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A FRAMEWORK FOR IMPROVING INTEGRATIVE FACTORS IN C^{3}I SYSTEMS OF THE ARGENTINE ARMY

by

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A framework for improving integrative
factors in C^3I systems of the Argentine Army

by

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ABSTRACT

Achieving integration and interoperability among various different systems is a challenging task. In the particular case of the Argentine Army, this task comprises the reorganization of current applications and their integration with programs under development at different stages. The purpose of this thesis is to identify and analyze the up-to-date tools and techniques that can help the development efforts of the Argentine Army to integrate and make interoperable its current and future systems. This thesis attempts to serve as only a guide for the introduction of ideas, models, tools, and techniques related with the factors that can improve the interoperability in the C^3I system of the Argentine Army. It also attempts to be a compendium of up-to-date information to be used by people who are working in the management of related fields in the Argentine Army.

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I. INTRODUCTION

A. BACKGROUND

> The problem of commanding and controlling armed forces, and of instituting effective communications with and within them, is as old as war itself.[Ref. 1]

Martin Van Creveld, in his book Command in War specifically treated the problems that are related to the C^3I system, particularly those problems related to decision-making, communication and the central issue of how a commander may cope with uncertainty.

Although the problem of command and control is not new, its evolution has been exponential in modern times, especially since World War II. The growth is due to several factors: [Ref. 1: p. 1-4]

1. The increased demands made on command and control systems is due to the greatly enhanced complexity, mobility, and dispersion of modern armed forces.

2. Technological developments that have multiplied the tools at the disposal of command and control systems, especially in the field of communications and data processing technology.

3. Changes in the nature of the command and control process, resulting from the interactions of factors 1 and 2 mentioned above, that have led to an explosion in data processed by any given command and control system to carry out any given mission.

4. An increase in the command and control systems' vulnerability, due to the increment of their electronic emissions that make them prime targets, and the appearance of new and more accurate weapons systems that use those electronic emissions for guidance.

It is known that the needs for command and control systems arise from the size, complexity, and different components of an army, and it also varies according to the relation between those factors. In others words, the command and control systems increase in scope with the sophistication of the forces.[Ref. 1: p. 6]

> Precisely because the complexity of armed forces and the multiple missions that they must do, make complete coordination more important than ever, and owing to the unprecedented range of gadgets at its disposal, the role that command may play in determining the outcome of present-day military conflict is crucial. By making possible a faster, clearer reading of the situation and more effective distribution or resources, a superior command and control system may serve as a force multiplier and compensate for weaknesses in other fields, such as numerical inferiority.[Ref. 1: p. 4]

The solution to the problems mentioned above can be treated using two different approaches: one is the technological approach, and another one is the human or organizational approach. The success of a solution will depend on the degree to which each of these approaches complement the other.

Although it will not be treated in extended detail in this study, the organizational approach should be kept in mind while reading this thesis because the human being is not just a component of the C^3I systems. He is an integral part of the C^2 process itself, in both sides of any conflict, friend and foe, and he becomes a major source of the complexity of the C^3I systems.

While the purpose of any command and control system is to support the commander (decision-maker), it is also important to remember that the human mind provides the most effective command and control system found in nature, and its internal functions have been used to develop models for actual structures and processes of the command and control systems. [Ref. 2]

The integration and interoperability of the C^3I systems have been shown to be main issues in the technological approach as a way to reduce the uncertainty of the war.

The manner in which the technological approach is intended to be carried out is shown below:

> In the executive summary of the July 1987 Defense Science Board (DSB) report, the first recommendation of the board stated:
> To assure the operational effectiveness of the systems for the support of command and control, we recommend that a strong institutional process be put in place to:
>
> - establish and maintain an architecture for the command and control of U.S. forces operating under either national or allied command that links all elements of the command and control structure from both top down and bottom up;
> - establish and maintain the standards needed to achieve interoperability and operational effectiveness in the field and enforce adherence thereto;
> - provide conceptual guidance and technical support to field commands as they evolve their command and control systems within the overall architecture and interoperability standards. [Ref. 3]

Considering the Argentine Army specifically, it can be seen that the concepts of C^2 were implicit in its doctrine, but were incorporated as an explicit doctrinal issue only recently.

The first steps to design a suitable C^3I architecture and C^3I systems that fit the Argentine Army's needs have already been taken, but important concepts still remain uncertain. These concepts could help to improve the design and development of those systems.

> At the present time the Argentine Army has a considerable investment in computer and communications equipment that has been procured and installed without regard to system integration or interoperability. The SIIFE Project (Sistema Informático Integrado de la Fuerza Ejército) was the first attempt to organize information processing in the Argentine Army.[Ref. 4]

Subsequent projects attempted to continue the original SIIFE project, but for several reasons they did not reach their integrative objectives. Those projects targeted primarily the Fire Control Systems and Logistic Systems, but they suffered from a lack of understanding of interoperability issues and isolated their focus on development, disregarding the impact on other interrelated programs.

B. PURPOSE

With the constant incorporation of new technology in military operations through new systems or modernization of old systems, the importance of integration and interoperability becomes more relevant as a means to improve the effectiveness of the systems and to provide the Commander with more accurate and timely information.

As the C^3I concepts mature in the Argentine Army by their being included in its doctrine and by developing a C^3I architecture, the requirements for integration and interoperability will increase extraordinarily.

In view of these requirements, the purpose of this thesis is to identify, and analyze the up-to-date tools and techniques that can help the development efforts of the Argentine Army to integrate and make its current and future systems interoperable.

This thesis only attempts to be a guide for the introduction of ideas, models, tools, and techniques related with the factor that can improve the interoperability of the C^3I system of the Argentine Army. It also attempts to be a compendium of up-to-date information to be used by people who are working in the management of related fields in the Argentine Army.

C. SCOPE

The scope of this thesis will be limited to the C^3I system environment. A plethora of information has been published regarding C^3I systems, but it is difficult to synthesize the various concepts of concern.

This study will be limited to exploring the integrative factors of C^3I systems. This thesis is not an attempt to cover the technical information related to each one of the aspects of interest, but it is meant to provide a general description and understanding of them and how are they related in a C^3I system.

Information about C^2 processes and C^3I system architectures will be provided to assist the reader in his familiarity and understanding of the issues.

D. ORGANIZATION OF THE STUDY

This thesis consists of eight chapters and it can be divided in three parts. The first part includes Chapters I to III and presents the information required to get a basic understanding of the material to be analyzed. Chapter II will contain the description of the C^2 process and some models used to represent it. Chapter III will cover the general information about C^3I system architectures and will catalog the main integrative factors of those systems.

The second part will include Chapters IV to VI. Chapter IV will address the information handling, integration, and description of the improved tools available today. Chapter V will deal with the communication means and will discuss the communication characteristics as well as analyze mobile communications in the tactical environment and its contribution as an integrator. Chapter VI will investigate the networking role in the C^3I systems, providing reference models and addressing the internetworking issues also.

The third and last part will consist of Chapters VII and VIII. These chapters will contain a summary of the study in a format that proffers applicable recommendations for the Argentine Army concerning each one of the issues that were analyzed in the previous chapters.

II. GENERAL CONCEPTS OF COMMAND AND CONTROL

A. INTRODUCTION

The terminology of C^2, C^3I, C^4I, etc., have been used in a confusing fashion to identify different systems and/or groups of systems or processes in the Command and Control literature.

The terms were expanded or contracted according to the perception that a particular group has of C^2. Such is the case of the communicators who perceive communications as a central component of C^2 and use the term Command, Control and Communications (C^3); or the computer technicians that perceive the computer as a key factor in the systems and name them Command, Control, Communications and Computers (C^4), and so on [Ref. 5].

These different perceptions produce confusion and misuse, particularly for the average person who does not usually deal with C^3I literature, and these perceptions become the main source for the profusion of acronyms in the literature.

If it is desired to produce a methodological approach to C^2 processes and C^3I systems, it is necessary to use a correct, common interpretation of the terms involved; otherwise as in all other sciences, no theory can be developed and the community will perpetuate the misunderstandings and arguments without achieving their particular and general goals.[Ref. 6]

Descartes advised us with the following maxim: "Define the meaning of words precisely and you will save mankind half of its confusion"[Ref. 6: p. 4]

1. C^2 **definitions**

The official definition of Command and Control given by the U.S. Department of Defense (DOD) is:

> Command and Control: The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.[Ref. 7]

The different concepts implicit in this definition will be exposed and analyzed later in this chapter, but two concepts must be emphasized and distinguished so that they may be used later.

The concepts are that Command and Control is a "system" but also a "process". The C^2 system is constituted by all the physical components and structures that allow C^2 to be performed. On the other hand, the C^2 process is the intrinsic part that is concerned with how C^2 is performed. The functionality of the C^2 system is the C^2 process [Ref. 8].

The definition given by Robert E. Conley is clear enough to easily understand the point:

> Command and Control (C^2) is a process of resource allocation (management) by a knowledgeable, recognized point of authority to accomplish a given objective(s).[Ref. 4: p. 5].

2. C^3 and C^3I definitions

Another important term in need of a clear definition is the Command, Control, Communications and Intelligence (C^3I) system, because it is the most widely used acronym related to the foundation of Command and Control.

The extension of the Command and Control definition to include the term Communications results from the need to make explicit the physical support of the C^2 process by allowing the communication of a commander with his forces and support of the actual relationships among components and subsystems. The acronym C^3 has gained its own entity, and a clear definition is beginning to appear in the literature. Examples are the definition of C^3 given by Dr Gerald P. Dineen (Former Assistant Secretary of Defense (C^3I), USA):

> The C^3 systems of the DOD are the means by which our military commanders, under the direction of the president as the commander-in-chief, employ the military strength of our nation. Reliable communications, information processing, surveillance and warning, electronic warfare and counter-C^3 are essential for effective C^3.[Ref. 9]

Also consider the brief definition provide by Kenneth L. Moll:

> The command, control and communications system is a collection of elements which display the properties of the command and control process.[Ref. 5: p. 25]

The incorporation of the term Intelligence into the definition represents the commander's information needs with regards to the enemy situation, and the interaction of these needs with the Command and Control process.

B. C^2 AND C^3I PROCESS MODEL

Several criteria have been used to develop C^2 process conceptual models. The model must be simple, must represent the essential C^2 functions, must be understood by the commander, and must be measurable and complete. The model is measurable and complete if the C^2 process itself is described in terms of few functional components, and satisfies principles and theories advanced by other writers.

> Command systems consist of organizations, procedures, and technical means; command itself is a process that goes on within the system, and makes use of information in order to coordinate people and things toward the accomplishment of their missions.[Ref. 1: p. 262]

Each definition presented so far has emphasized in different ways such concepts as planning, direction, coordination, control, and commander, so they may be considered key issues in the Command and Control process.

1. Lawson's conceptual models

Dr Joel S. Lawson, Jr., from the Naval Electronic Systems Command, in his report entitled "The State Variables of a Command Control System" presented the conceptualization of C^2 as a cybernetic process [Ref. 10]. The details of Lawson's model for C^2 process are shown in Figure 1. [Ref. 2: p. 24]

In his initial conceptualization and subsequent refinement, Lawson identifies five basic functions with their interfaces to the environment. The SENSING function has responsibility for gathering data from the environment. The PROCESS function accounts for the extraction of meaning from the data collected by the sensing. The COMPARE function

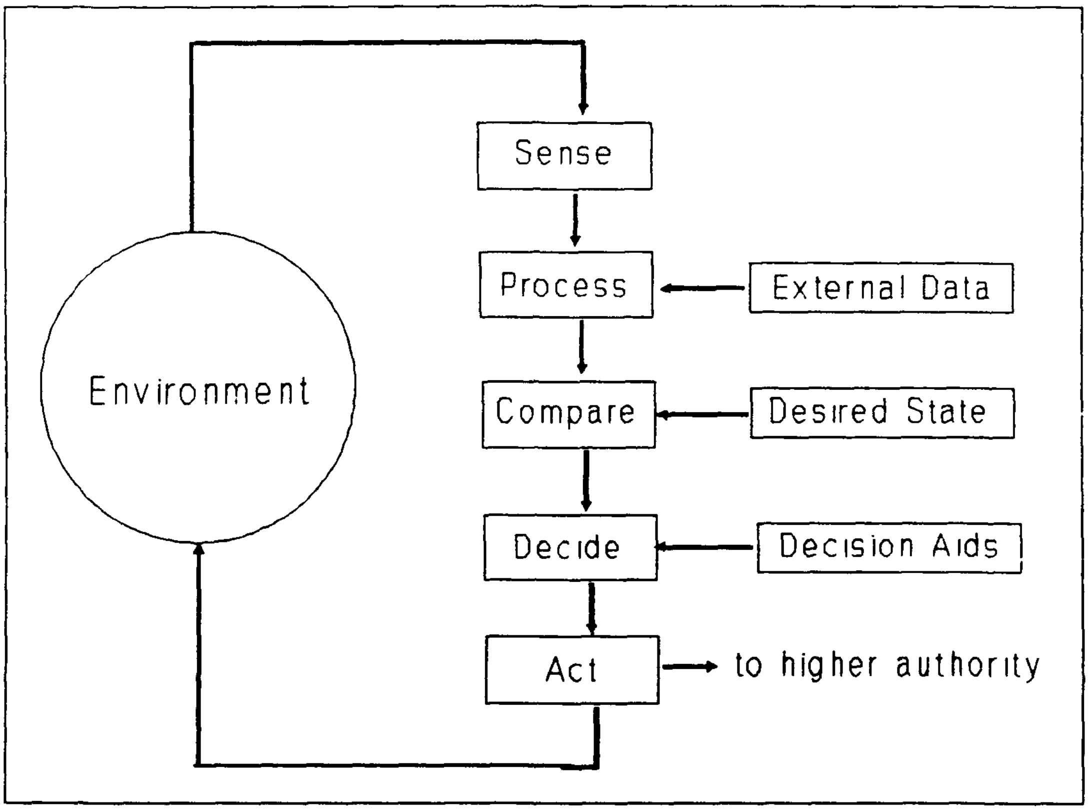

Figure 1. Simple C^2 process model

compares the state of the environment with a desired state. The DECIDE function acts upon the COMPARE function by deciding what should be done to reach the desired state. Finally, the ACT function executes that decision.[Ref. 2: p. 24-25]

This simple conceptualization was expanded by Lawson to explicitly include the Intelligence/Analysis process and its interaction with the C^2 process, and to develop the C^3I process as shown in Figure 2.

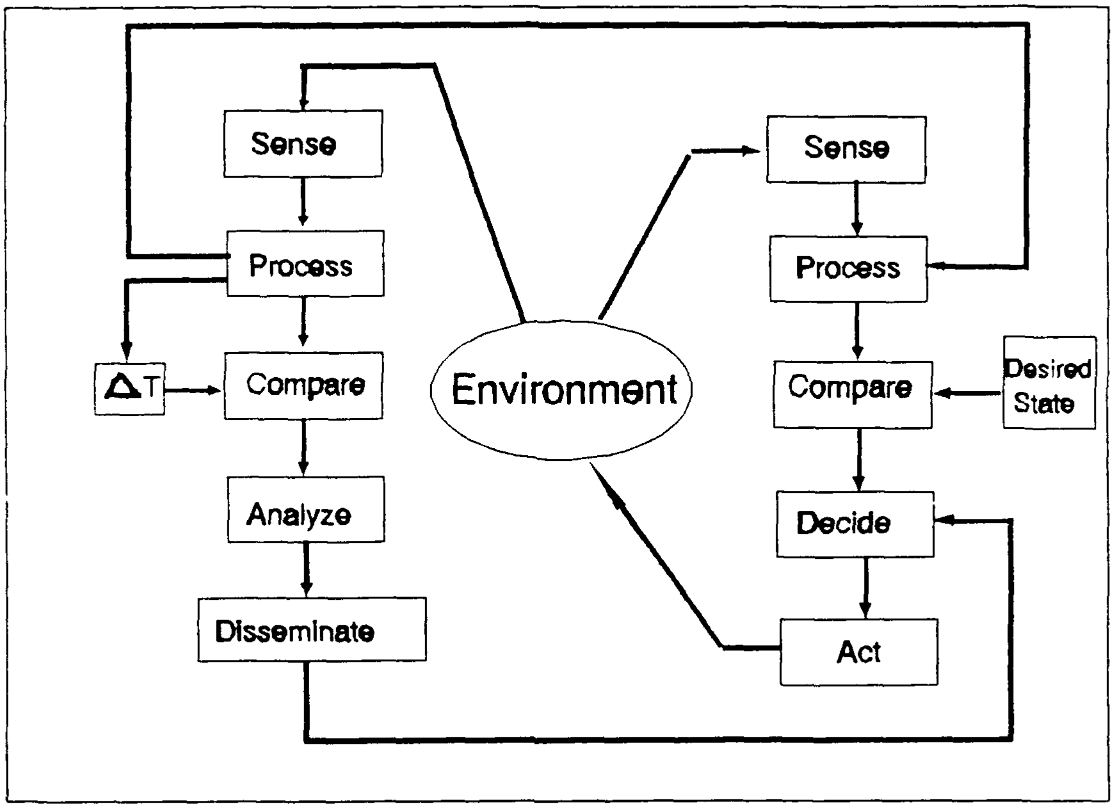

Figure 2. Lawson's C^3I process model

Lawson's conceptualization constituted the starting point for several C^2 process analyses and models, although some of Lawson's concepts may be not practical or applicable anymore.

In evolving the basic model, there are those who believe that the simple Lawson model could be expanded to include more complex analysis of the C^2 process, by "nesting" as shown in Figure 3 [Ref. 11].

> Several such control systems could be "nested" to reflect a military hierarchy of "command", where the environment of a senior authority includes the environment of a subordinate authority. The desired state of the subordinate's environment is dictated by the actions of the senior. Participation of several subordinate activities could be

reflected, with each of their environments included (possibly with overlap), in the environment of the senior authority. Such a representation could be useful in highlighting the real need for cooperating elements to coordinate their actions.[Ref. 11: p. 15]

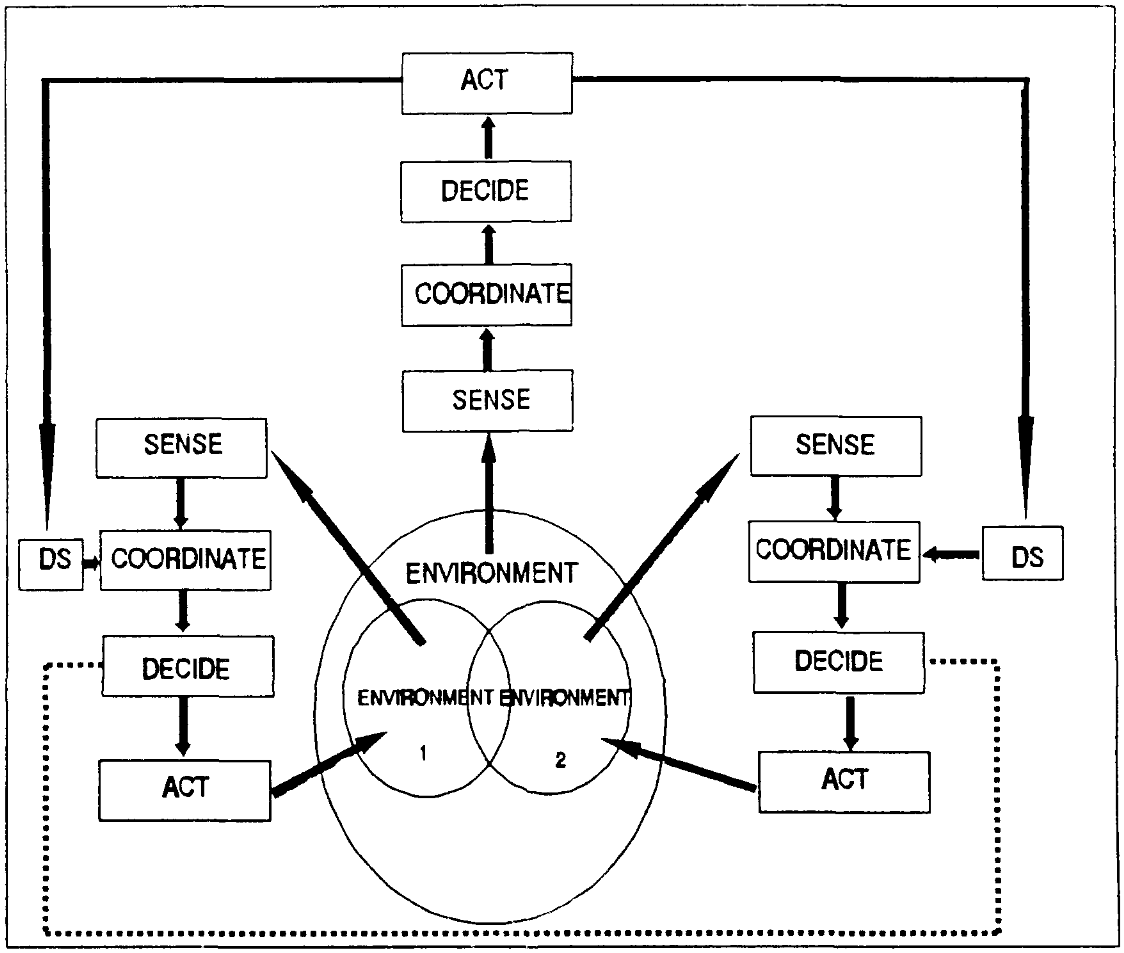

Figure 3. System of "nested" C^2 processes

2. Combat operation process model

This model was presented and analyzed by George E. Orr, Major USAF, in Research Report No. AU-ARI-82-5, in July 1983.

Figure 4 represents the basic O-O-D-A structure suggested by Col John Boyd. The O-O-D-A loop is simple, but requires substantial expansion in order to be useful.

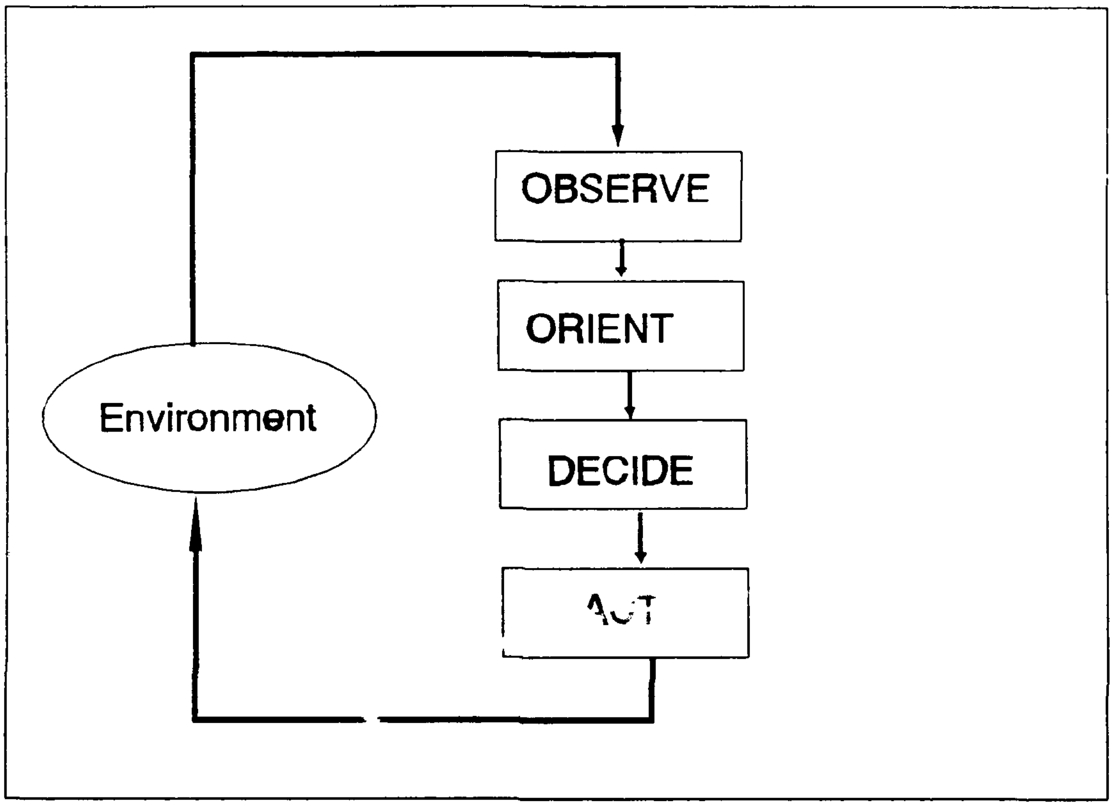

Figure 4. Boyd's O-O-D-A loop structure

Figure 5 presents the Conceptual Combat Operation Process Model presented by Orr. The primary differences between the Lawson/Boyd models and the Orr model are:

- The inclusion of explicit interfaces to higher and lower levels.
- The inclusion of a generic INTELLIGENCE/ANALYSIS block with extensive connections to other blocks.[Ref. 2: p. 27]

The process is intended to represent the combat operations process at any specified level of the military

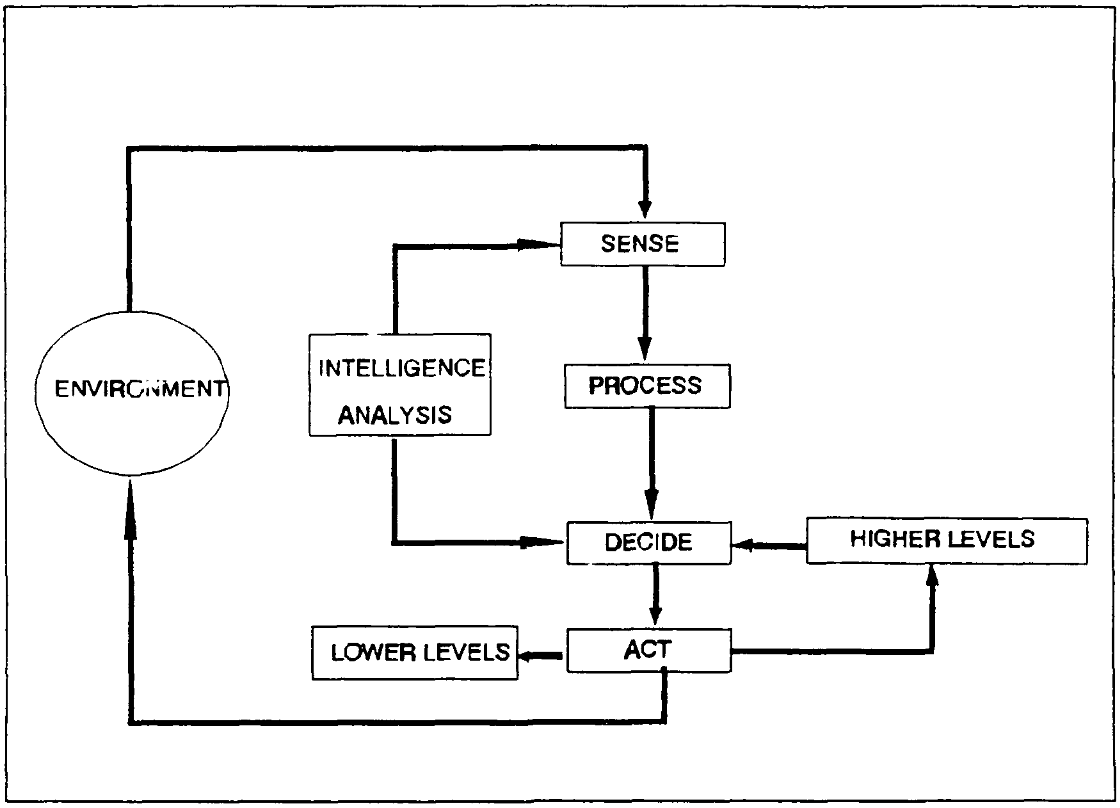

Figure 5. Orr's conceptual combat operation model

hierarchy. The Intelligence/Analysis function is not very important at the force application level. In this point, Orr's model is basically identical to Boyd's model with the Sense and Observe functions related together. Boyd's Orient function is a merging and identification of the Process and Intelligence/Analysis in Orr's model. The Decide function and Act function are the same in both models and in Lawson's model as well.

At higher levels in the hierarchy, Orr's model approximates Lawson's model in the sense that it interprets the Intelligence/Analysis function as a function that starts to operate separately.[Ref. 2: p. 27]

3. A reference model

A practical model, "Command and control: Reference model" (C^2RM), is under evolutionary research and development under the sponsorship of the Joint Directors of Laboratories (JDL), Technical Panel for C3 (TPC3), Basic Research Group (BRG). This model intends to provide a framework for research and development of Command and Control for many of the same or analogous reasons which motivated the evolution of the International Standards Organization (ISO) Open System Interconnection (OSI) Reference Model for communications. [Ref. 12]

Such a model will be used as a reference and will be described in general in the following chapters, especially where the interoperability and networking issues require so.

Figure 6 shows the general structure of the C^2 paradigms presented by the C^2RM.

> It is the goal of C^2RM to provide the framework of choice to guide the development of a consistent set of standards and specifications for interoperability and to offer substantial protection of extensive investments in acquisitions by promoting modular reusable technologies. The advantage of this model is that it has the flexibility to incorporate many features of existing paradigms and to accommodate a wide variety of perspectives while promoting a greater common understanding of the levels of interoperability required among C^2 system components.[Ref. 12: p.1-2]

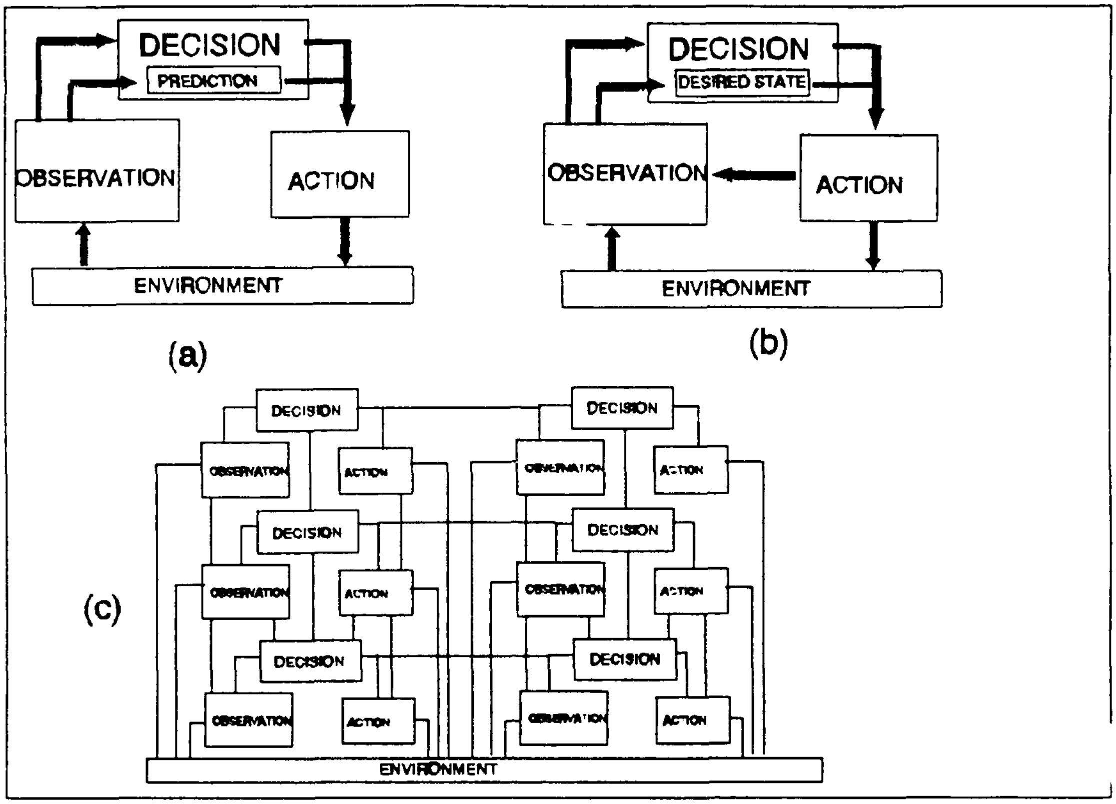

Figure 6. The general structure of C^2 paradigms

Figure 6(a) represents the Main Cycle with Feed-forward. Figure 6(b) shows the Main Cycle with Feedback, and Figure 6(c) explains the distributed, nested, layered, coordinated and hierarchical Main Cycle. Each of the blocks represents a complex, collective and compound process.

> The common denominator of all C^2 paradigms can be shown to be decision theoretic in nature. To each system-level Observation there corresponds a system-level Action. A system-level Decision is invoked to select a system-level Action for a given system-level Observation. Sequences of system-level Observation-Action pairs characterize the Dynamics, i.e., the rules of behavior and evolution, of the system-level decision process. This structure and the associated overall cyclical process, also called C^2 process, is inherent in any C^2 paradigm.[Ref. 12: p. 8]

C. CONCLUDING CONSIDERATIONS

1. Model limitations

A detailed description of several other models is obtainable today, but it is beyond the scope of this thesis to include them because these other models would confuse rather that clarify the basic concepts.

However, it is in the interest of this study to point out the realistic issues of the process, because weaknesses appear in the implementation of these idealized diagrams, and interoperability and integration then become relevant concepts.

> While these diagrams are invaluable in helping us understand the C^2 process, the abstractions and idealizations they include are very limiting....Attempts to generalize the simple cybernetic loop (Figure 1, 2) by introducing nested and concurrent processes (Figure 3) has led very rapidly to the Achilles heel of systems engineering: the curse of dimensionality.... By then, the simplicity and elegance - the strengths - of the cybernetic loop have been lost.[Ref. 10: p. 2]

The cost of this oversimplification is too high if the intent of these models is for "real world" applications, where elements of the environment and the threat are beyond theoretical control and where uncertainty has its reign.

Yet, the models presented above are essential to progressing with the identification of new weaknesses or key factors in the Command and Control process and the C^3I systems which support it.

The use of these models will allow the improvement of the C^2 process and contribute to reaching the mythic goal of developing a theory of C^2 that could help to get a better understanding of how to cope with uncertainty in combat.

In the following chapter, this study will attempt to present some of the "realities" that have to be considered in the application of those models by analyzing some key factors for C^3I systems interoperability.

2. Focusing C^3I system's role

C^3I has two general requirements, information and action, to accomplish its purpose of observing and providing warning and assessment of the intentions of adversaries, of collecting and processing information on the status of friendly and hostile forces, of supporting operational planning and decision making, and of communicating commands to forces.[Ref. 4: p. 7]

Based in the stochastic nature of military operations, it is possible to analyze the role of the C^3I systems and their range of application. Uncertainty is everpresent on a battlefield and combat results are difficult to predict.

Additionally, another school of thought exists, the deterministic, which believes that the unpredictability of military operations is caused by a lack of knowledge and by the lack of techniques to supply that knowledge. Depending on which school of thought is applied, it will be the role that will be assigned to the C^3I systems into any organization. If military operations are fundamentally deterministic, then placing emphasis on aspects of C^3I systems which resolve uncertainty and provide detailed resolution of the battlefield is justified. But if military operations are fundamentally stochastic, then emphasis should shift toward aspects that help in the management of the forces distribution, identification of focus of problems, determination of possible maneuver, and favorable attacking positions.

The separation line is not as clear and simple as described above, and the stochastic perspective seems be more realistic. Nevertheless, C^3I system improvements can cut down a great amount of the uncertainty that currently exists in battle. But no matter how complex and efficient the C^3I systems could be, the stochastic nature of the military operation will emerge again when the C^3I systems begin to reach the limits of their resolution.[Ref. 2: pp. 85 - 87]

D. SUMMARY

This chapter has been designed to provide the basic definitions and concepts relating to C^2 processes and C^3I system supports. The material covers different conceptual models used for the C^2 community. These models present the relationship among different system components.

The evolution of the efforts for modelling the C^2 process, in order to develop a related theory about C^2, has also been described.

"Reality" imposes many constraints that have made impossible, so far, the consolidation of such a theory, making this pursuit a permanent challenge, where the C^3I systems have an important role to play.

III. INTEGRATION IN C^3I SYSTEM ARCHITECTURE

A. C^3 ARCHITECTURES

1. Overview

An architecture is essentially a interrelated set of building blocks. It provides a conceptual and general framework to develop systems and interrelations among them, by internal interfaces and by external interfaces with the environment.

An architecture is a framework for design, a framework which permits isolation of design problems with reasonable confidence so that if each can be solved separately, the system as a whole will operate as required [Ref. 13].

In the literature, the C^3 systems architecture is used to delineate a theoretical framework, within which individual design can be performed for different subsets of C^3 systems. For example, it is possible to find individual references and separate descriptions of communications, networks, or information architectures.

A C^3 architecture is comprehensive and acts as an amalgam for all those subsets, providing a better way to fulfill the requirements of the C^2 process.

> The architecture of a C^3 system is the initial stage of the overall system engineering process. C^3 architecture is the arrangement of (or process of arranging) the basic elements of a C^3 system into an orderly system framework.

> The singular characteristic of a C^3 system is that it describes the interrelationship between selected elements of the system. The C^3 architecture will be expressed as a set of assumptions, statements and diagrams describing the interoperation among the system elements.[Ref. 3: pp. 82]

2. Architecture Visions and Levels

As shown in Figure 7, the C^3 architecture can be seen as a three-faceted pyramid that represents different visions. The description of the information vision of the C^3 architecture will be addressed in Chapter IV and the description of the communications vision will be addressed in Chapter V. The remaining facet is discussed in this section.

The following description of the architecture levels is a summary of the concepts expressed by Victor J. Monteleon and Dr. James R. Miller.[Ref. 3: p. 82 - 83]

The C^3 systems are not isolated systems, but they are immersed in a general context. That context can be idealized for developmental purposes, and it provides a goal for the system developers. This context also defines the boundaries of the C^3 systems, and levels of the architecture can be specified depending on the boundaries of the system.

- Processing Architecture: It is defined by the architecture of the system processing elements.
- Nodal Architecture: It is the architecture of the node itself. The node can be a facility space, a command, a platform and also a network. The nodal architecture provides a blueprint of the relationships of the basic system elements of the node. One example is that a node could have a fully distributed architecture, a partially distributed architecture (such as independent subsystems interfaced through a local area network) or a centralized architecture.

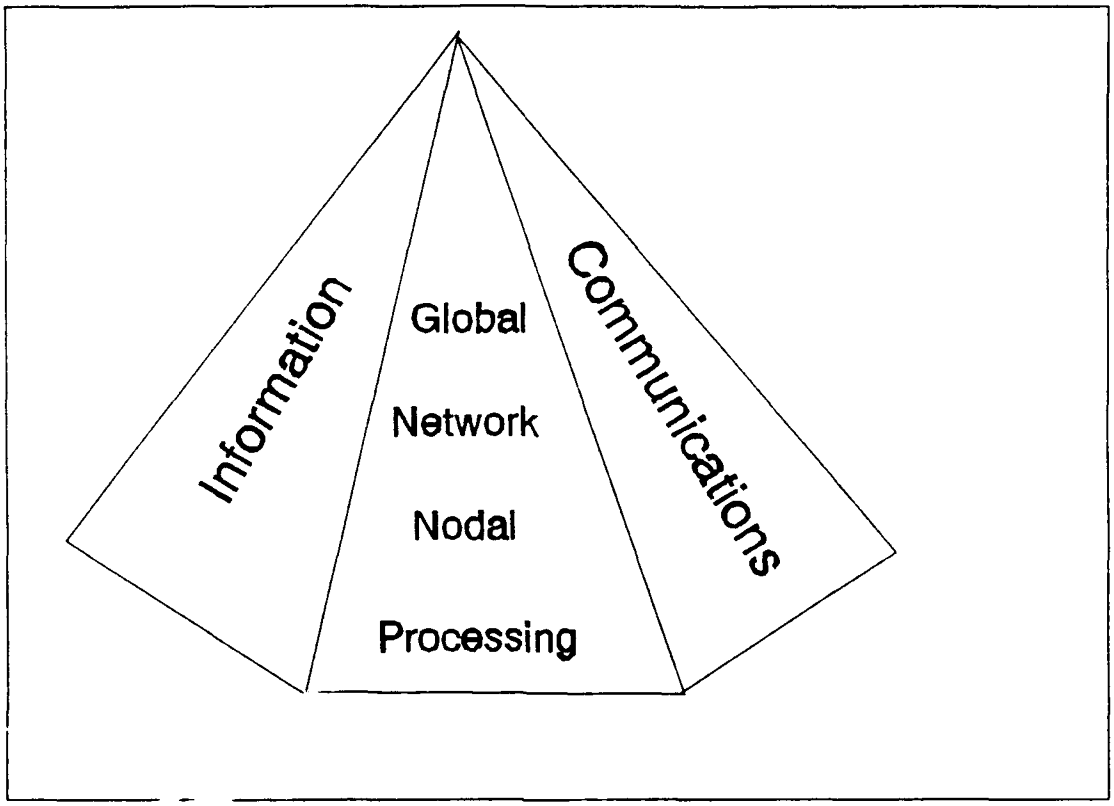

Figure 7. C^3 architecture: Vision and levels.

- Network Architecture: It is the relationships of the nodes to each other and the means by which they are connected to form larger operational units or networks. In the case of a command node the integration of a space-related subsystem into the node requires a network architecture for the overall node. The connection of the nodes in a meaningful manner to form a larger unit also requires a network architecture. The characteristics of the network architectures will be addressed in Chapter VI.

- Global Architecture: It consists of the interconnections between networks to form global networks. It is, in essence, an architecture for a network of networks.

B. INTEROPERABILITY IN TACTICAL C^3 ARCHITECTURES

1. Interoperability

This study is focusing its research on interoperability aspects of the C^3I systems, particularly those issues related to networks, tactical communications, and data processing systems. These issues will be treated extensively in the following chapters.

The following definition will prove useful:

> Interoperability: the ability to provide services to and accept services from other systems and to use the services so exchanged. [Ref. 7: p. 182]

Interoperability is one of the functional criteria that any military C^3I system should meet to accomplish its two general requirements of information and action, as described in Chapter II.

It should be understood that interoperability is not a simple technical matter; to the contrary it is a complex subject that results from the combination of several variables, such as doctrine, procedures,planning, training, requirements, standards, etc.; and it involves all the levels of command.

Tactical C^3I systems are neither isolated nor self-sufficient systems, they are designed and implemented as a part of higher level systems.

Following is presented a classification of C^3I systems according to the command level that they support: [Ref. 11: p: 99]

- National (Strategic) level: these systems serve to national authorities and are controlled by national committees and organizations with national priority missions and worldwide scope.

- Theater-level (Joint Forces): these systems are focused on theater-wide operations. They are controlled by respective theater commander on chief, and include the headquarters support systems of the unified commands.

- Tactical-level: these systems serve commanders below the level of the service component commander. They include the subsystems of the senior tactical headquarters, subsystems used by lower levels of command, and subsystems used by the individual unit commander as the final link in the C^2 structure.

National C^3I systems have the advantages of clear lines of authority, well-defined doctrine, procedures and role of the participants, as well as a finite number of interfaces that facilitate the interoperability of the systems. Theater and especially tactical C^3I systems are much more complex, with greater information requirements and with less time to operate inside the enemy decision cycle and retain the initiative; these aspects make interoperability, difficult to attain at these levels.

The AirLand Battle Doctrine with its basic principles of initiative, depth, agility and synchronization emphasize the role of interoperability as a key factor in the achievement of success in the modern battlefield [Ref. 14]. Under the AirLand Battle Doctrine interoperability is not restricted to one service alone; instead the doctrine is an important approach to accomplish interoperability among different services. The Army Tactical Command and Control

System (ATCCS) is an example of a wide initiative that touches upon all battlefield functions from the forward line of troops back to theater boundary; and it is a joint effort to reach real interoperability between the U.S. Army and the U.S. Air Force.

To improve the interoperability in tactical C^3I systems it is necessary to identify the variables that could be controlled to obtain that improvement. Planning is one of those variables and maybe the most effective. To assure effective interoperability, the planning should be done in advance. This conceptual process includes:

- Identification of interoperability needs.
- Translation of those needs into well defined C^2 requirements.
- Comparison of current Command and Control systems, Communication systems, and Information systems against the C^2 requirements, looking for inconsistency with the stated doctrine and mission objectives for any command level.

The entire planning process should be driven by C^2 requirements that constitute a main factor in achieving interoperability.

Another variable to enhance C^3I systems interoperability is the design of C^3I systems architecture, suitable for the doctrine and mission of each particular service and the design of a joint systems architecture to achieve interoperability among the different services. Examples of the efforts already accomplished in that direction include: [Ref. 15]

- The design and implementation of the Army Tactical Command and Control System.
- The development of Functional Interoperability Architectures.
- The development of Commander in Chief Interoperability Architectures.

2. Tactical C^3 architecture

Based on operational requirements for five major battlefield areas (BFA), the U.S. Army developed a integrated C^3I system known as the Army Tactical Command and Control System (ATCCS). As is shown in Figure 8, the ATCCS system consists of five major BFA's: Maneuver (MVR), Fire Support (FS), Air Defense Artillery (ADA), Intelligence/Electronic Warfare (IEW) and Combat Service Support (CSS). The tactical communication systems that provides the communication backbone for each BFA within its intended operational area are: Area Common User System (ACUS), Army Data Distribution System (ADDS) and the Combat Net Radios (CNRs) [Ref. 16]. The following is the description of each BFA given in the Ninth Symposium of Armed Forces Communications and Electronics Association (AFCEA). [Ref. 4: p. 32]

1. Maneuver Control

The maneuver control area comprises the facilities employed to plan, direct, coordinate and supervise the combat activities of a combined arms force as it closes with and destroys the enemy by use of fire and maneuver. This includes the command, control and coordination of combat, combat support and combat service support elements of the forces in accordance with the commander's scheme of maneuver.

2. Fire Support

The fire support area comprises the facilities employed for command, control and coordination of activities related to surface target development and the weapon systems and munitions available to engage those targets in order to suppress, neutralize or destroy them in support of the force commander.

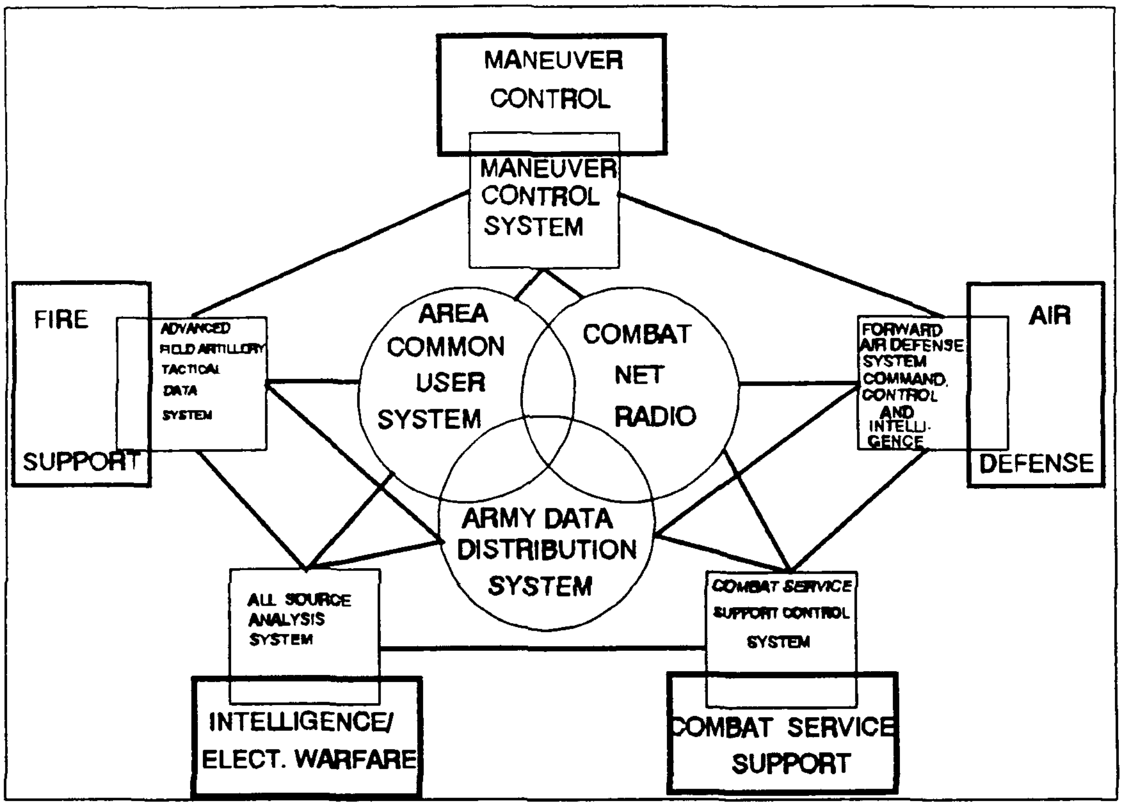

Figure 8. Army Tactical Command and Control System

3. Intelligence/Electronic Warfare

The intelligence/electronic warfare area comprises the facilities employed for command, control and coordination of activities related to intelligence collection, combat information development, operations security and electronic warfare.

4. Air Defense

The air defense area comprises the facilities employed for command, control and coordination of Army activities related to air defense management and the weapon systems and munitions available to destroy airborne targets in support of the force commander.

5. Combat Service Support

The combat service support area comprise the facilities employed for the command, control and coordination of the activities related to logistical support, personnel administration and soldier support available for the execution of those functions in support of the force commander.

The ATCCS is an integrated family of automated, interoperable C^2, communication and information systems that provide C^3 support to the five BFAs described above.

C. SUMMARY

This chapter presented the basic definitions and understanding of architecture in general and the tactical C^3I architecture in particular. The structure of the architectures was described and it was shown how imperative it is that the architecture reflect flexibility in its structure to allow the commander to tailor it to the actual situation, in time and organization, that he could face to better accomplish his mission.

It also discussed a classification of C^3I systems, and analyzed two, among many, variables that can improve interoperability on those systems. Lastly, it described the components of tactical C^3I systems actually implemented in the U.S. Army.

IV. DATA PROCESSING IN TACTICAL C^3 ENVIRONMENT

A. C^3I INFORMATION SYSTEMS

1. Overview

Most of the C^3I systems have considered the single "C" (Communications) part of the system as a critical factor of system development, and they only secondarily addressed data processing. The data processing functions included tend to be mainly communication-oriented with message processing and automated data base entry. The lack of attention toward information systems at the beginning of the development of C^3I systems has produced an increment of interoperability problems in these systems. These problems arise because many C^3I systems have been designed assuming that the information comes into the system already processed. The information systems have been limited to the Sense function, part of the Compare function, and the Act function of the Command and Control process.

Due to the dynamics of the "real world" and technological developments, military operations are changing toward a single and integrated battlefield. This change requires a balanced development between a C^3I system's components and C^2 process functions.

A clear description of the reasons is given by Gen. Donn Starry, USA (Ret):

> The command and control problem goes something like this: To fight the battle successfully, the commander has to find out what is going on, decide what to do about it, tell somebody what to do, then keep track of how the battle is going. He needs to turn that information-decision cycle in time inside the enemy's information-decision cycle so that, instead of simply reacting to what the enemy does, he can seize the initiative. [Ref. 17]

2. Information System Functions

In the tactical integrated C^3I information system, it is possible to identify four primary functions: [Ref. 18]

1. Information transport: This function includes integration of voice, graphics and imagery within the information system that allows the use of communication means in a better way.

2. Information collection: This function will be carried out by sensors and data processors, providing integrated intelligence and real time targeting information.

3. Information management: This function will cover the collection, management and distribution of information needed by the battlefield Commander and his forces to synchronize their actions effectively. One key characteristic of an information management system will be its existence in distributed networks overlaid on the information transport system.

4. Information denial: This function will be performed by using jamming, self-protection and deception to enhance combat effectiveness.

B. DATA FUSION PROCESS

Due to the technological advances and the dynamic changes in military operations, the amount of information that must be analyzed for any level of command has increased enormously.

Today, to achieve a reduction in uncertainty when transforming the raw data into information by technological means, the development and use of a more sophisticated process of data fusion is required.

The current technology in computers, hardware and software, can provide such tools. It also becomes a key factor in the preparation and execution of information exchange that takes place in any C^3I system.

The fusion of data is carried out by each and every one of the system's components of the nodal ATCCS. The achievement of an integrated battlefield will be the result of improvement in the fusion process that provides a greater information level and operational significance, true interoperability, and integration of large and non-comparable systems and their related subsystems. The fusion process also makes possible the positive identification of targets and extrapolation of results.

According to Gen. Federico V. Romano (Italy), the fusion process concept can be segregated into three subconcepts: Modularity, Correlation and Processing, and Integration. [Ref. 19]

1. Modularity

The module is a subunit with an input/output relationship clearly established so that each module is fully interchangeable with its analogous counterpart produced and built elsewhere. The requirement of modularity is the use of common software to permit the modules to communicate with each other, and that each module should receive as input the output of a preceding module, regardless of the structure of the composite system.

Modularity also implies that there are a minimum number of modules to allow the composite system to automatically adapt its outputs according to the environmental changes. If the modularity concept is not applied constantly, the information content and the information flow rate could suffer degradation and become useless at the end of the process.

2. Correlation and Processing

To make the best and most effective use of the data gathered from different sources, it is necessary to correlate them. The correlation of the data from multiple sources will produce an outcome that will provide the following advantages:

- The information level, in a generic way, will be greater than the sum of the individual contributions of each source.
- The operational value will benefit from the synergistic effect of the correlation itself and therefore will exceed that of each single source.

Two important aspects should be considered in the design of a correlation and processing system: the architecture of the data base and the comparison process. The architecture of the data base will determine the optimization of search techniques used to locate data rapidly that, in turn, enhance the timeliness of the correlation process. The comparison is a more difficult process. In this process the data received from different sources are analyzed to determine if they belong to, or define, the same entity or target.

3. Integration

Integration makes it possible for a commander to get a global perception of the battle situation. It also requires creating a system starting from various modules and sub-modules. Depending on the characteristics of the modules, and the quantity and quality of their links, it will be possible to reach different levels of system integration. The integration has also the advantage of both avoiding undue duplication and gaining flexibility.

C. CURRENT TACTICAL INFORMATION SYSTEMS

The five nodal systems of the ATCCS have their corresponding main information systems, as shown in Figure 8. Each system consists of several subsystems and their interrelationships. Fcr the purpose of this thesis, only the main and integrative system of each BFA will be addressed. A general description of each of those systems is provided below: [Ref. 20]

1. Maneuver Control System (MCS)

The MCS is a collection of computer equipment and software that support operations planning and control at the ATCCS maneuver control nodes. It is designed to assist the commander and his staff by providing information on his own forces, enemy forces and the characteristics of the battlefield. The MCS provides battlefield information by collecting, processing and displaying data generated within the air/land combat environment.

2. Advanced Field Artillery Tactical Data System (AFATDS)

AFATDS is a single, integrated battlefield management and decision support system that satisfies command and control, deep battle and light infantry division requirements. It will function at levels from artillery forward observer through theater headquarters as one of the five battlefield automation systems of the ATCCS. It provides fully automated support for planning, coordination and control of all fire support assets (mortars, close-air support, naval gunfire, attack helicopters and offensive electronic warfare, artillery cannon, rockets and guided missiles) in the execution of close support counterfire, interdiction and suppression of enemy air defense. AFATDS supports fire planning and coordination of the employment of all services to complement the commander's scheme of maneuver, also it will set up detailed commander's guidance in the automation of operational planning, movement control, targeting, target value analysis and fire support planning and execution.

3. Forward Area Air Defense System Command, Control and Intelligence (FAAD C^2I)

The FAAD C^2I is a computer-based command and control system. It is dependent on the Army data distribution system (ADDS) to alert and integrate Army FAADs against enemy forces ranging from helicopters to high-performance aircraft. It provides accurate information in real time for FAAD weapons and command posts. It consists of command and control command posts and sensors that provide air surveillance and identification in the battlefield area. The mission is accomplished through the collection, digital processing and dissemination of target information; generation of air threat warning and weapon control orders; and target data processing and display capabilities at battery, platoon and fire unit levels. The system also provides target tracking information to armor, infantry and aviation units having secondary air defense capability and missions.

4. All Source Analysis System (ASAS)

The Army's all-source analysis system is a computer based battlefield commander's intelligence support system. ASAS receives, stores and rapidly fuses real world battlefield information for presentation to commanders in support of the decision-making process. ASAS will have direct connectivity to ATCCS, enabling the battlefield situation to be coordinated from division to echelons above corps. This connectivity, as well as direct connectivity between ASAS and the Air Force's enemy situation correlation element (ENSCE), will assist commanders in making well-advised and timely decisions unconstrained by time and location. ASAS/ENSCE are referred as "the central nervous system of the deep attack" because it supports the targeting process by early identification of high value targets and by providing accurate descriptions and locations to the weapons system. Both are the key to success in deep attack missions an engagement of follow-on forces.

5. Combat Service Support Control System (CSSCS)

The CSSCS is an evolutionary software development designed to provide timely and reliable logistics, medical, financial and personnel information essential for planning and decision making by theater and tactical maneuver force and logistics commanders. The system also provides automated C^2 capabilities for analysis of current operating allowances, sustainment planning and execution of CSS plans in support of combat operations. CSSCS provides an automated interface between the other ATCCS's functional areas and the theater standard army management information systems (STAMIS) that are part of the CSSCS's functional area.

D. TECHNOLOGY OF DECISION AIDS IN C^3I SYSTEMS

While the reduction of uncertainty through the technological approach that enhance the collection, comparison or integration of data and its transformation into information, is essential to successful C^3I systems, it is not enough. This information must be converted to knowledge through a process similar to the one depicted in Figure 9 [Ref. 10: p. 3].

One way to achieve this is through training, simulations, war games, and exercises; a second way is to reduce the commander's knowledge needs via organizational design or

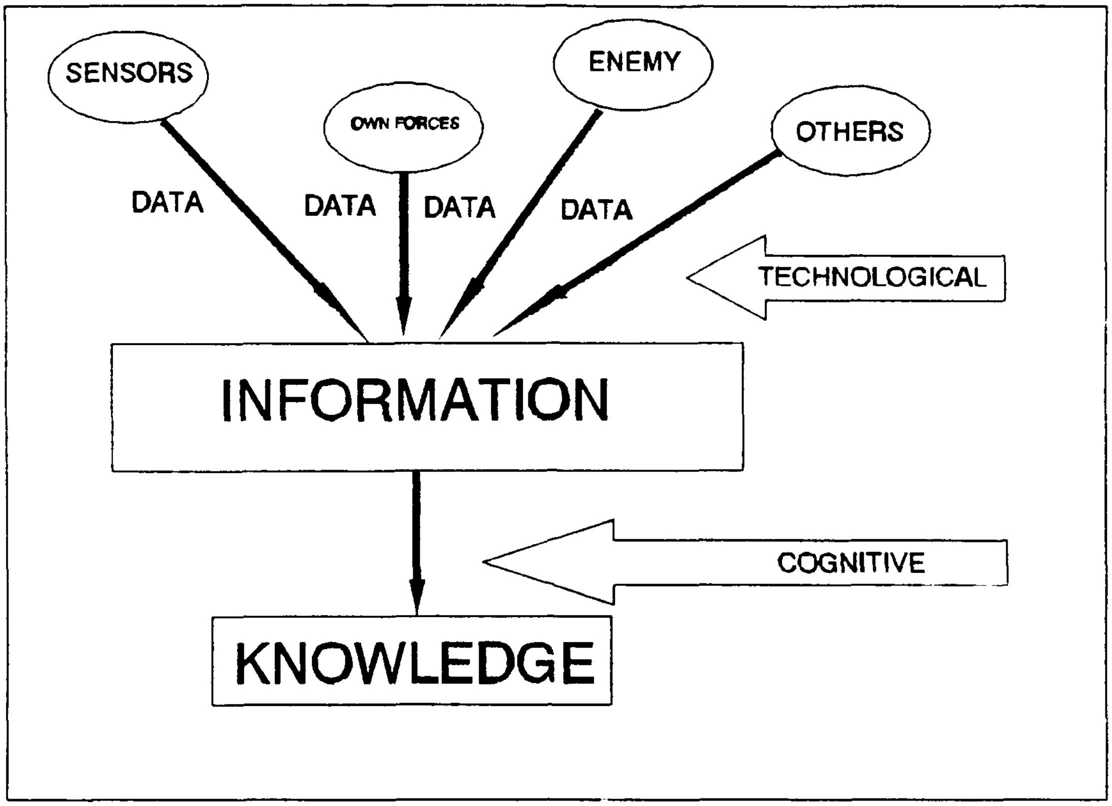

Figure 9. Data, Information and Knowledge

through the use of decision aids, to improve his/her decision-making process[Ref. 10: p. 4].

The evolution of the cognitive processes that allow this conversion have not improved at the same rate as the communications means and weapon systems. This has produced the under-utilization of those resources.

Decision aids (DA) should be considered as an integral component of the C^3I systems. They should be applied to each and every one of the C^2 process functions. The DA also must be considered as a component that improve the commander's intelligence, not as substitute of it.

> Decision Aids can help military personnel by reducing stress, information overload and manual tasks; by providing experts in military decision making with a fail-safe check list; by guiding novices through unfamiliar decision making situations; and by applying a logical structure to decision making . . . Time originally spent correlating messages, plotting points on a map and looking up information in publications can now be spent analyzing incoming information or applying it where it is more useful. [Ref. 21]

The application of decision aids to the decision making process can range from the simple automation of a task to the use of artificial intelligence for complex automation of an expert's heuristic reasoning ability.

The techniques or tools used in the problem solving process depend on the type of problem to be solved, and how it is structured.

Usually four categories of problems are defined : [Ref. 22] [Ref. 23]

- Deterministic problems: These are well structured and are more operational in nature.
- Stochastic problems: These involve considerable uncertainty and require dealing with many unknowns.
- Complex problems: These are ones that involve many interacting variables that are highly interdependent and that change over time or are combinatorial in nature.
- Organizational problems: These problems require much more human intervention for their solution. The necessary manager skills include understanding of human behavior, interpersonal interaction, conflict resolution, negotiation, and leadership.

According to their structure the decision for problem-solving can be classified as: structured, semistructure, and unstructured. [Ref. 22][Ref. 2]

A decision is unstructured when:

- The objectives are ambiguous and non-operational, or if the objectives are operational, they are numerous and conflicting.
- It is difficult to predict in advance the effect on decision outcomes of the actions taken by the decision-maker.
- It is uncertain what actions taken by the decision maker might affect decisions.

Table I shows a matrix with the relationship between the different categories of problems and the type of decisions that decision-makers have to make to solve them. Using this classification scheme, the way in which decision aids can be used in problem-solving can be represented. The general idea of this chart is the more complex and unstructured the problem, the more direct human intervention is required for its solution. Into each block is shown the frequently used decision aids for the particular type of decision and problem. These decision aids range from highly standardized tools and techniques, as in the upper left hand box, to the application of highly human interacting tools, like in the last two boxes at the lower right hand of the chart [Ref. 22].

The decision aids became an area of highest importance in the growth of C^3I systems. When implemented, they will help to reduce the interoperability problems by performing better data control. In this manner, the excessive production of data in the current environment will be transformed into useful information applicable for use by the commander and his staff.

TABLE I. DECISION AIDS APPLICATIONS CHART

Problem Decision	Deterministic	Stochastic	Complex	Organizational
Structured	Operation Research. Decision Analysis. Conventional Prog.	Operation Research. Decision Analysis. Conventional Prog. Simulation Process.	Operation Research. Decision Analysis. Conventional Prog. Simulation Process. Expert Systems	Operation Research. Decision Analysis. Conventional Prog. Simulation Process. Expert Systems
Semistructured	Stand alone Decision support system.	Stand alone Decision support systems (As integrator of OR, DA, SP, ES or CP)	Stand alone Decision support systems (As integrator of OR, DA, SP, ES or CP)	Stand alone Decision support systems (As integrator of OR, DA, SP, ES or CP)
Unstructured	Scenario Analysis (Several stand alone DSS and ES assist the analysis)	Scenario Analysis (Several stand alone DSS and ES assist the analysis)	Decision support systems with highly human interaction	Decision support systems with highly human interaction

This study will describe how the decision aids should be applied to the decision making process by using the following techniques or tools:

- Operations research
- Artificial intelligence

1. Operations Research

Operations research is a scientific approach to problem solving that is based on the extensive use of quantitative analysis. These techniques are highly structured and well defined, and their applications are usually made to model physical entities or events that are clear-cut or repetitive. These situations occur in an unambiguous environment, with clearly delineated procedures and responsibilities, and the problems are well defined so that they can be solved by applying specific algorithms.

Operations research is the most widely and intensively used technique since its development during World War II. Included in operations research methodologies are: statistics, computer simulation, Pert/CPM, linear programming, queuing theory, nonlinear programming, dynamic programming, and game theory.

Another evolutionary approach is decision analysis. It is a more general methodology than operations research. Its purpose is to impose logical structure on a decision maker's reasoning process by using: analytic models of expected utility, multi-attribute analysis, and bayesian hierarchical inference.

The decision analysis approach is applied mainly in the solution of complex problems. It attempts to break that complex problem into small pieces and requires a quantification by the decision maker of his perceptions and values for each facet of the problem. The quantifications are then combined using the mentioned probabilistic techniques and models for dealing with uncertainty.[Ref. 21: p. 45]

The problems addressed by these techniques include: determination of course of actions, and determination of optimal resource allocations.

2. Artificial Intelligence

The evolution in Artificial Intelligence (AI) has reached the level that has made possible the implementations of decision aids based in AI as part of C^3I systems. There are many areas of AI research, but two apply most to decision aids: Expert Systems (ES) and Decision Support Systems (DSS).

a. *Expert Systems*

Expert systems are computer programs that can perform specialized tasks that constitute professional expertise at a level of (or beyond) a human expert. They are also called knowledge-based systems since they rely on reservoirs of knowledge.

For the expert system to be useful it should be constrained to a specific area of expertise or domain. This may be determined if the following criteria are met:

- The expert system answers questions about subjects in its realm of understanding.
- It solves problems that do not have algorithmic solution.
- It exercises planning by progressing from a given state to a goal state.
- It reacts to changes in its environment.
- It is capable of altering its own reasoning based on observed trends.

The expert system role related to interoperability has gained relevance with the increase in systems' complexity. This area of application covers all the functional areas of the C^3I systems, especially the areas of communication, information processing and intelligence.

Possible communication applications of expert systems include: planning, managing, interconnection of tactical communication means; routing, and allocation of channel capacity base on real constraints.

The expert systems capabilities also could partially serve three major intelligence functions that supplement the human limitation:[Ref. 25]

- Fusion of multi-source data into a mosaic view of targets, conditions and situations.
- Indicator highlighting of various forms. For example, the aggregation of sensor observations from different times and places and in different forms to note the thresholds of activity sufficient for triggering an indicator.
- Hypothesis verification in the sense of showing that collected information is tending to confirm or to deny some previously imagined, institutionalized scenario of a potential situation and its dynamics.

Related to the information processing, the expert systems could be useful in the data distribution, formatting, and routing of information in interconnected tactical networks.

b. *Decision Support Systems*

Decision support systems are computer-based systems that allow the user(s) to make effective decisions in semistructured or unstructured problems. [Ref. 22]

The application fields of the DSS are broader than the field of expert systems due to their advantages in dealing with unstructured decision, their flexibility in human-system interaction, and the improvement of personnel efficiency. An additional reason for the wider scope is that they are more "friendly" decision aids for the commander and his staff. The following additional reasons account for the increased level of interest and the requirement for employing DSS: [Ref. 22]

- The DSS fits in with the general trend in information system development, as office automation, advanced integrated systems, etc.
- Improvements in computer hardware capabilities, availability, and software maturity (In both languages and in DSS's generators).
- Increased user sophistication and renewed interest in quantitative methods by improving heuristic.
- DSS's provide a familiar representation for decision-makers conceptualization, facilitate functioning of the decision process's operations, and provide control aids that allow the decision-maker to exercise direct personal control over the whole decision process.

The efficiency and utility of the DSS will depend greatly on the design of the Man Machine Interface (MMI). The ill-structured nature of the decision in a combat situation makes the use of these tools more suitable than any conventional solution. However, the need to provide the commander and his staff with a powerful, interactive interface make its achievement both conceptually and technically difficult. Current studies suggest that 80% of a DSS developmental effort is devoted to the MMI design. [Ref. 22]

c. *Review of ES and DSS Applicability*

Table II depicts a comparison of the main characteristics between the ES, DSS, and conventional programs [Ref. 22]. The table shows the advantages and disadvantages of ES, DSS, and conventional programs in the problem-solving process. This is performed by relating and grouping comparative factors by area of application (domain), reasoning and searching techniques, data characteristics, user interface, and systemmaintenance.

E. SUMMARY

The intention of this chapter has been to present the basic description of information systems in the tactical environment through the description of its functions. It has also attempted to describe the transformation process, where data collected by multiple sources is fused into knowledge using technological and cognitive methods. The design and implementation of information systems was also reviewed.

Later, current tactical information systems implemented in the ATCCS were described.

Finally, decision aids and their role in the C^3I systems were described. The DAs were also classified according to the type and structure of problem that they help to solve, and their comparative characteristics were presented so that the reader would have a better understanding of their application fields.

TABLE II. MAIN CHARACTERISTICS OF ES, DSS, AND CP

EXPERT SYSTEMS	DECISION SUPPORT SYSTEMS	CONVENTIONAL PROGRAM
	Domain	
1. Specific area of expertise	General, mechanistic areas	General, mechanistic areas
	Reasoning and search techniques	
2. Heuris reasoning	Mechanistic/monotonic reasoning	Mechanistic/monotonic reasoning
3. Symbolic manipulation	Numeric & alphabetic manipulation	Numeric & alphabetic manipulation
4. Dynamic decision process	Static decision process	Static decision process
5. Remembers information	Doesn't remember information	Doesn't remember information
6. Prediction & inference	What-if-scenarios	If-then-scenarios
7. Data pattern driven	Control driven	Control driven
8. Multiple solutions	Single solution	Single solution
9. Search intensive	Computation intensive	Computation Intensive
10. Recursive	Iterative	Iterative
11. Certainty factors	Truths of falseness	Truths or falseness
	Data characteristics	
12. Uncertain & incomplete data	Exact & factual data	Exact & factual data
13. AI data structures	Fixed, hierarchical data structure	Fixed, hierarchical data structure
14. Dymanic & static variables	Static variables	Static variables
	User interface	
15. Natural language dialogue	Menu/command interface	Menu/command interface
16. Generates and reviews summaries	Generates summaries	Generates summaries
17. Quantitative and qualitative	Quantitative	Quantitative
	System maintenance	
18. Expert/Knowledge Eng. developed	User maintained	Programmer maintained
19. Expert/Knowledge Eng. maintained	User maintained	Programmer maintained

Regarding this last point, and in conclusion, it is considered necessary to continue the research and implementation of Decision Support Systems. They will supplement human abilities in using general knowledge to respond effectively in real time, emulate and follow human reasoning processes, acquire and apply knowledge, manipulate and communicate ideas, and focus human attention on relevant information. The early application of AI to the C^3I systems indicates that this technology will be able to bring solutions for many current C^3I system problems.

V. TACTICAL COMMUNICATION IN C^3I SYSTEMS

A. COMMUNICATION SYSTEMS

The systems supporting the U.S. Army's tactical communication are: Area Common User System (ACUS), Army Data Distribution Systems (ADDS), and Combat Net Radios (CNRs), as depicted in Figure 10.

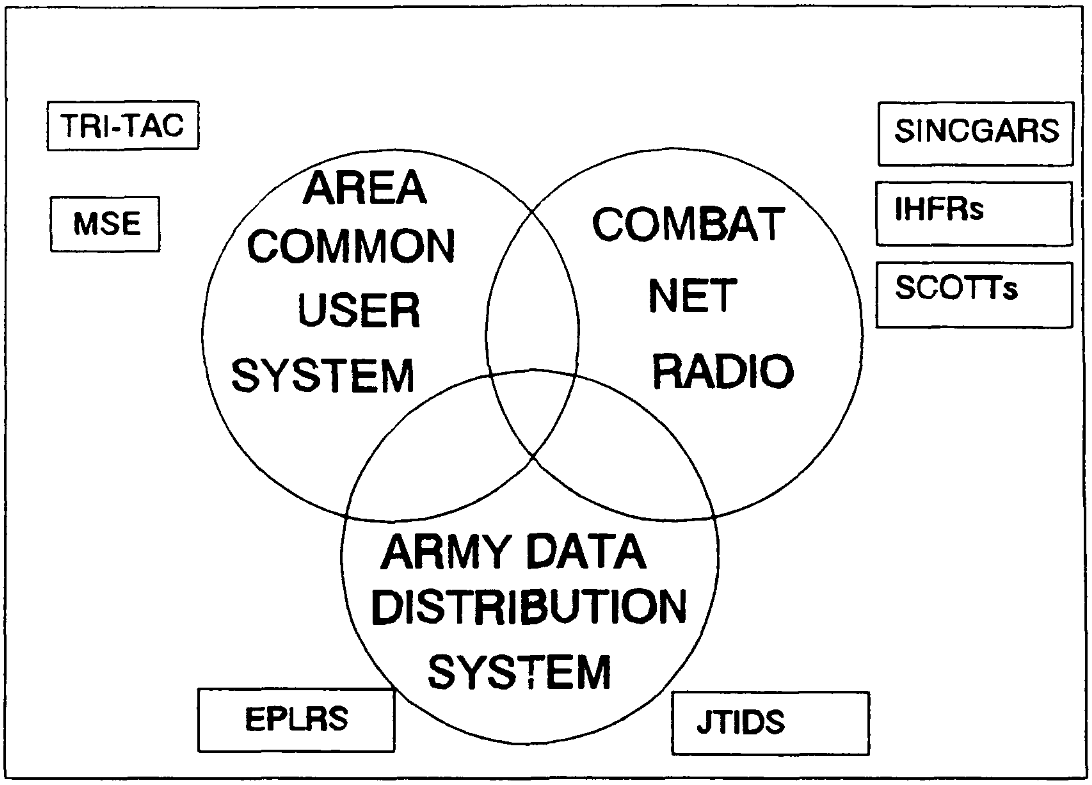

Figure 10. ATCCS Communication Networks

These systems are the foundation that sustain the transfer of data generated by information systems. They also support and integrate the Command and Control communications of the five BFAs.

The systems meet the conditions of reliability, rapidity and comprehension required for modern communications infrastructure. The following sections will describe each of these systems, their related subsystems, and their interrelationships. [Ref. 20: p. 314 - 335]

1. Area Common User System

ACUS is the area system that provides the backbone of tactical communications. It will also be the key to achieving interoperability between the Army's networks. ACUS consists of two basic area systems: TRI-TAC, a multi-service communication system and family of equipment; and the corp area system, Mobile Subscriber Equipment (MSE). Similarities on engineering and operational characteristics exist in the architectures of both systems. MSE is the largest fielding effort made by the U.S. Army for tactical communication systems. [Ref. 26]

2. Combat Net Radio

CNR has three primary subsystems: Single Channel Ground and Airborne Radio System (SINCGARS), Improved High Frequency Radios (IHFRs), and the Single Channel Objective Tactical Terminals (SCOTTs). This is the system primarily employed by the front line unit, in combination with Enhanced Position Location Reporting System (EPLRS).

The combination of these communication systems provides a secure flow of voice and data communications from the strategic levels to the front line. The interoperability issue has been incorporated into the design and fielding of these systems.

a. SINCGARS

SINCGARS is a family of very high frequency (VHF), frequency modulated (FM) radios that provides the primary means of communication from the brigade to the platoon level. Although the system is designed to support voice/data line-of-sight communications and record traffic messages, voice will be, in the short term, the dominant application of this system. [Ref. 20: p. 313 - 314]

The radio units ensure reliability, electronic counter-countermeasures, maintainability, and communications security. The system is able to operate using a spread-spectrum technique known as frequency hopping. This technique allows the system to operate efficiently in a hostile environment due to its antijamming characteristics. The system design goals include a manual-mode interface with the ACUS, and in the near future, an automated-mode interface. SINCGARS is also suited to the rapid tempo of operations by allowing a commander to rapidly change nets as he moves about the battlefield.

b. IHFR

IHFR is a family of High Frequency (HF) radios that supports voice and data communications. The system provides dedicated beyond "line of sight" (LOS) communication, and constitutes backup for satellite communication. These units also contain an application module that provides antijamming capability by using a frequency hopping technique. [Ref. 27]

c. SCOTT

SCOTT is a satellite single channel communication system that provides secure voice and data capabilities. These units have been developed to operate in an electronically-hostile environment. It is a man-pack system that is especially suitable for use by small, mobile units such as special operations forces. [Ref. 26: p. 25]

3. Army Data Distribution System

ADDS consists of two main subsystems: EPLRS and the Joint Tactical Information Distribution System (JTIDS). ADDS provide an integrated, effective, and efficient means to communicate in near real time, and to control data transfer on the battlefield. The integration of both systems is one of the major military efforts to accomplish tactical interoperability.

a. *EPLRS*

EPLRS system was designed to support tactical operations on the battlefield with a reliable data communications system. It provides tactical units with electronic real time position and navigation capabilities [Ref. 26: p. 26]. The system links the high-priority elements of each BFA, and also provides communication between these areas. These links are implemented through use of automatic integral relays with interfaces to the host equipment at each end. The system supplies individual paths with data rates up to 1,200 bps. The collection of the data can be done automatically in tens of seconds. [Ref. 20: p. 314]

b. *JTIDS*

JTIDS constitutes the Army's primary data distribution system forward of the brigade areas for those units with weapons systems requiring near-real response times. The JTIDS deployment is from brigade to theater level. This LOS system provides data distribution capabilities using common data link standards in ultra high frequency (UHF). It also includes facilities that support voice subsystems. [Ref. 27: p. 130]

B. MOBILE SUBSCRIBER EQUIPMENT

MSE represents the new-generation battlefield integrator systems that are being fielded around the world. The RITA of the French Armed Forces and the CATRIN of Italian Army are also examples of this new type of system. RITA and MSE systems have minor differences, most of them due to interface requirements to make them interoperable with older systems.

MSE provides both mobile and stationary users in corps and division areas with automatic switched, survivable, secure voice, data and facsimile communications. A packet switching capability is also available to effect communication between computers. MSE is the full-featured all-digital telecommunications system for the tactical battlefield. [Ref. 20: p. 312]

The description of the MSE system will follow the outline made by Captain John Melville Blaine, U.S. Army, in his thesis at the Naval Postgraduate School [Ref. 28]. The system description was broken down into five functional areas: area coverage, wire subscriber access, mobile subscriber access, subscriber access and system control.

1. Area Coverage

The MSE networks' capabilities and services are designed to support tactical corps consisting of five divisions in a geographic area up to 37,500 square kilometers. The communication network will consist of Node Centers (NC), Radio Access Units (RAU), and System Control Centers (SCC).

> The MSE system lets subscribers communicate with each other on a discrete address basis, using fixed directory numbers regardless of a subscriber's battlefield location. The area coverage is provided by the tandem switched network interfaced with mobile subscriber access and wire subscriber access functions. Area coverage also provides flood search routing and a means of interfacing with non-MSE networks such as TRI-TAC switches, other services TRI-TAC unit level circuit switches, and NATO Architecture. [Ref. 28: p. 9]

Node Centers: The communication network consists of 42 NCs interlinked by LOS radio trunking. The NCs will usually be separated by 35 to 40 Km and linked with at least three other NCs. They provide robust command and control access for both stationary and mobile subscribers as they move about the battlefield [Ref. 26: p. 26]. NCs are the backbone of the network and operate relatively independently of existing command structures, providing communications to the users on an area basis. Each NC consists of a Node Center Switch (NCS), two RAUs, four LOS terminals, a Node Management Facility (NMF), and a Node Support Vehicle (NSV). [Ref. 28: p. 9-10]

Node Center Switches: NCS combine in a single switching function the digital switching, flood search routing and subscriber management. They provide access for mobile and 24 local wire MSE subscribers and perform all node switching and control functions in the MSE network. NCS supply automatic tandem switching for the system and network interface for subscriber access elements. They also furnish automatic subscriber finding features that allow permanent subscriber address assignment. [Ref. 28: p. 11-13]

Radio Access Unit: The RAU provides an automatic interface between mobile subscribers and the network. The number of mobile subscribers supported by each RAU is a function of the NCS to which it is connected. It is also a function of the density or distribution of the mobile units in that particular geographic area. The average number of mobile subscribers per RAU is 25. The RAUs allow the users to: [Ref. 28: p. 13]

- Access the network and dial up any other subscriber, either static or mobile, without having to know their physical location.
- Maintain communication on the move, as long as they are in the area of coverage of any RAU.
- Automatic reaffiliation to the nearest RAU, whether a user call is in progress or not.

Node Management Facility: NMF provides the equipment and space required by the node commander to manage resources. NMF, deployed as part of each NC and LEN, connects to the NCS and the large extension node switch (LENS) at each site.[Ref. 28: p. 15]

2. Wire Subscriber Access

Wire subscriber access gives static subscriber access to the network, through large extension nodes (LEN) and small extension nodes (SEN). LEN and SEN consist of switchboards located at battalion and higher headquarters command posts as well as LOS radio links to connect the switchboard to the grid network through the NCs. [Ref. 26: p. 26]

3. Mobile Subscriber Access

Mobile subscriber access permits subscribers to place or receive calls while moving through the battlefield. The mobile subscriber radio telephone (MRST) is the user terminal that permits the mobile subscriber to access the network. It provides subscribers a means of discretely addressing switched common-user subscribers via radio linkage to the RAU. This feature enhances mobility in a battlefield. The equipment is also designed to provide a digital data port. [Ref. 28: p. 19]

4. Subscriber Access

The subscriber terminal allow users to place calls and pass data through the MSE network. The main pieces that make up the subscriber access area are: [Ref. 28: p. 21 - 22]

- Digital nonsecure voice telephone (DNVT): It is the primary subscriber terminal used in the MSE system wire access areas. DNVT is a digital, four-wire telephone set which is capable of transmitting and receiving digital information and signaling. It provides data interface for the connection of facsimile or single subscriber terminal (SST) data devices.
- Facsimile: The unit can transmit digital or analog facsimiles in black and white or eight shades of gray graphic or text information between remote and/or centralized communications facilities. The traffic can be sent in noncompressed, compressed, or compressed with error detection data modes. The operational data rate is 16 Kbps.

The single subscriber terminal (SST) is a user terminal available for data message handling through the network but is not an integral part of the subscriber access area. SST interfaces with the data port on both DNVT and DSVT and passes data through the MSE system to interoperate with the automatic message switch of TRI-TAC.

5. System Control Center

The SCC is mainly a command and control facility. It also includes some of the technical control functions necessary to manage the highly centralized MSE network. The SCC is an automated facility that accesses the network through any NCS or LENS. The network managers are assisted by the SCC to perform the following: [Ref. 28: p. 23 - 24]

- System engineering
- Frequency engineering and management
- Directing deployment of system assets
- Maintaining status of resources
- Enabling a rapid response to changes in mission and subscriber demands

The specific software tools provided by the SCC are:

- LOS and VHF frequency management
- COMSEC management
- High-point surveys
- Signal path profiling
- System logistics and personnel
- Equipment status reporting

6. System Interoperability

The MSE system meets the known requirements to interface with the TRI-TAC system, CNR system, NATO systems, and host nation commercial telephone systems. Commercial office interfaces are necessary to permit users access to the local commercial telephone system in the area of operations. [Ref. 28: p. 27-28]

C. TACTICAL MOBILE COMMUNICATIONS

The modern tactical communication systems are highly dependent upon wireless communication and spread-spectrum techniques. Mobile and secure telephone and digital transmission features are the factors that enhance the concept of battlefield mobility. They also introduce in the command and control process the timing required by modern commanders and their staffs to conduct the battle.

Due to the importance of these systems, it is imperative to have a clear understanding of the various key, and controversial, issues that determine a mobile communication architecture. George Calhoun is his book Digital Cellular Radio includes as key issues: [Ref. 29]

- Selection of analog versus digital technology
- Wideband versus narrowband systems channelization of the radio spectrum
- Choice of multiplexing techniques

Because of the importance and the scope of the last two issues, they will be treated in detail below. Regarding the first issue, the technological evolution and currently fielded military applications determine the predominance of digital technology. This technology presents greater capacities and better performance than the analog technology.

1. Channelization of the Radio Spectrum

Channelization has been the keystone of mobile radio for fifty years. Because of the scarcity of spectrum, the channelization assumption has driven radio engineers to look for ways of reducing the bandwidth of the voice circuits. [Ref. 29: p. 340]

There are two broad and very different ways to parcel up the total available spectrum into individual telephone channels: narrowband and wideband systems.

a. Narrowband Systems

In narrowband systems the total available spectrum is divided into a large number of relatively narrow radio channels, defined by carrier frequency. These types of channelized systems have a number of common characteristics. [Ref. 29: p. 277]

- They imply the necessity of sharply defined emissions limitations on individual transmitters to avoid adjacent channel interference.
- The transmission occurs within the coherence or correlation bandwidth. It means that two signals on near-adjacent channels will tend to fade at the same time. If a fade occurs, the entire narrowband transmission will be affected.
- They are inherently blocking systems, and the blocking probability becomes the key measure of service quality. The number of calls that can be handled for a base transmitter are limited to the number of operating channels. As the blocking probability rises, the only recourse to reduce it is by adding channels per cell or by reengineering the cell structures to improve frequency reuse.

b. Wideband Systems

In wideband systems, instead of dividing the total available spectrum into a large number of individual channels, the entire channel is made available to every user. Furthermore, a large number of individual users can all use the same wideband channels simultaneously. These systems are known usually as spread-spectrum systems, and their characteristics include: [Ref. 29: p. 280 - 282]

- The transmission bandwidth exceeds the coherence bandwidth, consequently a multipath-induced fade does not affect the entire signal.
- There is no hard limit on the number of mobile users that can simultaneously access a transmitter base. There is not a blocking condition, instead there is a deterioration in the quality of the services.

The spread-spectrum (SS) techniques are the backbone of the modern tactical systems. These techniques are just now being experimented with for commercial applications. However, many details of this technique are still classified for security reasons. Spread-spectrum techniques solve many of the traditional RF problems, such as spectrum efficiency, mobile-unit cost, multipath, and interference. There are two major categories of these techniques: [Ref. 30]

- Frequency hopping SS (FH/SS)
- Direct sequence SS (DS/SS)

The essential shared characteristics of these techniques are: [Ref. 29: p. 355]

- The transmission of a voice circuit over a bandwidth much wider than would be normally required in a conventional channelized radio system.
- The coding of the transmission by means of a random sequence that is shared by both transmitter and receiver.
- The assignment of different random sequences to distinguish different users.

2. Multiplexing and Access Techniques

> The terms "multiplexing and "multiple access" refer to the sharing of a fixed communication resource (CR). There is a subtle difference between multiplexing and multiple access. With multiplexing, users' requirements or plans for CR sharing are fixed, or at most, slowly changing. The resource allocation is assigned a priori, and the sharing is usually a process that takes place within the confines of a local site. Multiple access, however, usually involves the remote sharing of a resource, such as a satellite. With a dynamically changing multiple access scheme, a system controller must become aware of each user's CR needs; the amount of time required for this information transfer constitutes an overhead and sets an upper limit on the efficiency of the utilization of the CR. [Ref. 30: p. 476]

Different methods exist for allocating individual channels to individual users on demand. Also, the access system should allow any user to utilize any channel in a fully trunked system. The procedure to accomplish this is called multiple access.

There are three categories of alternatives to implement multiple access: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). Figure 11 illustrates how each of these alternatives deals with the signals in the frequency and the time domain.

a. *FDMA*

FDMA is the simplest multiple access arrangement; it is the implementation of frequency differentiated narrowband channels within the total available spectrum. Each user is allocated a fixed portion of the frequency spectrum. The characteristics of this type of multiple access scheme include: [Ref. 29: p. 365 - 367]

- The mobile unit must have frequency agility, that is, it must be able to tune to every one of the available frequencies.
- The transmission is continuous in both directions, and it is required that duplexer circuitry be available at the mobile and at the base station radios for simultaneous operations.
- The system is simple and synchronization is not required.
- The system requires the use of guardbands, which become unused portions of spectrum.
- The system performance is frequency dependent, and is greatly affected by channel interference, and fading.
- The distribution of channel per frequency band is limited.

b. TDMA

TDMA is a more complex architecture. It provides the user with the full channel capacity but divides the channel usage into time slots. TDMA structures can differ in the bandwidth of the carrier frequency or the bit rate in the channel, and in the number of time slots defined in the channel. The characteristics of this type of multiple access scheme include: [Ref. 29: p. 369 - 373]

- The requirement of guard time, which results in unused time intervals between slots.
- The requirement of a synchronization scheme because of the complexity of system operation in the time domain.
- The limited distribution of channels per cell.
- The received signal is affected by multipath propagation produced by reflections from a building, the terrain, discontinuity in the atmosphere, etc.

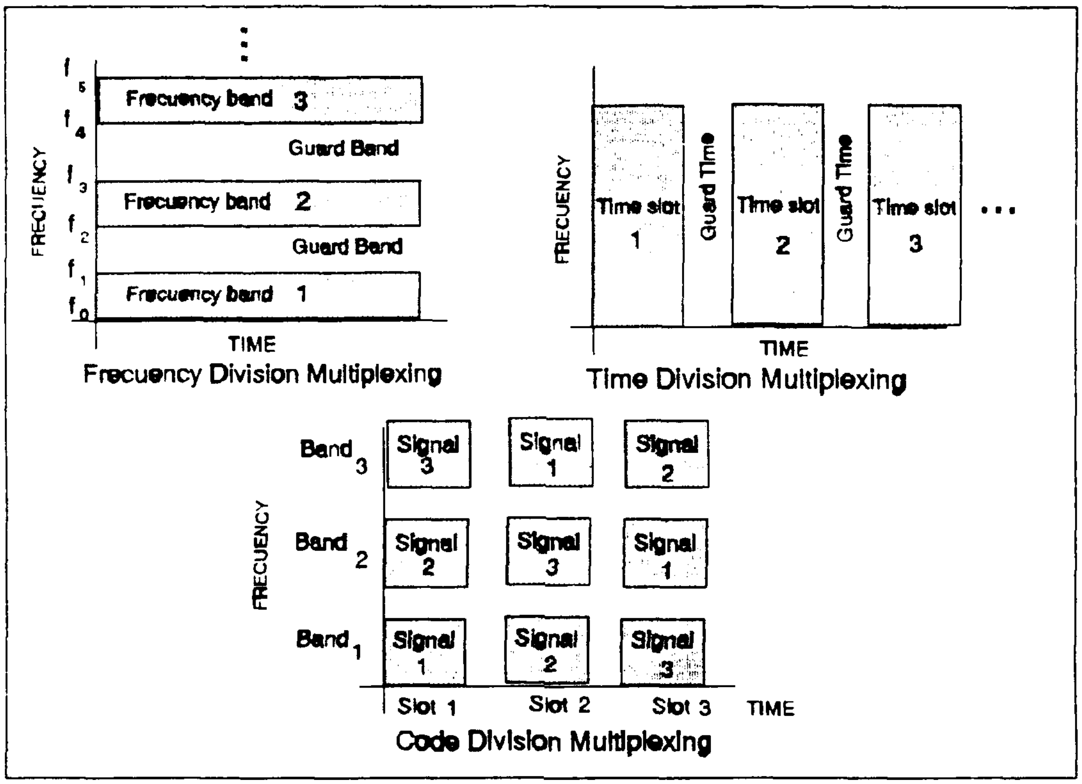

Figure 11. Multiplexing Compared

- Transmission from the mobile units is not continuous, but occurs during specified time slots only.

c. *CDMA*

CDMA is the form of multiple access employed by spread-spectrum wideband systems. These systems are based on the principle that each user is distinguished from all other by the use of a unique pseudonoise (PN) code. In an FH/SS system, this code is used to generate a unique sequence of frequency hops. In a DS/SS system, the code is used to generate the randomized noiselike high-bit-rate signal that is mixed with the information signal to spread the spectrum. The characteristics of this type of multiple access scheme include: [Ref. 29: p. 373 - 379]

- Despite the scheme's complexity, synchronization is not required.
- The distribution of channels per cell is unlimited.
- Fading resistance. If a portion of the spectrum is affected, only during the time a user hop goes into the affected portion of the spectrum will the user experience degradation.
- Jam resistance.
- Communications privacy is ensured since the transmission cannot easily be intercepted by unauthorized users without the PN code.

D. CONCLUDING CONSIDERATIONS

The technological characteristics and design of the tactical communication systems that have been presented provide complete, reliable, and secure links throughout all command levels in the battlefield. The systems have enough flexibility to be tailored by a commander to his/her own communications needs and leadership style.

Communication technology has provided excellent systems, but these systems should be utilized with a disciplined information flow to take major advantage of their capabilities. This issue manifests the link between the information needs and the communication needs. A lack of balance in this relationship could waste important and vital resources at critical times.

Two systems appear as the core of the C^3I system from the tactical mobility point of view: SINCGARS and MSE. These systems improve ground tactical communication support, and their embodied technology thus permits the commander greater freedom on the battlefield. The experience from the military operations in the Middle East will confirm the issue, or if they show that the systems suffer from a lack of interoperability, major efforts should be devoted to solve those failures that jeopardize the implementation of the total integrated battlefield concept.

Finally, the trends in mobile communication promise a more efficient use of the spectrum, a better quality of service, and a greater system capacity by using spread-spectrum techniques and implementing CDMA multiplexing and access scheme.

E. SUMMARY

This chapter has presented the current tactical communication systems that support the information flow in the U.S. Army at the tactical level. The three major communications systems and their corresponding subsystems were also described.

The MSE system was described in more detail due to its importance for interoperability in the tactical environment. Later, the basic concepts underlying mobile communications, such as channelization of the radio spectrum and multiple access schemes were analyzed. Finally, conclusions about tactical systems and likely future developments in the mobile communications field were proffered for the reader's consideration.

VI. NETWORKS IN INTEGRATED C^3 SYSTEMS

A. OVERVIEW

This chapter focuses on C^3 network concepts, and will provide background and analysis about networks in a tactical environment.

The highly mobile and distributed C^3 environment requires a secure and reliable data flow among subscribers of any level of command. That data flow can be provided by various tactical and strategic networks. To achieve an integrated battlefield, it is essential that these networks be developed with an interoperable orientation.

Understanding networks requires that the concept be defined and that a distinction be made between networks and communications, because both terms, despite their differences, are usually used interchangeably.

A network consists of the collection of nodes that send to or receive from other nodes information and data together with the transmission paths, called links, which are used to effect the exchange of information and data. Nodes may be located at ground command posts, on aircraft, on sensors, or on satellites in earth orbit. The communication means used to establish the links include antennas, wire, coaxial cable, or optical fiber. [Ref. 31]

> The C^3 network concepts address the mathematical and logical processes, and procedures that control and manage the C^3 network, and its associated processes and communications links. This network provides the high performance, fault-tolerant, secure, and survivable C^3 environment within which the battle-management algorithms function. Topics addressed as part of the C^3 networks concepts include protocols, distributed control concepts, distributed operating systems, and management of distributed data bases. [Ref. 31: p. 2 - 3]

The boundaries between networking and communications are not clear, so it is necessary to emphasize their differences and applications.

1. Communications

Communications concepts are related to: [Ref. 31: p. 3]

- Established links between node pairs that have sufficient capacity, acceptable low error rates, and acceptable high resistance to interception.
- Choice of the means to accomplish the communication that include transmission medium, multiplexing techniques, modulation and detection schemes, and spread-spectrum techniques, etc.
- In the setting of standards, communication functions are carried out by the lower levels or layers.

2. Networking

Network concepts are related to: [Ref. 31: p. 3]

- Managing communication resources so that messages are delivered reliably, with minimum delay.
- Procedures to promote a robust network so that functions can be accomplished even in cases of node and link failures or under heavy traffic conditions. These procedures include algorithms for specifying location of point-to-point links, implementing adaptative routing strategies, providing message flow and congestion control, etc.

- In setting standards, networking functions occupy the contiguous and higher level communication functions.

B. NETWORK ARCHITECTURES

A network architecture encompasses hardware, software, data link controls, standards, topologies, and protocols. It describes the components, how they operate, their relationships, and what physical form they take.

Figure 12 depicts the International Standards Organization (ISO) Open System Interconnection (OSI) reference model. This reference model does not specified protocols, but provides an accepted and suitable framework for the development of standards. The reader should note that no unique approach to solve the interoperability problem is prescribed.

The majority of the protocols that make up the different architectures are base upon the concept of layered protocols. The software and hardware at the network stations consist of a wide range of functions to support the communications activities. To handle the complexity of these functions many systems are designed and structured with layering of the functions. A layered protocol can provide: [Ref. 32]

- A logical decomposition of a complex system into smaller and more comprehensible parts (layers).
- Standard interfaces between the layered functions.
- Symmetry in functions performed at each layer in a system. Each layer in a station performs the same function(s) as its counterpart in other stations.
- A means to predict and control any changes made to logic.

1. Seven Layer ISO Model

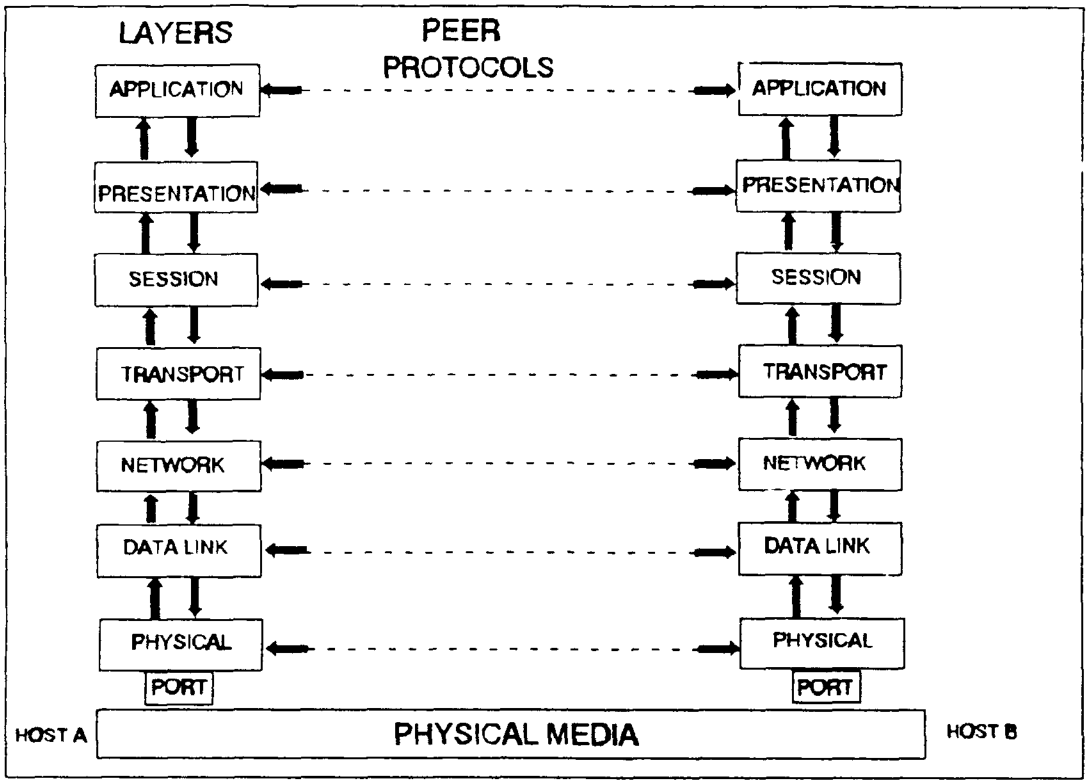

Figure 12. The OSI model

A detailed description of the ISO model can be obtained from a variety of sources, so in this section only the main features of each layer will be presented: [Ref. 32: p. 283 - 284]

- Layer 1. Physical layer: Provides physical connection between equipments. The functions within this layer are responsible for activating, maintaining, and deactivating a physical circuit between communicating devices.

- Layer 2. Data link layer: It is responsible for the transfer of data over the channel. Its functions include providing for the detection of transmission errors, and providing mechanisms to recover from lost, duplicated, or erroneous data.

- Layer 3. Network Layer: It is responsible for the transfer of data through a communication subnet. It provides the services of network routing and congestion control. This layer specifies the type and format of packet to send through the subnet.

- Layer 4. Transport Layer: It is responsible for the reliable, sequenced delivered, error control, and flow control of data from end to end, over a network. It establishes, maintains, and terminates a logical connection between users.

- Layer 5. Session Layer: It serves as the user interface for the transport layer. The layer provides for an organized means to exchange data between users.

- Layer 6. Presentation Layer: It performs the services of encoding, data compression, and data encryption. This layer provides for the syntax of data, that is data representation.

- Layer 7. Application Layer: This layer supports user application processes. Particularly, this layer deals with the semantics of data.

Some criticisms of the OSI model are: [Ref. 32: 286 - 287]

- The scope of the functions performed in any given layer is somewhat arbitrary.

- The layers require substantial computational resources to perform their functions.

- Design trade-offs between layers still need to be undertaken in the formulation of standards meeting military requirements.

- Duplication of functions exists across several layers.

2. Other Network Architectures

The efforts toward standardization were, and are, made by governments, international organizations, and leading computer and communication companies. In this section, the reader will learn about architectures developed by the U.S.

Government, DOD, IBM, and Digital Equipment Corporation. This is not an exclusive list, but it should illustrate the diversity in the established standards. It also shows the complexity of making the current networks interoperable with each other.

1. GOSIP: The U.S. Government Open System Interconnection Profile (GOSIP) represents the final agreement on a set of OSI protocols for computer networking that is used by U.S. government agencies for product and services acquisition. It provides implementation specifications from standards issued by the most well known leaders organizations, such as ISO, CCITT, and others. [Ref. 32: p. 288]

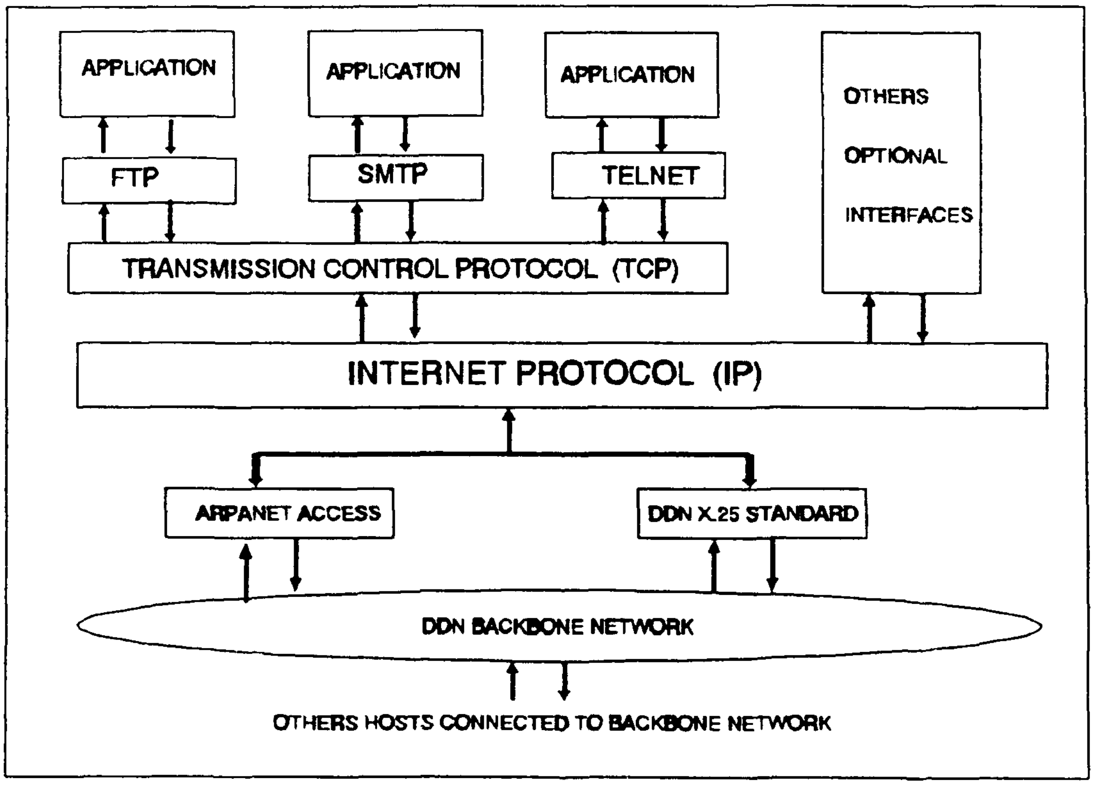

Figure 13. DDN Model

2. SNA: Systems Network Architecture (SNA) was developed by IBM as its major commitment to communications systems and networks. It is a specification describing the architecture for a distributed data processing network. It defines the protocols and rules for the interaction of the components in

the network. SNA also uses the layering concept, with the disadvantage that the layer's boundaries are not well defined throughout all the SNA's documentation. [Ref. 32: p. 290 - 291]

3. DNA: Digital Network Architecture (DNA) is the major data communications network developed by Digital Equipment Corporation. It was developed as a distributed network, and uses a layering concept in its design. The goals of DNA include providing resource-sharing capabilities, supporting distributed computation, supporting a wide range of communications facilities, and creating a common user interface across varied applications. [Ref. 32: p. 295]

4. DDN: Defense Data Network (DDN), as shown in Figure 13, is a packet switching network based on the ARPANET technology. DDN has been designed to provide survivability, security, and privacy. DDN is also a dynamic routing network, and adjusts itself to any link or node failure without interrupting the service for the subscribers. It has two major functional areas: the backbone network, which consists of the packet switches and the trunks between them; and the access network that consists of the user access lines connected to the backbone. DDN also provides extensive monitoring of the system, and a secure traffic transmission, with end-to-end encryption, if needed. [Ref. 32: p. 297 - 298]

Figure 14 depicts a comparison by layer of SNA, OSI, and DNA models. Figure 15 shows the OSI layers, and a comparison between ISO, CCITT, and DOD protocols.

C. **NETWORK LEVELS**

The distribution of data is required for all levels of command. The exchange of data between levels can be done utilizing a single homogeneous network or a non-homogeneous network of networks. The use of a single homogenous network is virtually impossible due to the diversity of requirements that the design may have to satisfy.

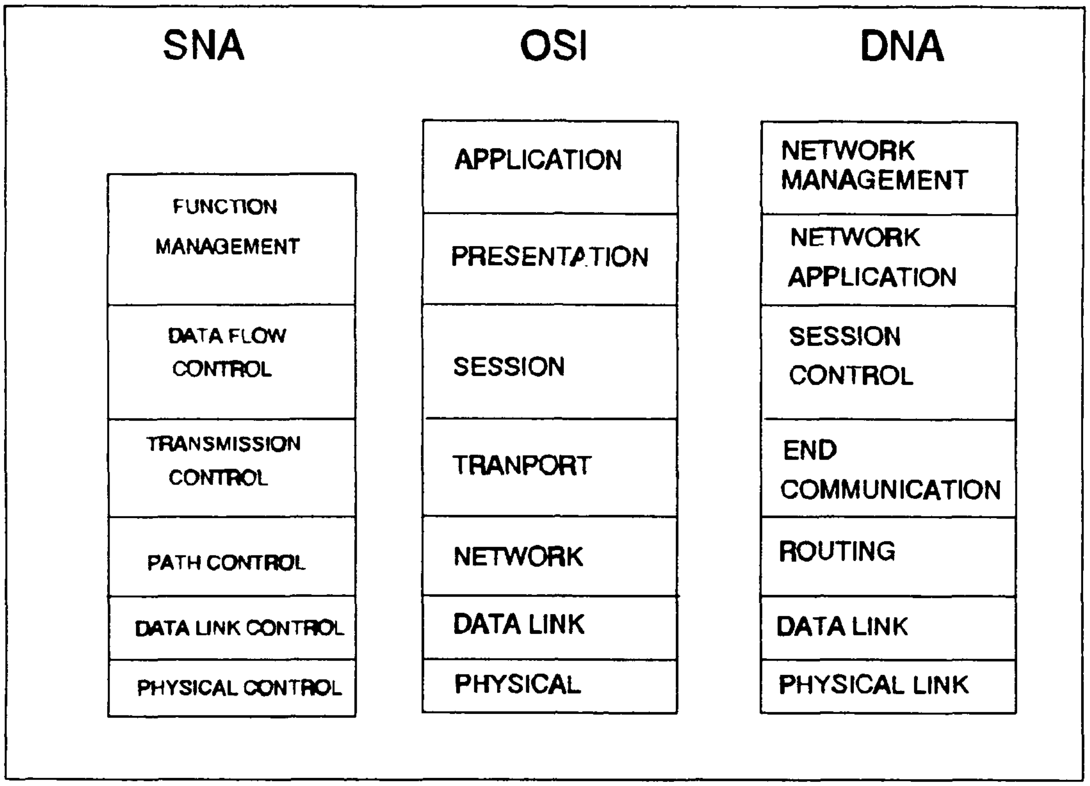

Figure 14. OSI, SNA, and DNA layers equivalences

The analysis of the data requirements, and how these data are distributed between the command levels, is required to design networks and their interfaces. These must be suitable to satisfy requirements from the local user to the internetwork information exchanges. In this analysis, it is possible to identify three levels where the data distribution takes place: [Ref. 33]

1. Cell: The data is generated and distributed locally

2. Area: The data distribution is done between cells.

3. Long-haul: It is the distribution of data between widely dispersed units, and between tactical and strategic environment.

<table>
<tr><th>OSI</th><th>ISO</th><th>DOD</th><th>CCITT</th></tr>
<tr><td>APPLICATION</td><td>FTAM</td><td>FTP
SMTP</td><td rowspan="2">X.400</td></tr>
<tr><td>PRESENTATION</td><td>VTP</td><td>TELNET</td></tr>
<tr><td>SESSION</td><td>ISO SESSION</td><td rowspan="2">TCP</td><td rowspan="2">*</td></tr>
<tr><td>TRANSPORT</td><td>ISO TRANSPORT</td></tr>
<tr><td>NETWORK</td><td>ISO IP</td><td>IP</td><td rowspan="3">ISDN
X.25
X.21</td></tr>
<tr><td>DATA LINK</td><td rowspan="2">*</td><td rowspan="2">*</td></tr>
<tr><td>PHYSICAL</td></tr>
</table>

* NO PROTOCOLS DEVELOPED FOR THESE LAYERS

Figure 15. Protocols Comparison

The design of these data distribution networks must be oriented by the critical concept of information-knowledge transformation. Only meaningful and useable information has to be distributed over the networks, in opposition to today's practice of transport and distribution of raw data.

1. **LAN**

The user may have local computer facilities in this cell. When using these facilities, the users require transfer of data capabilities among all the local users. A suitable solution for these local data distribution requirements is given by the use of a Local Area Network (LAN). [Ref. 33: p. 28]

The characteristics that define a LAN include: [Ref. 34]

- It is operated in a limited geographic area.
- It uses a unique transmission technology.
- Its typical transmission capacity ranges from 1 Mbit/s to 20 Mbit/s.
- It is usually owned by the organization that uses the facility.

Particularly of interest in LANs is the data link layer of OSI model, which is divided into two sublayers:

- Logical Link Control (LLC) that is responsible for the error and flow control, and
- Medium Access Control (MAC) that is responsible for the access control to the transmission medium, and assures that only one station transmits at a time.

2. WAN

The LANs that satisfy needs of local data transfer are not suitable for distribution of data over long distances. The units, locally served by LANs, are mobile and are usually dispersed over long distances. A suitable solution for long distance data distribution is given by the Wide Area Network (WAN) [Ref. 33: p. 28 - 29]. The communication means used at this level to carried out the data transfer will usually be radio distribution networks. Some of these radio networks include those discussed in Chapter V, such as MSE, EPLRS, SINCGARS, and JTIDS. WANs might be used to provide connections between LANs and to interface with long-haul networks. [Ref. 33: p. 28]

3. Long-Haul Networks

This type of network is designed to satisfy the needs of passing information between widely dispersed units, or between tactical and strategic environments. The communication means for long-haul networks usually involves the use of satellites or land line networks. [Ref. 33: p. 28 - 29]

D. INTERNETWORKING

The information generated locally could be needed at a higher level. Since this information is reachable only by long-haul networks, the networks must be connected. The need for mobile networks, with high reliability and survivability, can be achieved by the integration, directly and automatically, of all the communication resources available. However, the internetwork concepts contain some very difficult technical problems such as the utilization of different security devices by the different networks, and the internetwork naming and addressing in a dynamic environment.

It is possible to identify three key elements in the integration of networks into a cohesive, multiple-security-level internet: interfaces, packet switching technology applications, and communication security system. [Ref. 33: p. 28 - 29]

1. Interfaces

The interconnection of different networks can be achieved by interfaces such as bridges or gateways through the use of standard protocols, such as the Internet Protocol (IP) of the DOD.

a. *Bridge*

The bridge is the simplest of the internetworking devices. It is used to interconnect LANs that use identical protocols for layers 1 and 2 of the OSI model (Identical Medium Access control (MAC)). The use of bridges to connect different LANs instead of building a unique and long LAN depend on several reasons: [Ref. 34]

- Improving reliability by partitioning a network into self-contained units.
- Improving performance if devices can be grouped so that intranetwork traffic significally exceeds internetwork traffic.
- Enhancing security by adding control mechanisms, and by grouping traffic, tasks, or devices that have different security needs.
- Geographical conditions, if the grouped devices are separated in different locations.

b. *Gateway-Router*

A router is a general purpose device that can be used to connect several types of networks. It relays packets between heterogeneous networks at layer 3 of the OSI model level. It has to solve the differences among networks in a number of aspects, such as: [Ref. 34]

- Network access protocol/interface
- Addressing scheme
- Unit of delivery
- User access control

These problems are solved by using Internet Protocol (IP) implemented on top of the network layer, or logical link control (LLC).

c. *Gateway-Protocol Converter*

This device is the most complex in an internet working scheme. It translates protocols at OSI layer 4 and higher. The gateway-protocol converters solve the problem of interconnecting network architectures that are not compatible with the OSI model protocols. These gateways provide a way to permit the coexistence of OSI-based and non-OSI-base products. They also allow the planning and implementation of a smooth migration to an exclusive OSI strategy.

The use of this type of facility implies potentially strong limitations in performance due to its bottleneck potential. Overcoming this limitation involves a trade-off between traffic efficiency and host software complexity by incrementing the number of gateways used to interconnect the networks. [Ref. 34]

2. **Packet Switching Technology**

Computer networks are usually packet switched, occasionally circuit switched, and rarely message switched.

Internetworking of diverse users by using packet switching technology should provide an acceptable alternative to the current and costly point-to-point links.

Figure 16 shows the interconnection of different networks with the layers, protocols, and gateways involved. [Ref. 32: 496 - 597] [Ref. 34]

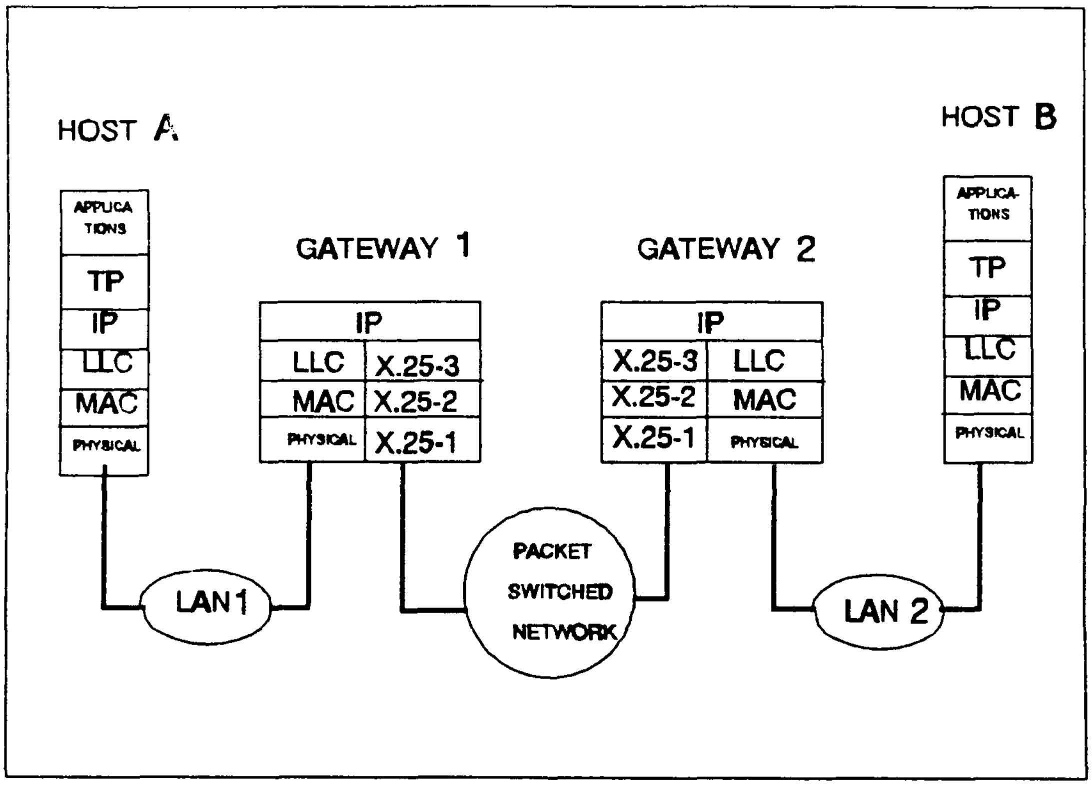

Figure 16. Internetworking scheme

In a packet-switched network, a message is broken down into data units, called packets, that are delivered from node to node in a store-and-forward manner. That means, at each node, each packet is received, stored briefly in main memory, and then forwarded to the next node, until it reaches the destination node, where the packets are rearranged, if they arrived out of sequence.

Packet switching technology has several advantages over circuit or message switched, such as: [Ref. 34]

- The limit in the amount of data in each packet speeds the transmission, by reducing dramatically retransmission delays at the intermediate nodes.
- It is more suited for interactive traffic.
- It allows the interconnection of dissimilar networks.
- It improves the line efficiency since each line can be shared on a dynamic basis without dedicating resources to any end user.
- It is possible to assign different priorities to packets of messages, send the same packets of messages to many destination, or reroute them in case of nodes failure.

Packet switching technology also provides an excellent basis to integrate digitalized voice with other digital data services into a common packet switched network, by the proper design of the network interface and flow control protocols. [Ref. 34] [Ref. 35]

3. Multilevel Security Systems

A multilevel security system should have the capability of integrating users operating at different security levels into a common network for transmission. At the same time, the system should allow users to isolate selected groups of users operating at the same security levels from those not authorized to operate at such levels. It must also assure the security in an end-to-end basis by the encryption of the information prior to its insertion into the first network, and then decryption only when the information arrives at its final destination.

E. INTERNETWORKING IN THE U.S. ARMY

The three major Army systems, ACUS, ADDS, and CNRs, were not engineered to be interoperable on an automatic basis. The integration of these systems into a homogeneous network will be the result of the efforts that are strongly supported by the Army in order to achieve an efficient data distribution.

Achieving an integrated information network will require the study, solution, and implementation of applications in such issues as: [Ref. 26: p. 27]

- Providing high speed data distribution in the CNRs system.
- Automating gateways between tactical area systems and strategic systems.

In September of 1989, an internet test bed demonstration linking multiple existing and emerging tactical and strategic packet-switched networks was performed. In the demonstration, gateways and packet switches embedded in the current voice circuit switches integrated the equipment of strategic networks with the echelon-corps-and-below networks to provide direct virtual circuits between computers. Selected MSE users were also connected to the test network by using front end communications security devices which could isolate them from another unauthorized MSE users. The connection between

SINCGARS network users and a MSE node in the division area was achieved, allowing the SINCGARS user access to the test network.[Ref. 36]

The Army envisions the achievement of an integrated data network by upgrading existing architectures while providing investments for advanced technology, that could include: [Ref. 26: p. 27]

- Full application of packet switching technology.
- Implementation of wireless digital distributed LANs.

F. SUMMARY

The network and network integration concepts were presented in this chapter, and these concepts were differentiated with respect to the communications concept. The international standards and some non-standard, but already implemented, network architectures were also described. Later in the chapter, the different requirements and levels of data distribution, and the types of networks that better fit each of these levels were enumerated. The internetworking issue was described through a general discussion and through the description of its key elements.

As a final consideration, the integration of the three major tactical networks of the U.S. Army was discussed as a practical matter, and future trends in the evolution of tactical networks were listed.

VII. INTEROPERABILITY IN ARGENTINE ARMY SYSTEMS

A. BACKGROUND

1. Introduction

The previous chapter presented and described information systems, communication systems, and networks in a tactical environment. The reader was provided with a discussion of how these concepts are related to each other, and how they might provide greater C^3I systems integration. In this chapter, these concepts will be linked with the C^3I system of the Argentine Army (AA).

Early computer applications were developed in the AA without regard to system integration or interoperability. They satisfied user needs only on a functional basis. In the 1970s, the first attempt of integration was made by development and partial implementation of an integrated information system, known as SIIFE (Sistema Informático Integrado de la Fuerza Ejército). At the same time, a secure and independent system for the intelligence area was also developed.

In the 1980s, the development of systems to complement the partially implemented SIIFE were initiated in the logistical function from brigade to unit level. The AA also designed and developed the first fire support system to support field artillery units. Lately, the AA recognizes that the separation between information processing and information transferring is becoming less distinct. The AA is integrating these two areas under a unique command, and it is aware of the inherent high risk that such reorganization implies. A failure in this integration will almost guarantee that there will develop isolated areas with scarce or no capabilities for efficient exchange of information between them. In the last few years, as C^3 concepts have been introduced to the current AA doctrine, the AA has carried out several analyses, planning efforts, and actions with the objective of integrating the existing and developing system into a modern C^3I system. These analyses include issues such as: [Ref. 4: p. 46]

- Satisfaction of operational requirements
- Joint development efforts
- Standardization and commonality
- Integrated logistic support planning
- Transition to extensive, common, secure, digital communications
- Mobility of equipment
- Intra/interoperability

The initial step is being taken presently, by defining an initial architecture for the C^3I system, as well as the definitions of the initial programs and projects within that architecture.

2. Initial Architecture

Figure 17 depicts a probable initial architecture for the tactical C^3I system of the AA, which resembles the nodal architecture of the ATCCS of the U.S. Army.

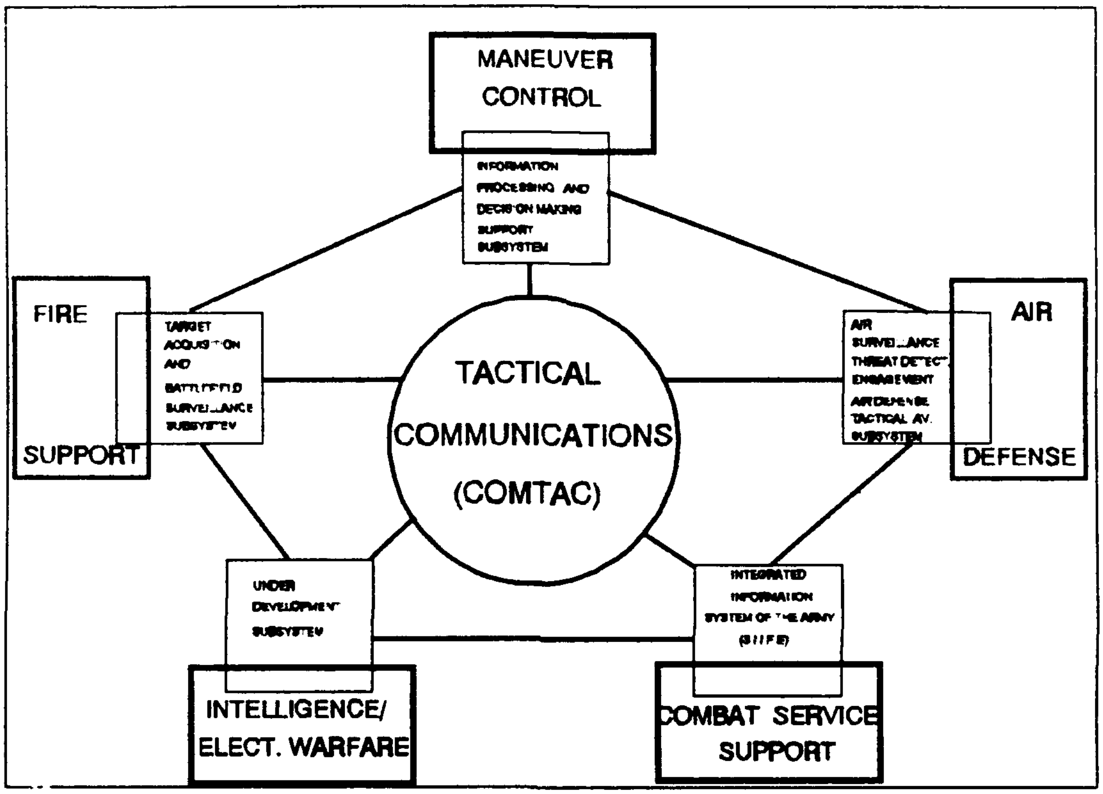

Figure 17. Initial Architecture of AA C^3I System

The definition of an initial architecture were proposed by the C^3 Department of the Argentine Army Staff after completion of two studies, the C^3 System Study and the C^3 Command Center Study. Both studies established the basic operational requirements and main capabilities to be performed by the future C^3I system of the AA.

The operational requirements were the following: [Ref. 37]

- Provide warning about enemy attacks and describe magnitude and type.
- Provide permanent evaluation of the current situation of own forces.
- Collect information about the potential enemy threat in order to formulate analysis and evaluation of the current situation.
- Assist planning support and decision making process.
- Transmit orders and control the mission execution.
- Coordinate actions in time and space.
- Protect and secure the stored and transmitted information.

The nodal control systems were proposed to establish within each of the functional areas the managing, coordinating, and processing of internal information while coordinating information flow with the other control elements.

To accomplish the data processing, the architecture proposed that each node of the system should contain a data processing center, which will be responsible for the administration and distribution of data generated in its area of interest. Gathering, correlating, selecting, and validating data from different sources could be implemented through a hierarchy of tactical fusion centers, which will provide an optimum mix of the battlefield information to the whole system.

To integrate the nodes and to carry the information flow between nodes and to higher levels of command, the architecture proposes an integrated communication system. This system should provide voice-data communication and interface with the public communication systems. It should also provide high mobility, interoperability, jam resistance, and distribution of data over the whc .e system.

The initial architecture provides the framework to develop a C^3I system, which will provide management, coordination, and mutual support. It will also reduce or eliminate the typical node problem presented by the current single centralized system.

a. ***Information Systems***

The architecture for the C^3I system proposes to associate an information system with each of the nodes, as depicted in Figure 17. Some of the C^3I subsystems exist and are evolving, others are in the design or definition phase. The main characteristics of existing or under-definition systems are: [Ref. 37]

- The Target Acquisition and Battlefield Surveillance Subsystem (VICATAB), which has the objective of acquiring land targets, processing the data obtained by the sensors in the data correlation centers and supporting the field artillery units.

- The Air Surveillance, Air Threat Detection, Engagement of Air Defense Artillery and Tactical Army Aviation Subsystem (VIAER), which has the objective of gathering, evaluating, and presenting the information about enemy air activities, evaluating threats, and assigning targets to fire units.

- The Information Processing and Decision Making Support Subsystem (PROIN), which has the objective of gathering, evaluating, and presenting information about the status of both own and enemy forces.

- The logistic functions could be supported by SIIFE, that can be easily expanded to satisfy logistics needs at any level of command. Therefore, this system will require suitable interfaces to obtain interoperability with the new systems under development.

b. Communication System and Networking

The reorganization that is facing the AA is affecting, particularly, its communication systems. In relation to the communications requirements of the C^3I systems, there is continuing analysis of the final communications architecture that will serve as backbone and support for voice/data communications from the front line to the strategic level. Therefore, the initial definition of the communication system presented as basic requirement by the C^3 Department is presented:

- The High Reliability and Survivability Communication Subsystem (COMTAC), which has the objective of offering fast, secure, and continuous communication support to all the operative units, as far as battalion and company levels, and linking the tactical system with the national and strategic communication system.

3. Interoperability Challenge

Optimal C^3I integration will require certain tradeoffs between C^2 system design drivers and supporting systems features and utilities. In developing of C^3I system many factors can be identified as requirements to achieve integration and interoperability. Some of these factors are doctrine, operational techniques, hardware, planning, logistics support, encryption algorithms, procedures, and training. In addition, some technical parameters are also required, such as frequencies, terminal capabilities, application software, coding, and protocols.

A list of constraints in achieving interoperability in the AA include:[Ref. 37]

- Poorly defined concepts, doctrine, and procedures for joint operations
- Different phasing of system developments
- Independent service budget for development and procurement of new systems
- Undefined standards for interfacing information systems
- Lack of methodology for system effectiveness evaluation
- Resistance to change by program managers
- Lack of trained personnel to manage the development and integration of the new system
- Sunk cost investments in hardware and software

B. IMPROVING INTEROPERABILITY IN AA C^3I SYSTEM

The search for interoperability improvements in the AA C^3I system can not avoid addressing the issues analyzed in this thesis, and some general, but no less important, issues that are results of the new system requirements and the current reorganization.

Particular interoperability issues include the concept addressed specifically in this thesis:

- Data processing and information systems
- Communications and networking

General interoperability issues to be considered in the design and implementation of the C^3I system include:

- Analysis of commercial components applicability
- Planning of personnel training and reeducation programs

1. Data processing and Information Systems

In any of the existing or under development subsystems of the AA C^3 system, the data processing requirements will be increased enormously as they are fielded. In order to cope with the new data flow that the new system will generate and to accomplish the information system functions desired, the development of integrated information systems, which will rely on integrated communication systems, is a must.

The information systems associated with the defined subsystem in the AA C^3I system should be designed to provide the following:

- Exchange capabilities: word processing, electronic mail, graphics processing, partitioned and replicated data base.
- Decision support capabilities: relational data base manager system (DBMS), graphic integration, map/photo correlation, and spreadsheet models.

The DBMS will be the core of those systems, and it should contain all the information that is available about the forces in the area of interest, which include:

- Positional information indicating past and present locations of forces.
- Historical data indicating the past intentions of forces in the area of interest to provide decision support input to staff personnel.

- The rules of engagement as an analyst's decision support aid.
- Terrain and weather data.
- Message traffic to update the other portions of the data base as automatically as possible.

As important as the DMBS will be, the development of a friendly application interface, which allows analysts to track own and enemy forces in a near-real-time manner, must support the decision making process.

The potential application of operations research and artificial intelligence techniques (ES and DSS), that were addressed in Chapter IV, should be applied along all C^2 functions. These applications will facilitate the analysis of data, their correlation, and concentration into information and knowledge, providing expertise to the personnel in a short period of time.

2. Communications and Networking

Accomplishing C^3I system interoperability will require the development of a strategic/tactical voice/data distribution program. It should provide a universal voice/data distribution system, which will facilitate data integration of subsystems (VICATAB, VIAER, SIIFE, and PROIN) and their transport from the battlefield to national level. The communication and networking needs should be satisfied by using systems ranging from civilian to military application. The definition and design of the current COMTAC subsystem could be expanded to reach this comprehensive structure.

The adoption of open systems or internetwork architectures, such as those represented by the ISO OSI model, provides a guide for specification of technical standards, interfaces, and internet gateways to be used in designing and planning subsystems requiring interconnection to the C^3I system in a manner that can be implemented gradually using evolutionary strategies.

In order to improve the AA C^3I system interoperability, the following characteristics should be included in its design:

- Development of distributed systems based in the modularity concept. The degree of distribution will dependent on the operational situation.
- System capability of rapidly adapting to changes in the environment. This characteristic will allow the system to sense the environment and alter its configuration to ensure continuity in the operations.
- Because security issues are an important impediment for interoperability, security problems must be solved before interoperability goals can be met.

Artificial intelligence techniques are envisioned effectively to plan and manage multiple, interconnected, and tactical communication media. The applications of artificial intelligence could include control routing, allocation of channel capacity, dynamic rerouting, and network reconfiguration.

The design of the such data distribution system could include:

a. *Brigade and below Levels*

At brigade headquarters and unit levels, the adoption of a single standardized LAN technology appears as a suitable solution to satisfy the user needs. LANs will facilitate the transition and transportability of the new system. According to the experience of the United States Marines Corp (USMC), in Operation Desert Shield/Storm, Ethernet LANs using coaxial cable have proved to be more reliable and robust in the field than twisted-pair wiring [Ref. 38].

b. *Operational Theater Level*

A solution for operational theater level could be the implementation of WANs by interconnecting LANs using multiple transmission media. These media could be dial-up telephone lines and high-frequency tactical radio. At this level, the communication links should include the national data/voice communication networks, where available, that will increase the capacity and speed of the tactical communication links.

c. *Strategic Level*

The interconnection of the WANs by national long-haul networks will provide to the strategic level on-time and accurate information from the battlefield. They will be the packet switching backbone network, which will provide a high level of modular nodes with increase in traffic volume, secure routing, and high priority data transmission. It will also provide a CCITT X.25 standard to support different protocols on an optional basis.

d. *Mobile Communication System*

The COMTAC subsystem should consider the advantages of developing an integrated mobile, secure voice, data and record communication system. The development of such a subsystem into COMTAC should be based in wireless communications using digital cellular technology, spread-spectrum techniques, and TDMA/CDMA multiplexing and access techniques.

e. *Position Location System*

PROIN subsystem will require tracking the position of friendly and enemy forces. A complex system like EPLRS would require huge investments for its acquisition and maintainability, in case the system were available for foreign non-NATO armed forces. The implementation of a cheaper solution could be the use of Global Position System (GPS) terminals, when they are available by bilateral agreement or public release, in combination with radio systems and tactical data distribution systems. These systems could be used to pass the position information from the front line through all levels of command.

3. Personnel training

The reorganization of the communication and information processing areas will imply a tremendous challenge for the AA. It should include a whole training program and a reeducation of the personnel from middle management through senior management positions. These training programs will not affect the personnel work environment, but they could affect the balance between the military and the civilian work force market. The military personnel will become, after the training, communication-information specialists, that have few counterparts in the private sector. The ways the specialists could be retained in the military should be assessed before any implementation take place. In the area of tactical systems, it is important that the developing and future systems will include the requirement of no dedicated operators by using well-designed user interfaces. These characteristics will allow the users of the systems to be fully trained to use the system in a relative short time period.

4. Commercial Components Applicability

Since the AA budget is restricted and because of the nearly parallel evolution of military and commercial requirements for computer and communications components, the implementation of the C^3I system in the AA could be done by using commercial-off-the-shelf (COTS) hardware and software products as components of its subsystems. Most of the COTS are sufficiently ruggedized to meet military requirements, and only a few products should have to modify their commercial standards.

C. SUMMARY

This chapter has briefly introduced the origin and current status of the C^3I system of the AA. The description of its subsystems was also presented. Later, the issues that could affect the achievement of interoperability in the AA C^3I system were addressed. Finally, alternative bases for the improvement of the subsystems were discussed.

VIII. CONCLUSIONS

In spite of changing technology, the functions of C^3I systems will remain the same. For many years, the AA has been capable of maintaining extensive unprocessed data links with their units and has not used the current technology to modify C^2 functions. The improvement in communications, networking, and data processing will bring in the future a larger amount of data from old and new sources, but this data must be edited and transformed into information and/or knowledge before reaching the staff work table.

Accomplishing these tasks will require the design, development, and implementation of a C^3I system, which is an ambitious enterprise. This thesis has been written with the objective of helping the Argentine Army in its efforts to furnish its C^3I system with as much interoperability as possible. The particular constraints and restrictions lead to the recognition that it will be necessary to adapt the ideas, concepts, tools, and techniques presented by this thesis to the reality faced by the AA today.

The ideas, models, tools, and techniques introduced in this thesis, along with the integration of the C^3 concepts into the doctrine of the AA, could provide a source of technological update, helping the AA to maintain its operational capabilities in the near future.

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