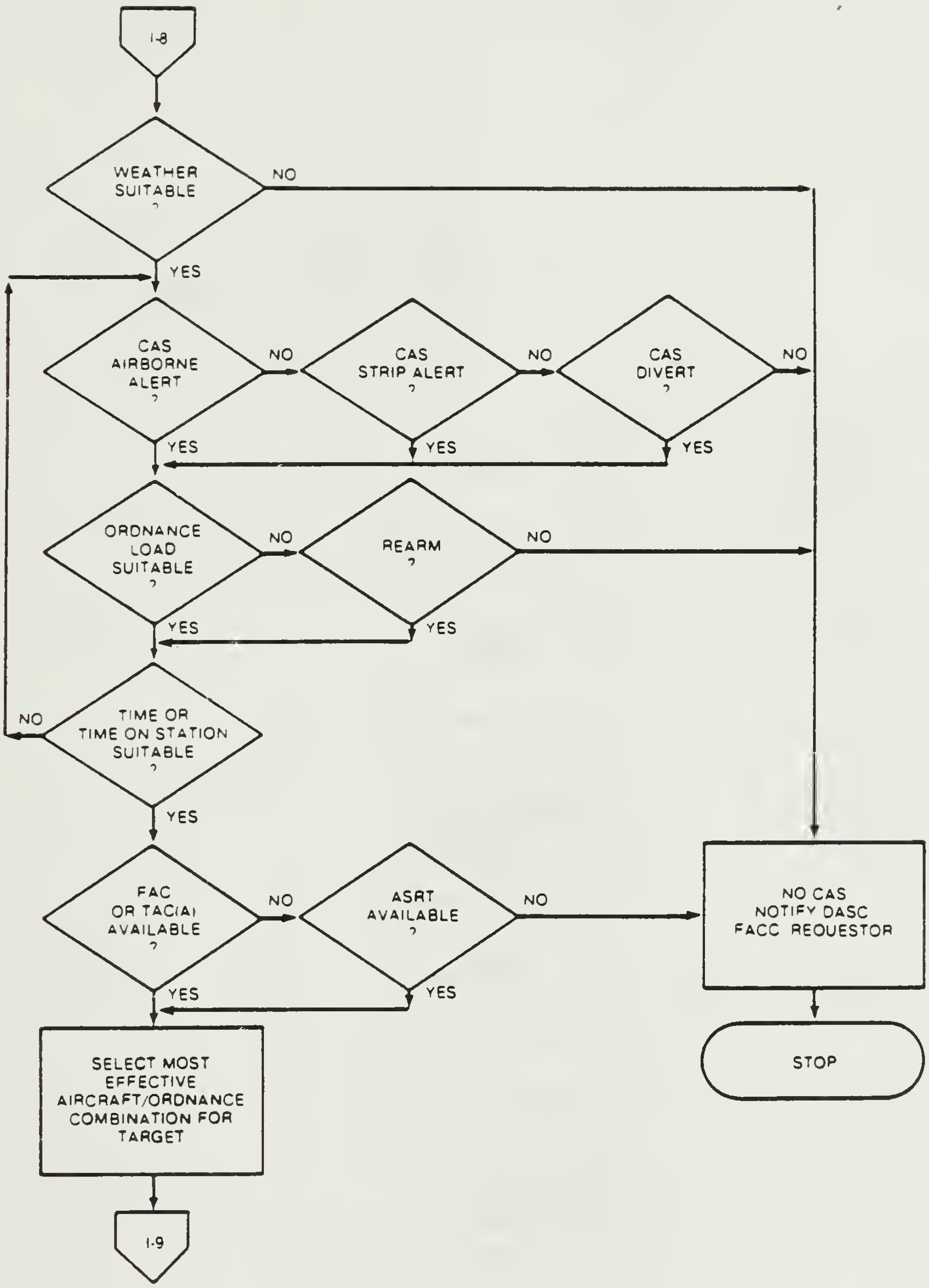
TARGET COORDINATION & SAFETY CHECKS
FIRE SUPPORT COORDINATION CENTERS

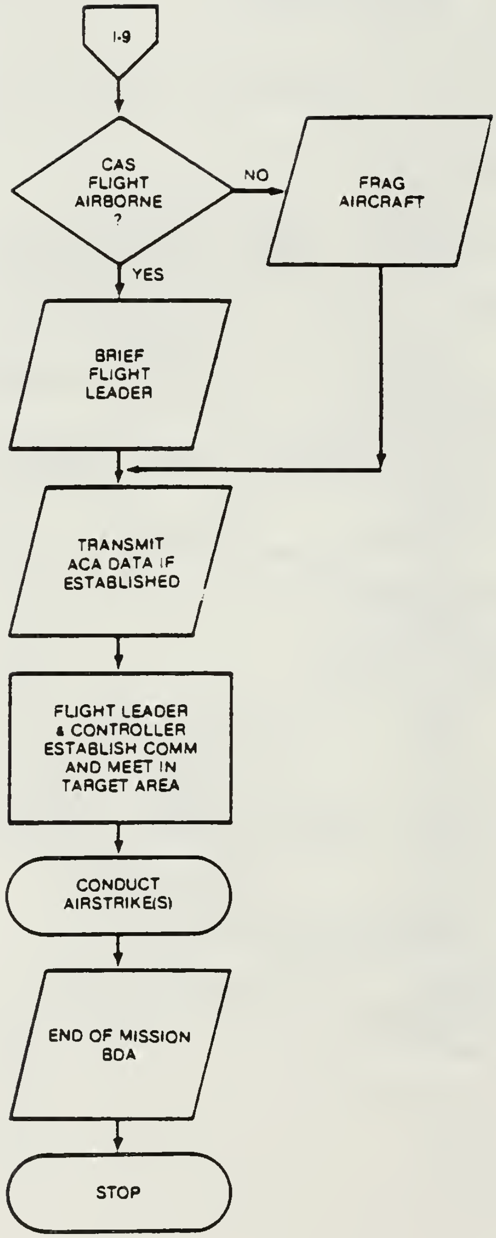


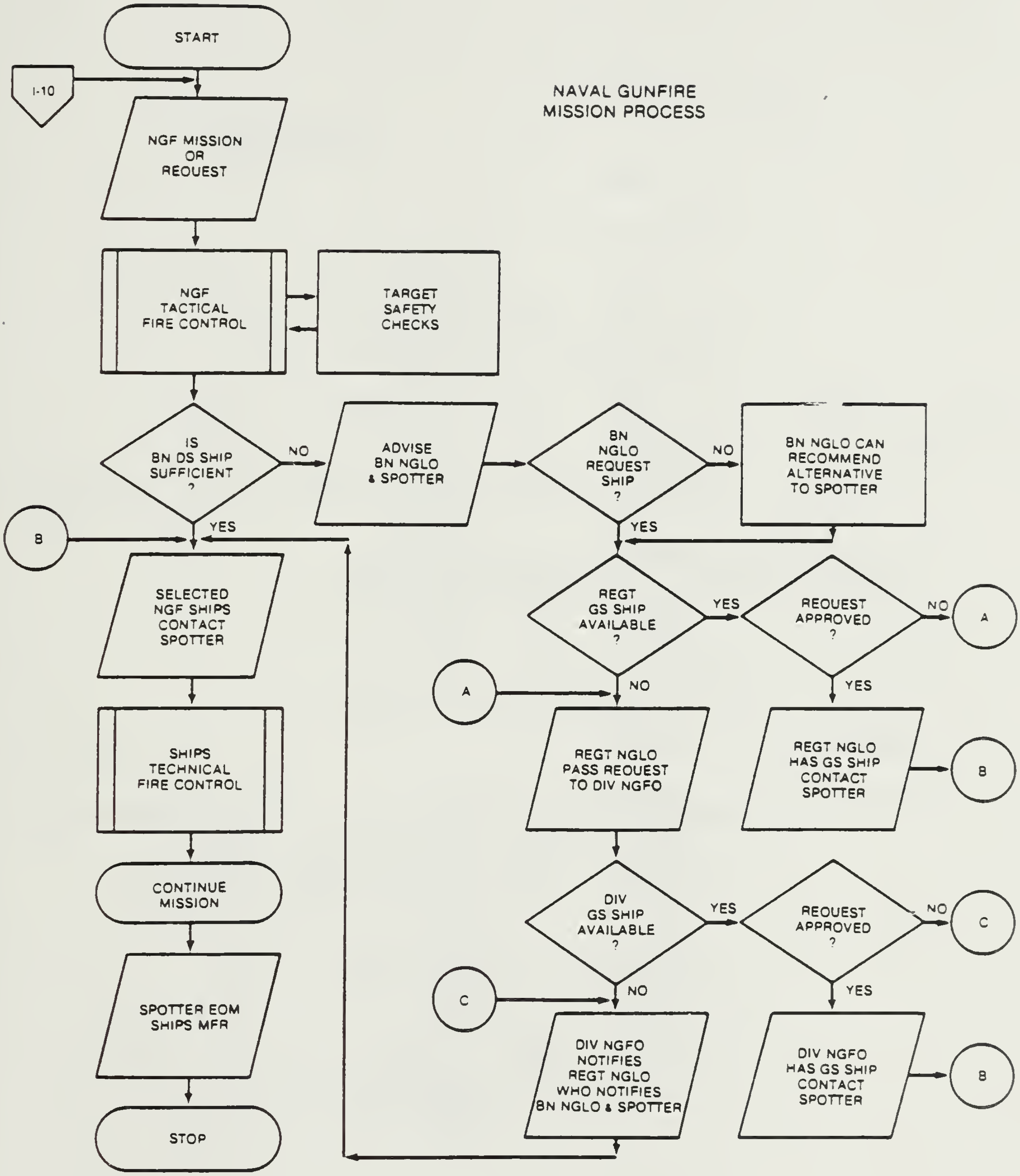

1-6
CAS MISSION ?
YES
NO
ACA REQUIRED ?
YES
NO
IS A CURRENT ACA SATISFACTORY ?
NO
YES
FSCC & DASC (OR SACC & TACC) ESTABLISH ACA
TARGET IN RFA ?
YES
NO
COORDINATE WITH ESTABLISHING UNIT HQ
MISSION CLEARED ?
NO
YES
IS AN RFL IN EFFECT ?
YES
NO
TARGET BEYOND RFL ?
YES
NO
IF CAS MISSION, IS IT UNDER POSITIVE CONTROL ?
NO
YES
COORDINATE MISSION WITH ESTABLISHING UNIT HQ
MISSION CLEARED ?
YES
NO
CANCEL MISSION NOTIFY ALCON
STOP
IF ACA ESTABLISHED TRANSMIT TO ALCON
MONITOR MISSION
STOP

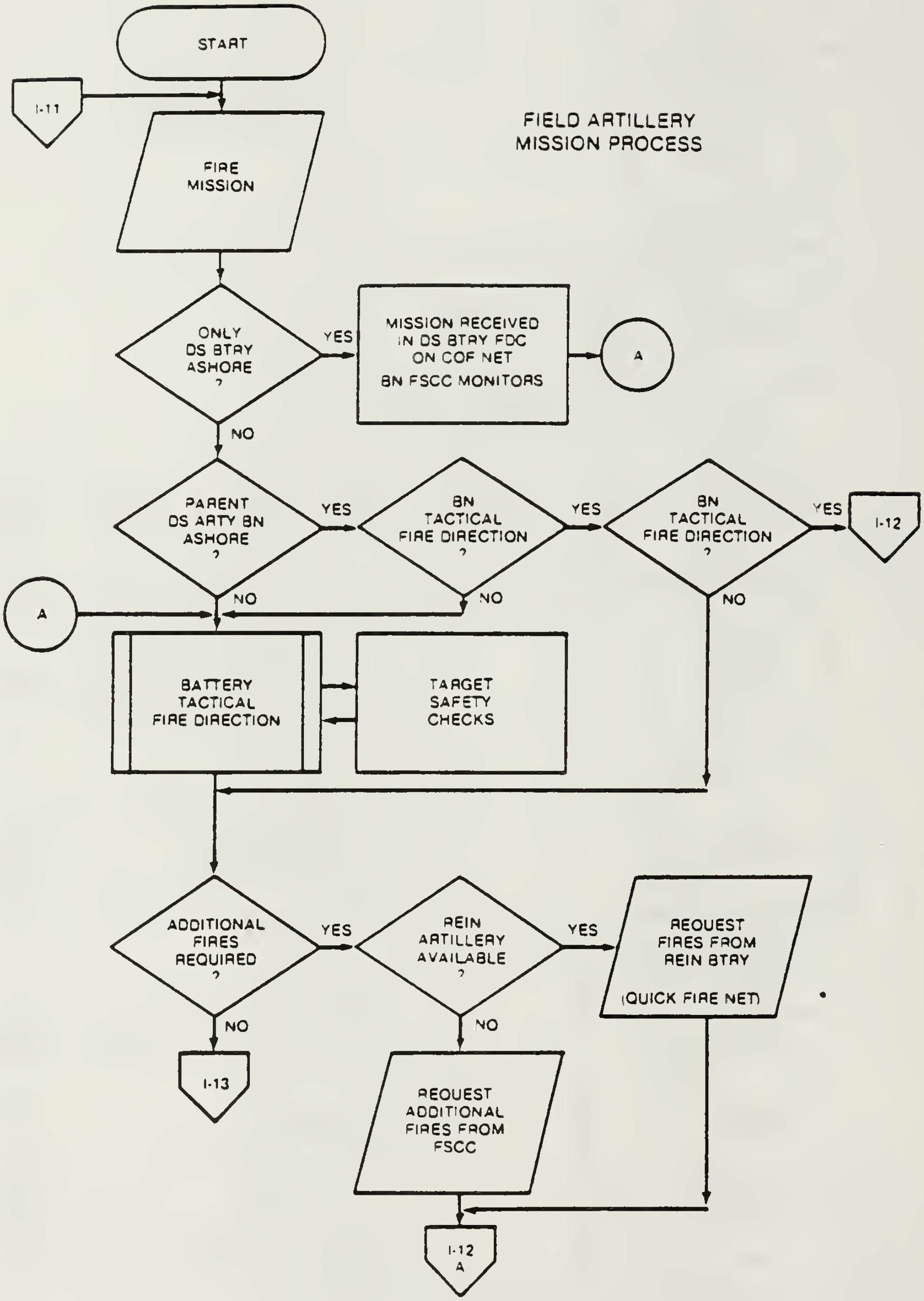
CLOSE AIR SUPPORT
MISSION PROCESS



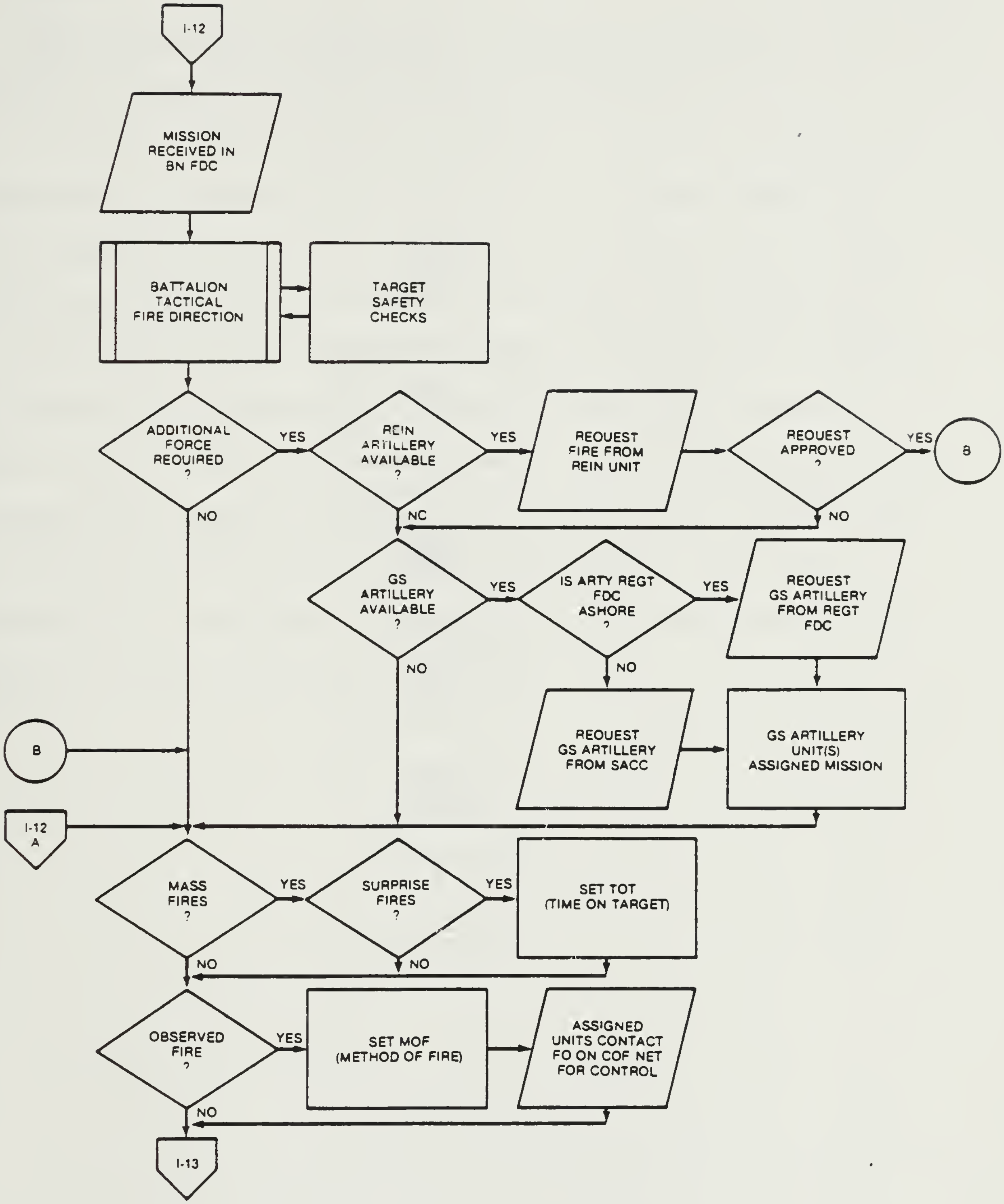

I-8
WEATHER SUITABLE ?
NO
YES
CAS AIRBORNE ALERT ?
NO
CAS STRIP ALERT ?
NO
CAS DIVERT ?
NO
YES
YES
YES
ORDNANCE LOAD SUITABLE ?
NO
REARM ?
NO
YES
YES
NO
TIME OR TIME ON STATION SUITABLE ?
YES
FAC OR TAC(A) AVAILABLE ?
NO
ASRT AVAILABLE ?
NO
YES
YES
NO CAS NOTIFY DASC FACC REQUESTOR
STOP
SELECT MOST EFFECTIVE AIRCRAFT/ORDNANCE COMBINATION FOR TARGET
I-9

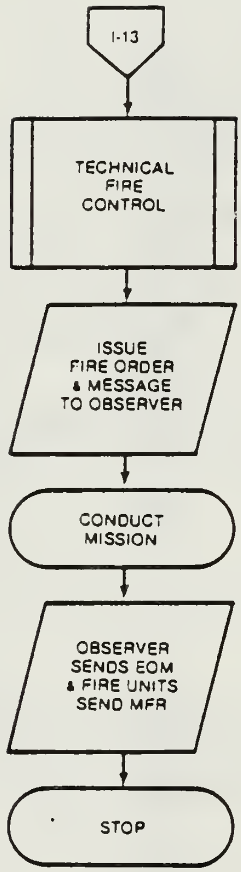

I-9
CAS FLIGHT AIRBORNE ?
NO
FRAG AIRCRAFT
YES
BRIEF FLIGHT LEADER
TRANSMIT ACA DATA IF ESTABLISHED
FLIGHT LEADER & CONTROLLER ESTABLISH COMM AND MEET IN TARGET AREA
CONDUCT AIRSTRIKE(S)
END OF MISSION BDA
STOP


NAVAL GUNFIRE
MISSION PROCESS
START
I-10
NGF MISSION OR REQUEST
NGF TACTICAL FIRE CONTROL
TARGET SAFETY CHECKS
IS BN DS SHIP SUFFICIENT ?
NO
YES
ADVISE BN NGLO & SPOTTER
BN NGLO REQUEST SHIP ?
BN NGLO CAN RECOMMEND ALTERNATIVE TO SPOTTER
B
SELECTED NGF SHIPS CONTACT SPOTTER
REGT GS SHIP AVAILABLE ?
REQUEST APPROVED ?
A
SHIPS TECHNICAL FIRE CONTROL
REGT NGLO PASS REQUEST TO DIV NGFO
REGT NGLO HAS GS SHIP CONTACT SPOTTER
CONTINUE MISSION
DIV GS SHIP AVAILABLE ?
C
SPOTTER EOM SHIPS MFR
DIV NGFO NOTIFIES REGT NGLO WHO NOTIFIES BN NGLO & SPOTTER
DIV NGFO HAS GS SHIP CONTACT SPOTTER
STOP



FIELD ARTILLERY
MISSION PROCESS
START
I-11
FIRE MISSION
ONLY DS BTRY ASHORE ?
YES
MISSION RECEIVED IN DS BTRY FDC ON COF NET
BN FSCC MONITORS
A
NO
PARENT DS ARTY BN ASHORE ?
YES
BN TACTICAL FIRE DIRECTION ?
YES
BN TACTICAL FIRE DIRECTION ?
YES
I-12
NO
NO
NO
A
BATTERY TACTICAL FIRE DIRECTION
TARGET SAFETY CHECKS
ADDITIONAL FIRES REQUIRED ?
YES
REIN ARTILLERY AVAILABLE ?
YES
REQUEST FIRES FROM REIN BTRY
(QUICK FIRE NET)
NO
NO
I-13
REQUEST ADDITIONAL FIRES FROM FSCC
I-12 A


I-12
MISSION RECEIVED IN BN FDC
BATTALION TACTICAL FIRE DIRECTION
TARGET SAFETY CHECKS
ADDITIONAL FORCE REQUIRED ?
YES
NO
REIN ARTILLERY AVAILABLE ?
YES
NO
REQUEST FIRE FROM REIN UNIT
REQUEST APPROVED ?
YES
NO
B
GS ARTILLERY AVAILABLE ?
YES
NO
IS ARTY REGT FDC ASHORE ?
YES
NO
REQUEST GS ARTILLERY FROM REGT FDC
REQUEST GS ARTILLERY FROM SACC
GS ARTILLERY UNIT(S) ASSIGNED MISSION
B
I-12 A
MASS FIRES ?
YES
NO
SURPRISE FIRES ?
YES
NO
SET TOT (TIME ON TARGET)
OBSERVED FIRE ?
YES
NO
SET MOF (METHOD OF FIRE)
ASSIGNED UNITS CONTACT FO ON COF NET FOR CONTROL
I-13


I-13
TECHNICAL
FIRE
CONTROL
ISSUE
FIRE ORDER
& MESSAGE
TO OBSERVER
CONDUCT
MISSION
OBSERVER
SENDS EOM
& FIRE UNITS
SEND MFR
STOP

H. SUMMARY

The preceding discussion has provided a discussion of command and control and fire support coordination in the United States Marine Corps to the extent deemed necessary to understand the proposed application of an expert system to fire support coordination. Detailed flow charts of the fire support planning and coordination processes were provided to show that the process has been formalized by the Marine Corps and hence can be readily automated, in particular using expert system technology. While fire support coordination is a complex and dynamic process, it is the authors' belief that the application of expert system technology is not only plausible, but desirable in order to stay technologically abreast with the modern battlefield.

VII. THE APPLICATION OF EXPERT SYSTEM TECHNOLOGY TO COMMAND AND CONTROL OF FIRE SUPPORT COORDINATION

A. INTRODUCTION

Previous chapters have presented an overview of artificial intelligence and expert system technologies, system design considerations, United States Marine Corps organization and staff functioning, as well as a brief view of possible applications throughout the Marine Corps. However, one of the most useful applications has yet to be investigated. The application of expert system technology to the command and control of MAGTF fire support coordination could provide efficiency unobtainable by the current means.

B. JUSTIFICATIONS

Before allocating resources for the development of an expert system for fire support coordination, one must consider the justification. There are many reasons for using expert system technology in fire support coordination, but most importantly, a fire support coordination expert system could increase the survivability of Marine Corps tactical units on the modern battlefield.

Historically, war has been characterized by extreme stress, uncertainty, and confusion. Technology has exacerbated the situation which existed previously by drastically increasing the tempo of war to the point that current manual fire support coordination methods are too slow and methodical to keep pace with constantly changing scenarios. A properly designed expert system can alleviate significant problems associated with fire support coordination. It is quite obvious that an expert system will not be subject to the fatigue exhibited by human beings when placed in a stressful environment. Barring technical failure, an expert system can provide continuous fire support recommendations for the duration of conflict. While not being able to eliminate confusion endemic to the battlefield, through the knowledge base and mathematical probabilities, the expert system will reach a more coherent solution than a Fire Support Coordinator experiencing stress and approaching bounded rationality provided that the human inputs are accurate and timely. Finally, the expert system can resolve the uncertainty issue by optimizing the probability of events occurring, rather than on "gut feeling". Anyone familiar with the study of probability and statistics can relate to the frequency with which mathematical calculations refute what appears to be an obvious solution.

There are other advantages of a fire support coordination expert system which enhance the war fighting ability of the unit. The constant availability of an "expert's" knowledge when human experts are not available, the commensurate decrease in required staff size, or effort, as a result of inherent capabilities, and resident memory capability to record past actions are all significant advantages to the status quo. The most significant advantage, however, is speed. Current command and control functions have not remained on a par with weapon characteristics and unit mobility. The application of an expert system to fire support coordination could resolve the inequity.

Distributed expert systems could be employed during amphibious operations to provide effective control and efficient utilization of Amphibious Task Force fire support assets. Thus, the distributed expert system could control employment of naval gunfire and naval aviation during the assault phase and ensure limited degradation of fire support during the passing of control from the Commander of the Amphibious Task Force to the Commander of the Landing Force. Once firmly ashore, the distributed expert system could control normal MAGTF fire support coordination while continuing to integrate remaining amphibious task force assets. Such an application would prevent inefficient duplication of effort with fire support assets during critical time periods of the amphibious operations. The argument for distributed expert systems is equally valid for joint operations with the Army, Air Force, and foreign services. The expert system would facilitate joint service fire support planning, coordination, and employment which would prevent costly duplication of effort.

C. FEASIBILITY

The value of expert system technology in the fire support coordination process appears to be significant, but feasibility remains an unanswered question. As indicated previously, prerequisites exist for determining the viability of expert systems in specific applications.

1. Existence of an Expert

At least one respected and acceptable expert must exist. While defining what characterizes an "expert" in the field of fire support coordination may prove difficult, sufficient numbers of individuals, such as those Marines who write the USMC Field Manuals, exist who have been formally trained and constantly practice the art of fire support coordination to provide the "expert" knowledge necessary for creation of the knowledge base.

2. Task Definition

The task must be well defined and have a bounded domain. While the coordination of supporting arms is extremely complex, the task can be defined. The flow charts provided in Chapter VI are unrefutable proof that the task has been defined. In fact, the same flow charts could be used as a basis for further refinement and automation of the process. The domain, however, appears more ambiguous. Some subsets of knowledge base data are obviously finite. For example, the list of munitions, with relative ranges and other characteristics, can be easily ascertained. While slightly more complex, relating target information to appropriate munitions may also be determined. However, appropriately modeling terrain, weather, and enemy intentions appears to be a more difficult task. Nevertheless, such modeling can be done to the extent necessary to provide satisfactory results in computing target solutions. In any case, the results will be as good, or better, than can be achieved manually and will be obtained much faster.

3. Problem Solving Approach

The expert system must be able to provide the user an explanation of the problem solving approach. This prerequisite can be easily achieved through proper software development. Knowledge base "heuristic rules" may be reviewed by the user as they pertain to the specific situations, providing an "explanation" of how the expert system arrived at the recommended solution.

D. DISTRIBUTED DATA BASES

The application of expert system technology to fire support coordination is not confined to the processes indicated in the flow charts of Chapter VI. Full potential will not be realized until the fire support coordination data base becomes part of a larger system of distributed data bases. This is a means by which several expert systems can work on unrelated tasks, circumventing current state of the art technology which only works in well defined, narrow problem domains. By automatic transfer of data from logistics and intelligence data bases, the expert system can provide solutions based on "real time" information faster than the staff officers can assimilate the raw data. Certainly, the system need not be limited to logistics and intelligence, but may be expanded to all systems which can provide current information which is pertinent to the fire support coordination problem

E. BASIC DESIGN REQUIREMENTS

Marine Corps Air Ground Task Forces are prepared to conduct various types of amphibious, mechanized, heli-borne, and infantry operations throughout the world. In order for an item of equipment to be faithfully and regularly utilized by these MAGTF's, it must be designed pragmatically. Simply stated, if the expert system weights too much, is too large, or is unreliable; it will seldom be utilized. As an example, the current automated data processing machines, organic to units with in the MAGTF, perform a myriad of tasks relating to personnel administration, logistics, and maintenance; but are seldom used during tactical exercises because of their size and weight.

Based on these considerations, we feel that the expert system technology supporting Fire Support Coordinators throughout the MAGTF must comply with certain design criteria. The system should use Very Large Scale Integration to achieve the smallest and lightest design possible, but must also be engineered to military specifications to insure that it is robust enough to withstand the rigors of tactical employment. At a minimum, size and weight should not prohibit an individual Marine from carrying systems which will be employed at the regimental or battalion level with his basic combat load. For maximum utility, the expert system must also be compatible with portable power sources and be adaptable for vehicular configuration. While the preceding design considerations are not all encompassing, they are representative of the notion that the expert system must truly be a tactical system

F. EXPERT SYSTEM CONSIDERATIONS

Although the preceding arguments strongly support the implementation of expert system technology, we would be remiss if we did not acknowledge the use of expert systems is not without drawbacks. Certainly the "power" of such technology could lead to over-dependence and culminate in deterioration of skills necessary to implement manual FSC processes in case of expert system failure. More probably, perhaps, is the user's reluctance to accept or use the system once it arrives, since the natural aversion to technological change is well documented. Even more significant, perhaps, will be the difficulty in developing the knowledge base from "experts" and other system related problems such as: cost, data base maintenance, hardware maintenance, rule base maintenance, et al.

However, the authors believe that the results of over-reliance on the system can be averted through proper training procedures. Additionally, once the users are satisfied that the expert system utilizes valid techniques and frequently provides the same solutions as those determined through other means, but much faster; the expert system will be readily accepted. Finally, the technical aspects of developing the system, while not a particularly easy problem to solve, can be overcome just as they have been overcome in the many applications of expert systems which are currently in use. Continued advances in expert system technology in the private sector will overcome current technical problems.

VIII. FINAL REMARKS AND CONC'USION

In this thesis, the authors have provided an overview of artificial intelligence and expert systems and proposed an application to command and control of fire support coordination in the Marine Corps. They assumed that the reader had no previous knowledge of the expert system technology and only minimal knowledge of the organization and functioning of the United States Marine Corps. The authors defined expert systems, studied the design process in terms of man/machine interface, and provide an in-depth discussion of Marine Corps organization, staff functioning, and fire support coordination. They then narrowed the discussion of expert system technology to fire support coordination processes and, in our estimation, proved not only the feasibility; but also the desirability of that application.

The detailed fire support coordination problems encountered on fast paced modern battlefields must be solved within compressed time blocks under conditions of unusual stress, fatigue, and emotion. Even the best Fire Support Coordinator cannot be expected to function effectively under these conditions without some type of assistance, considering the target rich environment which may be anticipated. Indeed, the utilization of expert system technology for fire support coordination still encompasses the benefits embodied in a man-machine system while significantly reducing the complex tasks required of man. With the machine providing output for human consideration man merely supplies the required inputs, remaining in control of the system and making the ultimate decisions. Therefore, under stress filled conditions the system should be more reliable. Additionally, such automation of the fire support coordination process should lead to improved response times for conducting MAGTF fire support coordination planning, and hence more timely placement of rounds on target. Thus, the overall combat effectiveness of MAGTF's should be improved. With these considerations in mind, we feel that employment of an expert system to aid the Fire Support Coordinator is not a luxury, but a necessity if the Marine Air Ground Task Force is to survive on the modern battlefield.

APPENDIX A

GLOSSARY

Artificial Intelligence - The branch of computer science concerned with developing machines that can reason, understand human language and speech, recognize the physical world around them through vision systems, move around the world and solve difficult problems.

Backward Chaining - Reasoning from a conclusion back through a set of rules whether the rules do not lead to that conclusion. Also called goal driven reasoning. Compare forward chaining.

Blackboard - A system for allowing two or more knowledge sources to cooperate by posting messages to each other in a 'blackboard'. Used in complex real-time expert systems.

Breadth - How wide a range of issues an expert system covers: how wide the decision tree is. Compare depth.

Cognitive Science - A general term covering all those branches of science concerned with the study of thinking, including artificial intelligence, psychology, and linguistics.

Decision Tree - A way of representing a complex series of choices as a branching diagram looking like a tree.

Decision Support Systems - Computer systems intended to provide managers and executives conveniently with information useful to making business decisions, e.g. sales figures, market projections, a means of carrying out 'what-if' calculations, scheduling, and expert advice. Usually based on mathematical techniques.

Declarative Programming - The technique of providing a computer with a description of a situation and a goal and letting it work out the solution through logic, rather than specifying the steps to be carried out as in procedural programming.

Depth - How many layers of questions an expert system goes through to make a decision. How high the decision tree is. Compare breadth.

Domain - The specific area of expertise of a human expert or expert system.

Expert System - A computer system that embodies the skill of a human expert, e.g. a doctor, an oil geologist or an accountant, providing advice or solutions.

Forward Chaining - Reasoning forward from fact and rules to see what conclusions they lead to. Also called data-driven reasoning. Compare backward chaining.

Frames - Any one of several ways of holding knowledge in structures rather than as rules. Some frame-based systems divide knowledge into 'classes' and 'subclasses', e.g. ships, steamships, sailing ships, ketches, sloops, etc.

Fuzzy Logic - A way of reasoning approximately using indicators such as 'true', 'not very true', 'many' and 'few'.

Goal-driven Reasoning - Another name for backward chaining (q.v.).

Heuristic - A rule of thumb, one which is not guaranteed correct but which is found useful. Much of the knowledge in expert systems consists of heuristics.

Heuristics Model - A description of a domain in terms of heuristics and experience of how it behaves, rather than theory.

Human-computer Interface - The hardware and software systems with which the user interacts with a computer, giving it instructions and receiving results.

Induction - Reasoning from specific instances to a general rule, working out a rule from examples.

Inference - The process of reaching conclusions through logic.

Inference Engine - The part of knowledge-based system that takes the given facts and rules and works out the conclusions that follow from them.

Intelligent Front-end - A human-computer interface that uses knowledge-based techniques to provide a more powerful and helpful service to the user.

Intelligent Robotics - More flexible and powerful robotics systems than conventional ones that simply follow a set of preprogrammed movements.

Knowledge Engineering - Building a knowledge-based system in cooperation with a human expert: corresponds to programming in conventional computing.

Knowledge Representation - The means whereby knowledge is held in an expert system, e.g., rules, frames, or semantic networks.

Knowledge-based Systems - Computer systems that consist of large amounts of knowledge rather than algorithms: roughly the same as expert systems.

Machine Learning - Techniques whereby computers can learn from their own experience rather than being told. A chess-playing machine, for instance, can learn a particular move leads to defeat and so remember not to make it again.

Metarules - Rules about rules. Used to control the operation of a system.

Natural Language Processing - Ways of getting computers to handle human language, for example accepting instructions in ordinary English rather than in programming language. A technology still in its infancy.

Parallel Processing - Computing many different things simultaneously rather than one after the other as in a von Neumann computer. This is essential for much advanced AI and requires very different computer architecture.

Pattern Recognition - The ability of a computer to detect patterns, such as the shape of a letter on a page or a particular sound in speech.

Probability - The mathematical way of describing likelihood, as a ratio similar to 'odds'.

Procedural Programming - The conventional way of driving a computer by giving it a sequence of instructions, as opposed to declarative programming (q.v.).

Rapid Prototyping - A way of constructing expert systems by building a simple system quickly using some conventional tool and then successively refining the system with experience of its use.

Real-time Systems - Those that are fast enough to keep up with events in the outside world. For instance, air-traffic control systems have to be real-time. Conventional 'batch' computing runs in its own time.

Robotics - The science of general-purpose machines with arms and grippers, much used in manufacturing. Soon robots will be able to move about and see as well.

Rule-based Systems - Computer systems in which information is encoded as rules rather than as algorithms or frames.

Semantic Network - A way of representing objects and concepts and the relationship between them as a diagram.

Shell - A tool for building expert systems which is basically an empty system into which a knowledge base can be loaded.

Speech Understanding System - A system for deciphering human speech, recognizing the sounds and distinguishing the separate words.

System Builder - Another name for toolkit.

Toolkit - A set of software tools for building an expert system, much more elaborate than a shell. The best known are ART, KEE, and Knowledge Craft.

Uncertain Reasoning - Reasoning with information that can be graded using certainty factors or probabilities and manipulated by the inference engine.

Uncertainty - A measure of how much confidence is placed in a piece of knowledge, used in uncertain reasoning.

Viewpoint - A partition of a knowledge base used for exploring 'what-if' possibilities without confusing the system with mutually contradictory assertions. Also called 'context' or 'world'.

Vision System - The television, electronics and computer programs enabling a computer or robot to decipher the physical world around it by sight.

The terms contained within this Appendix were drawn from EXPERT SYSTEMS IN BUSINESS, Vol 1, Number 1, June 1987, pp. 27-28.

APPENDIX B

MILITARY ACRONYMS

ACA - Airspace Coordination Area
ACE - Aviation Combat Element
ALO - Artillery Liasion Officer
AOA - Amphibious Objective Area
ATF - Amphibious Task Force

BLT - Battallion Landing Team
BSSG - Brigade Service Support Group

CAS - Close Air Support
CATF - Commander Amphibious Task Force
CLF - Commander Landing Force
COC - Combat Operations Center
CSSE - Combat Service Support Element

DASC - Direct Air Support Center
DS - Direct Support

FAC - Forward Air Controller
FDC - Fire Direction Center
FMF - Fleet Marine Force
FO - Forward Observer
FOT - Frequency of Optimum Transmission
FSC - Fire Support Coordinator
FSCC - Fire Support Coordination Center
FSCL - Fire Support Coordination Line
FSSG - Force Service Support Group

GCE - Ground Combat Element
GS - General Support

LF - Landing Force
LUF - Lowest Usable Frequency

MAB - Marine Amphibious Brigade
MACG - Marine Air Control Group
MAF - Marine Amphibious Force
MAGTF - Marine Air Ground Task Force
MASS - Marine Air Support Squadron
MAU - Marine Amphibious Unit
MOS - Military Occupational Speciality
MSSG - MAU Service Support Group
MUF - Maximum Usable Frequency

NGF - Naval Gunfire
NGLO - Naval Gunfire Liasion Officer

RLT - Regimental Landing Team

SACC - Supporting Arms Coordination Center
SEAD - Supression of Enemy Air Defense
SYSCON - System Control

TACC - Tactical Air Coordination Center
TAD - Tactical Air Direction
TECHON - Technical Control

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Thesis
A3346 Albano
c.1 An initial study examining the feasibility of expert system technology for command and control of supporting arms in the United States Marine Corps.