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by

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The result is a test of the MCES. The MCES approach is expanded with C2 theory and ftware design techniques. This expanded approach provides the means to build an air fense C2 systems model which can be synthesized to reflect operational employment of the system. This model becomes a "descriptive tool" for analysts and C2 system users to fine and evaluate measures to determine the C2 systems effectiveness. Representative asures are developed for the model at the subprocess (functional), C2 process and teractive process (C2 system) level.

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Evaluation Methodology for Air Defense Command and Control System

by

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Submitted in partial fulfillment of the
requirements for the degree of

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

ABSTRACT

This thesis uses the Modular Command and Control(C2) Evaluation Structure (MCES) to formulate and address operational air defense command and control issues for the central European theater. (This evaluation structure provides a framework and tools to address C2 issues). The intent is to use the MCES along with the Identification Friend, Foe, Neutral (IFFN) testbed to address operational issues for this C2 system.

The result is a test of the MCES. The MCES approach is expanded with C2 theory and software design techniques. This expanded approach provides the means to build an air defense C2 systems model which can be synthesized to reflect operational employment of the C2 system. This model becomes a "descriptive tool" for analysts and C2 system users to define and evaluate measures to determine the C2 systems effectiveness. Representative measures are developed for the model at the subprocess (functional), C2 process and interactive process (C2 system) level.

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I would like to offer my gratitude to the personnel at Identification Friend, Foe, Neutral (IFFN) Joint Task Force (JTF), the professional members of the Military Operations Research Society (MORS), and my thesis advisors. Each group has helped with this thesis in a different way.

IFFN JTF offered an existing C2 architecture for study and the operational issues related to that architecture, which drove this analysis. I would like offer my personal thanks to Colonel David Archino and Major Mike Gray for helping me define and clarify the issues presented in this thesis.

The members of MORS offered many ideas which have been incorporated within this thesis. Their theories, analysis techniques and C2 evaluation structure provided the tools to address the issues.

Finally, I would like to thank my advisors, Lt Col John Malokas and Dr. Ricki Sweet. Lt Col Malokas helped me maintain an operational perspective while writing this thesis. Dr Sweet provided me with the professional involvement through MORS research efforts in C2 evaluation structures.

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I. INTRODUCTION

This thesis will focus on developing a method to model air defense command and control (C2) systems. The purpose of this model is to provide a descriptive tool which allows analysts to determine measures for C2 systems effectiveness.

The model will address challenges issued by Michael Athans in his article "The Expert Team of Experts Approach to Command and Control (C2) Organizations." [Ref. 1] Athans asserts that,

> At the present time we do not have . . . a systematic, analytical, quantitative methodology that can be used to (1) Analyze the interations between a fixed C2 organization and a fixed C3 system architecture, and develop really meaningful and relevant MOE's.

During the 1986 Military Operations Research Society (MORS) C2 Evaluation Workshop, the Test Director for Identification Friend, Foe, Neutral (IFFN) Joint Test Force (JTF) issued a similar challenge to the working group participants [Ref. 2]. He asked the group to do the following:

> Develop a tool . . . specific to air defense that allows IFFN to evaluate the flow of C2 information throughout the C2 structure and determine if it is useful or not in winning the war . . . meeting the mission objectives . . . and operational issues IFFN plans to address.

The test director's statement suggests the model's usefulness will depend on how well it let's you answer operational issues. Therefore, the model will be developed within the Modular Command and Control Evaluation Structure (MCES). This evaluation structure provides a framework and tools to first state the command and control problem in relation to a specific bounded C2 system. Additional tools within the structure provide a means to,(1)define and model the C2 process, (2) develop measures to evaluate the C2 systems ability to perform the C2 process, and (3) define a suitable "data generator" to support the measures.

This thesis will enhance the MCES approach with the C2 theory of other writers to produce a C2 systems model specific to air defense. This model should be able to completely describe the C2/C3 system (Athans Terminology) and allow analysts to formulate measures that address the issues and problem statement. Moreover, the model will provide a visual means to communicate the analysts' results to the C2 systems users.

II. DEFINITIONS

A. OVERVIEW

Before jumping into the problem definition and the analysis we must come to grips with the terms that will be used to describe the C2 systems and variables of interest within those systems. The sources for these definitions come from the MCES document produced in the 1985 C2 Measures workshop sponsored by MORS. Some additional definitions are provided by Joint Chief of Staff (JCS) publications and George Orr's book, Combat Operations C3I: Fundamentals and Interaction. Other definitions have been created to advance a command and control theory that will allow analytical study of command and control systems.

B. COMMAND AND CONTROL

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of his 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 his mission. [Ref. 3]

C. COMMAND AND CONTROL SYSTEM

> An integrated system comprised of doctrine, procedures, organizational structure, personnel, equipment, facilities, and communications which provides authorities at all levels with timely and adequate data to plan, direct and control their operations. [Ref. 4]

A useful way to look at command and control systems is to break the system down to its component parts. The MCES document lists three components: "physical entities," "structure," and "C2 processes." While these terms are accurate they are not a complete list of the component parts. The additional concept of a separate intelligence process, advanced by Lawson [Ref. 5: p. 25], may be needed to fully define the support to the C2 system. Perhaps other supporting processes such as a communications process will also be useful. Intelligence and communications processes will be considered support processes in relation to the systems major process of command and control.

Definitions for "structure", "physical entities," "C2 process," "intelligence process," and "communications process" follow:

1. Physical Entities

> Refers to equipment (Computers and peripherals, modems, jammers, antennas, computer local-area networks), software, facilities, and people. [Ref. 6: p. 2-3]

2. Structure

> Identifies the arrangement and interrelationships of physical entities, procedures, protocols, concepts of operation, and information patterns. (This frequently reflects doctrine and may be scenario dependent). Such arrangements are often spatial and temporal. [Ref. 6: p. 2-3]

3. C2 Process

> Reflects "what the system is doing" and the functions carried out by the C2 system--sensing, assessing, generating, selecting alternatives, planning and directing. [Ref. 6: p. 2-3] [Lawson would also include a processing function which converts sensed data into information for assessment [Ref. 2]. This thesis will adopt the concept of an additional process function].

4. Intelligence Process(aka INTELLIGENCE/ANALYSIS Function)

The intelligence process is performed by a separate staff agency which cuts across C2 nodes. Where an intelligence function is provided there is a interactive relationship between the commander's assessment and the intelligence assessment. The intelligence function can be seen to amplify the commanders assessment. According to Orr the intelligence process does the following:

> It provides the framework for assigning meaning to observed activities and situations. It forecasts changes in the current situation. [Ref. 7: p. 28]

5. Crosstell(XTEL) Process (A Subset of Communications Process)

The XTEL process is a critical function within a geographically distributed C2 system. The XTEL process definition is provided below:

> That process which provides for sharing of information throughout C2 system to support strategic and tactical decisions. The process can also support implementation of those decisions.

This shared information gives commanders at higher levels a more complete picture of the current situation. However, there is a distinct set of rules that governs what information is shared, who receives what information and how information differences are resolved. Therefore, this process will have its own underlying structure. Another aspect of this XTEL process is that it allows comparison or fusion of information which may improve the completeness and accuracy of information held at any particular node.

D. THE FORCE PROCESS

The C2 system's purpose is to direct some force within the environment. If a C2 node is performing all C2 functions to direct the weapon system, the functions performed by the weapon system and its munitions will be considered functions within a separate "force process." These force functions can be lumped into macro functions of MANUEVER, ACQUIRE, ENGAGE and MISSILE FLYOUT.[1] (An indepth study of these functions will be offered in the model synthesis section. The macro functions will be split into functions which parallel the C2 process functions. Conditions will be specified for when these functions become part of the C2 process.

E. BOUNDARY AND MEASURES

The C2 system boundary and measures are mutualy dependent on each other and the application (i.e., acquisition, operational) for which the analysis is being done. For example, in an operational application problem, the process to be performed might be battle management. Therefore, the C2 system physical elements that perform and support that C2 process would form the C2 system boundary. Figure 2.1 illustrates how these measures relate to boundaries. The MCES document provides the guidelines for measures and boundaries.

1. Measure of Performance (MOP)

> Measures of performance are specified inside the boundary of the C2 system. [Ref. 6: p. 2-4]

The performance of a C2 process function would be an example of a measure of performance (MOP).

2. Measure of Effectiveness(MOE)

> Measures of effectiveness are specified outside the boundary of the C2 system. [Ref. 6: p. 2-4]

The effectiveness of the C2 process coupled to some subset of the force process would form a measure of effectiveness (MOE) for the C2 system. This could be measured by looking at some force action or the lack of

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[1] Lawson includes some time for the force to move (manuever) in his time analyisis of force employment. This function will be considered the first function in the "force process." [Ref. 10]

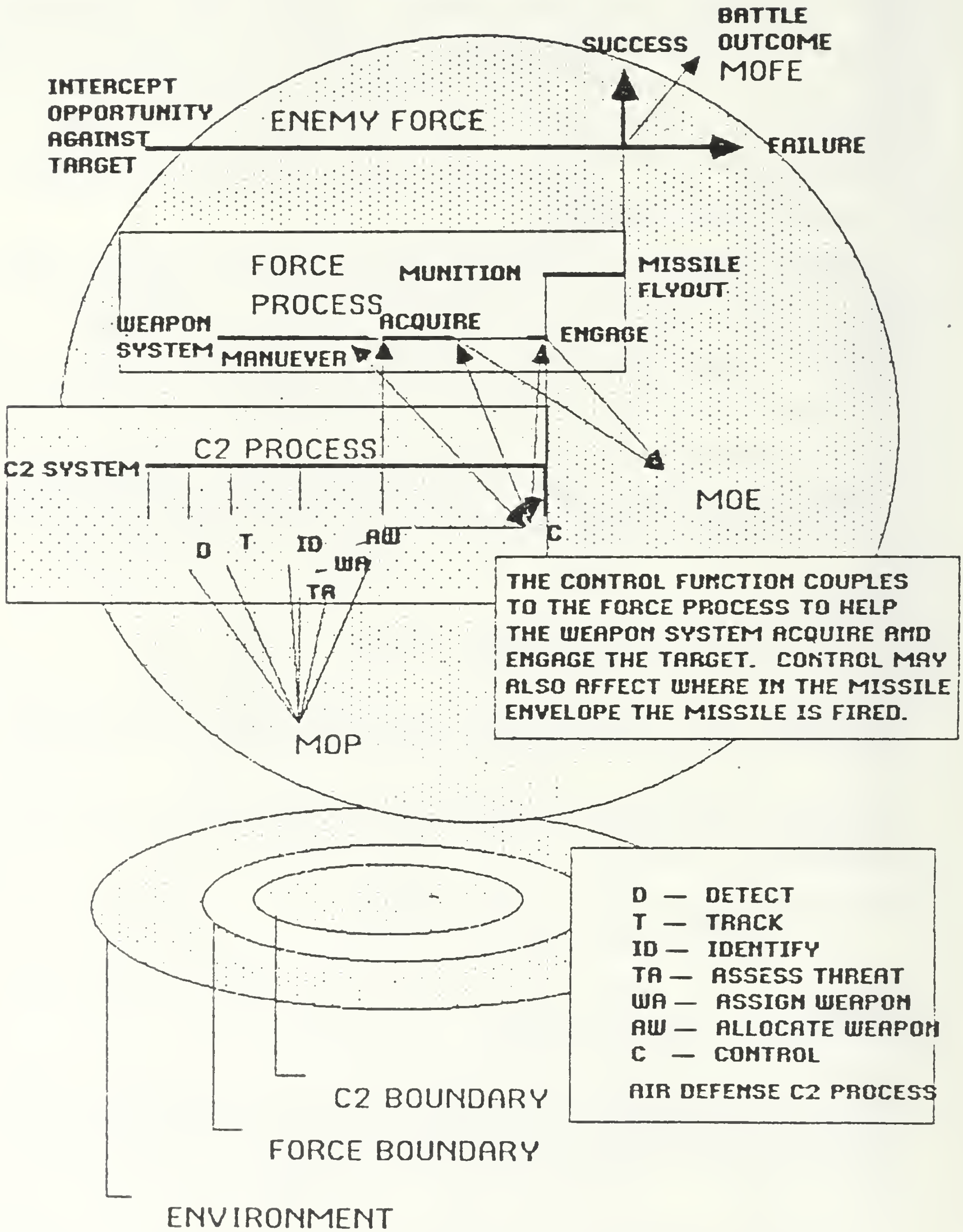

Figure 2.1 Measure Relationships

some force action which the C2 system is directing. For example, the probability of ENGAGE includes ACQUIRE and ENGAGE (missile firing) but not the force function MISSILE FLYOUT.

3. Measure of Force Effectiveness (MOFE)

Measures of force effectiveness are specified outside the boundary of the force. [Ref. 6: p. 2-4]

The effectiveness of the C2 process coupled to the entire force process would form a measure of force effectiveness (MOFE). This could be measured by looking at battle outcome such as target destruction with its the corresponding effect on the enemy force.

F. DECISIONS

No discussion of a command and control system would be complete without considering decision making. Decision making is a complex human activity which is based on perceptions of the environment. It involves perceptions of the present state which are formed through the assessment function. (Remember, Orr's intelligence/analysis function provides the framework for assigning meaning (perception) to observed activities and situations) Decision making also involves perceptions of future states which a commander feels he can influence by selecting various alternative actions. Decision makers may even consider controlling the perceptions of the enemies decision makers in order to create an advantage on the battlefield. However, this discussion will not explore how decisions are made. Instead, it will define the scope of the decisions made within the air defense C2 system.

1. Tactical Decisions

This is a working definition to be used within the context of this thesis. The usage of the word tactical in reference to decisions is a relative term.

> Tactical decisions determine immediate responses to perceived threats in the present state.

In an air defense problem a tactical decision would be assigning a fighter to a target. It is a reflexive response using the resources which are available to take care of a present situation.

2. Strategic Decisions

Again this is a working definition and is a relative term.

> Strategic decisions determine aggregated responses to an integrated perception of threats in both present and future states.

In the air defense problem strategic decisions include positioning for Airborne Warning and Control System (AWACS), committing reserves against a mass raid or even changing firing doctrine to automatic for a PATRIOT SAM Battallion. There is an implied requirement to form perceptions of the capabilities and availability of ones own forces in both present and future states when planning the aggregate responses.

These two definitions help to describe how the C2 system operates. If the C2 system operates primarily with tactical decisions, it is simply reacting to the enemy. It becomes predictable and can be controlled by the enemy. However, if the C2 system provides decision makers the means to make strategic decisions, the enemy's tactics can be countered. His goals can be denied as the decision maker can adjust his forces to meet both present and anticipated future situations.

III. THE AIR DEFENSE PROBLEM

A. THE MISSION

Protection of friendly forces and territories from an air attack is the primary mission for air defense forces. The elements within this mission include an enemy air threat, its mission goals and an air defense force that must deny the enemy its goals. The enemy will attack various elements within our force structure or its supporting elements. Targets include our ground forces, airfields, supply depots, lines of communication or transportation, command centers and surveillance capabilities.

B. C2 CONTRIBUTIONS TO MISSION

The air defense command and control system, therefore, must help decision makers identify air threats and direct sufficient forces to meet them. All this must be done within an environment filled with friendly, enemy and neutral aircraft. The enemy will try to conceal his identity. Friendly aircraft (those which are attacking the enemy's forces) must conceal their identity from the enemy while somehow revealing it to friendly air defenses. Additionally, the enemy may attempt also to disguise their goals with feints or try to saturate the air defense system beyond its capacity. Therefore, the command and control system must be able to determine the size of the enemy force and mobilize sufficient forces to counter it.

C. THE AIR DEFENSE C2 PROBLEM

With this mission background we can formulate a general problem statement that addresses the effectiveness of the air defense C2 system:

> How effective is the air defense C2 system in the central region in Europe in providing decision makers

> the means to assess and employ air defense assets to meet overall mission objectives? [Ref. 2]

To fully attack this problem we must consider potential physical and structural changes to the C2 system, which may be caused by external forces or internal decisions. For example, a physical change could occur when the enemy takes out the Airborne Warning and Control System (AWACS), thereby removing that physical entity. Structural changes could be made by decision makers when they delegate more authority downward or change tactics in response to increased traffic volume. Therefore, we can more fully study the C2 system by focusing our study in the following way.

1. Structure

> Focus on the effectiveness of the C2 process when the C2 structure (and its attendant changes in tactics and procedures) is varied. [Ref. 2]

2. Physical Entities

> Focus on the effectiveness of the C2 process when physical entities are added or lost.

This more detailed problem statement leads us to the following evaluation approach (See Figure 3.1), for which data can be generated by the Identification Friend, Foe, Neutral (IFFN) Joint Test Force (JTF).

3. Testbed Requirements and Test Approach

a. C2 System

> Simulate with men and equipment the existing command and control system which provides battle management to air defense forces in the central region of Europe. (Existing refers to 1989 baseline system)

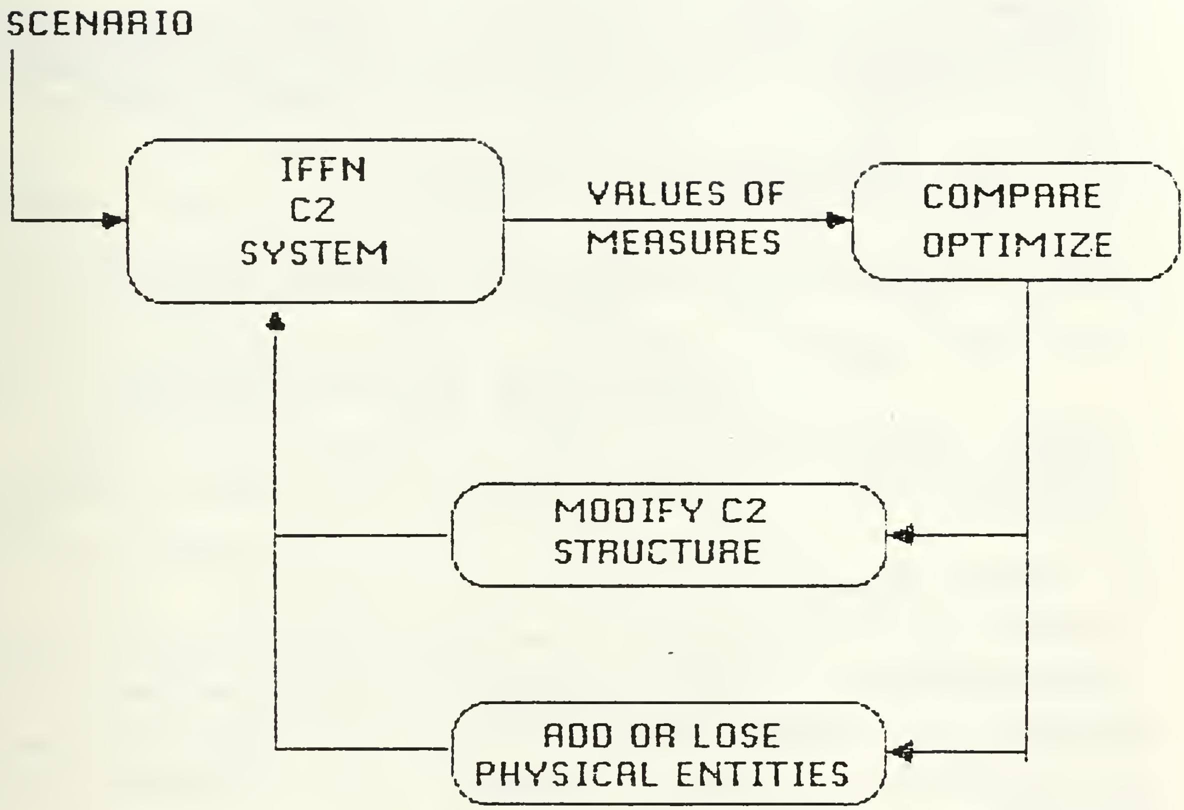

Figure 3.1 Evaluation Approach

b. Weapon Systems

Simulate the weapon systems the C2 system controls with men and equipment. (IFFN is limited to beyond visual range (BVR) weapons, F-15 fighter, HAWK and PATRIOT SAMS)

c. Scenario

Present a realistic (Friend,Foe,Neutral) scenario to test the C2 systems response. (Response is the C2 system's measured capability to control weapon systems in environment to kill the enemy and protect friends).

d. Modifications to Structure

Vary structure by using existing operational concepts.

e. Removal or Addition of Physical Entities

Remove or add physical entities which will be available in 1989.

D. INTERIM SUMMARY

As an interim summary let's quickly recap what we have covered so far. We have presented a mission statement and related that statement to an operational, central European environment. A problem statement, which addresses the effectiveness of the air defense C2 system in terms of controlling forces to perform that mission has been formed. Finally, the problem focused on the effectiveness of the C2 system process when the "structure" was varied or the "physical entities" were added or lost. What remains to be done is to determine the user's operational perspective, which identifies the issues that effectiveness measures must address.

E. THE OPERATIONAL ISSUES

There are two ways to determine the users operational perspective. The C2 systems' capability to support either tactical decisions or strategic decisions may be addressed. From a tactical perspective, the issues would center around performing part or all of the C2 process given a target and given a resource to project against it. The focus of the issue would be on immediate (present state) tactical capability without regard to priorities, resource constraints, or the enemy's overall goals.

Strategic issues would consider the enemy's overall goals, and the resources available in the present and future states to deny him his goals. Tradeoffs would be made such as which points to defend and how many resources to commit. Table 1 presents a list of issues, which address the C2 systems ability to support a commander's strategic decisions involving the structure of the C2 system.

Now we can begin to see interrelationships between tactical issues and strategic issues. Tactical issues address capabilities under a given situation with a static C2 system. Strategic issues address the C2 system's aid in helping decision makers to form a perception of the present or future environment and meet that situation with appropriate resources and the appropriate tactical structure to employ them.

In the next section we will build an air defense C2 system model by introducing processes and putting them together. We will start with a modified MCES C2 process model and work towards a more specific air defense C2 process model. A significant number of C2 process models are reviewed in Appendix 1 of this thesis, which provides the basis for revising the MCES model. The C2 theory behind these models and a thorough study of the current central European air defense system forms the foundation for the Air Defense C2 systems model.

TABLE 1

AIR DEFENSE ISSUES ("STRUCTURE")

I CAN THE OVERALL COMMANDER MAINTAIN STRATEGIC DIRECTION OVER FORCES TO ACCOMPLISH MISSION GOALS WHILE DELEGATING CONTROL TO LOWER LEVELS IN THE C2 STRUCTURE?

A. WILL THE C2 SYSTEM ALLOW THE COMMANDER TO ORCHESTRATE THESE CHANGES IN TEMPO WITH THE BATTLE AS THE SITUATION CHANGES?

B. DO APPROPRIATE FEEDBACK MECHANISMS EXIST TO ALLOW THE COMMANDER TO MONITOR THE SITUATION AND EFFECTS OF LOWER LEVEL ACTIVITIES?

C. HOW DOES THE COMMANDER IMPLEMENT THESE CHANGES?

1) ARE CHANGES READILY UNDERSTOOD BY ALL CONCERNED COMMANDERS AND WEAPON SYSTEMS OPERATORS?

2) WHAT INFORMATION ABOUT THE ENEMY AND FRIENDLY FORCES IS NEEDED TO MAKE THESE DECISIONS?

3) HOW DOES THE C2 SYSTEM PROVIDE THIS INFORMATION?

4) ARE CORRECT PERCEPTIONS FORMED EASILY?

II CAN PRIORITIES FROM OUTSIDE THE AIR DEFENSE C2 SYSTEM BE READILY TRANSLATED INTO AIR DEFENSE PRIORITIES?

IV. THE AIR DEFENSE C2 SYSTEM MODEL

In this section we will develop a complete C2 system model which performs the battle management functions necessary to control air defense forces in central Europe. The C2 system bounds are defined by geographic areas of responsibility within the NATO 4ATAF sector and the physical elements (command centers and information sources), which are needed to perform or support the C2 process. The command centers that perform these functions are listed below:

- SOC-Sector Operations Center
- CRC-Control and Reporting Center
- CRP-Control and Reporting Post
- BDG FDC-Brigade Fire Direction Center
- BN FDC-Battallion Fire Direction Center

Information sources considered to be within the C2 system are:

- NAEW-Nato Airborne Early Warning system
- SIS-Special Information System(Intelligence)
- Other Information Scources (i.e., Flight Plans)

Weapon systems also perform command and control functions under certain operational concepts. Therefore, the boundary of the C2 system will move to include the weapon systems when they perform C2 functions. The air defense weapon systems, which will be considered in this thesis are the F-15 Eagle (all weather fighter), the HAWK and PATRIOT SAMs. Figure 4.1 illustrates the physical elements for the air defense C2 system. [Ref. 8]

A. OUTLINE FOR BUILDING THE MODEL

The C2 system model will be built from the bottom up using the real world architecture as represented by the

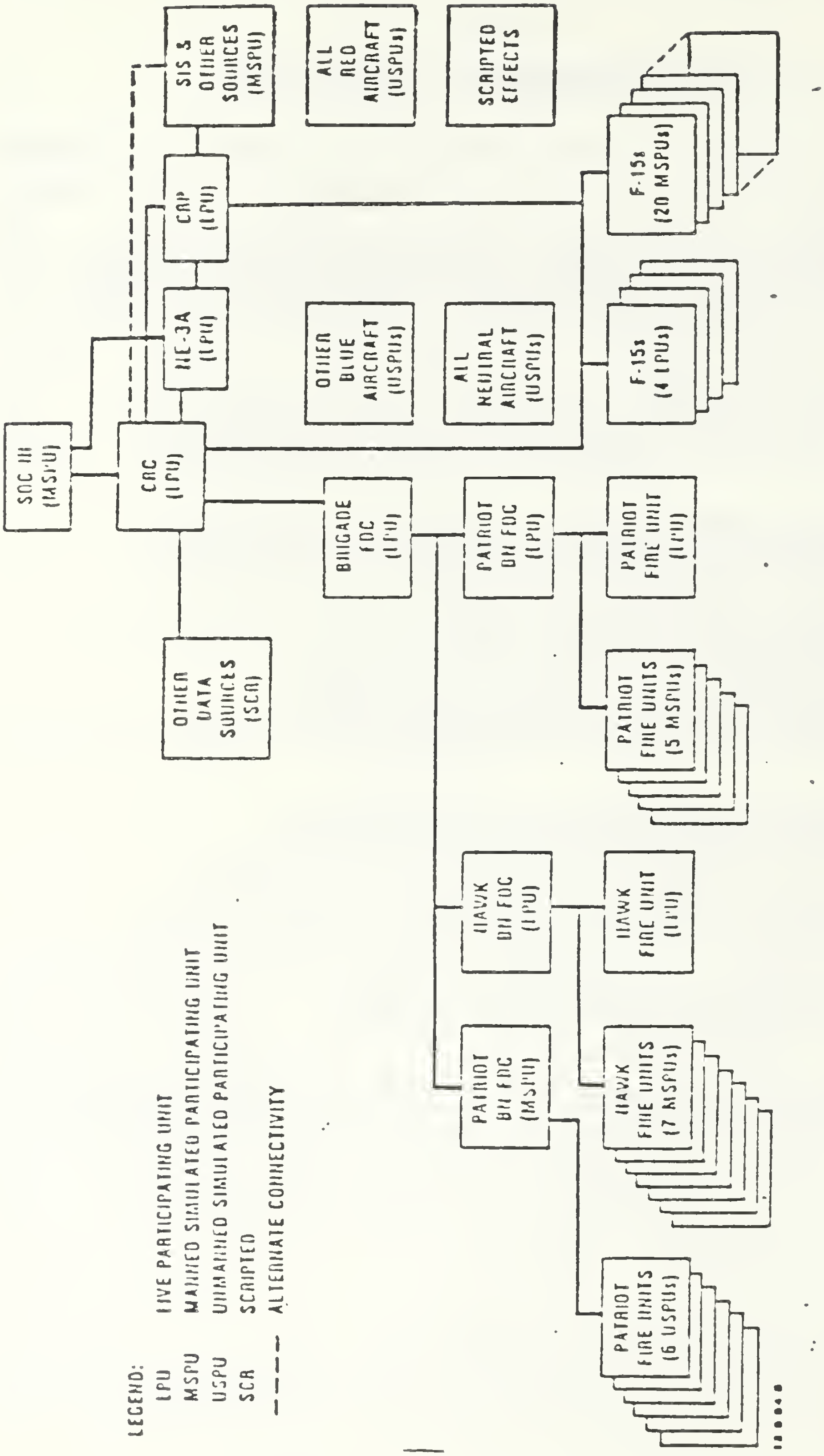

Figure 4.1 C2 System Elements

physical assets and structure available in central Europe. This C2 system is programmed to be operational in the 1989 Timeframe.[2] The following approach will be used to develop the C2 system model:

1. The C2 Process

- Modify MCES C2 Process model to include Lawson's PROCESS function (Reasons for modifications will be offered in section B)
- List modified MCES C2 process function definitions.
- Identify and define air defense C2 functions which form an "execution level" C2 process for air defense. ("Execution level" C2 process functions directly control weapons. This C2 process must be disassociated with any particular C2 node until you specify an operational concept which aligns the process to a command node or combination of command nodes and weapon systems).
- Map air defense C2 process to MCES C2 process.

2. Other Processes and Interfaces

- Define and interface XTEL process with C2 process.
- Define and interface intelligence process with XTEL process and C2 process.

3. The Higher Echelon C2 Process

- Nest higher echelon C2 process with execution level C2 process.
- Define functionality of higher echelon C2 process.
- Show interaction with higher echelons outside air defense C2 boundary.

B. THE MCES C2 PROCESS MODEL

This thesis will use the MCES C2 process model as a starting point to build the C2 systems model. However, one modification to the model will be made.[3] The SENSE function will be split into separate SENSE and PROCESS functions.[4]

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[2]IFFN JTF is building a testbed to conform to this baseline.

[3]This particular model represents a group effort by workshop members at the Jan 1985 C2 Measures Workshop sponsored by MORS at the Naval Postgraduate School in Monterey, CA.

[4]Lawson contends the PROCESS function should be represented independent from the SENSE function. (Deliberations from 1986 MCES workshop sponsored by MORS at Naval

The definitions for SENSE AND PROCESS will be altered to accomodate this modification. The ASSESS and GENERATE function definitions will also be changed to accomodate ideas that were presented in the decision making discussion in section 2. The modified model is represented in Figure 4.2 Definitions for each function follow:

1. SENSE

That function which collects data necessary to describe and forecast the environment. [Ref. 6: p. 5-5]

2. PROCESS

That function that transforms data into information about:

- The enemy forces' disposition and actions. [Ref. 6: p. 5-5]
- The friendly forces' disposition. [Ref. 6: p. 5-5]
- Those aspects of the environment that are common to both forces, e.g., weather, terrain, and neutrals. [Ref. 6: p. 5-5]

3. ASSESS

That function which assigns meaning (perception) to processed "information about the intentions and capabilities of enemy forces and about the capabilities of friendly forces"[5] to counter the enemy's intentions. Present and future state perceptions can be formed by decision makers within the ASSESS function.

Postgraduate School) [Ref. 2]

[5]The portion of definition which appears in quotes was taken verbatim from the original MCES definition for the ASSESS function. [Ref. 6: p. 5-5] The rest of the definition reflects decision making ideas, which were presented in section 2.

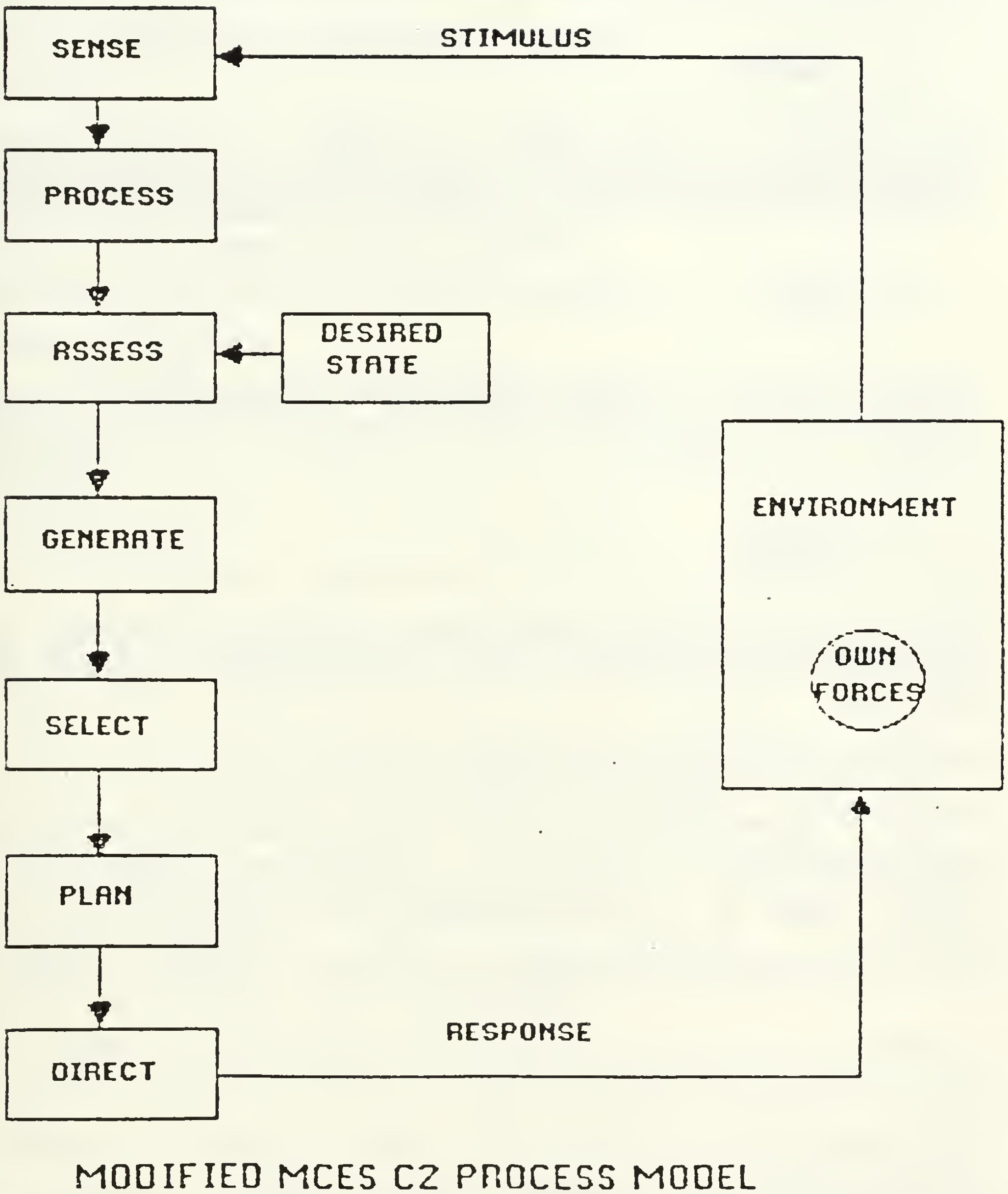

Figure 4.2 Modified MCES C2 Process Model

4. GENERATE

"That function which develops alternative courses of action to"[6] achieve mission goals. There is a possible recursive relationship between GENERATE and ASSESS as the impact of different alternatives can change projected perceptions of the environment.

5. SELECT

That function which selects a preferred alternative from the available options. [Ref. 6: p. 5-5] How this is done will differ from one decision maker to another.

6. PLAN

That function which develops implementation details necessary to execute the selected course of action. [Ref. 6: p. 5-6]

7. DIRECT

That function which distributes decisions to the forces charged with execution of the decision. [Ref. 6: p. 5-6]

C. THE AIR DEFENSE C2 PROCESS MODEL

The purpose of this thesis is to develop an air defense C2 systems model. Therefore, specific air defense funtions will be used to build the model. A typical air defense profile (as defined by IFFN)[7] will be used to identify

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[6]That portion of definition in quotes is taken verbatim from MCES definition for GENERATE function. [Ref. 6: p. 5-5] Mission goals replaces a reference to desired state in the original definition.

[7]This profile is a timeline sequence for a typical air defense interceptor from takeoff to missile impact. It includes some ALERT phase where an interceptor is scrambled and force process functions ACQUIRE, ENGAGE and MISSILE FLYOUT.

functions that provide command and control for air defense weapons. The air defense profile functions are listed below:

- *ALERT
- DETECT
- TRACK
- *TRACK CORRELATION (Correlate Track)
- IDENTIFY
- *IDENTIFICATION CONFLICT RESOLUTION (Resolve ID Conflict)
- THREAT ASSESSMENT (Assess Threat)
- WEAPONS ASSIGNMENT (Assign Weapon)
- WEAPONS ALLOCATION (Allocate Weapon)
- CONTROL(FIGHTERS)
- WEAPONS CONTROL AND MONITORING(SAMs)
- *ACQUIRE
- *ENGAGE
- *MISSILE FLYOUT

Several functions (identified by an *) will be deleted from the initial C2 process model and included within other processes. The reasoning for this will become clear as we build interfaces between the different processes. The TRACK CORRELATION and IDENTIFICATION CONFLICT RESOLUTION functions will initially be excluded from the C2 process. These functions will first be introduced as part of the XTEL process. They are only present when the capability to XTEL information exists. However, when they are present, the functions are part of both XTEL and C2 processes.

The ALERT function is the result of some C2 decision (i.e.,issue scramble order) and actions by the fighter (i.e.,takeoff, climb). This will not be considered a C2 process function. The ACQUIRE, ENGAGE and MISSILE FLYOUT functions are performed by the force that is changing the environment. These functions form the force process. Thus, the air defense C2 process can be described by functions beginning with DETECT and ending with WEAPONS CONTROL and MONITORING. This particular C2 process will form the execution level C2 process for control of both SAMs and fighters. Definitions for these functions were developed in the January 1986 MCES workshop. The air defense C2 process model is illustrated in Figure 4.3 These definitions are provided below:

1. DETECT

This is the function in which searches are carried out until the presense of objects in the area under surveillance is established. [Ref. 2]

2. TRACK

Establish and maintain continous contact(including lock-on for some systems) with detected object; establish location and direction of object; assign track number to each track for common reference. [Ref. 2]

3. IDENTIFY

Classify track as friend, foe or neutral with varying degrees of confidence. [Ref. 2]

4. THREAT ASSESSMENT

Evaluation of threats and selection of targets in accordance with higher echelon priorities. [Ref. 2]

5. WEAPONS ASSIGNMENT

Consider best option (SAM or Fighter Aircraft) given resource availability and select weapon systems. [Ref. 2]

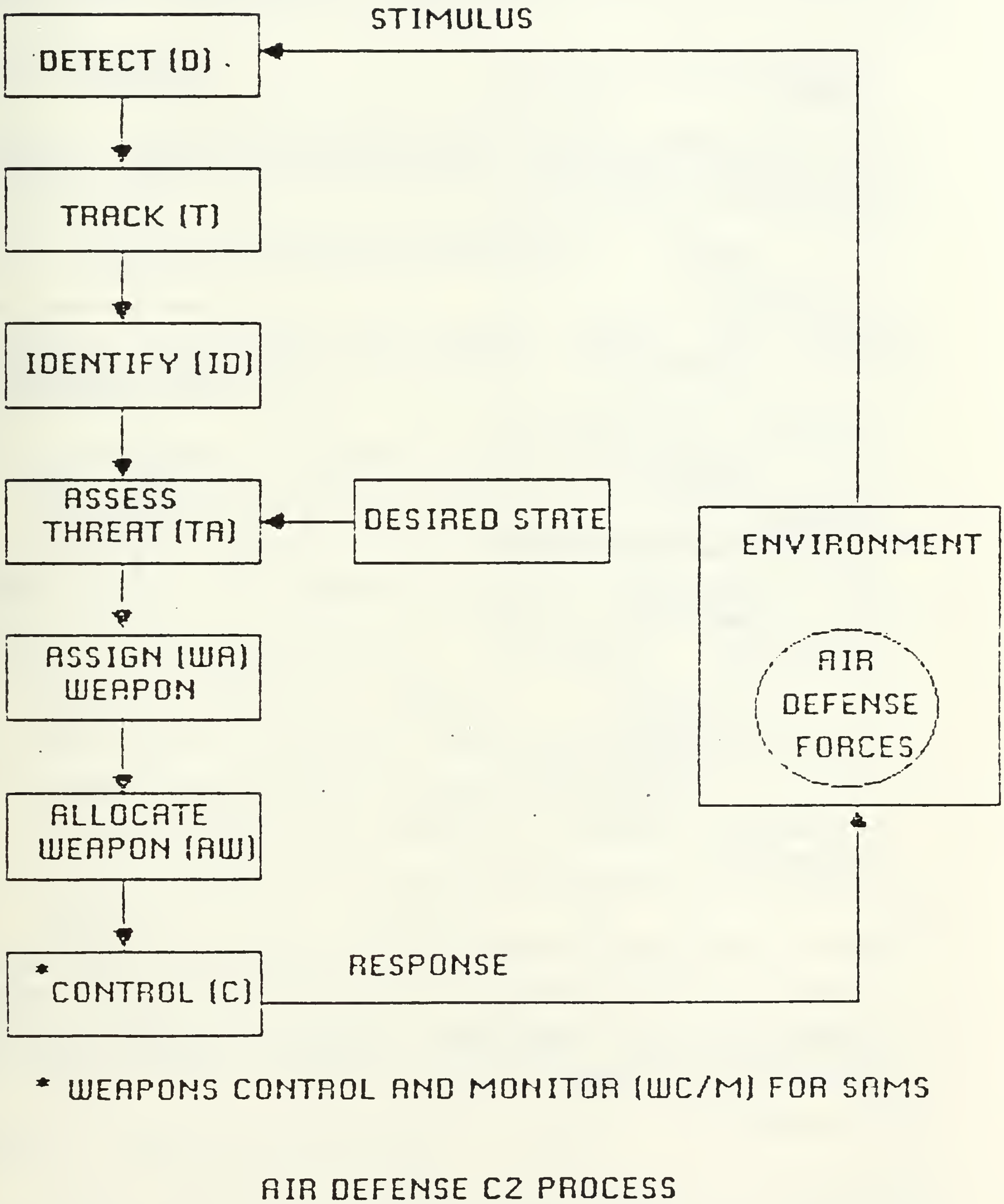
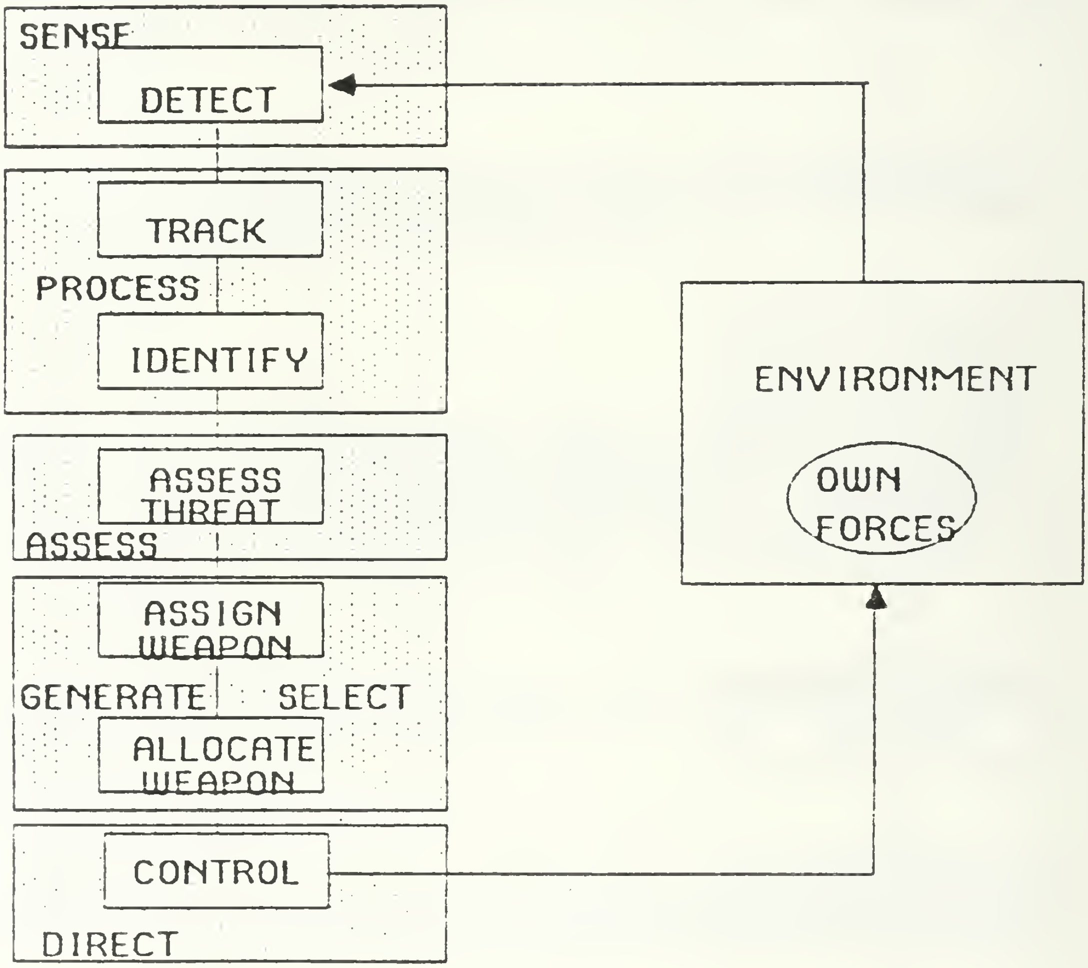


Figure 4.3 Air Defense C2 Process Model



THE PLAN FUNCTION DOES NOT CORRESPOND TO A REAL TIME ACTIVITY DURING THE EXECUTION PHASE. HOWEVER, NON REAL TIME PLANS ARE IN EFFECT SUCH AS RULES OF ENGAGEMENT(ROE).

Figure 4.4 Mapping between Processes

6. WEAPONS ALLOCATION

Consider options (within the selected weapon system) and pair specific weapons with targets and assign specific intercept controllers. [Ref. 2]

7. CONTROL

Direct fighter interceptor and provide information to fighter for target acquisition. [Ref. 2]

8. WEAPONS CONTROL and MONITORING

Monitor expenditure of weapons (SAMs) and inhibit engagements to preserve resources or protect friendly aircraft. [Ref. 2]

D. MODIFIED MCES C2 PROCESS VS. AIR DEFENSE C2 PROCESS

The final step in our development of the air defense C2 process is to compare it to the modified MCES C2 process for completeness. A mapping between these processes is presented in Figure 4.4 A listing for this mapping between processes is presented below:

- SENSE corresponds to DETECT
- PROCESS corresponds to TRACK and IDENTIFY
- ASSESS Corresponds to THREAT ASSESSMENT
- GENERATE/SELECT corresponds to WEAPONS ASSIGNMENT[8]
- GENERATE/SELECT corresponds to WEAPONS ALLOCATION[9]
- PLAN does not correspond to any function in real time.[10]

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[8]The GENERATE function is minimal as there are only two alternative choices (SAMs or fighters).

[9]Alternatives must be timely to meet intercept opportunities. Operators will tend to simplify this GENERATE function to meet time constraints.

[10]This PLAN function does not correspond in this execution level C2 process. The plan has been injected through desired state by higher echelons and is a "non real time" plan. Rules of Engagement (ROE) would be an example of a "non real time" plan.

- DIRECT Corresponds to CONTROL for fighters and WEAPONS CONTROL and MONITOR for SAMs.

The C2 process just described is an execution level C2 process which directly controls weapon systems. It is not associated with any command node or weapon system at this point.

E. XTEL PROCESS DEFINITION AND INTERFACE

The previous section described an execution level C2 process for air defense. This is a C2 process which affects direct control over air defense weapon systems. A node which is performing this process can operate independently by generating its own targets and using its own forces to engage them in accordance with higher echelon priorities or doctrine. However, in the complete C2 system there are many lateral or vertical command nodes, which have authority to engage targets. Each node normally has a specific geographic area or perhaps an altitude regime where they are responsible for intercepting hostile targets.

At an individual command node targets may enter its area of responsibility long enough for identification, but exit before an intercept can be made. Therefore, an individual node may produce information about targets it cannot use, which is useful to a C2 node that has a better intercept opportunity.

With these thoughts in mind, air defense C2 systems designers have built communications (XTEL) networks to share target information that is developed by the individual C2 nodes. This sharing of information can reduce the time needed to process a target since it may already be processed. Another benefit to this sharing of information is the ability to fuse information when several nodes have processed the same target. There is a potential to determine which node has the best information and use it to classify the target or at least influence the classification of the target. Hopefully, accuracy will be improved.

1. <u>Definitions</u>

The preceding discussion has pointed out the need to provide for separate XTEL process between nodes to share and fuse target information. As a starting point this process must have the following functions at each node which shares information:[11]

a. XTEL Function

Transfer and receipt of information via data link with some rules or filters, which specify where information is sent and what information will be received.

b. TRACK CORRELATION

Resolve location and track numbering disagreements in the C2 system. [Ref. 2]

c. ID CONFLICT RESOLUTION

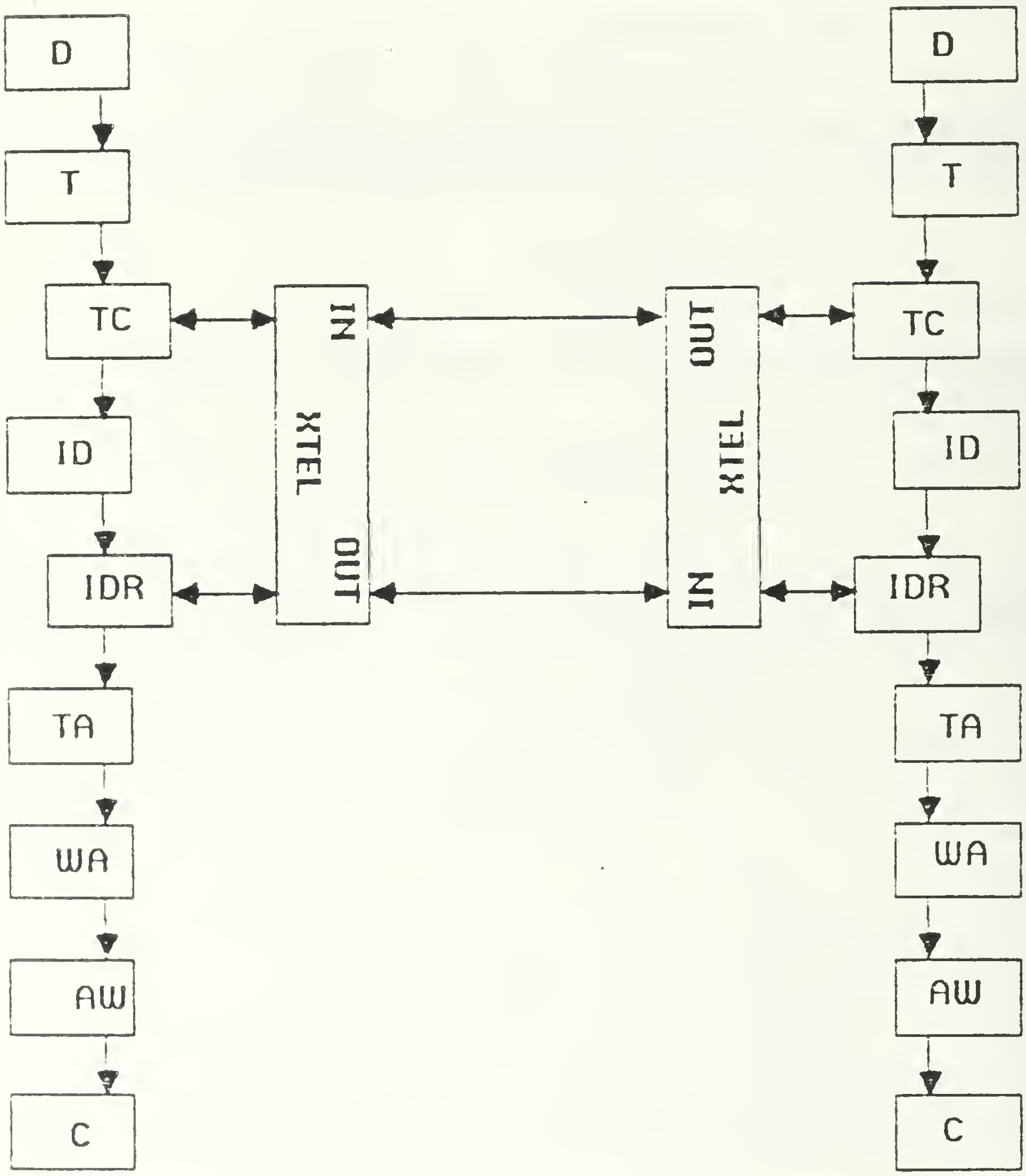
Resolve conflicts that may arise in the identificaton process between different C2 nodes. [Ref. 2] At some nodes this is a fusion process. At other nodes it is a binary decision process.

A conceptual model of this XTEL process is interfaced with two execution level C2 processes in 4.5 While a great deal of this process can be automated, manual intervention is still possible as part of the resolution process.

F. THE INTELLIGENCE PROCESS AND INTERFACE

The definition for the intelligence process was given in section 2. The definition described a staff agency, which helps to form the commander's perception of both present and future states of the environment. The intelligence process

[11]The XTEL process could also be viewed as a function. However, the TRACK CORRELATION and ID CONFLICT RESOLUTION functions can only be present when you have XTEL capabilities. Therefore these functions are grouped together and given the name XTEL process.



LATERAL OR VERTICAL C2 NODES
XTEL INTERFACE

Figure 4.5 XTEL, C2 Process Interface

can be viewed as a separate staff agency, which disseminates information to many C2 nodes to accomplish this task. But this is only one of the many ways this process can be interfaced into the C2 system. In this thesis, the intelligence process will be modeled to show its contribution to battle management in real time.

1. Definitions

The intelligence process functions will parallel the definitions provided in the MCES and air defense C2 process definitions. differences. Intelligence process definitions are:

a. SENSE

That function which collects data necessary to describe and forecast the environment.(Data sources differ from DETECT function for C2 nodes and the focus is on collecting data about the enemy).

b. PROCESS

That function that transforms data into information about the enemy forces' disposition and actions. (This implies identification)

c. INTELLIGENCE CORRELATION (IC)

Correlate intelligence information with track and ID information.

d. ASSESS

Examine information and look for patterns that indicate actions or intentions of enemy. Use patterns to forecast possible future changes in environment.

e. DISSEMINATE

Pass assessment to commanders throughout the C2 system.[12]

2. <u>Interfaces</u>

This intelligence process can be interfaced with the C2 process or with both the XTEL process and C2 process. This is illustrated in Figure 4.6

a. INTELLIGENCE CORRELATION Interface

The key for making intelligence information useful to a commander in real time is the INTELLIGENCE CORRELATION function. This function can form an interface with both the XTEL process and the C2 process.

b. ASSESS Interface

The intelligence process ASSESS function is interfaced with the C2 process at the ASSESS THREAT function as a supporting function. While the intelligence ASSESS function amplifies perceptions about the enemy, the decision maker performing the C2 process function, ASSESS THREAT, considers both enemy and friendly capabilities to form his perception of the environment. However, there are some time sync considerations.

The intelligence process may develop information about the enemy before the enemy comes into radar coverage. This would mean intelligence process functions, SENSE, PROCESS, ASSESS would be performed first. This intelligence assessment could be used to form some future state perception for the commander's ASSESS THREAT function. That commander could act to mass his own forces to deal with that future state. The intelligence officer could subsequently

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[12]The DISSEMINATE function will be excluded from the model because its major impact may be felt in non real time. This thesis will explore the interfaces with an intelligence process to a single commander to explore how the information can be used to affect real time decisions.

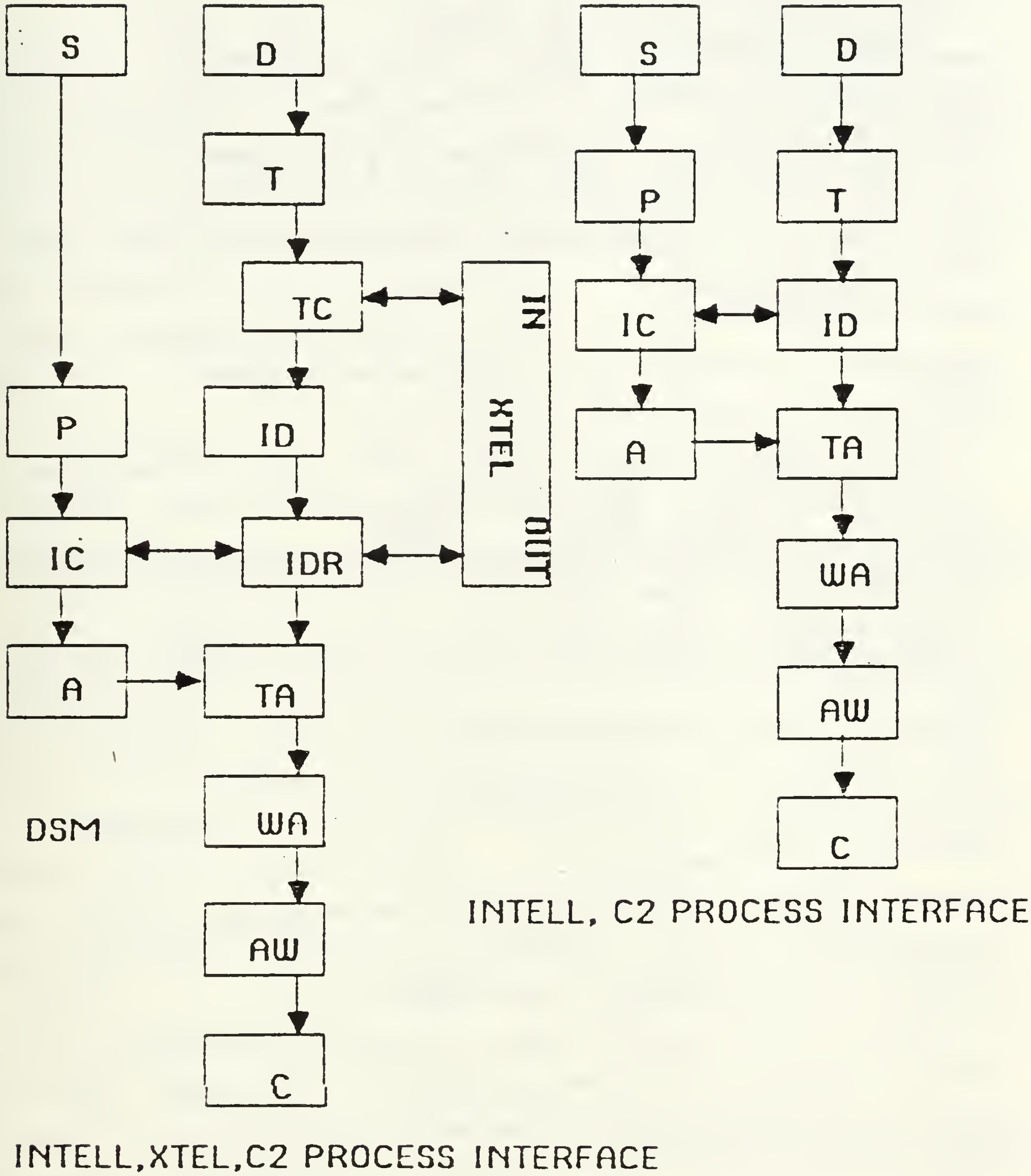


Figure 4.6 INTEL, XTEL, C2 Process Interface

confirm his assessment by performing the INTELLIGENCE CORRELATION function when the potential targets enter radar coverage.

G. THE HIGHER ECHELON C2 PROCESS

The functions of the higher echelon C2 process are difficult to describe in precise terms. Commanders at this level must consider strategies, which support or coordinate with cther warfighting missions. Therefore, they will make tradeoffs on priorities and resources, which consider more than one mission area. Depending on their overall assessment, they can control action themselves, delegate authority or provide direction to subordinates.(Lawson's analysis of APL model). [Ref. 10]

This higher echelon C2 process will be modeled with respect to command and control elements inside and outside the air defense C2 system boundary. Interfaces with these C2 elements are shown Figure 4.7

The figure illustrates two of the missions which would be managed at the Sector Operations Center (SOC). A coordination C2 element makes tradeoffs between close air support (CAS) and air defense missions. An example of a tradeoff decision might be imposing a rigid air defense ROE in an area where CAS operations are taking place. The air defense element at the SOC would direct the affected CRC to implement the ROE. That CRC would, in turn, pass the ROE to weapon systems under its control.

There are several other points illustrated by the Figure, which should be discussed. The XTEL process is interfaced laterally with adjacent C2 processes at the CRC level for the purpose of sharing 'intersection' information and improving the accuracy of that information. To some degree the weapon systems will also generate information and crosstell it to the command centers. The SOC is represented as a 'sink' for processed information because it does not

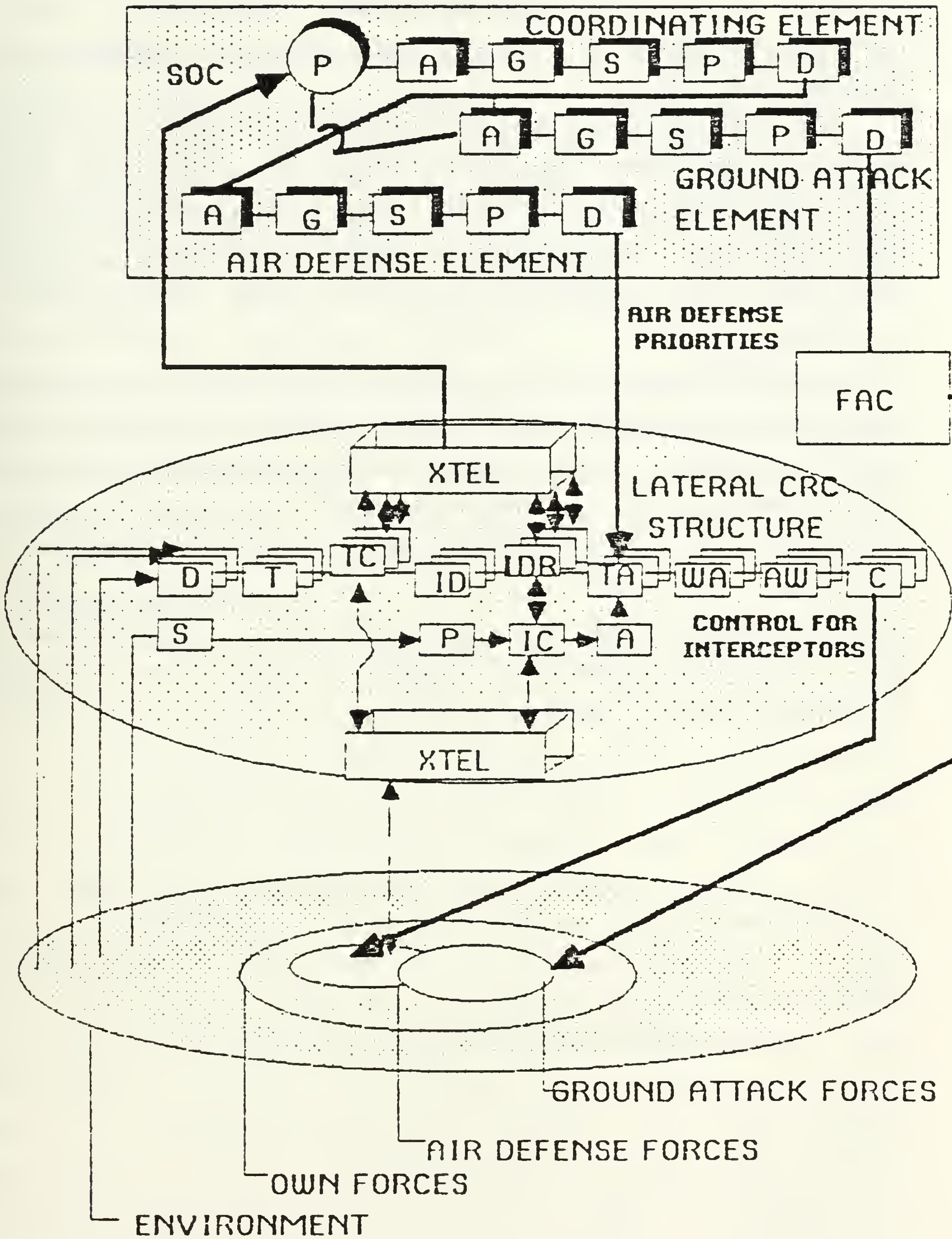


Figure 4.7 Higher Echelon C2 Process Interface

have its own organic sensors and responsibility to fuse information has been delegated to lower C2 elements. Finally, the CRC controls launch and recovery for all aircraft in addition to providing intercept control to air defense fighters.

The NAEW has been excluded from the Figure, but it would be interfaced with the XTEL process and share its information throughout the C2 system. The intelligence process has been interfaced at the CRC. The intelligence process it could have been interfaced at the CRC, CRP, SOC or NAEW.

H. SUMMARY

In this section we have built a complete C2 system to represent the command and control of the air defense forces. The C2 process, XTEL process and intelligence process have been integrated to build this system. However, we have not discussed the physical entities, which perform these processes. Nor have we discussed the structure (relationships) between these physical entities. The next section will relate "physical entities" (man or machine), "structure" and C2 system processes.

V. MODEL SYNTHESIS

This section will describe the interrelationship between "processes," "physical entities" and "structure." With this purpose in mind, a software design technique, "Data Flow-Oriented Design," will be adopted to modify our air defense model to show these interrelationships. This design technique will enable analysts to alter the air defense C2 system model to reflect different operational employment concepts through structural changes. It will also allow analysts to specify internal processing within C2 process functions as well as what or who does the processing. Fully developed, these techniques provide a means to build a "data generator," which tracks configuration, develops measures and data requirements for the IFFN testbed.

A. INTERRELATIONSHIPS

If you knew nothing about the C2 theory that has been presented in this thesis, terms such as process or physical entities would seem foreign to you. But you might still have a good feeling for how command and control works. Imagine a commander performing some kind of decision function. He passes his decision to several subordinates. In turn, these subordinates work out detailed instructions to implement the decision. Then they communicate these instructions to forces, which can act in the environment. In our command and control terms the commander and the subordinates were performing separate functions within a C2 process. The subordinates' function is related to the commander's function by the commander's decision (output) and the subordinates receipt (input). subordinates. In turn, the detailed instructions from the subordinates to the force coupled the subordinates function to the force function. This input/

output relationship forms a structure between separate process functions, which is required to perform the mission at hand.

The next step is easy. When you add the person and/or machine, which performs the function, you form the same structure between physical entities. Between people we call it the organizational structure. [Ref. 1] Between machines we sometimes call it a C3 system architecture. [Ref. 1] For this thesis we will use the MCES definition.

B. DATA FLOW-ORIENTED DESIGN

1. Data Flow Diagram (DFD)

Data flow-oriented design provides a natural methodolgy for describing a command and control system. It allows us to use data flow diagrams (DFDs) to show the input/output relationships that exist within the C2 system. Figure 5.1 shows a DFD for an air defense C2 process at a single command node.

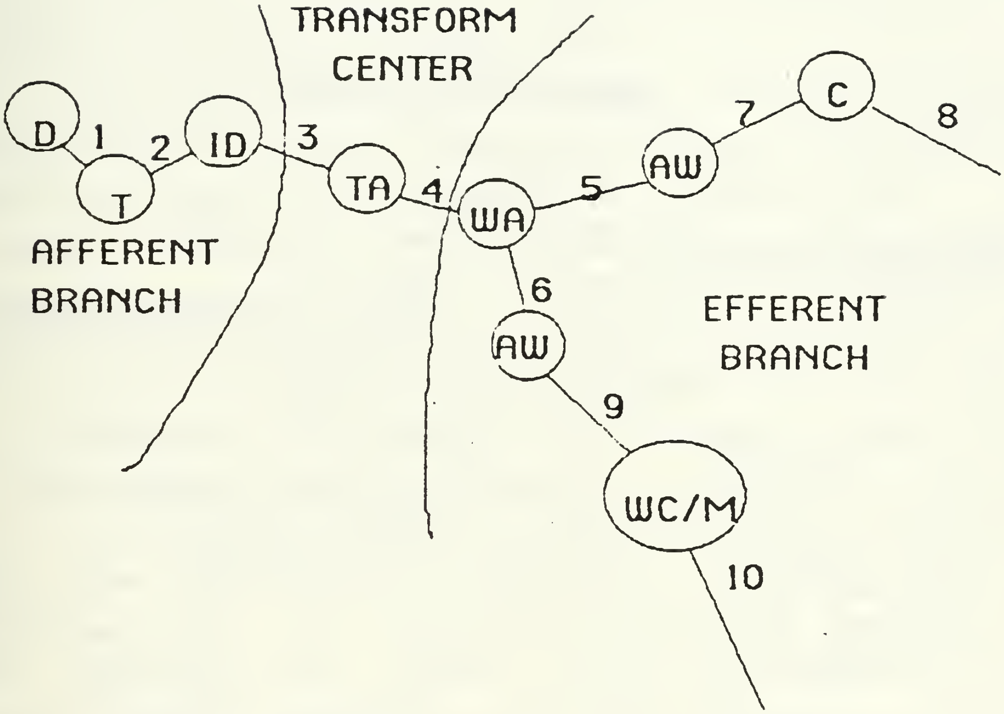
2. Transform Analysis

An analysis of this data flow diagram will allow us to establish a superordinate, subordinate relationship between the separate transforms within the DFD. By identifying the major transform center and identifying the information flow into (afferent branch) and out of (efferent branch) it, we can subordinate the individual processes to that transform center. Figure 5.2 demonstrates how transform analysis can be performed on the DFD to develop a structure chart.

3. Structure Chart Conventions

Additional structure chart conventions will be adopted to formalize the modeling approach to be used in this thesis. These conventions are listed below:

- Lines can only enter and exit function boxes at the tope or bottom.
- Functions are superordinate to functions below them and subordinate to functions above them.



1 RADAR CONTACT
2 CONTACT/POSITION/DIRECTION
3 FRIEND/FOE/NEUTRAL
4 PRIORITIZE FOE TARGETS
5 ASSIGN TARGET TO FIGHTERS
6 ASSIGN TARGET TO SAMS
7 ALLOCATE TARGET TO FIGHTER AND CONTROLLER
8 PROVIDE DIRECTION AND INFORMATION TO FIGHTER
9 ALLOCATE TARGET TO SAM FIRE UNIT
10 MONITOR ENGAGEMENTS

Figure 5.1 Single C2 Node DFD

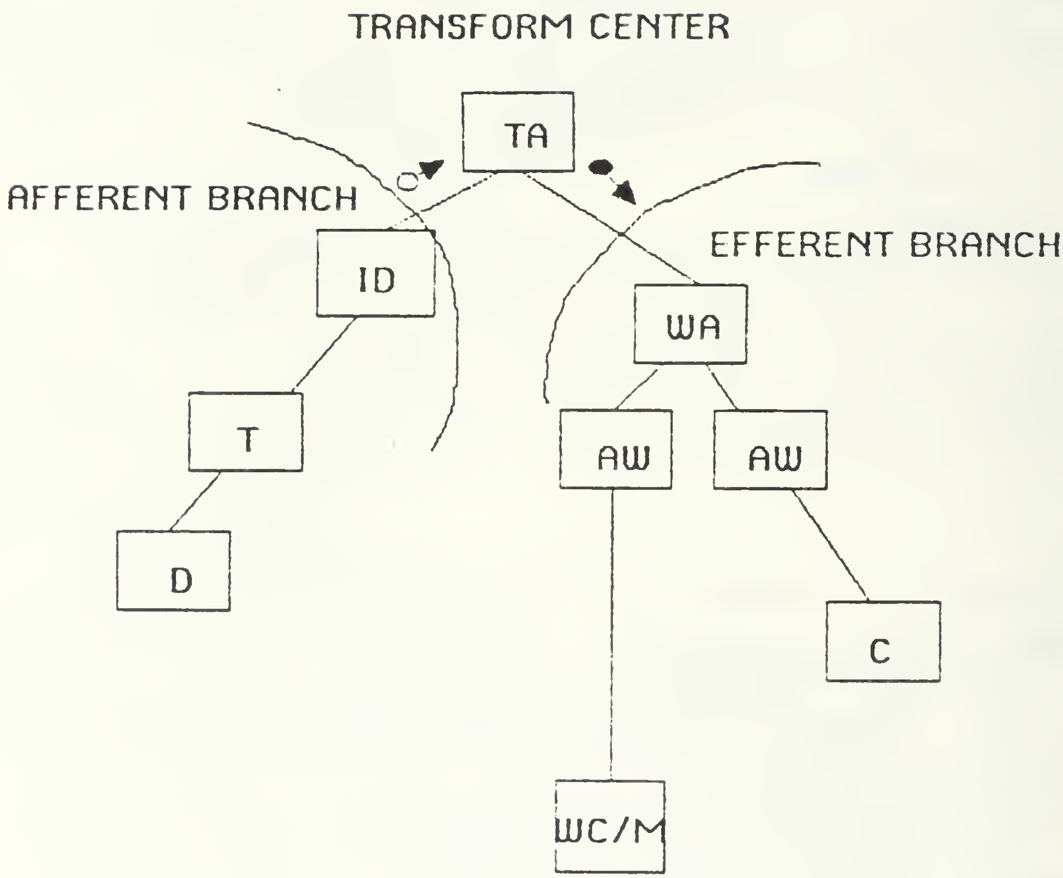


Figure 5.2 Single C2 Node Structure Chart

- Output can be information or control information. Examples of each are discussed in the following two paragraphs.

The ID officer performing the ID function tells the decision maker performing an ASSESS function which track is friend, foe or neutral. This is information which is used to perform the next function. Symbology for information on the structure chart is an open arrow.

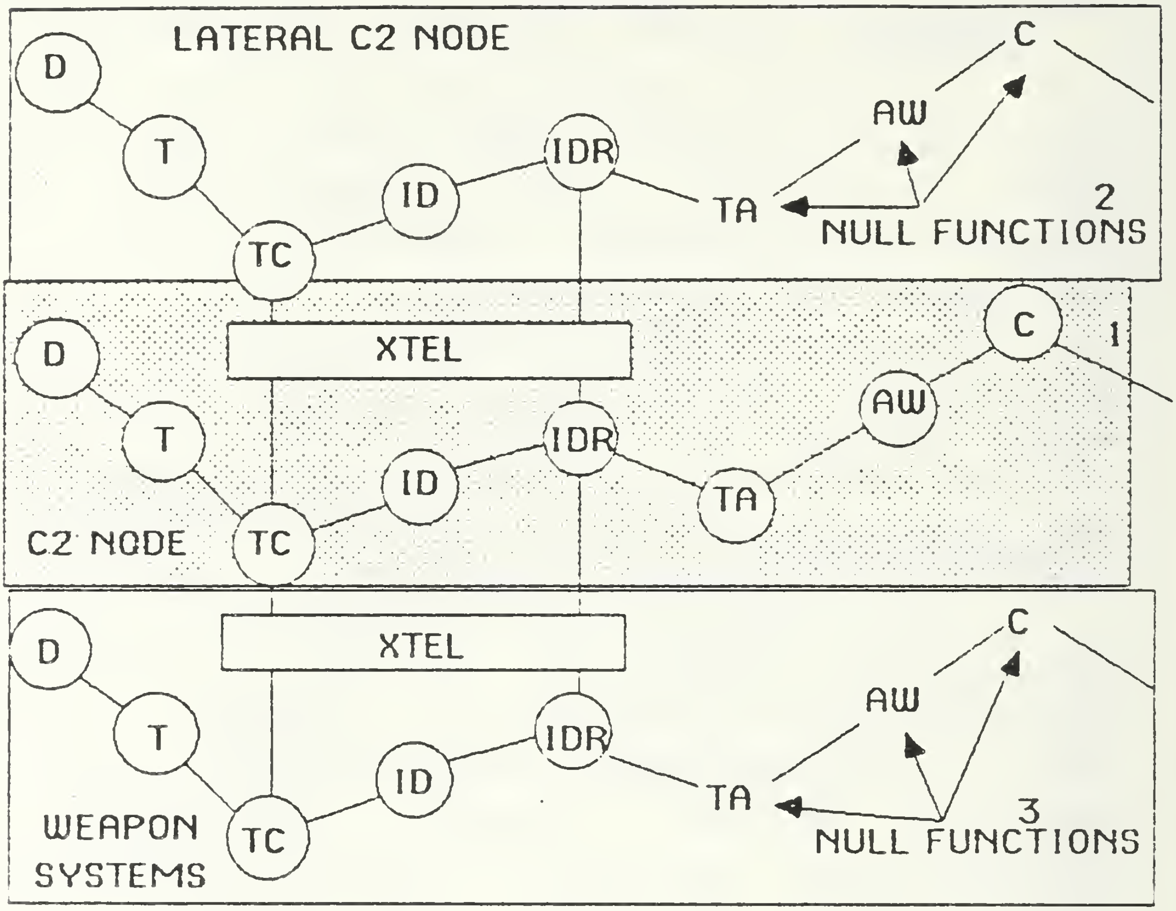
The decision maker performing the ASSESS function picks out which foes are the biggest threats and tells the Weapons Assignment officer which foe to target first. This is control information. It affects how the weapons assignment officer will perform his function. Symbology for control information on the structure chart is a solid arrow.

Notice when we talk about a function we can also say who is performing that function. Therefore, we have related both the processes and the people to a structure. We could take it a step further by aligning physical equipment to these same functions. Equipment consoles could be conFigured to aid the operator in performing certain functions and allow the output to be addressed to other consoles. This alignment would also conform to the same structure. However, the man would be aided in his ability to process information and communicate it through a machine structure that parallels an organizational structure.

C. THE NULL PROCESS

Now that we have the basics down let's look at a command and control node which is fully connected to other command and control nodes and weapon systems through a XTEL process. At the same time we will introduce the concept of a null process with respect to the weapon system being controlled.

Figure 5.3 is a DFD, which shows a command node that is controlling weapon system A. The command and control node may receive amplifying information through the XTEL process concerning targets from lateral C2 nodes or from weapon



1 CONTROL TO WEAPON SYSTEM A

2 THESE FUNCTIONS ARE NULL WITH RESPECT TO WEAPON SYSTEM A

3 THESE FUNCTIONS ARE NULL WITH RESPECT TO WEAPON SYSTEM A

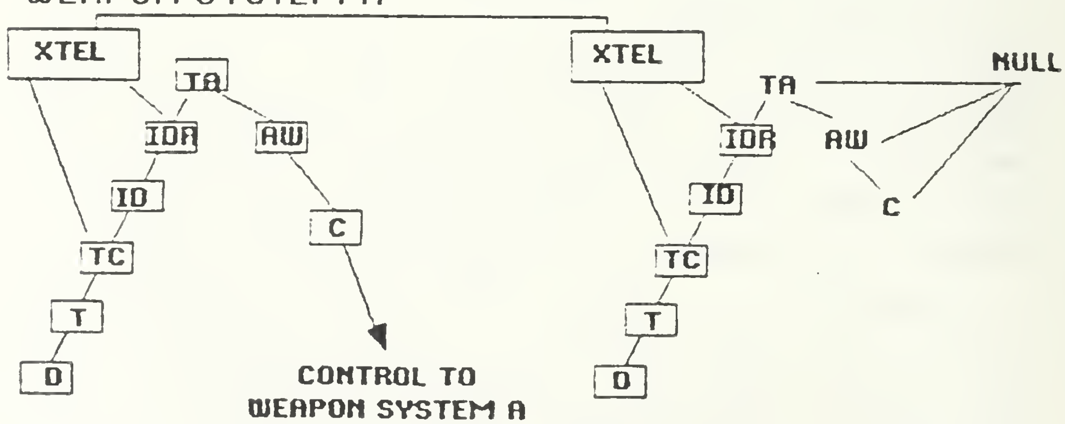


Figure 5.3 Null Process with Lateral C2 Node

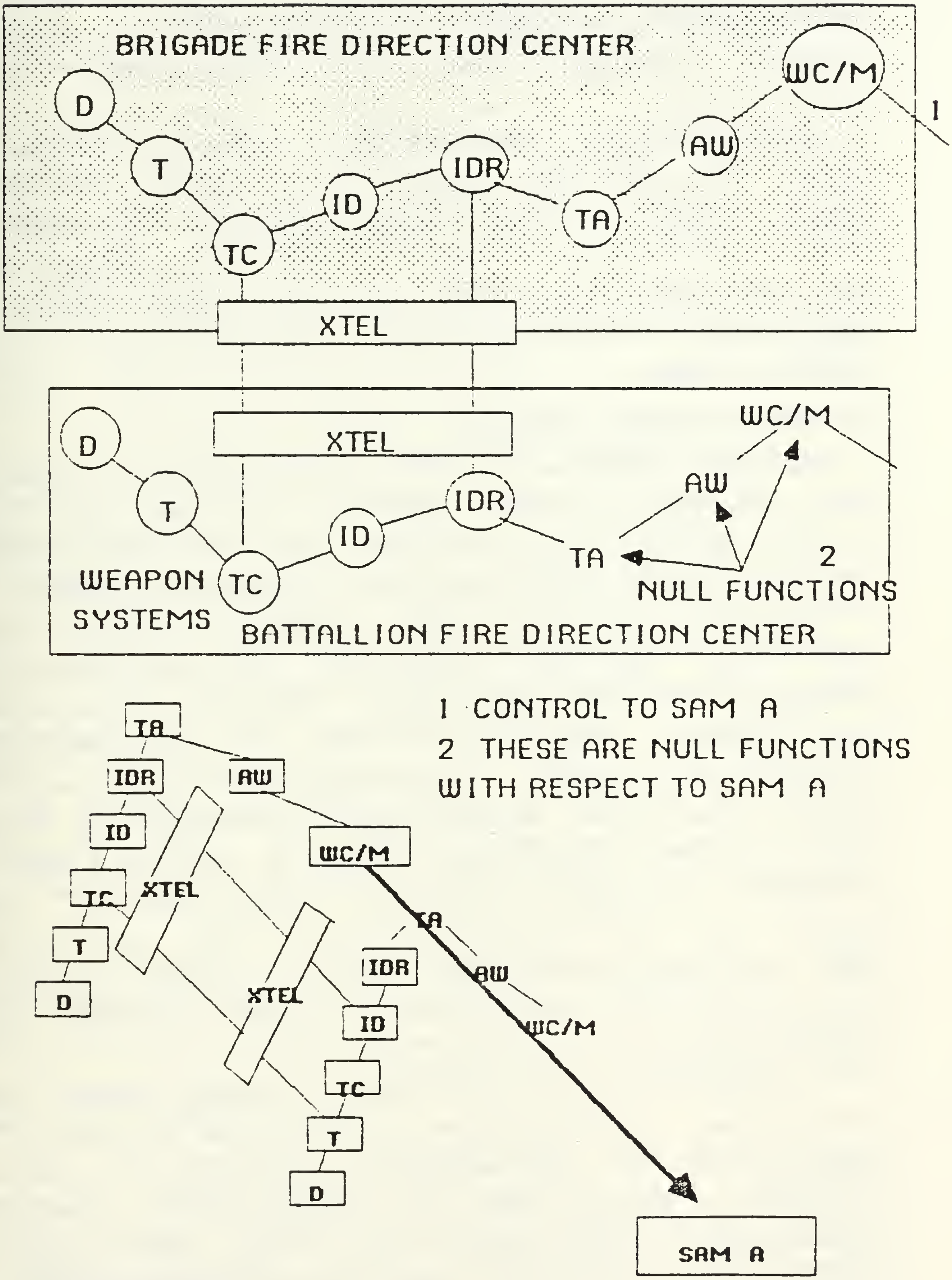


Figure 5.4 Null Process with Vertical C2 Nodes

systems. However, weapons control functions, (ASSESS,WEAPONS ASSIGNMENT/ALLOCATION,CONTROL), are null processes at lateral C2 nodes with respect to weapon system A.

This concept of a null process is even more useful when you consider C2 nodes, which can control the same weapon system. Figure 5.4 illustrates a Brigade Fire Direction Center (BDG FDC) and a Battallion (BN) FDC. Both C2 nodes have the potential to control the same SAM firing unit, but only one can exercise control authority over any given period of time.

D. WEAPON SYSTEM MODELLING

There is one final problem that we have yet to address. How do we model the weapon system? The answer will depend on the connectivity with the rest of the C2 system and/or the operational concept being used to employ the weapon.

For the first case, let's consider a fighter, which cannot share data link information. All instructions are through line of sight voice radio. Additionally the fighter has no means to identify the target due to equipment limitations on his aircraft. In this case the fighter is acting solely as the force. He must ACQUIRE and ENGAGE the target. The minimum set of functions to make up the force function of ACQUIRE is DETECT, TRACK and TRACK CORRELATE. This assures that the fighter has correlated the track to a C2 track that has been declared hostile. Figure 5.5 illustrates a C2 node controlling a fighter under the above circumstances.

In another case, we could design a weapon system, which can crosstell information to and from the C2 node. The weapon system also has some limited capability to identify the target. However, the current operational concept has vested control authority with the C2 node controlling the weapon. To some degree the weapon system has become part of the C2 system. The ID and track information it produces can influence the ID made at the C2 node that controls the weapon. But weapons control is still exercised by the C2 node, not the weapon. However, the weapon systems operator can normally intervene to prevent engagements of friendly aircraft if he feels the C2 node has made an error. Figure 5.6 illustrates a weapon system, which is operating under these conditions.

Decision makers also have the perogative to delegate some of their weapons control functions to the weapon systems. This allows them to use their manpower to concentrate on allocating targets to weapons systems without having to actually control them. The CONTROL function is now being performed by the weapon system. For example, an intercept controller will allocate a hostile target to a fighter by providing him intial target information (i.e., bearing, range, hostile). From that point on, the interceptor pilot controls himself by choosing his own intercept course. This relieves the intercept controller from the responsibilities for computing intercept geometry and verbally directing the interceptor. Figure 5.7 illustrates how the CONTROL function has migrated from the C2 node to the weapon system. The weapon system should still attempt to correlate the track with his controller unless time is a factor.

Other operational concepts are also possible. The weapon systems could allocate and control themselves. In this case they would only draw threat information from the C2 system and determine which hostile targets they could intercept (See Figure 5.8).

One last operational concept places all C2 authority down at the weapon system. The weapon system may benefit from the C2 nodes information if XTEL links are up. However the THREAT ASSESSMENT function is now vested at the weapon

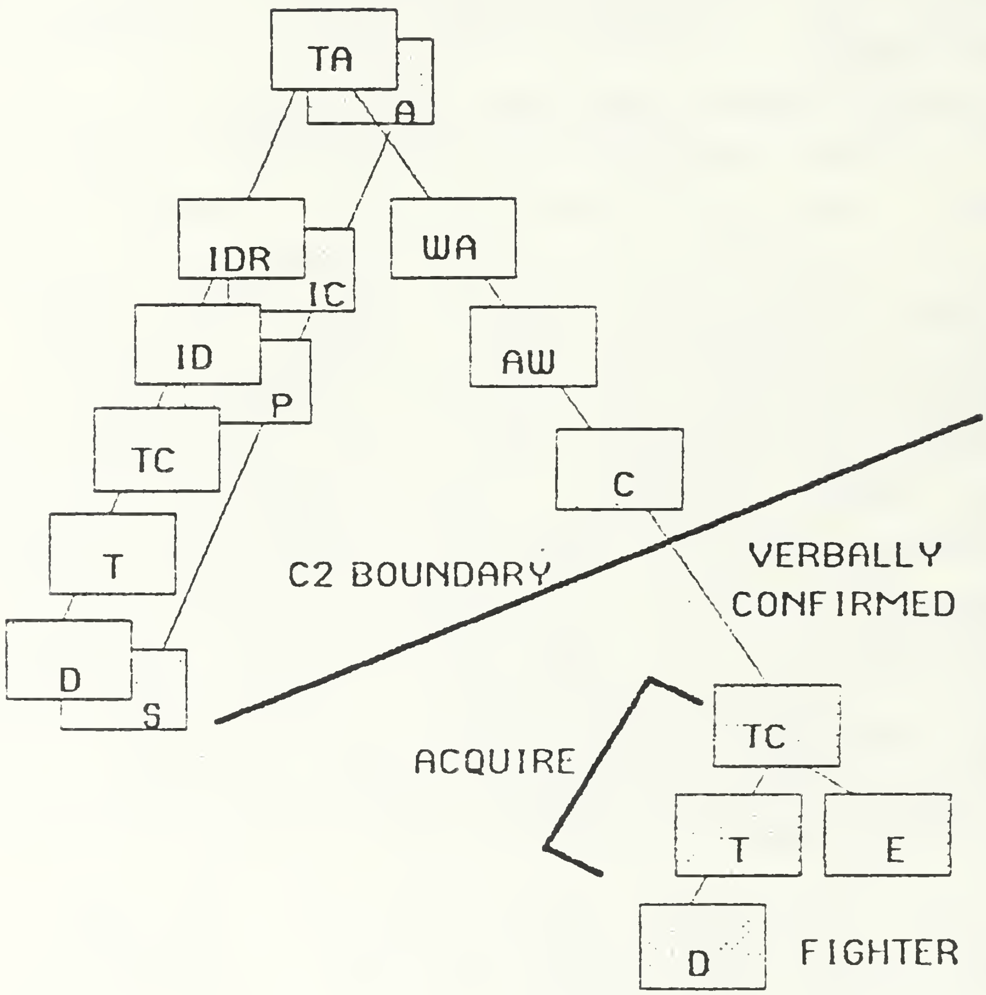


Figure 5.5 CRC Controls Fighter without XTEL Connectivity

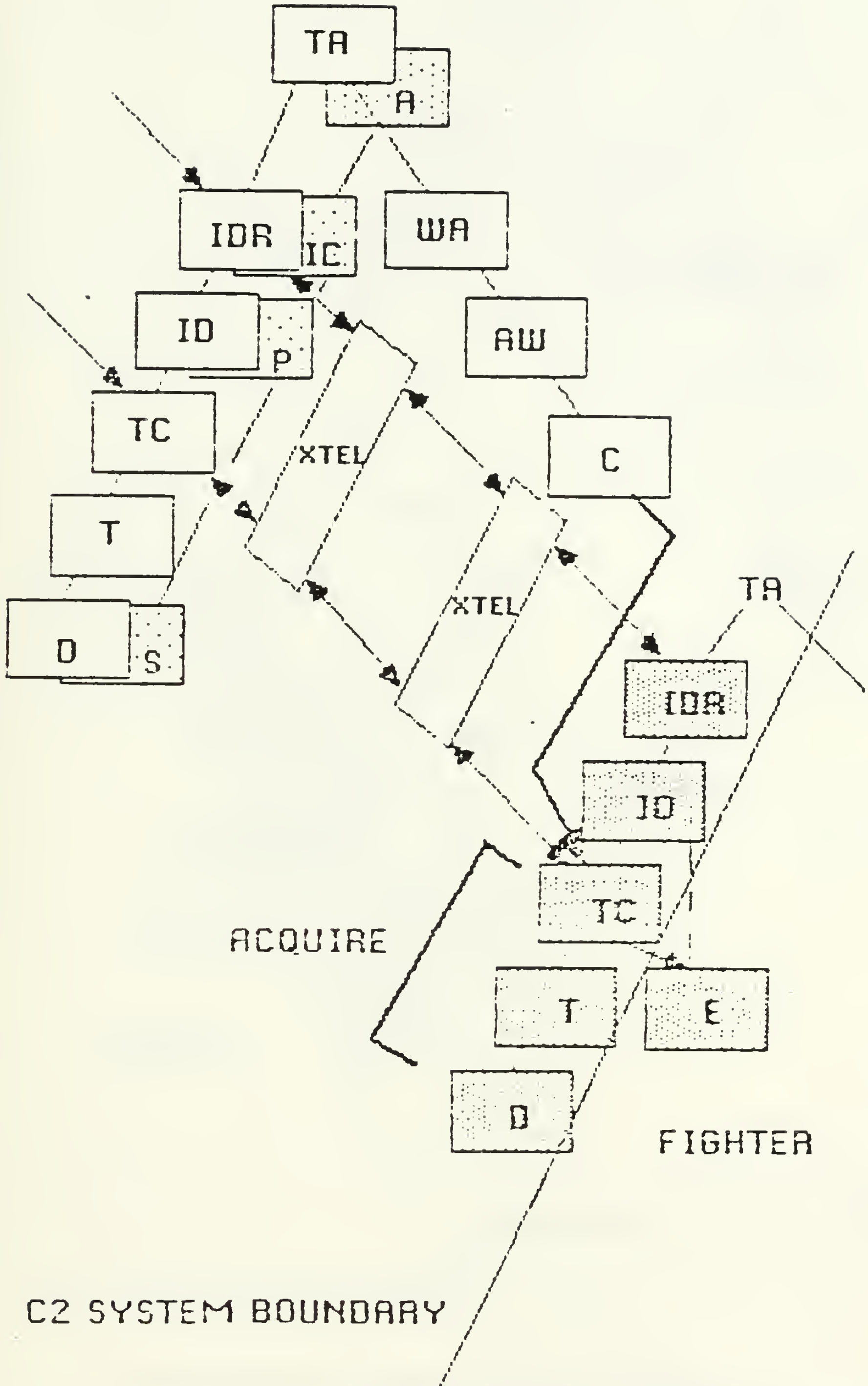
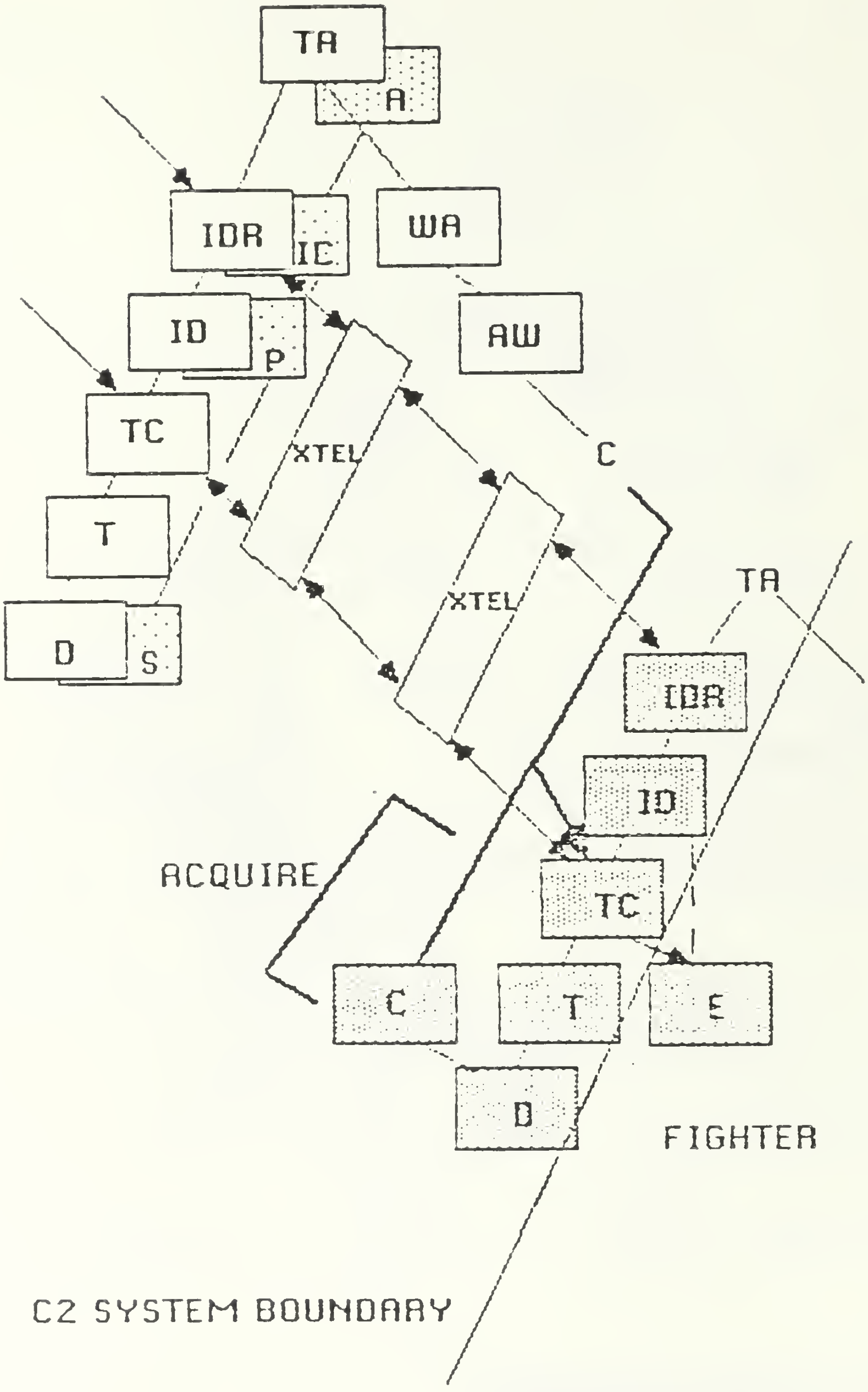


Figure 5.6   CRC Controls Fighter with XTEL Connectivity



CONTROL FUNCTION HAS
MIGRATED TO WEAPON SYSTEM

Figure 5.7 CRC Allocates Fighter with XTEL Connectivity

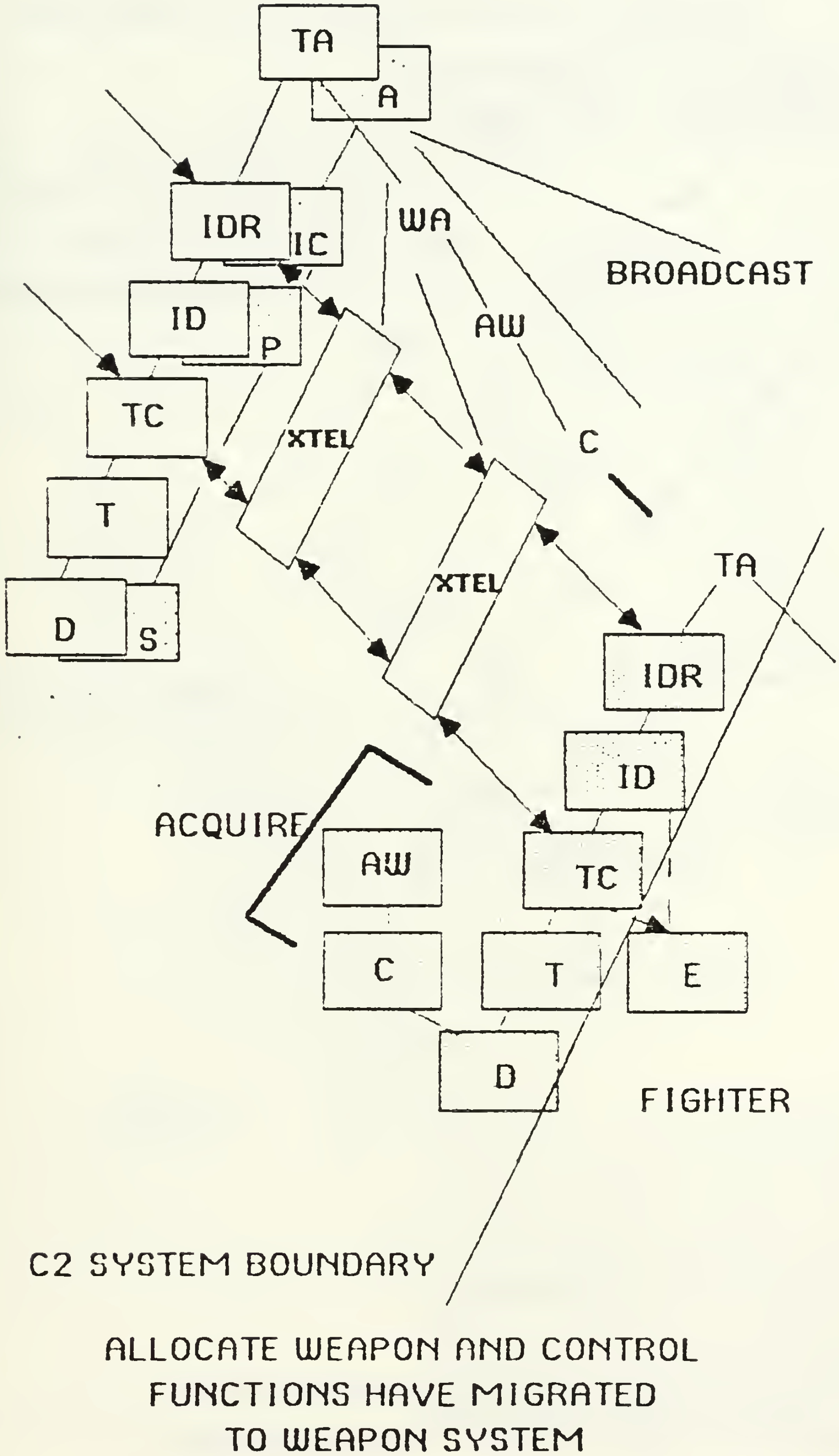


Figure 5.8 Fighter Allocates/Controls with XTEL Connectivity

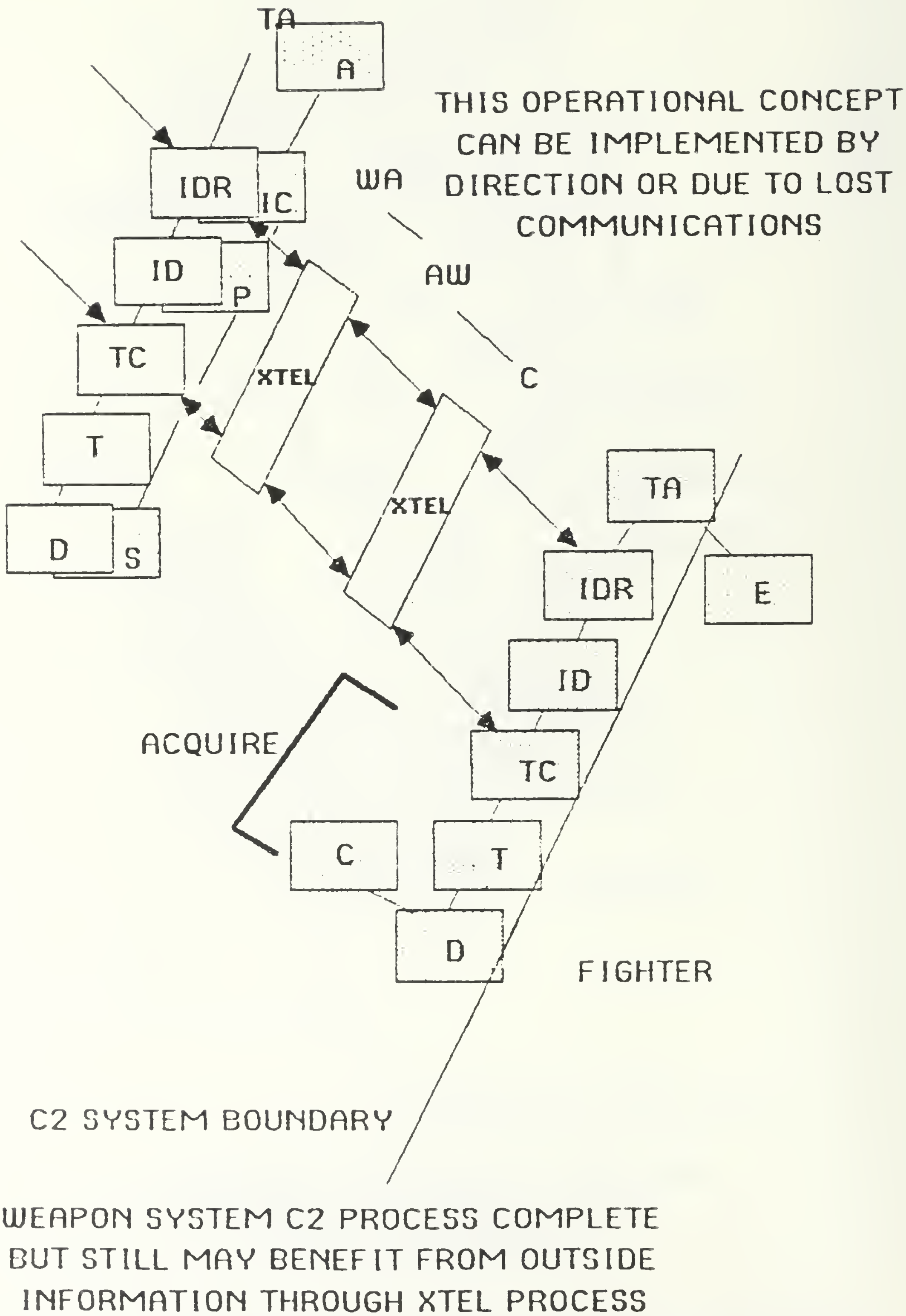


Figure 5.9 Complete Fighter C2 Process with XTEL Connectivity

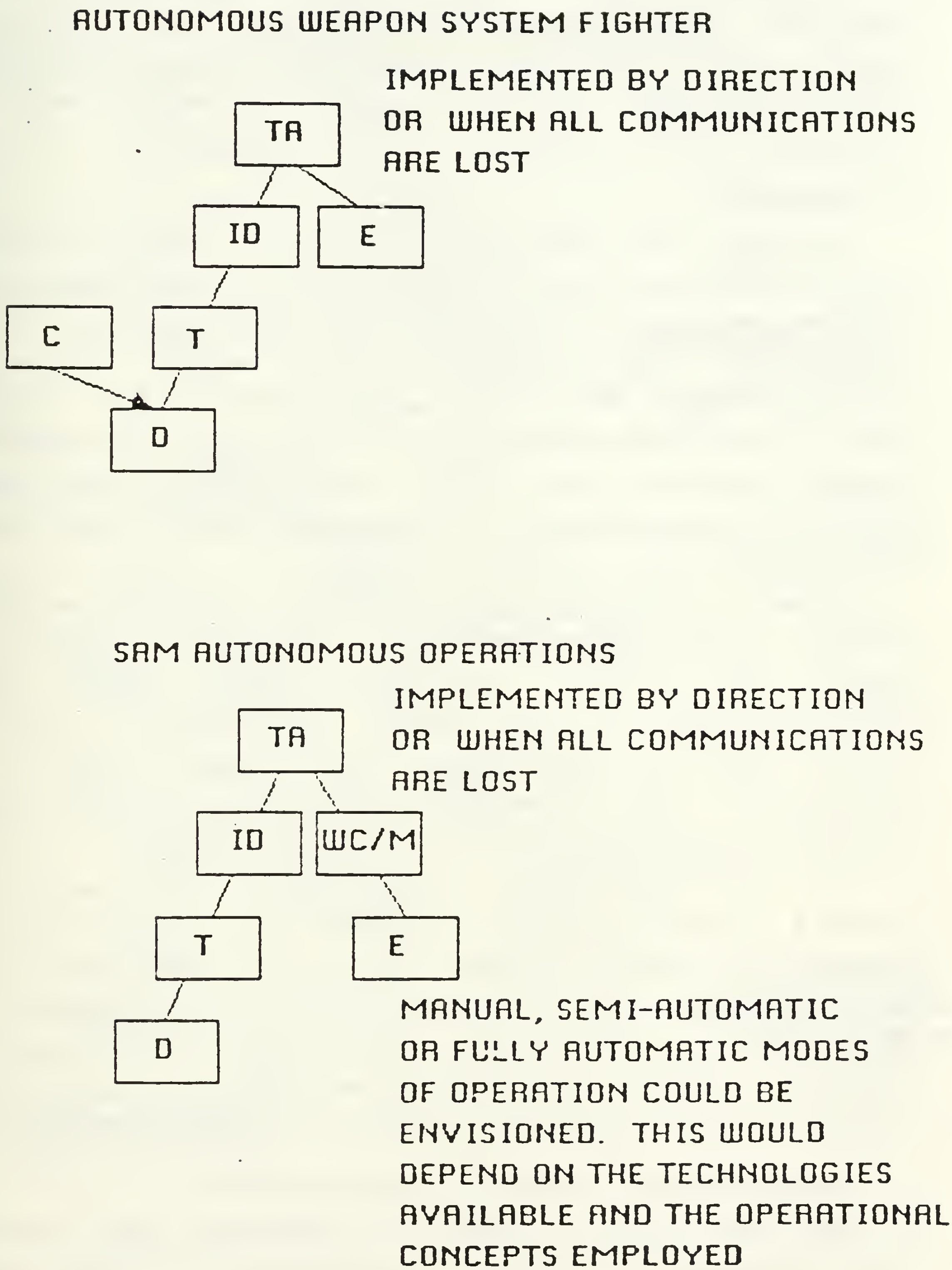


Figure 5.10 Fighter and SAM Autonomous Operations

system. This operational concept may be employed by direction of higher C2 authorities or due to disruption in communications. When all communications are cut off from a weapon system, that weapon system is operating autonomously and it constitutes its own C2 system. Figure 5.9 and 5.10 illustrates these concepts.

E. FEEDBACK

So far we have considered command and control as a one way information flow, but intelligent battle management will require feedback from the force to the C2 system. This feedback will report battle outcomes, weapons status and other operational limitations such as fuel status. Within the C2 system this information can be used for immediate tactical decisions and longer range strategic decisions. Figure 5.11 illustrates the information flow for this feedback from the force to the C2 system.

To some degree this information will trigger immediate tactical responses from the C2 system if circumstances permit. For example, interceptor A cannot accept target pairing because he is low on fuel. Interceptor B is available and has the fuel to make an intercept. This is an example of a tactical decision being made at a lower level in the C2 structure by substituting interceptors.

If immediate tactical capabilities do not exist to handle a situation, the information continues to pass up through the command structure. As many of these reports may be passed upward, an integrated picture of the situation can be constructed. This will allow higher level decision makers to consider committing more resources, or passing warning to facilities that may face an imminent air strike.

F. INTERNAL PROCESSING WITHIN THE FUNCTIONS

The last task in our modelling effort is to find some way to describe the internal processing at the functional

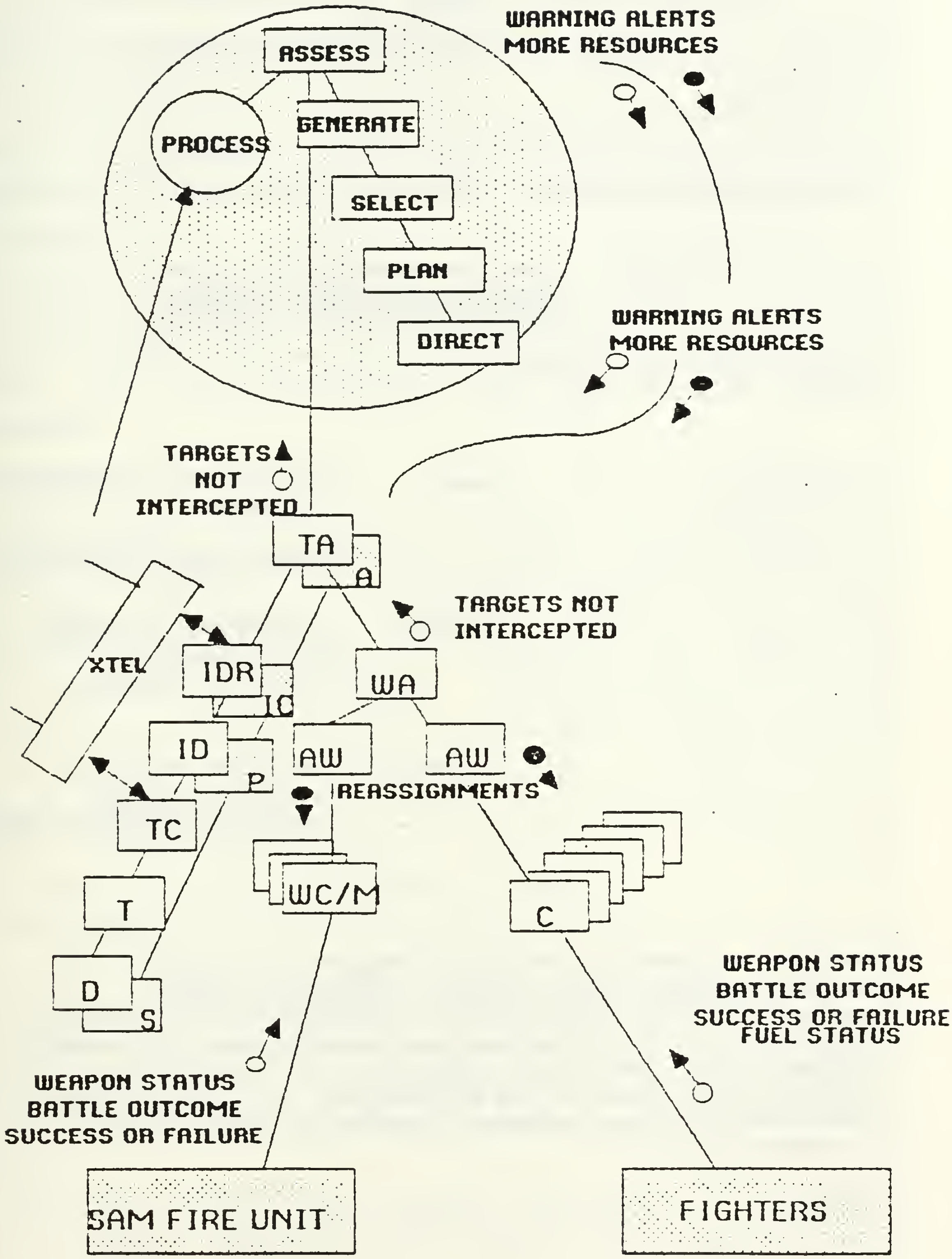


Figure 5.11 Feedback Information Flow

TABLE 2

ASSESS THREAT MODULE DESCRIPTION

TITLE: ASSESS THREAT (THREAT ASSESSMENT)

PURPOSE FORM PERCEPTION OF SITUATION AND DETERMINE WHICH THREATS ARE MORE IMPORTANT TO ENGAGE

INITIATOR: COMMANDER

COUPLING:

INPUT: IDENTIFICATION INFORMATION ON TRACKS

HIGHER ECHELON PRIORITIES

OUTPUT: TO WEAPONS ALLOCATOR ENGAGE TARGETS IN SPECIFIC ORDER

FEEDBACK: TO HIGHER ECHELONS UNABLE TO ENGAGE SPECIFIED NUMBER OF THREAT

PROCESS: USE CONSOLE CAPABILITIES AND OR JUDGEMENT TO DESIGNATE TARGETS FOR ALLOCATION CONSIDERING HIGHER ECHELON PRIORITIES. (THIS CAN BE A VERY DETAILED EXPLANATION, WHICH LISTS THE PRIORITIES AND RULES FOR APPLYING THE PRIORITIES. CONSOLE CAPABILITIES TO AID PROCESSING AND COMMUNICATE THE OUTPUT AND FEEDBACK CAN BE SPECIFIED. ALL THIS WILL HAVE A BEARING ON HOW FAST AND HOW ACCURATE THE FUNCTION CAN BE ACCOMPLISHED).

level. For example; what rules are used by the ID officer use to fuse information to make an identification? If several sources of information are used, what weight does he give to each piece of information? It would be impossible to put this kind of information on the structure chart. However, our chosen design tool provides for a module description, which will allow us to describe this internal processing.

The module description does several things. It allows one to provide details on internal processing, describe coupling and the purpose for each function. Table 2 is an example of a module description for the function THREAT ASSESSMENT.

G. SUMMARY

This section completes our C2 theory. The relationship between "processes," "physical entities," and "structure" have been explained. A specific design tool "Data Flow-Oriented Design", has been introduced and applied to the air defense C2 system model. It has allowed us to show the structure between man and the structure between machines by describing process input ,output , and feedback in hierarchical relationships. The design tool also provides for a detailed module description, which allows a detailed description of internal processing rules.

The concept of a null process eliminates confusion as to who is performing which function in the C2 process. This is provides a means to account for the redistribution of C2 functions to different "physical entities" when operational concepts are changed. The resulting C2 response (time, accuracy) may change depending on which entity performs the function.

The next section will use the air defense C2 systems model to develop measures which determine the effectiveness of the C2 system.

VI. MEASURES

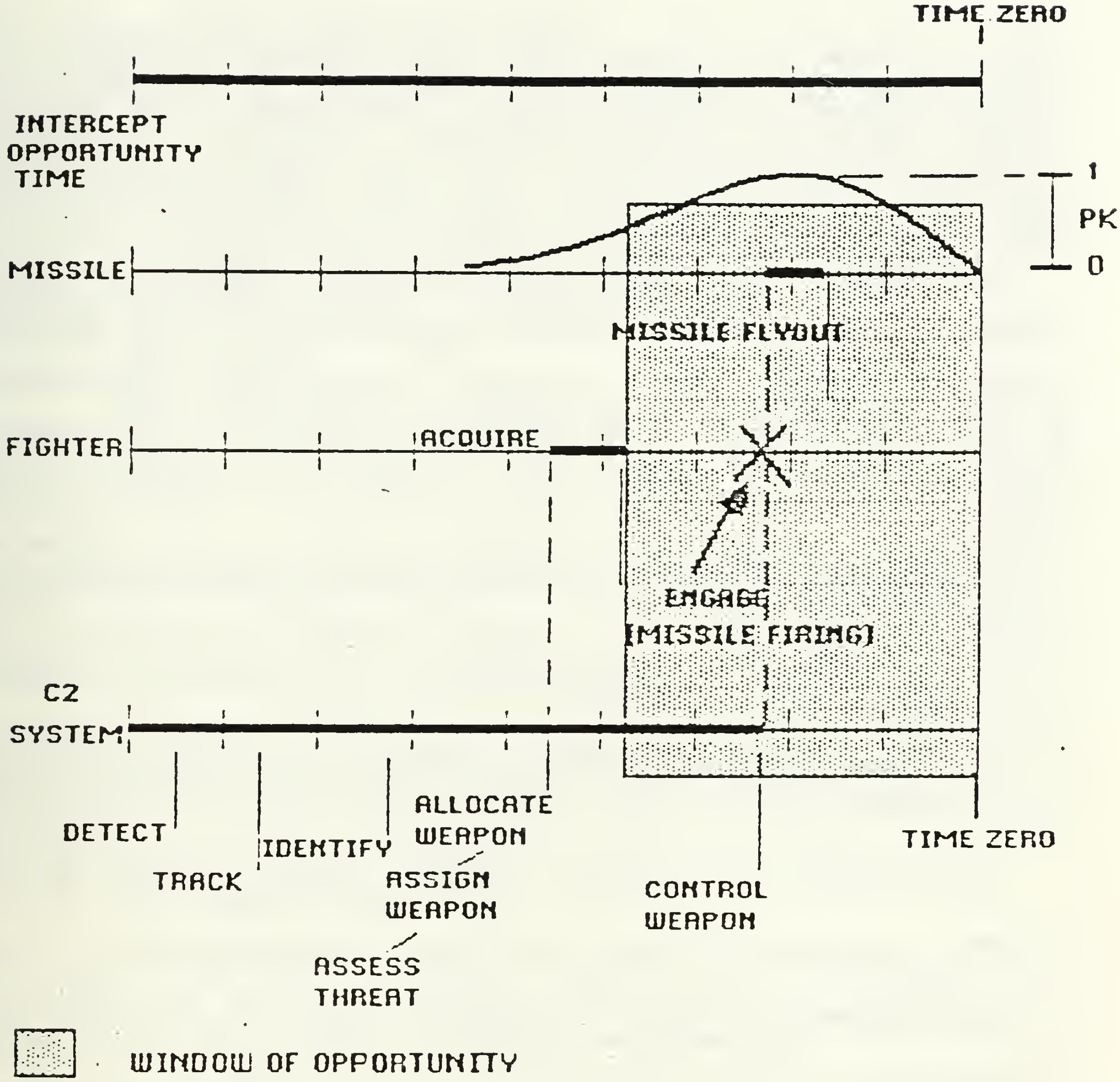
A. OVERVIEW

The Identification Friend, Foe, Neutral (IFFN) Joint Task Force (JTF) has developed numerous measures of effectiveness for evaluating an air defense C2 system. This thesis will not attempt to reinvent these measures. Instead, the IFFN measures will be examined for their completeness by using the C2 system model developed in the previous section. The model will also be used to develop new measures where existing measures do not exist.

B. MEASURES OF EFFECTIVENESS (MOES)

A good starting point for developing measures is to look at the C2 process. Remember the C2 process is a group of functions, which are required to control the force within the environment. The functions that make up this process are DETECT, TRACK, IDENTIFY, ASSESS THREAT, ASSIGN WEAPON, ALLOCATE WEAPON and CONTROL. If you can measure capabilities to do all the functions, this represents a measure of your ability to control the force within the environment. Thus, the ability to perform the entire C2 process is measured by a set of measures of effectiveness (MOEs) for the C2 system. These measures will be taken outside the C2 system boundary.

The effect of the last C2 process function, CONTROL, can be measured by looking at how that CONTROL function allows fighters to be vectored into firing positions while passing target information for weapons acquisition. This can be verified by doing a mission analysis to find the relationship between the C2 process and the weapon system force functions. Figure 6.1 is a time line analysis of a typical air defense profile. The control function on the C2 time



ACQUIRE TIME WILL VARY DEPENDING ON APPROPRIATE CONTROL DIRECTION FROM WEAPONS CONTROLLER , PILOT RADAR SKILLS AND RADAR CAPABILITIES

INTERCEPT TIME AVAILABLE DEPENDS ON RELATIVE FIGHTER AND TARGET POSITIONS AS WELL AS THE TARGET COURSE AND THE INTERCEPT COURSE. TARGET MANUEVERS CAN SHRINK TIME AVAILABLE BEYOND THE CAPABILITIES OF THE PILOT TO CORRECT WITH SUBSEQUENT CORRECTED INTERCEPT COURSE

CONTROL TIME EXTENDS UNTIL THE MISSILE IS FIRED ALTHOUGH THE PILOT CAN EXERCISE HIS OWN CONTROL AFTER HE HAS ACQUIRED THE TARGET. SOME OPERATIONAL CONCEPTS STILL REQUIRE WEAPONS CONTROLLERS TO FOLLOW THROUGH THE INTERCEPT UNTIL MISSILE FIRING AND COMBAT OUTCOME IS KNOWN. THIS IS A WAY OF PROVIDING FEEDBACK TO SYSTEM

Figure 6.1 Air Defense Profile Timeline Analysis line extends to a point where the fighter releases its missile (ENGAGE force function).[13] Therefore, the CONTROL function affects whether a target is acquired and intercepted by the weapon system. The event that signifies that these functions are complete is the missile firing.

The IFFN JTF has developed 9 "Mission Measures," which address whether or not a weapon system fires its missile at a target (friend, foe, neutral) before the target gets through the airspace, releases its ordnance or the weapon system itself comes under attack. These measures are listed below:

- The probability that a hostile attack aircraft will be intercepted before it can release ordnance on target. [Ref. 8: p. V-2]
- The probability that a hostile aircraft of any type will be intercepted, averaged over all hostile aircraft types. [Ref. 8: p. V-2]
- The distance that a hostile aircraft will be allowed to traverse through friendly airspace (measured from some far forward point such as the Fire Support Coordination Line(FSCL) before it is intercepted. [Ref. 8: p. V-2]
- The probability that a friendly interceptor will be intercepted by a friendly weapons system. [Ref. 8: p. V-2]
- The probability that a friendly interceptor will be intercepted by a hostile aircraft. [Ref. 8: p. V-2]
- The probability that a friendly SAM fire unit will be attacked by a hostile aircraft. [Ref. 8: p. V-2]
- The probability that a critical offensive weapon system, such as a friendly deep penetration aircraft, will be intercepted by a friendly air defense weapons system. [Ref. 8: p. V-2]
- The probability that any type of friendly aircraft, other than an interceptor or a deep penetration aircraft, will be intercepted by a friendly air defense weapons system. [Ref. 8: p. V-2]
- The probability that an aircraft of a neutral/non-aligned nation will be intercepted by a friendly air defense weapons system. [Ref. 8: p. V-2]

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[13] Measures of force effectiveness (MOFEs) would show a similar relationship between our force and the enemy by looking at the "battle outcome" at the end of missile flyout. IFFN cannot model missile flyout with enough fidelity to draw conclusions for MOFEs.

C. MEASURES OF PERFORMANCE (MOPS)

Inside the C2 boundary individual C2 functions must be performed to complete the C2 process for any given target. For a single command node we could consider this a chain of probability measures as shown in Figure 6.2 If this chain remains unbroken these individual MOPs contribute to the overall MOE with respect to the given target.

1. The ID MOP

The ID function is of particular importance. It is the dividing line that leads to four basic groups of our mission MOEs. Two of the four groups are "safe passage" measures and "fratricide" measures (see IFFN mission measures 4,7,8 and 9) for friend or neutral aircraft. The other two groups are "leakage" measures (see IFFN mission measures 5 and 6) and "mission accomplishment" measures (see IFFN mission measures 1 and 2) for a given hostile aircraft. The MOPs within the ID function (see Figure 6.2) directly lead to one of the four mission MOE groups at the bottom of the Figure.

2. The ASSESS THREAT MOP

In a tactical sense the idea is to shoot the bad guys and let the good guys go. This implies a simple first come first serve basis for the enemy aircraft. But for the overall warfighting goals some aircraft are more valuable to eliminate given that you have a finite limit on air defense assets. This suggests that the ASSESS THREAT function MOP should have some unknown objective function, which can be optimized by using available resources (allocated weapons) to produce "maximum value destruction" on enemy aircraft. We see this in the operational world as a heuristic when we specify taking out enemy bombers first and enemy interceptors second. Therefore, this function is where more strategic decisions are made within the C2 process. (Commanders and senior controllers typically perform the ASSESS THREAT

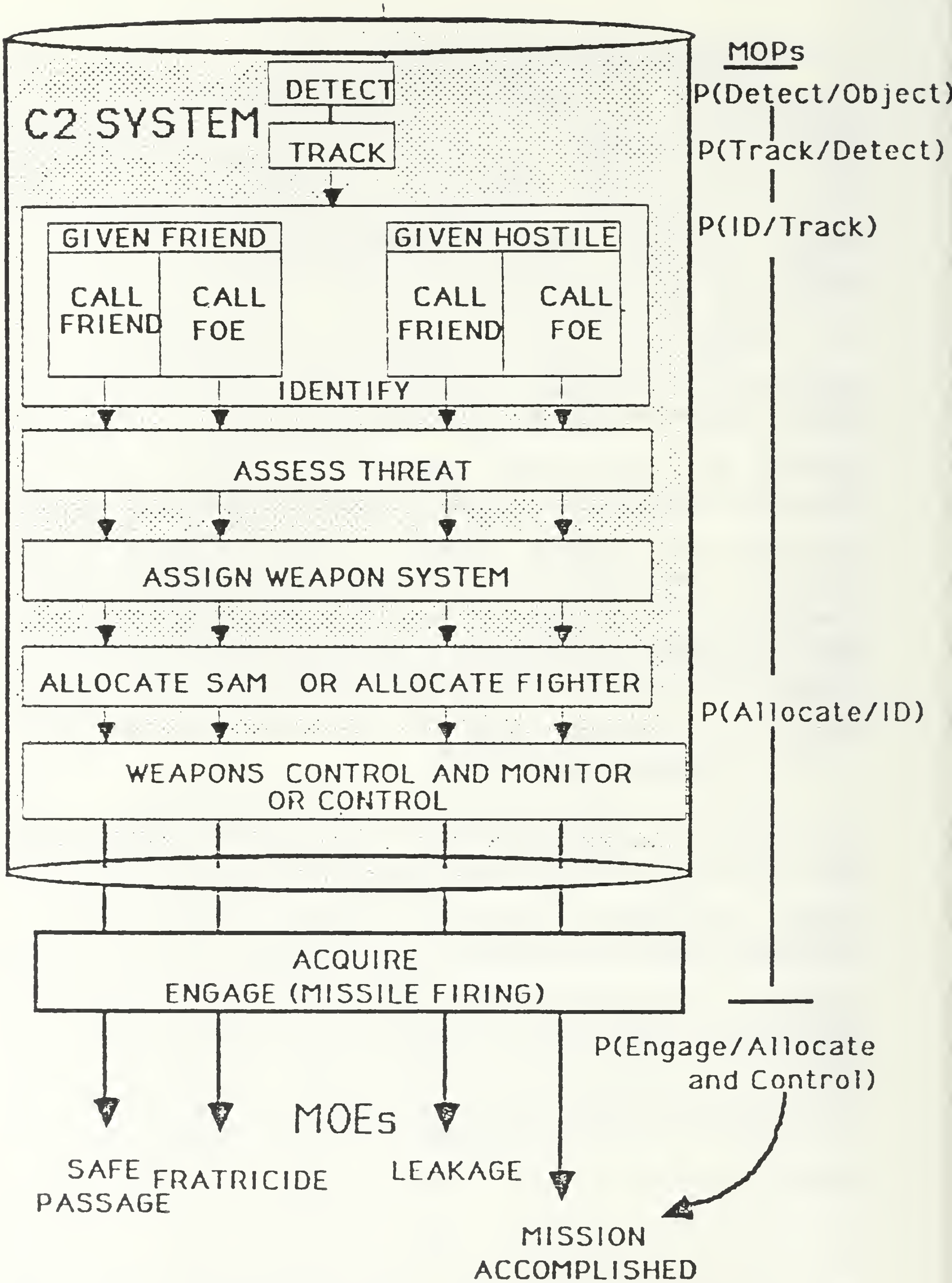

Figure 6.2 Relationship between MOPs and MOEs

function. An Intell interface at this function can shed additional light on enemy objectives to further differentiate the value of engaging specific enemy aircraft).

D. POSSIBLE INTERACTION MEASURES

So far we have only looked at MOEs and MOPs for a single command node. However, our C2 system is composed of many command nodes each with resources and the ability to control them. From this systems perspective we want to optimize resource use between C2 nodes to prevent simultaneous engagements but permit sequential engagements if intercepts are missed. This leads to a "coordination" MOE for optimizing resources and a "reallocation" MOE to prevent the MOP chain from breaking on the C2 systems level. The "coordination" and "reallocation" MOEs are listed below:

- The probability that a target is intercepted by more than one weapon at the same time.
- The probability that a target is reallocated and fired upon given that it was previously allocated to a weapon system, which could not make the intercept.

This measure may have good or bad effects. If one missile is sufficient to destroy the target then the other missile would be considered wasted. If two separate C2 nodes are allocating the target at the same time this may indicate a lack of coordination. However, if a target gets through one layer of the air defense system, the C2 system should be able to reallocate another weapon against the target. To define this measure it will be necessary to go beyond a simple process model and use the C2 system model we developed and synthesized in sections 4 and 5.

E. C2 SYSTEMS MODEL USED AS A FIRST LEVEL "DATA GENERATOR"

The reallocation MOE will require feedback from the weapon systems or controllers to let the weapons allocaters know that an intercept has become impossible due to some constraint (i.e., tactical positioning, enemy maneuvers, fuel limit).

Several events should be defined to support this measure. (Events will fall into one of three categories. They are defined by some ouput from a function, an acknowledgement to instructions, or some action The examples for the "reallocation" MOE will fall into one of these categories). The following discussion demonstrates how these events can be derived from the C2 system model.

First, let's conFigure the C2 system model to conform to a centralized operational concept placing fighters and SAMs under the control of Control and Reporting Center (CRC). The SAMs will generally intercept targets in a forward area and the interceptors will take care of targets in the rear area. However, this is not a hard and fast rule. Therefore, targets that are initially given to SAMs should be reallocated to fighters if they get through. Figure 6.3 illustrates the C2 system model and geographic representation of the situation. The following list of events support the proposed measure:

- Events (1),(2),(3) represent allocation of the target to SAMs through a distributed decision structure in the CRC. This could be considered one event, ALLOCATION.
- Event (4) represents feedback such as target got through. Event (5) relays the same information to the central weapons assignment officer.
- Events (6) and (7) represent the reallocation of the target to fighters. Again this may be a distributed decision structure.
- Events (8) and (9) represent acceptance of the allocation by controller and interceptor.

The preceding events were C2 events. The following force events (friend and foe) are also required to accurately define the measure:

- Event (10), the target enters SAM engagement zone.
- Event (11), the target exits SAM engagement zone.
- Event (12), the target enters fighter engagement zone.
- Event (13), the fighter fires on target.

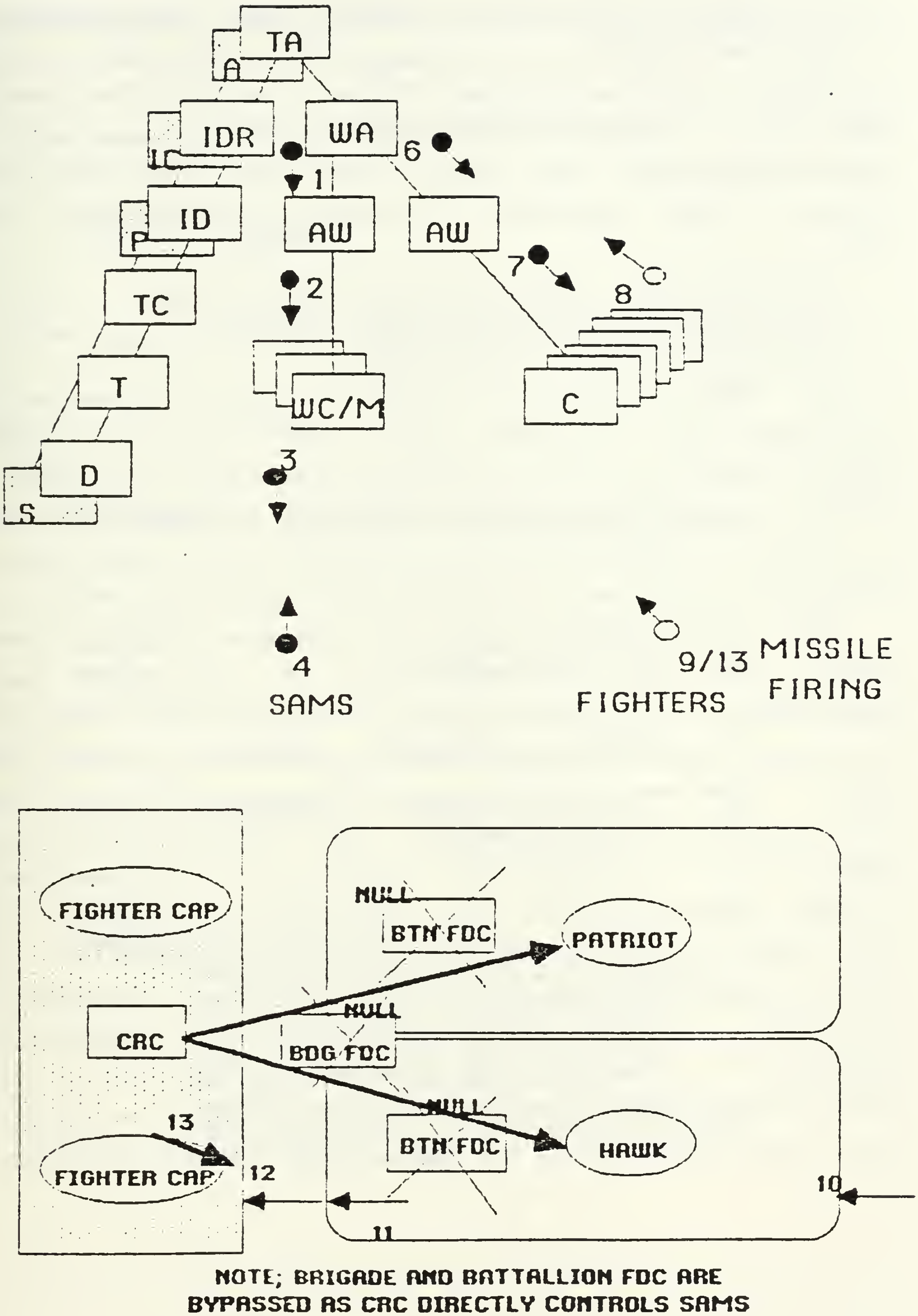

Figure 6.3 Events Required for Reallocation

F. C2 SYSTEMS MODEL USE AS A SECOND LEVEL "DATA GENERATOR"

For test purposes it is important to describe in detail how these events are driven. Let's examine the feedback event (4) by looking at a hypothetical module description at the SAM fire unit. See Table 3 for the ENGAGE force function at a SAM fire unit. The key questions are listed below:

- When does the intercept become impossible?
- How to alert higher echelons that the target will get through?

The answer to the first question could be answered from the Process section of the module description for the SAM's ENGAGE function. (The SAM force functions are ACQUIRE and ENGAGE) This section would describe how to engage the target by stating launch parameters so that the man-in-the-loop can determine if necessary conditions for launch are met.[14]

The second question could be answered by the Process section and the Coupling section of the ENGAGE module description. The Process section would describe what action the weapons operator takes when the intercept becomes impossible. Some possible alternative options are cancel intercept and alert higher echelon. The Coupling section would describe how the feedback of such action is communicated. This may require a phone call or perhaps the machine interface allows an alert to pass from console to console, which calls attention to the missed target. It is important to understand how this is done, because the response time through the system will be affected by these man-machine interactions. This knowledge of the options also let's you define the events which are required for data generation.

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[14]Typically weapon systems can display range parameters to aid a human decision maker.

TABLE 3

ENGAGE MODULE DESCRIPTION

TITLE: ENGAGE

PURPOSE ANALYZE SHOT OPPORTUNITY AND COMMIT WEAPON

INITIATOR: WEAPON SYSTEM OPERATOR

COUPLING

INPUT: ALLOCATION TO ENGAGE TARGET

OUPUT: ALLOCATION ACCEPTANCE

FEEDBACK: BATTLE OUTCOME SUCCESS OR FAILURE

PROCESS: USE WEAPONS DISPLAY TO DETERMINE IF SHOT OPPORTUNITY IS WITHIN WEAPONS PERFORMANCE PARAMETERS. TYPICALLY THIS WILL BE SOME COMBINATION OF RANGE AND RANGE CLOSURE RATE BETWEEN OWN FORCE AND ENEMY FORCE. FIGHTERS MAY CONSIDER THEIR CAPABILITY TO MANEUVER INTO THESE PARAMETERS. IF PARAMETERS CANNOT BE MET DO NOT COMMIT WEAPON AND NOTIFY CONTROLLING C2 ELEMENT.

G. INTERIM SUMMARY

Let's quickly recap the discussion on measures. The IFFN mission MOEs were examined with a time line analysis to show the relationship between the C2 system and the weapon system. These mission measures conform to our section 2 definition of an MOE.

A strait forward analysis of the C2 process showed that an accuracy MOP for the ID function would lead to different mission MOE groups. Another C2 process function, ASSESS THREAT, was looked at in terms of its contribution to strategic decisions within the C2 process. A linear programming approach was suggested for finding an MOP to quantify the contribution of the ASSESS THREAT function (MCES WORKSHP).

However, these MOEs and MOPs could be derived from a single C2 node or by considering the entire C2 system without any interaction. Therefore, two new measures were offered which described some of the possible interactions between the individual C2 nodes within a larger C2 system.

At this point it became necessary to move from a simple process model view of the C2 system and use the C2 systems model developed in sections 4 and 5 to show the interactions. This C2 systems model was used at two levels. The first level described the interaction between nodes or weapon systems. The second level (Module Description) let us look at the internal processing and communications capabilities (coupling) for individual C2 or force functions.

In the rest of this section we will use the C2 systems model to address some representative issues from those given in section 2 of this thesis. We will freely move from the first and second levels of the C2 system model to look for interactions and define the internal processing necessary to support the functionallity of the C2 system.

H. ID INTERACTION EFFECTS THROUGH THE XTEL PROCESS

If you consider the entire C2 system C2 nodes are interconnected with voice links to decision makers and by the XTEL process to share target information. (Voice links will provide another dimension for measurement as these links can affect the ID process and weapons control process. However, they will not be discussed in this thesis). These interconnections will produce effects that alter the MOPs for the C2 functions of any individual node. As an example the XTEL process is designed to strengthen the identification performance at individual C2 nodes by sharing information throughout the C2 system. The key measurement issues are listed below:

- Is indirect ID information more accurate?[15]
- Is indirect ID information delivered to the right place in time to be used?
- Is the indirect ID information accepted when it is better?
- Will indirect ID information be rejected if the information is not as good as direct information?
- Is fused ID information (direct and indirect) more accurate?

The intercept time avaliable will place a time constraint on the C2 system to perform the identification function. Therefore, an individual C2 node will use its own organic (direct) information when C2 system information cannot be delivered in time. Thus, the C2 node can be viewed as operating by itself or interconnected with the C2 system, depending on time constraints for each target. Figure 6.4 is a data flow diagram, which illustrates these concepts.

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[15] "Indirect identification refers to the determination of the identification category of an observed aircraft using information that is relayed to the user from an indirect source, such as the C2 network. Note that direct identification information gained from a direct source becomes indirect identification information when it is passed through the C2 network to other users." [Ref. 8: p. 3]

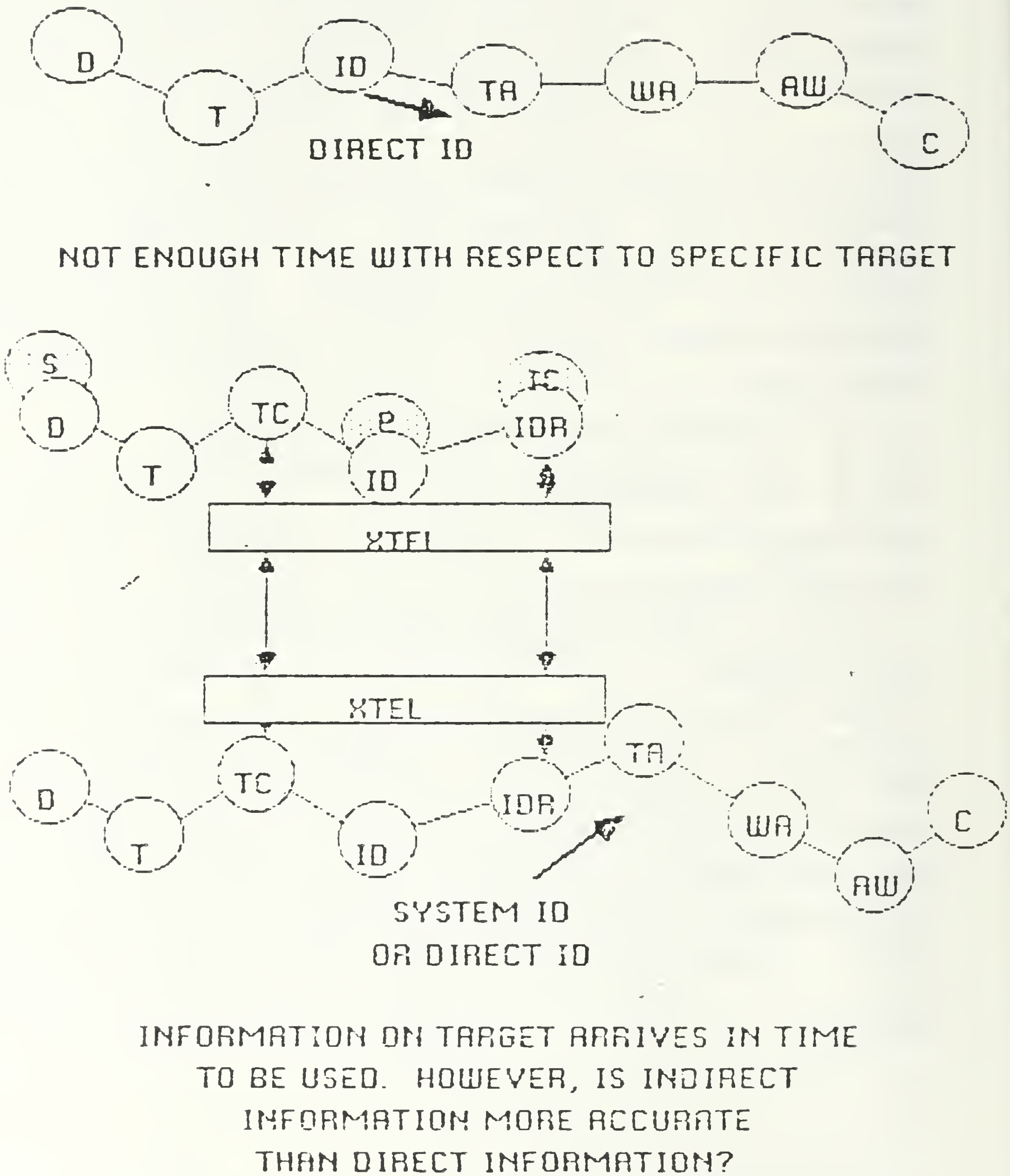

Figure 6.4 ID Interaction through XTEL Process

1. <u>Direct ID Information Accuracy MOPs (IDA)</u>

The Institute for Defense Analyses (IDA) has proposed several measures to address the indirect identification issue. This has been done by proposing accuracy measures for both indirect and direct ID information for the purpose of comparison. Their MOP for direct ID is listed below:[16]

- P(Identification category given true identity) [Ref. 8: p. V-17]

This is an MOP for ID using direct ID information, which has been developed by the C2 node which is currently being evaluated. This measure is really four measures, which are generated by contrasting what the target is classified as (friend/neutral or foe ops category) compared to what the target really is (friend/neutral or foe). Figure 6.2 illustrates these four categories.

2. <u>Indirect ID Accuracy MOPs (IDA)</u>

For indirect ID information IDA has proposed the following accuracy MOP:

- P(Passed identifications are correct) [Ref. 8: p. V-19]

This MOP is also four measures. However, this time the measures address the accuracy of indirect ID information being received through the XTEL process at the C2 node being evaluated.

3. <u>Relative Timeliness of Indirect ID Information</u>

The second issue concerned the timeliness of the indirect information. The issue is restated below along with a measure from IDA Paper P-1765:

- Issue: Is indirect information delivered to the right place in time to be used?
- Measure: P(Identification includes amplifying information) [Ref. 8: p. V-19]

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[16]All measures specify that assigned ID category for target entering measurement volume is not "pending", "unknown" or "evaluated unknown" before target exits volume, allocation acceptance or target destruction by another unit. [Ref. 8: p. V-19]

However, this measure only partially addresses the timeliness issue. If we carefully examine the events that make up this measure, we find that the measure includes ID information which is not used. For example, if the ID information arrives before the target exits the measurement volume or another unit destroys the aircraft it is counted in the denominator of a probability measure. If a target only briefly enters the measurement volume and exits the usefulness or value of the information is questionable.

On the other hand, if the C2 node had ample opportunity to make an intercept before the target exited the measurement volume, then the information would be considered useful. Therefore, the problem is to reasonably define "intercept opportunity." But this could be difficult to do.

Another way to treat this problem is to limit the events, which define accuracy and timeliness measures. In these measures, eliminate targets that enter and exit the measurement volume and targets that enter the measurement volume and are destroyed by another unit. So we now define the accuracy measures to include only those targets that are classified as hostile and subsequently allocated. This cuts out two of our four "accuracy" MOPs for the ID function. But at least we know the information was useful for the C2 node being evaluated.

We can measure ID accuracy for measures which lead to fratricide or mission accomplishment. We can also measure whether an indirect ID arrived in time to be used for a target which was allocated as a hostile. These three measures are listed below:

- P(Hostile Ops Category/Hostile)
- P(Hostile OPs Category/Friend or Neutral)
- P(Hostile identifications contain indirect ID information)

The first two measures can be taken for both direct and indirect ID information. The third measure now gives us some idea if the indirect information arrived in time. However, we still do not know enough about how this information is used at the C2 node receiving the indirect information. Therefore, we will look at the remaining issues by proposing a second level look at the C2 system model.

I. ID CONFLICT RESOLUTION ISSUES

The remaining three issues concerned accepting, rejecting or fusing the indirect ID information. We need to know much more about the internal workings of the C2 system model to address these issues. We need to know answers to questions like:

- How is indirect and direct ID information used?
- Does the ID officer choose between direct and indirect information if time does not permit ID conflict resolution?
- Does indirect ID information influence the direct ID made by the ID officer?
- Does a machine choose between direct or indirect ID based on a quality index, which is piggybacked to the ID information travelling through the XTEL process?
- How often does a man override machine decisions?
- Can ID information from multiple sources be sampled and fused together to produce a single ID?

Answers to these questions would provide the rules (algorithms), which describe the internal processing of the ID CONFLICT RESOLUTION (IDR) XTEL process function. See table 4 for a module description of the IDR function. The Process section of the IDR module description would document these rules. The input and output (Coupling section) to this same module would describe the input and output to the C2 system, which is required to support IDR processing. The XTEL function of the XTEL process would route the output and accept the input form other IDR processes.

To sum it up, these rules define how ID information is used. The rules may be complex or simple. But it is necessary to know what ID information is actually used to allocate weapons. This leads to the following accuracy measure.

TABLE 4

ID CONFLICT RESOLUTION (IDR) MODULE DESCRIPTION

TITLE: IDENTIFICATION CONFLICT RESOLUTION (IDR)

PURPOSE: RESOLVE IDENTIFICATION CONFLICTS BETWEEN DIRECT AND INDIRECT ID INFORMATION

INITIATOR: IDENTIFICATION OFFICER

COUPLING

INPUT: INDIRECT ID (FROM XTEL PROCESS) MESSAGES TO CHANGE ID

OUTPUT: MESSAGES TO RESOLVE ID DIFFERENCE(I.E. REQUEST CHANGE ID OR CHANGE ID) (THROUGH XTEL PROCESS)

INPUT: CHECK ON ID FOR TRACK NO. (FROM TA FUNCTION IN C2 PROCESS)

OUTPUT: RESOVED ID (TO C2 PROCESS TA FUNCTION)

PROCESS: COMPARE DIRECT ID TO INDIRECT ID. INITIATE MESSAGES TO RESOLVE ID CONFLICTS. THERE MAY BE SOME HIERARCHICAL MACHINE STRUCTURE OR ORGANIZATIONAL STRUCTURE WHICH PLACES THE AUTHORITY TO MAKE CHANGES WITH SPECIFIC PHYSICAL ENTITIES. THERE MAY ALSO BE SET RULES OR ALGORITHMS WHICH ARE USED TO RESOLVE THE CONFLICTS.

- P(Hostile Ops Cat used/ hostile)
- P(Hostile Ops Cat used/friend or neutral)[17]

Hopefully, this measure will be greater than direct or indirect accuracy measures. But this depends on the rules that choose between or fuse together indirect and direct information. Figure 6.5 is a partial C2 system model, which illustrates these points.[18]

J. ID INFORMATION VALUE

In the above measures we have introduced a concept of "usefulness" for information, which corresponds to a specific C2 nodes use of ID information. This implies that information has some value. However, we only defined "usefulness" for identification of hostile aircraft. A complete evaluation of the XTEL process, which supports a C2 node, must include a "usefulness" for identification of friendly aircraft. In order to do this you should first define "intercept opportunity" with respect to the target aircraft's position, flight path and the units measurement volume.[19] Friendly force disposition would be excluded from the definition of "intercept opportunity."[20]

1. "Tactical Value"

These concepts define "tactical value" for the ID information with respect to the C2 nodes measurement volume. This "tactical value" only applies to the tactical decision to attack or not to attack a particular air track by weapons

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[17]There is an underlying assumption that these targets are subsequently allocated as hostile to weapon systems under the control of the unit being evaluated.

[18]Clear cut IDR rules may not exist for every type of C2 node (i.e., CRC vs. BDG FDC). The best place to measure the 'ID used to allocate', is at the WEAPONS ALLOCATE function.

[19]Definition of "intercept opportunity" would vary for each unit. No attempt will be made in this thesis to define "intercept opportunity."

[20]This assumes the weapons allocator can use the information given enough resources.

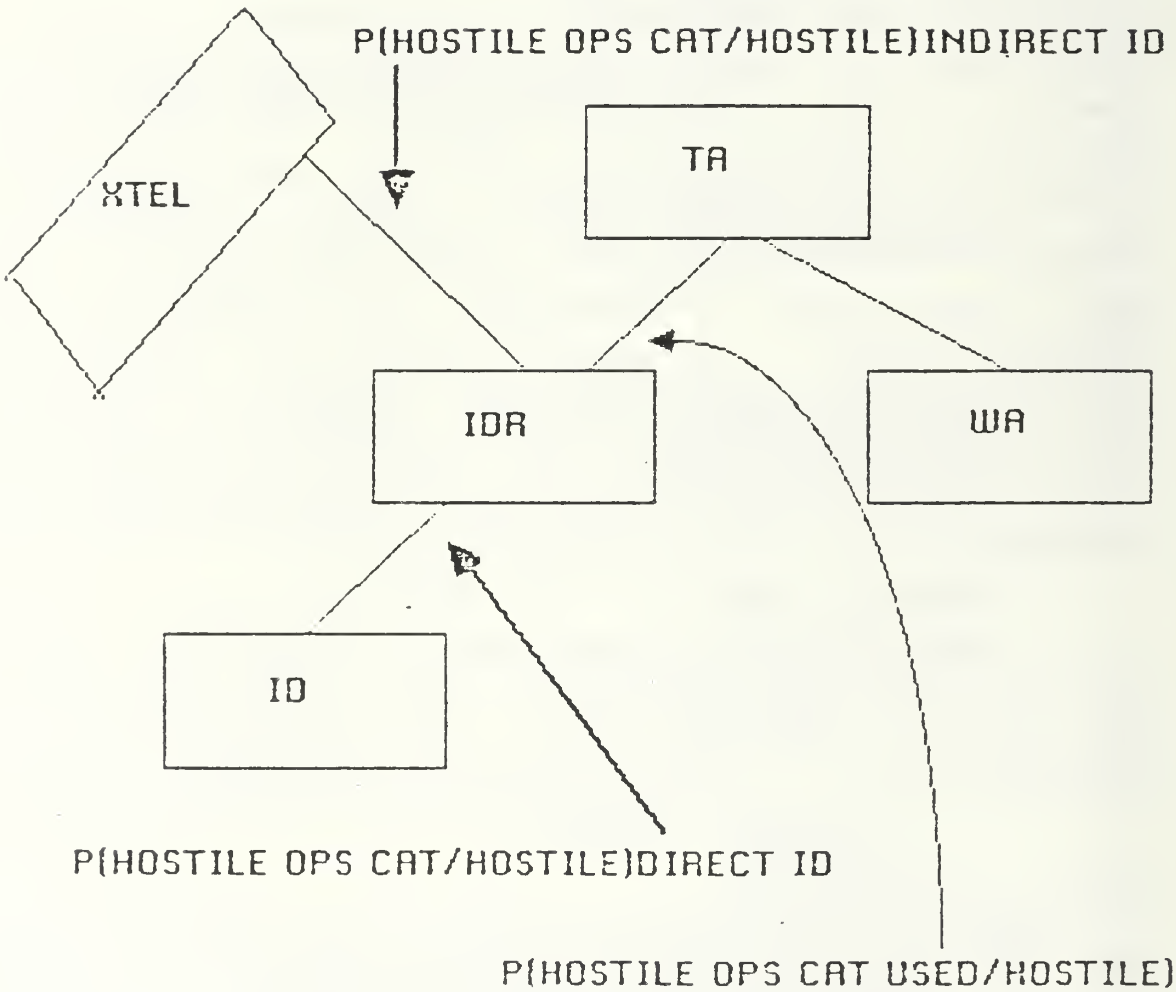

Figure 6.5 Measures for Direct, Indirect and Resolution ID

under the control of the specific C2 node. Furthermore, this value will change as a function of time and target motion. When the "intercept opportunity" no longer exists within a specified measurement volume its tactical value goes to zero with respect to that volume. However, the information on that track still has some "strategic value" for another C2 node, which can use the information to anticipate a tactical "intercept opportunity."

2. "Strategic Value"

The word anticipate implies that some future perception of the environment will be formed. If this anticipation is viewed on a C2 systems level, then many "intercept opportunities" may be anticipated. Consequently, some aggregated response can be formed to take advantage of this future situation. Variables that affect the "strategic value" of ID information are listed below:

- Response time to transfer information
- Where it is communicated
- How well it is perceived
- Geographic placement of sensors
- Capabilities to receive and display information beyond detection ranges.

A candidate measure for strategic ID information is given below:

- P(Indirect ID received before direct detection)

This measure should be applied to each measurement volume down through the weapon system. Probabilities for these measures should be high for small volume sensors and low for larger volume sensors. Figure 6.6 illustrates these ideas.

3. Alert/Warning Measures

To find out the tactical value of this strategic information with respect to a specific C2 node compare the following two measures:

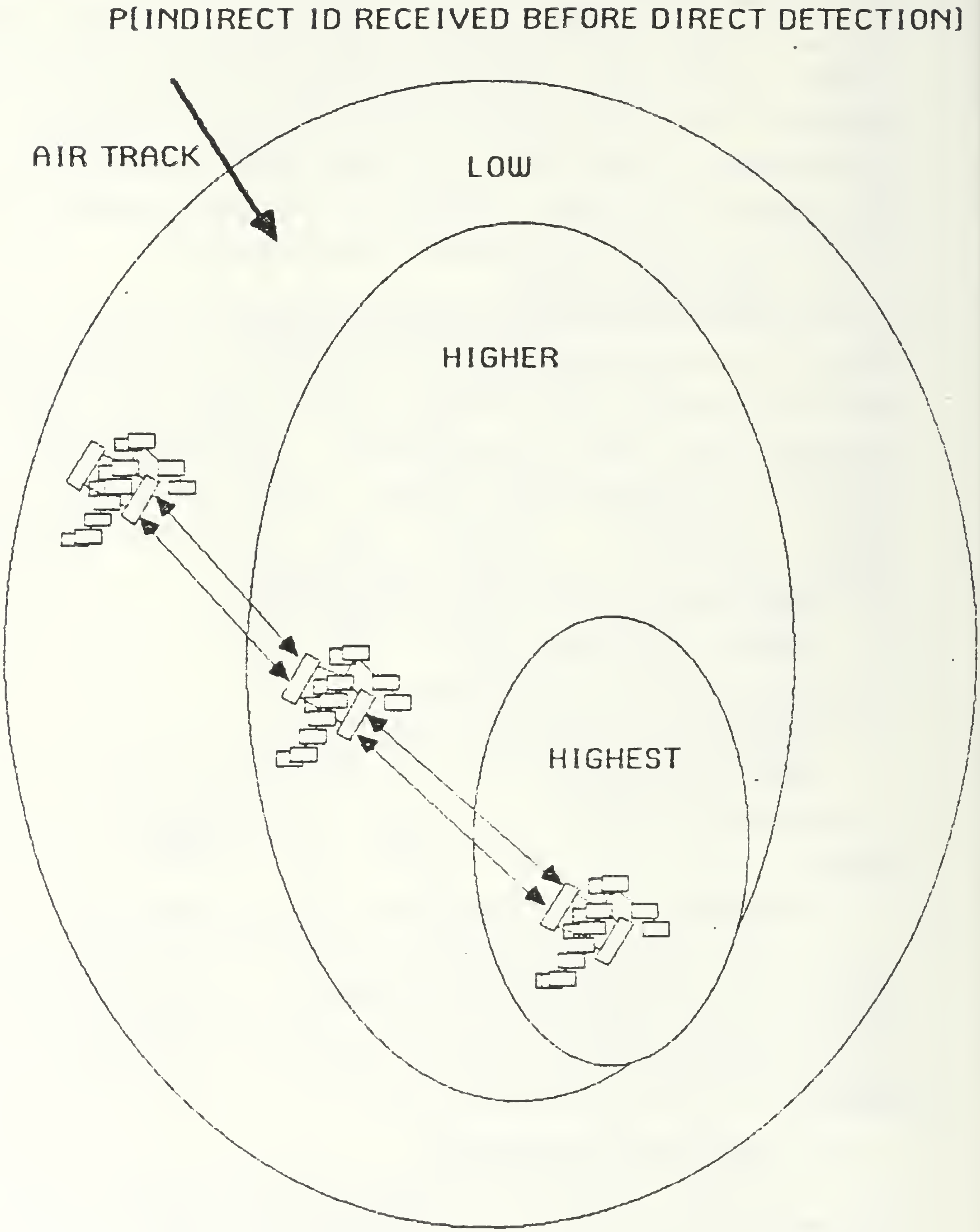

Figure 6.6 Strategic Value of Indirect IDs

- P(Target allocated given indirect ID received before direct detection)[21]
- P(Target allocated given indirect ID received after direct detection)[22]

If the first measure is greater than the second, the ID information provides some warning which increases chances for taking advantage of intercept opportunities.

So far in our development of measures we have looked at the probability of events occurring or not occurring. To some degree these measures have focused on timeliness in a relative sense. For example, the probability that amplifying ID information has been included in the ID for a target says something about the timeliness of that information given that we can show the information was useful (arrived within some reasonable "intercept opportunity" window) and accurate. However, there are other factors which have an effect on these measures.

K. RESOURCES (PEOPLE AND INFORMATION)

The weapons allocator and weapons controller and weapon system can be considered as resources, which must be available during an "intercept opportunity." If they are always available and perform their functions perfectly, then our probability measure would be a timeliness measure only. But we know this is not always the case. Therefore, our probability measures indicate how well the C2 system allows decision makers to use resources within some finite time limit.

1. Resource Use through Structure (The Weapons Control Transform)

The resources we will look at are the information about the environment (ID information) and the people/ machines, which use the information to control weapon

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[21]This assumes an "intercept opportunity" exists for the unit being evaluated.

[22]"Intercept opportunity" must exist.

systems in the environment. We have already looked at the timeliness of ID information. It was considered timely if it arrived in time to be used. Moreover, it could only be used if an "intercept opportunity" still existed when the information was received. A simple way to look at this problem is by breaking down the C2 process into two separate transforms. The first transform produces information. The second transform uses the information. (See Figure 6.7). Both transforms are constrained by time and resources. The following discussion will concentrate on the second transform.

L. AFFECTS ON RESOURCE USE THROUGH ALTERNATIVE STRUCTURES

Decision makers can affect how information is used through the "structure" of the organization by distributing functional tasks through that organization. In the second transform the following C2 process functions are performed:

- ASSESS THREAT
- ASSIGN WEAPON
- ALLOCATE WEAPON
- CONTROL WEAPON

The following resources are available to use ID information to perform these functions:

- Senior Controller
- Weapons Allocater
- Weapons Controllers
- Weapon Systems Operators and Weapon Systems

The C2 functions can be distributed through these "physical entities" (people and equipment) to provide optimum and timely control of weapons given the current threat situation. A hypothetical structure of a C2 organization performing these functions is illustrated in Figure 6.8 This particular example is confined to control of aircraft, therefore, the WEAPON ASSIGNMENT function will not be considered.

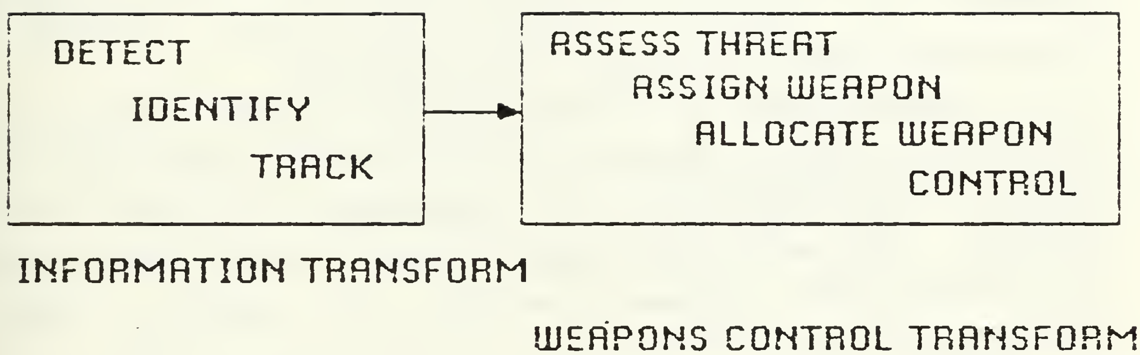

Figure 6.7 The Information and Weapons Control Transforms

1. The Weapons Control Transform as A Multi-phase Queue Model

This organizational structure can be viewed as a multi-phase queuing model using information to first ASSESS the threat, ALLOCATE weapons against the threat and finally CONTROL weapons to destroy the threat. A senior controller is performing a ASSESS THREAT function. He prioritizes the targets that will be allocated first. A single weapons allocator performs the ALLOCATE WEAPONS function. His queue is formed by the output from the senior controller. His output forms the queue for the CONTROL function, which is handled by 6 parallel weapons controllers. Figure 6.8 illustrates this multi-phase queuing model.

This queue is limited by the weapons controllers. They cannot accept allocations for more targets until they finish controlling aircraft currently allocated against targets. Even if you add more aircraft, more control cannot be provided until present intercepts are complete. One way to alleviate the situation is to change operational control concepts. This is done by moving the CONTROL function down to the weapon system operators (pilots). Figure 6.9 illustrates how the queuing model would change to accomodate these concepts. The weapons controllers could aid in the allocation of weapons against targets. Many more weapons could be paired against targets.

a. Queue Measures

The key measures of performance for this multi-phase queue is in the service time (1/u) for the allocation function. In the first model the number of controllers constrained the number of weapons that could be controlled. This artificially increased the allocation service time because controllers could not accept new targets until they were finished with the old ones. In the second model the CONTROL function has been passed to the weapon systems operators. The only constraint on allocation acceptance is the

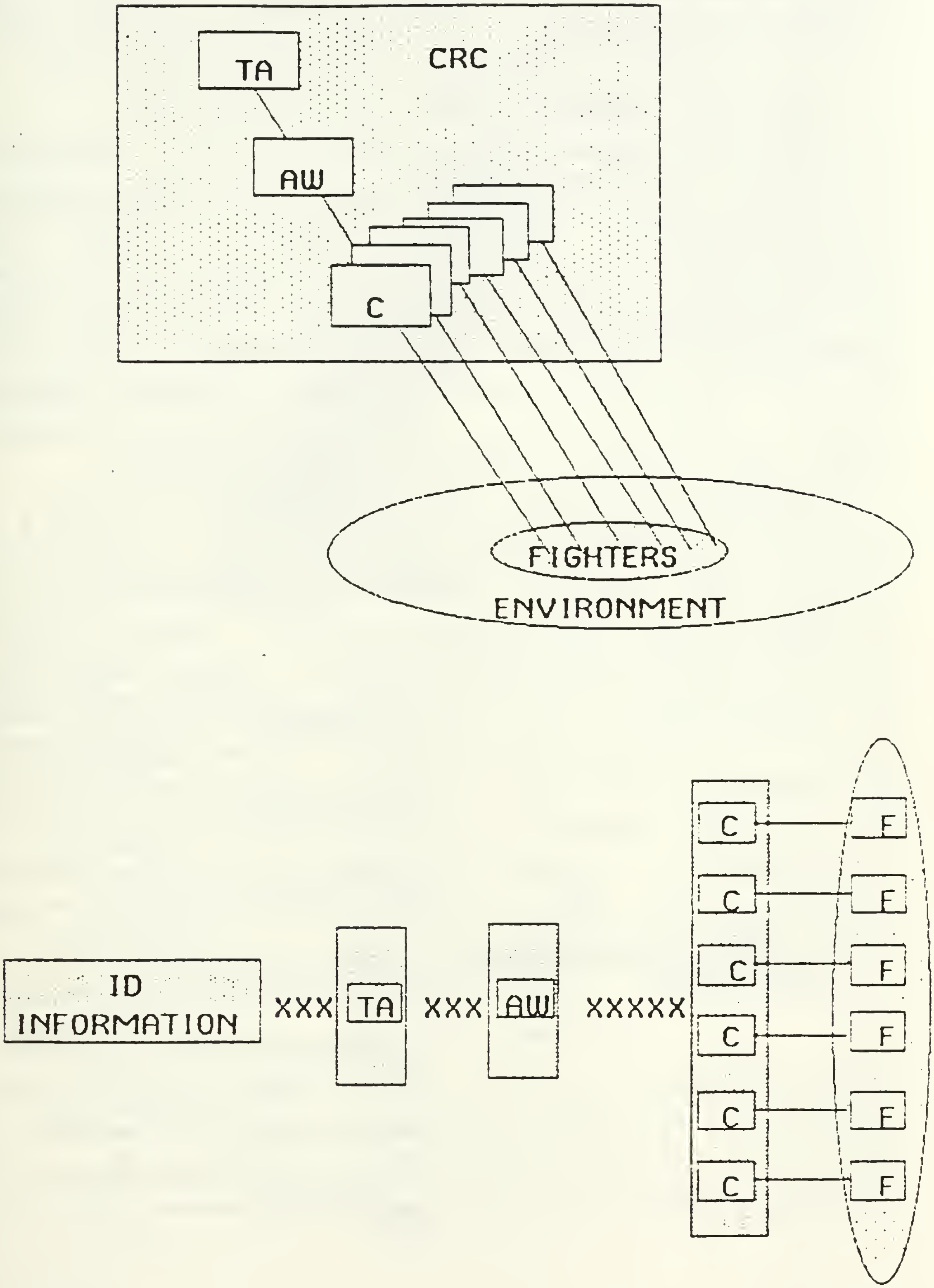

Figure 6.8 Weapons Control (A Multi-phase Queue Option 1)

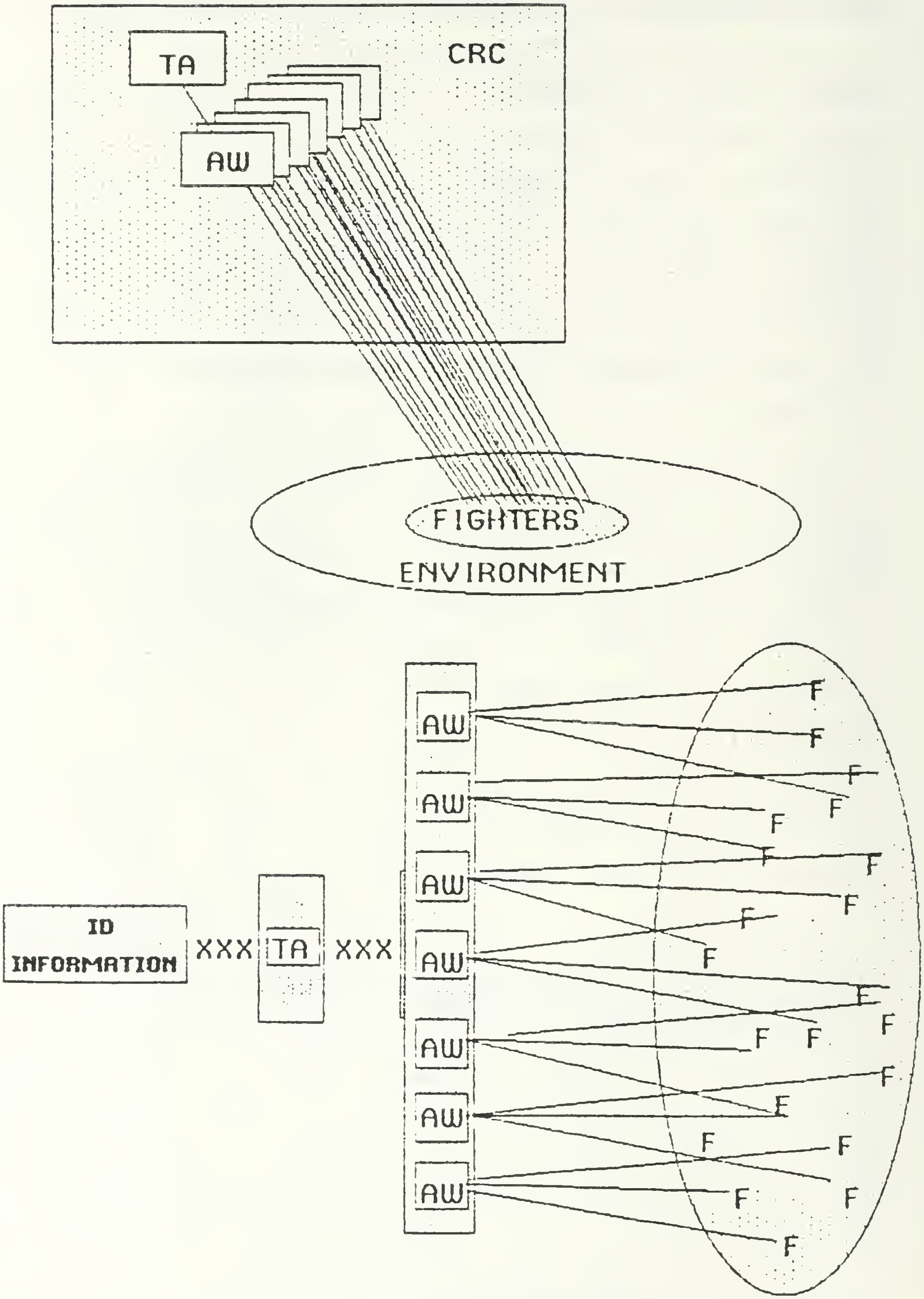

Figure 6.9   Weapons Control (A Multi-phase Queue Option 2)

number of weapon systems available.[23] Therefore, the allocation service time (1/u) is no longer artificially prolonged.

b. Queue Behavior

A few more points should be made about behavior in the queue. If the allocation time exceeds the remaining "intercept opportunity" time, then targets will leave the queue. This is a form of reneging. Because of this behavior, the queue can be very complex to analyze using analytic techniques. Most analytic techniques assume a first-in, first-served (FIFS) queue disipline. Also, these techniques normally assume a poisson arrival rate (M) and an exponential service time(M).

Our queue uses a priority system or even emergency (preemptive priority) system for a queue discipline. Also the arrival rate of ID information (lambda) and allocation service time (1/u) is unknown. However, these distributions for arrival rate and service times can be observed from the IFFN testbed. There are good simulation facilities (separate software programs), which can be used to model the queue performance using the observed distributions and measures to drive the system. Finally, this analysis method can allow for dynamic testing of the C2 system. This can be done by artificially increasing the arrival rate (lambda) to reflect increased traffic volume. This will provide a response to different traffic conditions through simulation without using the entire IFFN testbed.

M. TIMELINESS VS. ACCURACY

The preceding discussion has given us a means to measure the timeliness of the transform that uses the information. But we cannot consider this timeliness by itself. What kind of tradeoffs are we making when we move the CONTROL function

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[23]Available in this case must include some tactical position, which can take advantage of the available intercept opportunity.

down to the weapon system? Does the weapon system have less of a chance to acquire a target when it provides its own control? Will this change decrease a measure such as:

- P(Firing a missile given target allocation)

These questions can be addressed with appropriate measures. One candidate measure has already been offered in the preceding paragraph. But the real answers to these questions depend on what information the weapon systems operator needs to acquire the target. He may need just the information provided in the intial target allocation. However, if the target manuevers and radar contact cannot be established quickly, more information may be required to update the pilot. Some additional issues are listed below:

- Does the pilot need information only?
- Does he need directions (control)?
- Given target informaton can he provide his own control?
- What is the effect of data linking target information given the weapon system is allocated against an appropriate target by a weapons controller?
- Will the pilot take the initiative to control his own intercept?

N. SUMMARY

More measures could be defined but our intention is not to enumerate all possible measures. Instead, it is our purpose to show how the model can be used to derive measures and data events to support those measures. In this section we have derived measures, which apply to the entire C2 system (MOEs) and have found functional measures within the C2 system (MOPs) that lead to and support the overall set of system MOEs. Furthermore, we have looked at the interaction between C2 elements through a XTEL process, which can alter the ID MOP at the individual C2 node being measured.

We have also introduced the idea of information value, either "tactical" or "strategic" value based on present or anticipated intercept opportunities respectively.

Timeliness measures were derived with respect to resource availability and structure in the "weapons control" transform. Finally, a discussion of tradeoffs between timeliness and CONTROL function quality was offered.

The next section will summarize the thesis. Although the thesis had a single purpose, to develop a C2 systems model for IFFN testbed purposes, there is considerable C2 theory and lessons learned about the Modular Command and Control Evaluation Structure (MCES), which can be of use for other C2 evaluation applications. Therefore, the summary will address both of these areas.

VII. CONCLUSIONS

A. OVERVIEW

The conclusion for this thesis could be written from several different perspectives. Several tasks were accomplished at the same time. First of all, a specific analysis structure, the Modular Command and Control Evaluation Structure (MCES), was used to approach an air defense command and control problem. However, the use of an existing, operational command and control system (represented through IFFN) provided a test for the MCES. So the products of this thesis are twofold.

The first product is the changes and amplification of the MCES. The second product is the C2 systems modelling technique developed for the IFFN testbed. The technique is offered to IFFN to allow system users and analysts the capability to address operational issues through developement of measures and data events to support those measures. The test for the second product is whether or not the measures developed through use of the model adequately address the operational issues. We'll start with the MCES part of the summary by looking at how the MCES has been applied to the air defense problem.

B. MCES APPLICATION TO THE AIR DEFENSE PROBLEM.

The MCES focus is to address C2 analysis from the users or decision makers perspective. Figure 7.1 illustrates this overall analysis structure. [Ref. 6: p. A-18] This sentiment is captured in a single statement taken from the MCES.

> If MOEs are expected to be useful, they must be accepted by decisionmakers. [Ref. 6: p. 4-26]

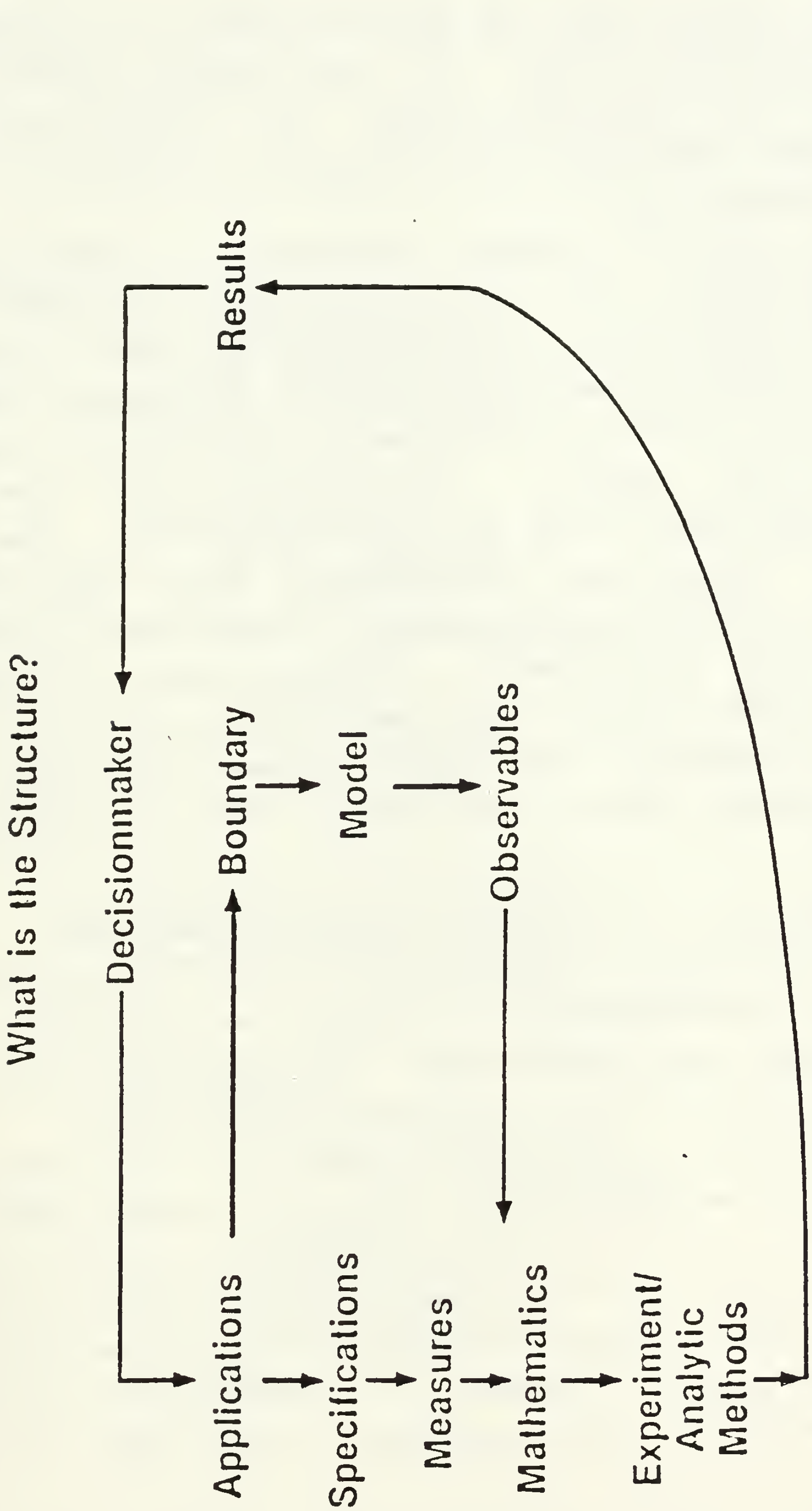

Figure 7.1 Analysis Structure

This implies that the decision maker is an integral part of the analysis process. He must become involved to first identify the operational issues. But he must continue his involvement throughout the evaluation process to maintain that perspective.

For the air defense problem the "application" is straightforward. It is an operational C2 system with an existing "structure" and "physical entities." Operational issues regarding identification have already been developed. (The IFFN JTF is in the process of building a testbed to address those issues). My startingpoint for the analysis was to thoroughly study this existing system. Then I could take the system users perspective.[24] With this background, problem statements were formed and additional operational issues were formulated. (A great deal of interaction between IFFN personnel and myself was required to form the problem statement. The problem statement was later refined by the working group at the January 1986 Workshop sponsored by MORS).

C. APPLICATION OF THE MCES EVALUATION STRUCTURE

At the workshop the Air Force Tactical Group applied the MCES evaluation structure to develop an evaluation plan to address the identified problem. Figure 7.2 illustrates the MCES evaluation structure that was used.

Initially we met with success. The "Application Objectives" were set and the C2 system bounding was already specified in existing IFFN documents. [Ref. 8] The real work began with the C2 process. We successfully defined an air defense C2 process and mapped that process to the MCES C2 process model. However, the mapping was not perfect. Some members of the workgroup felt that air defense

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[24]This was a two week indepth study of the central European air defense system as represented through IFFN. I also have background in the air defense mission as a weapon systems operator in the F-4 fighter.

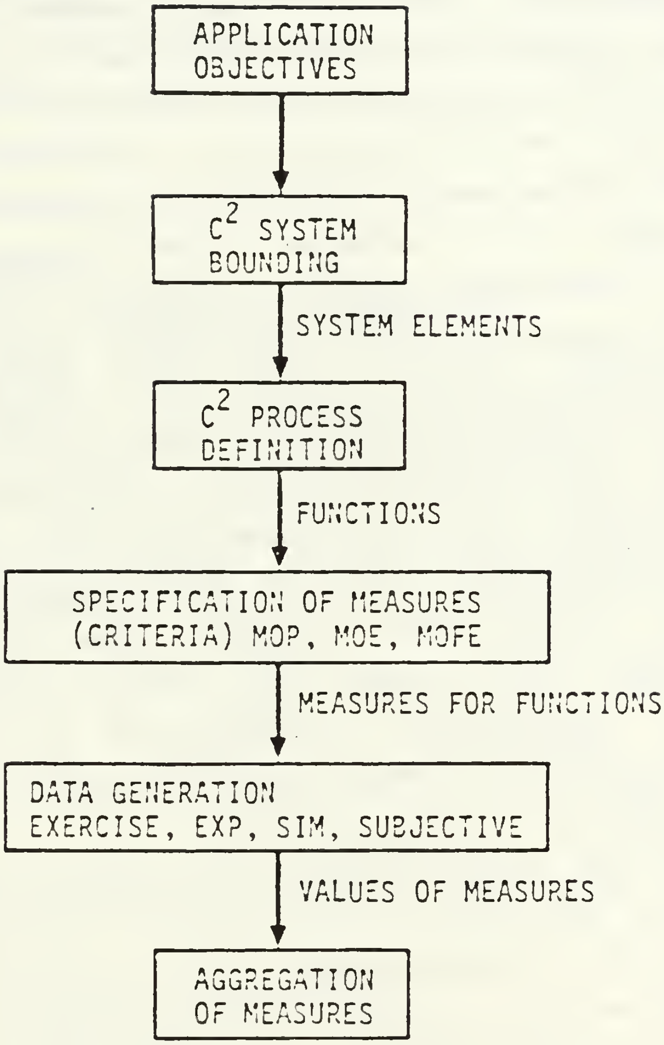


Figure 7.2 MCES Evaluation Structure

functions, TRACK and IDENTIFY, would map better to a new MCES function called PROCESS.(Lawsons C2 process model contains this function). The MCES did not adequately define the relationships between "physical entities" performing the C2 process functions to readily determine structure or how that structure might vary. With these successes and failures discovered, the working group agreed that the MCES process model should be enriched although no agreement was reached as to "how" it should be done. But the need was identified.

Next the working group took up the developement of measures. By using the air defense C2 process model we developed MOPs for individual process functions. Except for the ASSESS THREAT function they seemed to be a straightforward chain of conditional probabilities, which lead to C2 process MOEs. These measures were already known to IFFN.

The ASSESS THREAT function raised the issue of how well mission priorities could be translated into allocations. This led to a suggestion for some linear programming objective function which could change along with priority changes. This idea was new for IFFN at the MOP level although their mission MOEs allowed them to differentiate between interception of enemy bombers versus interception of all enemy aircraft.

There was some additional discussion of a "micro MOE," defined as the ability for the entire interconnected C2 system to perform a set function such as P(TRACK). (This idea was advanced by Lawson). But the real measurement issues are how do "micro MOEs" affect the ID at a node which is controlling aircraft or SAMS to ACQUIRE and ENGAGE the enemy. Again this was a modelling limitation.

With this background the thesis focuses on building an enriched air defense C2 systems model, which can readily be checked against the IFFN testbed configuration. A thorough review of C2 theory from other writers and some theory proposed by this writer is used to alter the MCES C2 process model and the definitions of the C2 process functions. An additional intelligence process is proposed to include George Orr's theory on the intelligence/analysis function. A XTEL process is proposed to explain interaction between C2 nodes at the PROCESS function level. This XTEL process is meant to explain the effect of "micro MOE' although this term has not been adopted within this thesis. The following section will summarize the changes to the MCES used within the thesis with the corresponding theory behind the change.

D. THEORY SUMMARY

1. Definition Changes and Additions

The MCES definitions are the fiber that holds together the MCES as an evaluation structure for C2 systems. Unless you can agree to what the system is, what it does, its boundaries and how to measure it you cannot have a cohesive evaluation structure. But the definitions must be able to completely describe the system and provide enough theory to describe how it functions. The air defense system studied (represented through IFFN) confirmed some of the definitions but pointed out weaknesses in others. Additionally, the definitions for the C2 system were not a complete set. The following review of definitions is provided to document the changes that were made to MCES definitions.

- Physical Entities-Unchanged
- Structure-Unchanged
- C2 Process-Unchanged
- Intelligence Process-Added
- XTEL Process-Added
- Measures and Boundaries-Partially accepted
- Decision Making Scope(Tactical or Strategic)-Added
- MCES C2 Process Functions-Changed

Justification for changes to definitions and added definitions are discussed in the following section.

2. Justification for Definitions

a. Intelligence Process

The ideas advanced by Orr in his discussion of the INTELLIGENCE/ANALYSIS function is not fully represented in the MCES C2 process functional definitions. Separate physical entities with their own chain of sensors, special processing techniques exist to perform this process. Existing theory by Lawson shows one way to interface this process with a C2 process.

b. XTEL Process

This could be just a function or considered a separate process. IFFN's need to deal with indirect ID issues, to explain interaction between C2 processes and examine their existing air defense C2 system forms the theoretical basis for this process. One purpose for this process is to produce the interaction between C2 nodes to improve probability of TRACK, and ID accuracy. Another purpose is to simply share information to provide decision makers a more complete picture of the environment.

c. Tactical Decisions

This definition reflects the more technical (reflexive) approach to decision making. Tactical decisions are immediate responses to perceived threats in the present state.

d. Strategic Decisions

This definition reflects the requirement to form an integrated perception of the environment (friend, foe and neutral) and formulate an aggregate repsonse to deal with that perception. Orr's INTELLIGENCE/ANALYSIS function provides the theory for this definition.

e. Measures and Boundaries

The concept of a relationship between measures and boundaries is maintained and used within the thesis. However, the specific examples within the MCES book did not fit the air defense C2 system. In fact, the examples appear to be off by at least a factor of one. (Probability of detection, number of targets nominated are given as examples of an MOE for the C2 system. They really measure C2 functions which fall inside the C2 system boundary. This conflicts with the relationship prescribed for measures and boundaries.)

f. PROCESS Definition

This thesis added Lawson's PROCESS function to the MCES C2 process model and defined it by splitting the MCES definitions for SENSE. There is a distinct difference between data (radar paint) and processed information. IFFN issues deal with developing processed information (Direct ID) and exchanging that information (Indirect ID).

g. ASSESS and GENERATE Functions

These definitions are changed to reflect Orr's INTELLIGENCE/ANALYSIS function and thesis definitions for "strategic" and "tactical" decisions. These definitions are restated below:

ASSESS-That function which assigns meaning (perception) to processed "information about the capabilities of friendly forces" to counter the enemy's intentions. Present and future state perceptions can be formed by decision makers within the ASSESS function.

GENERATE-"That function which develops alternative courses of action to" achieve mission goals. There is a possible recursive relationship between GENERATE and ASSESS as the impact of different alternatives can change projected perceptions of the environment.

h. SELECT Function

The SELECT function definition is changed to delete reference to evaluating each alternative option. We cannot say we will always evaluate every option. A machine algorithm might be instructed to do this but the man-in-the-loop will find shortcuts or rules of thumb, which may not consider all the options.

In the next section of this conclusion we will review some of the changes and additions which are needed to represent the real world air defense C2 system (as represented through IFFN). Figure 7.3 represents how the C2 process block of the "MCES Evaluation Structure" has been expanded. It expands in two directions. The first direction leads us to an air defense C2 system model and uses a technique to synthesize the model into a tool for analysts. These concepts will be reviewed in detal.

E. THE AIR DEFENSE PROCESS MODEL

By combining existing theory (MCES and others) with some new perspectives, this thesis has advanced requirements for two additional processes to be added to the C2 processes block. In fact these processes are given a purpose, their functions are defined and interfaces between them are suggested. This now becomes a C2 Systems processes block where all processes will be modeled and combined to build a complete C2 systems model. We'll start by tailoring the C2 process to fit the execution level air defense mission.

An air defense execution level C2 process forms the corner stone for the air defense C2 systems model. Its functions are identified and checked for their completeness against the modified MCES C2 process model. Functions within this process are defined specifically for the air defense mission.

However the goal is to build a C2 systems model for air defense. Therefore, interfaces are used to connect separate

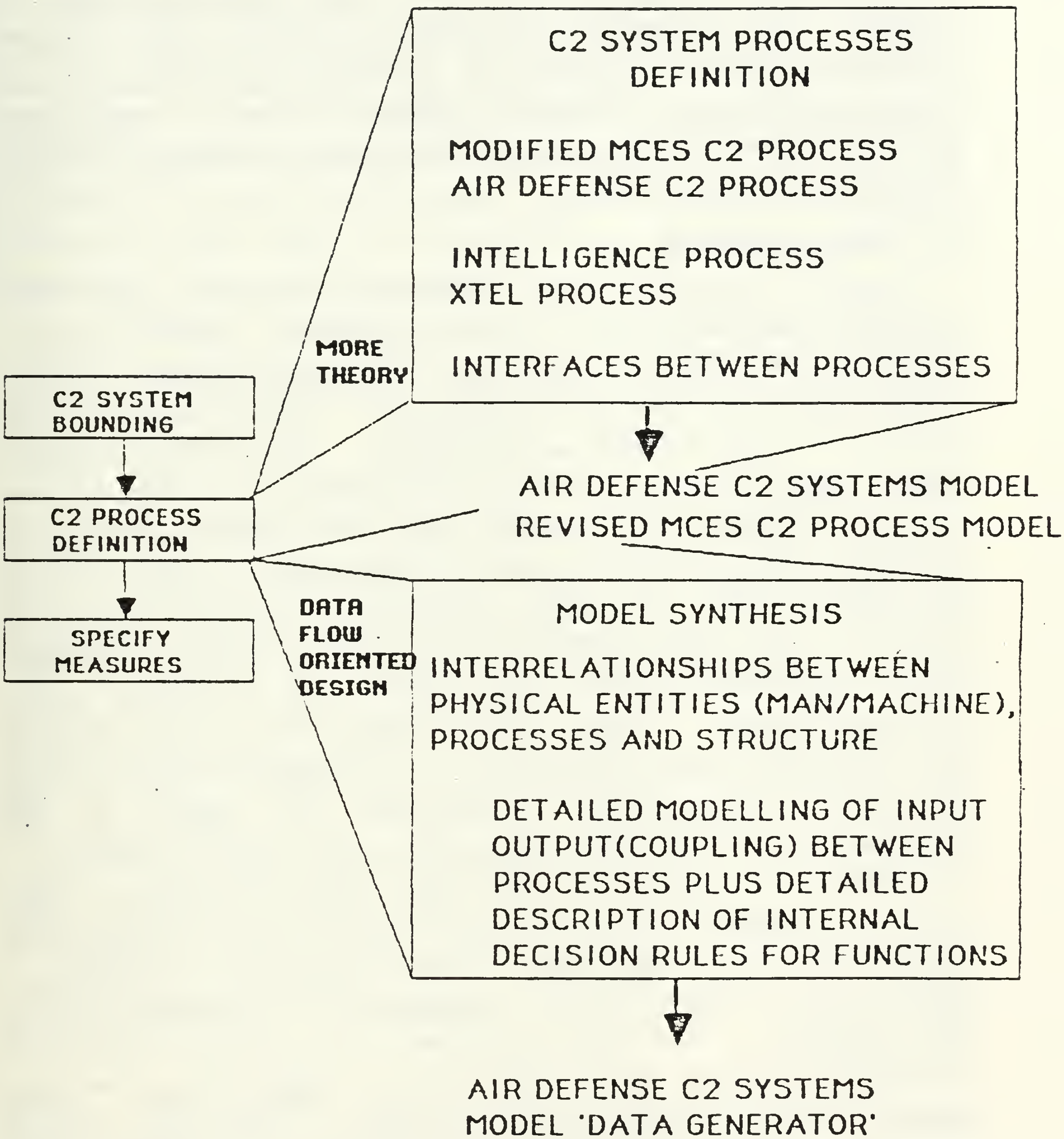


Figure 7.3 Partial Revised Evaluation Structure

C2 processes through a XTEL process. An Intelligence process is interfaced with the C2 process and Xtel process to account for the intelligence contribution to the C2 system. This connected C2 system is nested with a higher echelon C2 process which has responsibility to set air defense priorities and make tradeoffs between subordinate execution level C2 processes, which may be competing for the same limited resources.

F. MODEL SYNTHESIS

Many C2 theorists have expressed a need to show relationships between the C2 system processes, "physical entities" and "structure." The model synthesis section of this thesis uses a specific technique, "Data Flow-Oriented Design," to form these relationships. Data flow Diagrams (DFDs) are constructed to show information flow through the C2 process model. In a second step a transform analysis is performed on the DFD. From this transform analysis you can subordinate the individual C2 functions to the transform center. Some information is coming into the transform center (afferent branch) and out of the transform center (efferent branch). This provides superordinate, subordinate relationship between the process functions. Thus we have defined a hierarchical "structure" in terms of the information flow between functions within the C2 process.

The next step is to map those physical entities (man and/or machine), which perform functions and communicate output from the functions. This produces a "structure" between men. (This can be recognized as an organizational structure).

This structure could reside in a single node. Each command node can potentially perform all C2 functions to direct force actions in the environment. But under some operational concepts C2 process functions can be distributed between command nodes (i.e., Brigade and Battallion FDCs) or between command nodes and weapon systems (i.e., CRC and fighter).

Therefore the concept of a null process is introduced to conserve the C2 process functions when they are distributed. The C2 process funcitons can be divided but they must not be duplicated. Only one execution level C2 process can direct a weapon system although its decisions may be influenced by information coming from other execution level processes. Influence would come in the form of an indirect ID or priorities from a higher echelon.

With these techniques we can change the C2 system model to show relationships between "physical entities," "structure" and "processes" plus alter the structure to reflect different operational concepts.

All this gives us a first level model. However, many operational issues deal with the internal processing within C2 functions. For instance, some IFFN issues deal with the ID value of air space control procedures. These rules are specified externally but used internally within the ID function to determine ID. These rules when combined with other sources for ID into some decision loop or algorithm affect the internal structure of the ID function. Take them away and the decision loop (internal structure) is changed. So the module description (also specified by our design technique) documents this internal processing and how the information is input and output from the function.

At this point it is time to take a step back to see what we have produced. In section 4 we produced an air defense C2 systems model. In section 5 we used a technique to synthesize this model. The model can now show relationships between "processes," "structure"and physical entities" plus reflect changes to the "structure" caused by different operational concepts, which may be implemented. The air defense C2 systems model now becomes a "tool" to fully describe the

C2 systems operation and it is the effectiveness of those operations we wish to measure. The final section of this conclusion will test this "tool" by using it to develop some representative measures for the air defense C2 system.

G. THE TEST (DEVELOPING MEASURES)

We have come full circle from our initial purpose statements which were taken from Athans and the IFFN test director, Colonel David Archino. Athans advanced a need for,

> an analytical quantitative methodology . . . to analyze the interactions between a fixed C2 organization and a fixed C3 system architecture, and develop really meaningful and relevant MOEs.

Colonel Archino asked for the following:

> Develop a tool . . . specific to air defense that allows IFFN to evaluate the flow of C2 information thoughout the C2 structure and determine if it is useful or not in winning the war . . . meeting the mission objectives . . . and operational issues IFFN plans to address.

We have taken a path through and evaluation structure, the MCES, by defining the problem, bounding the system and building a representation of the C2 systems operation through a C2 systems process model. That model can be adapted with a specific technique to describe the systems operation as operational concepts change. So we have a "tool" to develop measures which assess the effectiveness of the C2 process in directing forces to meet the air defense mission.

1. Measures Concept Review

To develop measures we return to the MCES definitions. The most useful concept is the idea of boundaries and measures. The MCES provides the following guidlines for measures:

- MOP-Measured/Specified inside the Boundary of the C2 System
- MOE-Measured/Specified Outside the Boundary of the C2 system.
- MOFE-Measured/Specified Outside the Boundary of the Force.

This thesis interpreted boundaries of the C2 system in terms of the process it performs. This idea was also advanced for the force boundary. The force boundary is also bounded by the process it performs. Now the guidlines advanced in the MCES take on some additional meaning.

Measures of performance are measured inside the boundary of the C2 system. In the air defense C2 system you can specify MOPs for each function. The initial functions in the air defense C2 process such as DETECT, TRACK, IDENTIFY couple to other functions within the C2 process. When you move to the C2 functions, ALLOCATE WEAPON and CONTROL, these functions couple to separate "force process." These C2 functions can affect the force functions of MANUEVER, ACQUIRE, ENGAGE and MISSILE FLYOUT. The more complete the coupling the more we can say about the C2 systems contribution to the force to do its mission. For a partial coupling you could get measures of effectiveness for the C2 system. IFFN is looking at a process coupling for the "C2 process" to the "force process" functions MANUEVER, ACQUIRE and ENGAGE. These measures of effectiveness are measured by observation of a force action or lack of force action. IFFN looks at whether an air track (friend, foe, neutral) is ENGAGED or not ENGAGED.

This is nearly a complete coupling with the "force process." If IFFN could adequately model the "force process" function MISSILE FLYOUT they would have a complete coupling of the "C2 process" and "force process." The results would be measures of force effectiveness (MOFEs) as represented by the battle outcome.

2. The C2 System Measured as a Single Node

With this theoretical background we can begin to derive measures. In the measures section of this thesis we began with measures of effectiveness (MOEs) for the C2 system. (IFFN does not model MISSILE FLYOUT with enough fidelity to derive MOFEs). Initially we viewed the C2 system as a single node performing the "C2 process" and affecting the "force process" through the ALLOCATE WEAPON and CONTROL functions.

Measures of effectiveness were derived as if the C2 system was a single command node performing the "C2 process." We looked at a set of probabilities such as P(Detect/Object) or P(Track/Detect) etc., which would lead to the probability of performing the mission once CONTROL was affected with the "force process." But this view of the system is a reflexive view. It gives you an idea that as targets arrive, they will be shot down one at a time. This reflexive view parallels the idea of a C2 system operating with only tactical decisions.

3. Single Node Strategic Operations/Intelligence Interface

In a realistic scenario targets may not arrive one at a time or at the place of our choosing. The enemy may try to exploit our defenses by applying its force in mass at a time and place where our defenses are weak. Commanders (decision makers) must forecast future situations and manage our finite force resources in time sync with the enemy. This concept is advanced by Orr as controlling the power distribution. [Ref. 7] Even with our single node view of the C2 system we must take into account these concepts. The interface with a separate "intelligence process" working in concert with the commander can affect a more optimum power distribution with respect to present or future situations. Therefore we say that a "C2 process" with these capabilities will make more strategic decisions. It can form present and future perceptions of the environment and meet the enemy force with superior force (given forces are available to draw upon). But our single node is now being supported with intelligence capabilities. The interface between the "intelligence process" and the "C2 process" is at the ASSESS and ASSESS THREAT functions respectively.

4. Interactive Measures with Weapon Systems

In the next part of the measures section we looked at the C2 system in more depth. We specified a "reallocation" MOE which required interaction (feedback) from a weapon to the C2 system. Some of the techniques from the model synthesis section were used to specify a specific operational configuration. With this configuration established the system model was used to determine events which were needed to support the "reallocation" MOE. Events could be some output from a C2 function, an acknowledgement or some action in the environment. The systems model was now serving as a "data generator" pre-processor for configuration control of the IFFN testbed.

Feedback from a weapon system to a C2 node is only one of the possible ways the C2 system can interact. An air defense C2 system is made up from many command nodes. These separate command nodes produce information which has some local "tactical value" and information which may have some "tactical value" to another C2 node if the information can be used during an "intercept opportunity" window. IFFN JTF is addressing "indirect ID" issues, which deal with sharing this information throughout the C2 system.

5. Interactive Measures between Command Nodes (C2 Processes)

Our C2 system model, "tool," let's us view the C2 system as a set of C2 processes that interact through the XTEL process, which is interfaced at the PROCESS function at individual command nodes. Candidate measures were developed to deal with the "indirect ID" issues by looking at input and output relations between PROCESS functions. Also, a hypothetical second level look at the internal processing within the IDR module raised some additional questions, which can only be answered by examining the actual internal decision process within the IDR function.

More measures were developed, but they will not be reviewed in this conclusion. We have looked at enough of them to make some concluding remarks about the usefulness of the air defense C2 system model.

H. SUMMARY

The air defense C2 systems model that has been developed in sections 4 and 5 of this thesis is offered as a "tool" for IFFN JTF to address their operational issues. It has potential to describe the air defense C2 systems operation which may vary from one test design to another. IFFN JTF personnel will need to first validate this model with actual operational concepts, then develop a representation of those operations for each test design. With this representation they can look for possible measures which address their issues.

Hopefully, this evaluation methodology will provide IFFN JTF a cohesive theory and "tools" to address their operational issues on a C2 systems level.

APPENDIX A

C2 THEORY REVIEW

1. OVERVIEW

This section will address the need for a complete C2 systems model. Several models are reviewed for the purpose of showing capabilities of our present C2 models. Following this review, there will be a short discussion of what our models should be able to do in the future. The final part of this section will outline the new contributions to C2 modeling, which will be advanced in this thesis.

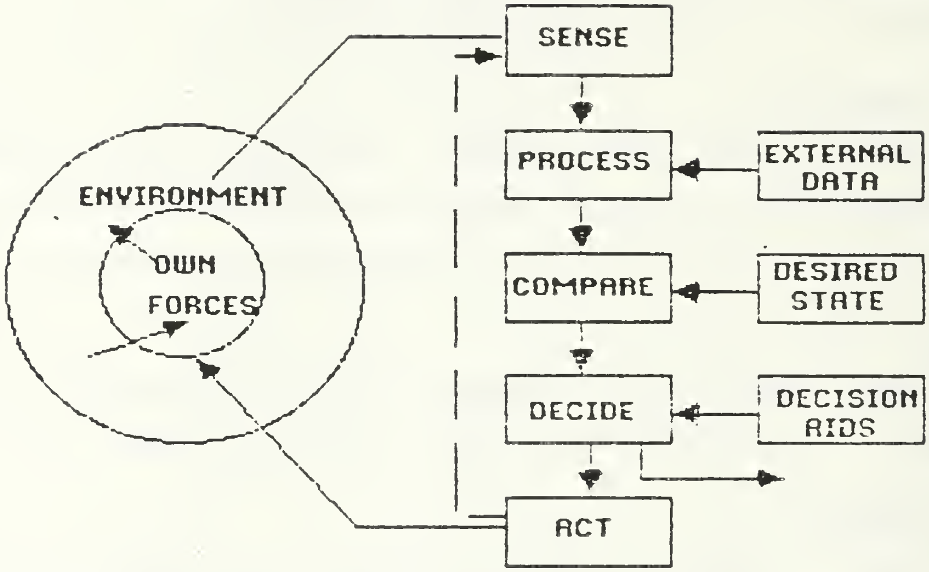
2. REVIEW

Many C2 theorists have introduced conceptual C2 models, which attempt to explain how a command and control system functions. These models were generic models, which serve as a starting point for building a more complete C2 system model. Therefore, a review of these models will help to introduce basic concepts, which must be incorporated within a more detailed model.

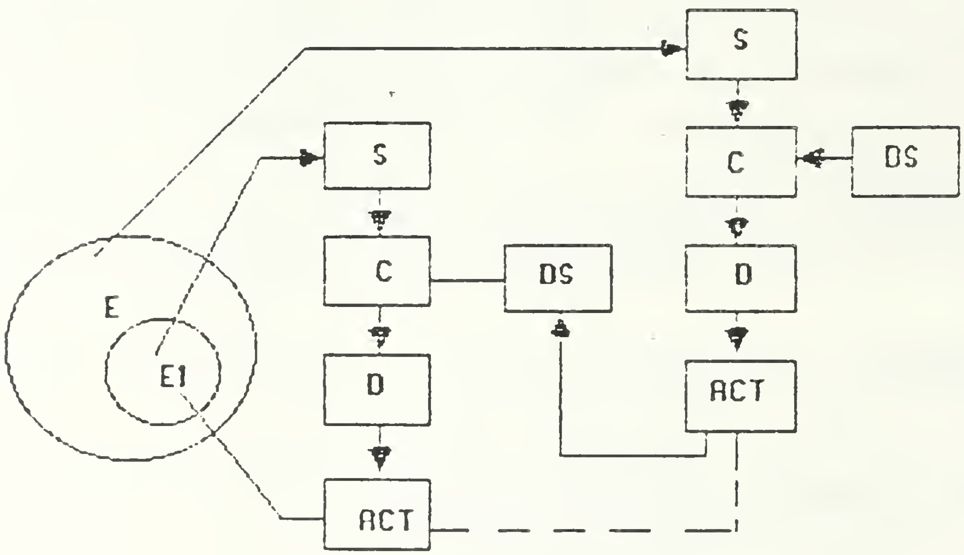
The following models will be referred to with a short discussion of their contribution to command and control theory:

- Lawson's C2 Process Model, C2 Nested Model, Coordination of C2 Processes [Ref. 10]
- Lawson's C3I Process Model [Ref. 5: p. 24]
- Applied Physics Laboratory (APL) Model by Carol Fox, Johns Hopkins University [Ref. 10]
- Dr. Tom Rona's Canonical Model [Ref. 10]
- George Orr's Conceptual Combat Operations Process Model [Ref. 7: p. 25]
- Michael Athan's C2/C3 Interface Model [Ref. 1]
- MCES C2 Process Model [Ref. 6: p. 5-4]

These models are presented in A.1, A.2, A.3, A.4 and A.5

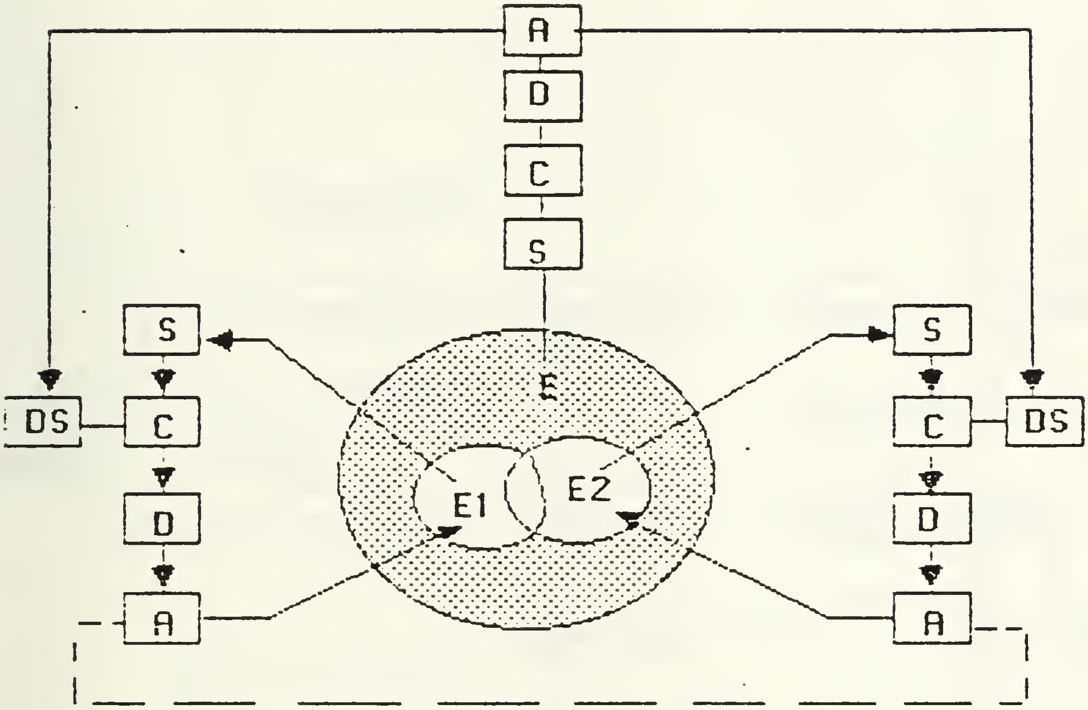


LAWSON DETAILED MODEL OF C2 PROCESS

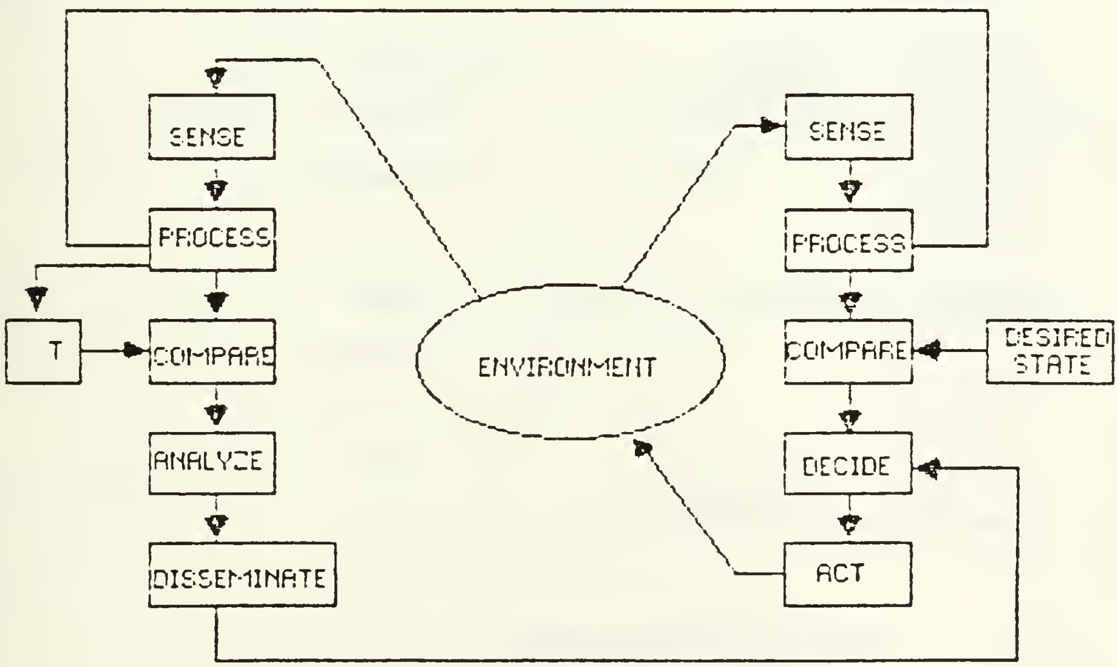


LAWSON NESTED C2 PROCESS

Figure A.1 Models1

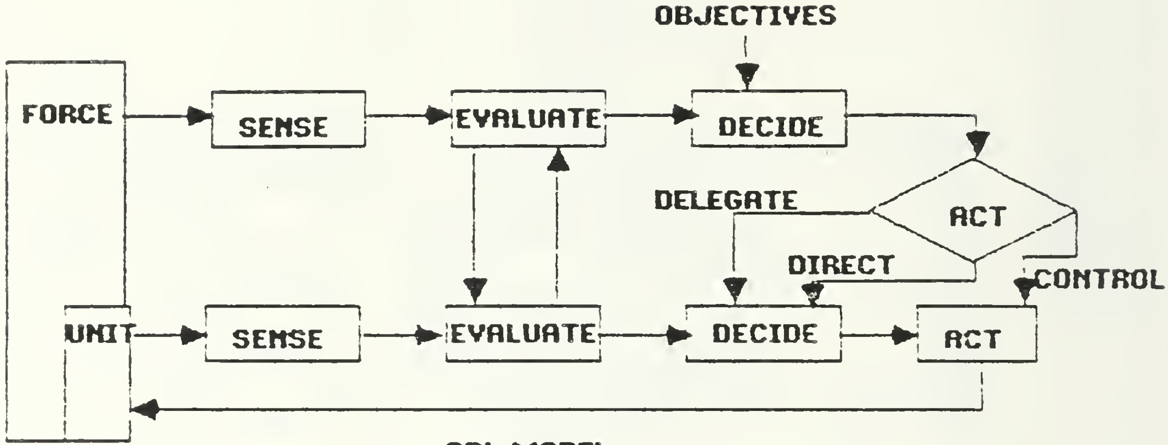


LAWSON COORDINATED C2 PROCESSES

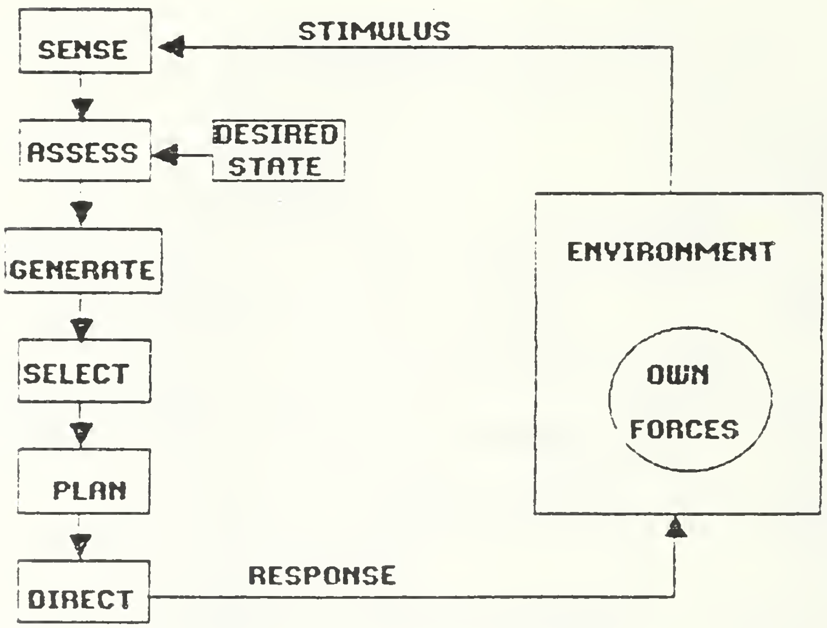


LAWSON C3I PROCESS MODEL

Figure A.2 Models2



APL MODEL



MCES C2 PROCESS MODEL

Figure A.3 Models3

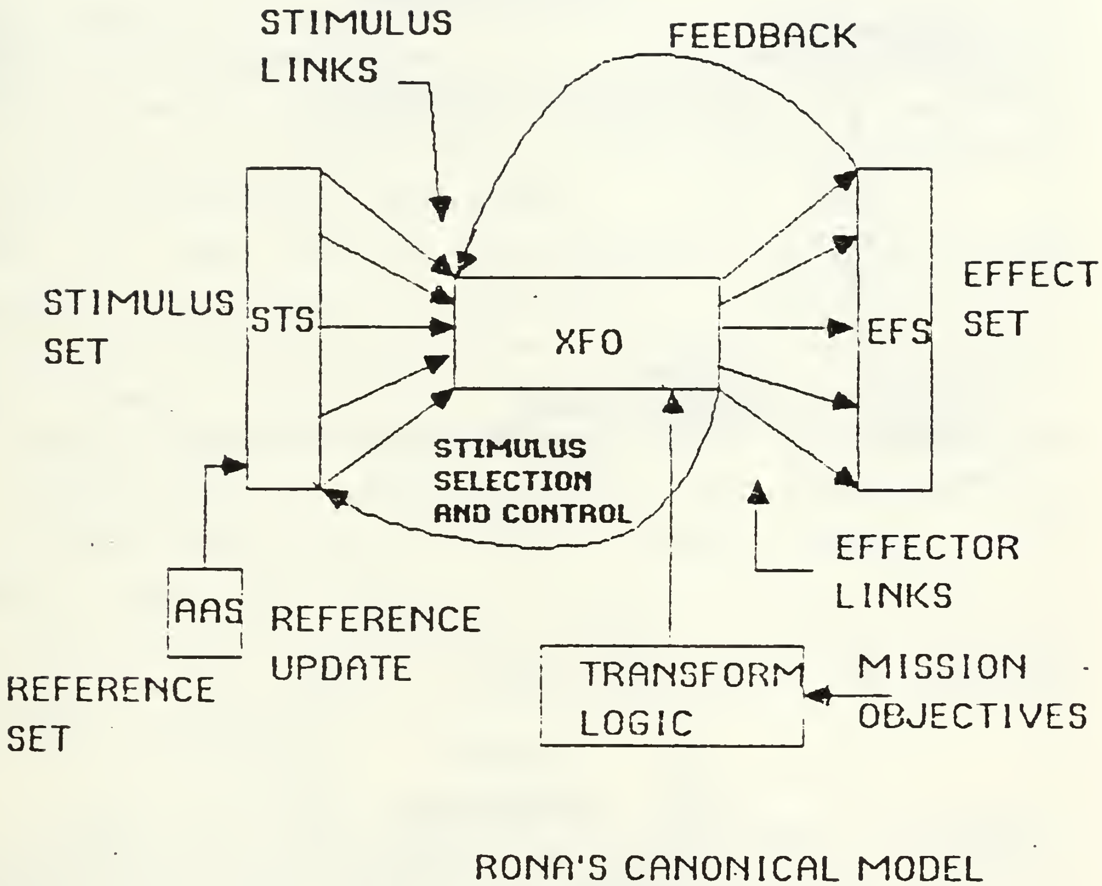
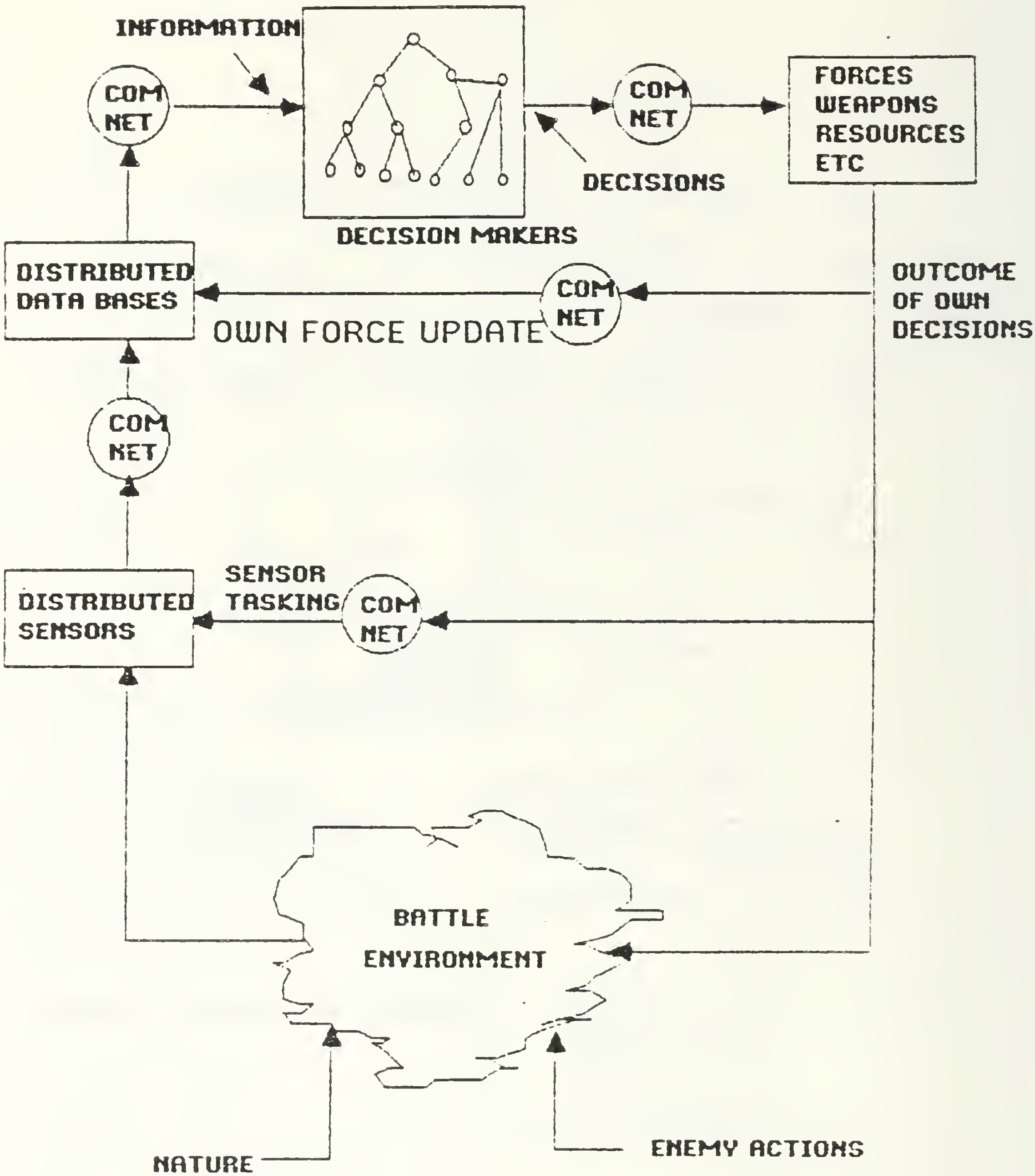


Figure A.4 Models4



THE C2/C3 INTERFACE
ATHANS

Figure A.5 Models5

In general these process models have explained "what the system is doing"(see definition of C2 process in section 2). Different authors have used different terms but they more or less say the same thing. Some models address only the C2 process (Lawson's C2 Process, MCES C2 Process) while others interface a separate intelligence process to produce Command, Control, Communications and Intelligence (C3I) models (Lawson C3I,Orr C3I).[25]

Some writers have shown how the C2 process can be nested with higher echelon coordinating elements (Lawson). Others have nested the C2 process model with a higher echelon with no implied coordination (APL Model).

The APL Model includes an information exchange between evaluaters at different levels which is equivalent to a separate XTEL process that allows sharing of information to create a common perception of the environment. Lawson's C3I model show a similar connection from the C2 process to the intelligence process. This configuration may allow intelligence correlation of track data to pass through a Xtel process in near real time.

Lawson [Ref. 10] points out another important conribution from the APL model. In his evaluation, he described the model as follows

> This model also makes explicit the fact that a commander may delegate some authority to a subordinate, or may provide him direction (set a "desired state"), or may simply bypass him and take direct control of action.

Dr. Tom Rona's model illustrates how feedback from the effectors (weapon systems) is directed back to the decision makers. This is a more accurate description of feedback relationships than those advanced by other models. Many C2

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[25]The seperate intelligence process partially explains the C2 systems capability to produce strategic versus tactical decisions.

process models send all feedback from the environment back through the sense function. Rona's model also shows how decision makers,who operate within his transform function(XFO), direct the sensors search patterns through the stimulus selection and control feedback loop.

Finally, Michael Athans provides a simplified model, which illustrates the need to find the relationship between the decision makers' organizational structure and the C3 system architecture[26]

3. SUMMARY OF MODELLING ACCOMPLISHMENTS

Considered separately each model contributes to a partial understanding of a complete C2 system. Different models have shown the following:

- C2 Process
- Nested C2 Process
- Coordinated C2 Processes
- C2 Process and Intelligence Process Interface
- C2 Process and Communications Process Interface
- Feedback to Decision Makers and Directions to Sensors through Feedback Loops.

4. NEW MODEL NEEDS

Michael Athans has challenged C2 theorists to combine the physical C3 system (hardware and communications structure) together with the C2 organization (structure) to account for the human element present within C2 systems. He takes his challenge a step further when he asserts that,

> One requires a set of consistent variables and rules which define how the output of an element becomers the imput to another, descriptions of serial, parallel, and feedback relationship. [Ref. 1]

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[26]Athan's C3 system architecture includes hardware, sensors, communications and the structural relationships between these elements.

5. MODELLING EFFORTS WITHIN THESIS

This thesis will attempt to answer that challenge by modelling what we have defined as the C2 system. In doing so it will relate the organizational structure (i.e. commander, weapons controllers, identification officers) to the C2 process. This means that a specific physical entity (person) is assigned a function within the process and that there is a one-to-one correspondence between the subordination of functions and the people that perform them.

A software design technique, "Data Flow-Oriented Design" [Ref. 9], will be adopted to develop the C2 system model. Data Flow Diagrams (DFDs) will be developed for the C2 system. A transaction or transform analysis will be performed on these DFDs to develop the final model. This final model will conform to conventions prescribed for structure charts, which provide the following:

- Superordinate and subordinate relationships between functions within a process.
- Information output from one function to another(coupling).
- Control information output which affects the internal processing of another function (coupling).[27]

Detailed module descriptions will be developed, which will describe the purpose, coupling and internal processing for each function on the structure chart.

1. The Null Process

The model will provide a visual means for identifying which C2 node is controlling the force within a layered C2 system. This will be accomplished by introducing the concept of null processes at nodes which do not have authority to execute forces when a specific operational structure is implemented by a decision maker.

[27]Both types of information can be seen to flow in both directions. From a superordinate it is considered direction. From a subordinate flowing back to the superordinate it is considered feedback.

2. Model Flexibility

C2 system flexibility as seen through model flexibility will be examined to see if it can accurately describe functional relationships when different operational concepts are employed.

6. SUMMARY

This section has introduced both new and old ideas about how to conceptually model a command and control system. These ideas are used in section IV to produce a complete air defense C2 systems model.

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