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EVALUATION OF COMMAND AND CONTROL CENTERS

DECISIONS AND DESIGNS INCORPORATED

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EVALUATION OF COMMAND AND CONTROL CENTERS.

by

Anne W. Martin Terry A. Bresnick [redacted] Dennis M. Buede

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This interim report documents the efforts of Decisions and Designs, Inc. (DDI) toward the development of a general model for the evaluation of proposed and existing Command and Control centers. Such a model is desirable in and of itself and, in addition, can serve as a stepping stone in the evolution of a science or theory of Command and Control.

The task of building a general evaluation model for C^2 centers is complicated by the large number and variety of systems designed for the gathering, transmission,

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) and analysis of information; specific systems used for these purposes vary within branches of the U. S. services and NATO as well as with the levels of C^2 centers in the overall commmand structure. The approach that DDI proposed to use in building the general model included: (1) developing specific resource allocation models for several C^2 centers chosen to represent different branches and levels of the command structure; (2) analyzing these specific models for commonality; and (3) extracting general principles which could be embodied in a generic C^2 evaluation model and could form the foundation of a science of command and control center design.

To enable DDI personnel to perform efficiently, a series of conferences were held with Air Force, Army, and Navy C^2 experts. The information gathered in the conferences was used to create the structure of a hierarchical evaluation model which can be used "as is" to evaluate C^2 center information capability, or can serve as a foundation for more specific C^2 evaluation models.

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EVALUATION OF C^2 CENTERS

1.0 INTRODUCTION

This report documents the efforts of Decisions and Designs, Inc. (DDI) toward the development of a general model for the evaluation of proposed and existing Command and Control centers. Such a model is desirable in and of itself and, in addition, can serve as a stepping stone in the evolution of a science or theory of Command and Control.

The task of building a general evaluation model for C^2 centers is complicated by the large number and variety of systems designed for the gathering, transmission, and analysis of information; specific systems used for these purposes vary with branches of the U.S. services and NATO as well as with the levels of C^2 centers in the overall command structure. The approach that DDI proposed to use in building the general model included:

(1) developing specific resource allocation models for several C^2 centers chosen to represent different branches and levels of the command structure;

(2) analyzing these specific models for commonality; and

(3) extracting general principles which could be embodied in a generic C^2 evaluation model and could form the foundation of a science of command and control center design.

To enable DDI personnel to perform efficiently the first of the tasks listed above, a series of conferences was held with Air Force, Army, and Navy C^2 experts. During these meetings, in which preliminary specific models were built, it became apparent to the DDI personnel involved in the project that the goals of the effort could be better served by using a "top-down" modelling approach rather than the proposed "bottom-up" approach. The "top-down" approach develops a general evaluation model for C^2 centers, by dimensionalizing C^2 needs and requirements at a fairly abstract level and then decomposing these relatively few abstractly stated requirements into concrete criteria against which systems can be evaluated. The "bottom-up" approach begins with the host of past, present, and planned systems, determines the functions that they serve, and attempts to abstract from these functions evaluation criteria which can be related appropriately to C^2 requirements.

The information gathered in the conferences with C^2 experts was used to create the structure of a hierarchical evaluation model for C^2 information capabilities. This structure, when augmented with weights which reflect the relative importances of the evaluation criteria included, can be used as is in the evaluation of C^2 center information capability, or it can serve as a foundation for more specific C^2 evaluation models.

Section 2.0 summarizes the meetings attended by DDI personnel and Air Force, Army, and Navy C^2 experts. Section 3.0 contains the general hierarchical model for the evaluation of C^2 information capabilities.

2.0 CONFERENCES WITH COMMAND AND CONTROL EXPERTS

DDI personnel met with C^2 experts to gather information about and build preliminary resource allocation models for different types of C^2 centers.

The implementation of DDI's resource allocation approach requires the steps described below.

1. Identify Variables to Which Resources Can Be Allocated. Variables over which resources must be distributed are identified. An attempt is made to characterize the problem by using variables that can be independently manipulated; that is, differing levels of resources can be allocated independently to each of the variables.

2. Identify Levels of the Variables that Vary from "Austere" to "Gold-Plated." The "austere" level involves a minimal resource allocation with minimal benefit. The "gold plated" level involves maximal resource allocation with, hopefully, maximal benefit. The levels of the variables from austere to gold involve increasing commitments of resources, which usually result in an increased level of benefit to the organization.

3. Assess Costs. A cost is assigned to each level of each variable such that the first level is the least expensive level, successive levels are increasingly more expensive, and the last level is the most expensive level on that variable.

4. Assess Benefits (Intra-Variable). The levels of each variable are assigned scores to reflect their relative benefit. Since incremental benefit is being considered, the minimum level is assigned a score of 0 and the highest level is assigned a score of 100. Intermediate levels are assigned values by comparing their improvement over the minimum level relative to the total improvement from the minimum to the highest level.

5. Assess Importance Weights (Inter-Variable Benefits). The variables are given importance weights by having the decision maker(s) assess the relative improvement or benefit of going from "austere" to "gold" on each of the variables. This step rescales the 100-point benefit ranges associated with each variable onto a common benefit scale by directly comparing the benefits associated with these 100-point ranges. For example, one variable may be assessed to have 200 points associated with its austere-to-gold range, while another variable has 100 points associated with its austere-to-gold range. This indicates that the increase in benefit from austere to gold for the former variable is twice as great as the improvement for the latter. The calculated relative benefit value for any level of a variable is proportional to the weight of the variable multiplied by the score on that level.

In the Air Force and Army meetings, C^2 variables were identified along with the systems which constitute the austere and gold-plated levels of these variables; skeleton DESIGN models composed of this information are included in the summaries which follow.

2.1 Summary of Conference with General Richard R. Stewart

The focus of the meeting was information : its gathering, flow, processing, and use for achieving objectives.

Figure 2-1 shows an information-flow diagram for command and control. The diagram serves as an aid in building a qualitative model of C^2; a preliminary version of the qualitative model, including three air missions, is shown in Table 2-1.

The next stage in the modelling effort is the organization requirements and capabilities in such a way that current and planned C^2 systems can be evaluated quantitatively. This phase was begun with the identification of three information variables of C^2 systems: DATA-RED, DATA-BLUE, and COMMUNICATIONS/DISPLAYS. In some cases, it is necessary to include ANALYSES as well as a variable. Tables 2-2, 2-3, and 2-4 show the skeleton C^2 DESIGN model structures for three Air Force Missions.

2.2 Summary of Conference with General John R. Deane, Jr.

After the initial modelling meeting, in which General Stewart served as an Air Force C^2 expert in order to develop design models for various air missions, a meeting was held in which General Deane aided in model-building for Army C^2 missions.

The work began with an effort to build design models similar to those previously built for air missions. General Deane determined that the structure and variables of such models would be identical for the three missions, Defend in Place, Defend-Successive Lives, and Attack; thus, only one

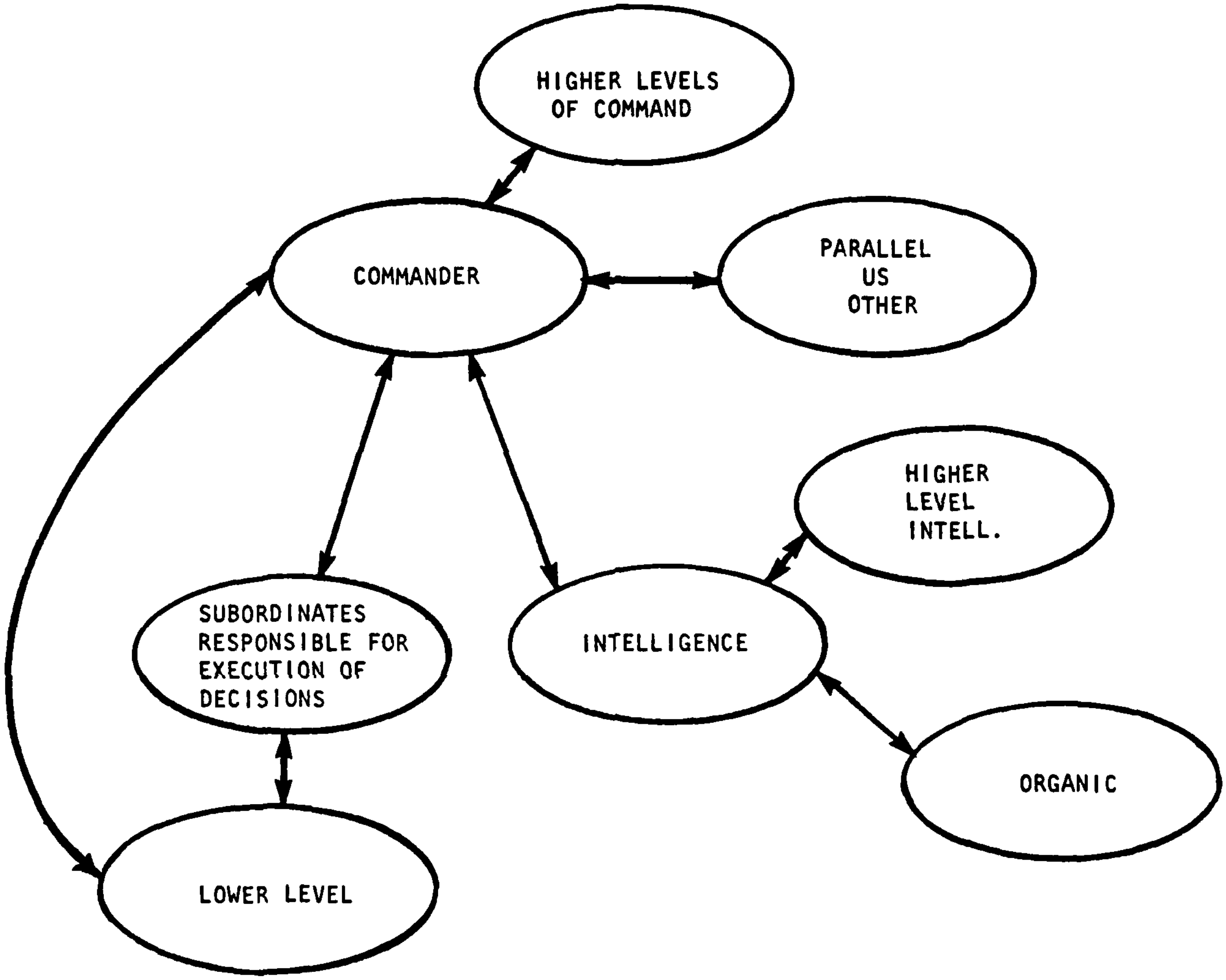

Figure 2-1
FLOW OF INFORMATION IN C^2

MISSION	RESPONSIBLE FOR:	INFORMATION NEEDED	DECISIONS	EXECUTION
AIR DEFENSE	RANGE: 200-600MI. INFORM FRIENDLIES COMMAND A/D CNTLER	STATUS U.S. NATO LOCATION U.S. NATO CAPABILITIES U.S. NATO RED T/O TIMES FLIGHT FOLLOW POST-SORTIE U.S./NATO STATUS	NATO OR U.S. WHEN/HOW T/O TYPE A/C, ORDNANCE	AIR DEFENSE CONTROLLER EXECUTES
AIR SUPERIORITY	RANGE: 200-600 MI. NEUTRALIZE RED AIR POWER (A/C, A/F, C^3, LOGISTICS BASE)	RED LOC OF A/F #,TYPE,CAP. OF A/C HARDNESS LOCAL A/D ENROUTE A/D BLUE/NATO #,TYPE,LOC OF A/C	CAMPAIGN PLAN: # SORTIES PENETRATION RTES ORDNANCE EXP. DAMAGE(RED) EXP. ATTRITION (BLUE)	EXECUTION OF CAMPAIGN PLAN MONITORING RECONN INFO PROC
BATTLEFIELD INTERDICTION	NEUTRALIZE RED RESERVES	RED TARGETING INFO: HARDNESS DISPERSION DEFENSE VALUE LOC. OF MOBILE TARGS. LOC. OF FIXED TARGS. POST SORTIE FAST COLLECTION OF DAMAGE INFO.	SELECT OBJECTIVES SELECT TARGS, A/C, MUNITIONS FOR BEST MATCH OF BLUE A/C & TARGETS	30 CONTINUOUS DAYS

Table 2-1

QUALITATIVE MODEL OF THREE A/F MISSIONS

COMM/DISPLAY				
Air Warning Air Fields Pilots Intelligence Comm Lines	Comm Line Telephone Through Air Field NSA only Land Line w/ limited RF			Remote Scope Continuous Digital Display Direct Digital
Red Database	LOS Radars A/F A/C No Pilot p(T/o)=.3 p(cross border)=.95 NSA Listening AWACS			OTH Radars All Wx Satellite Sensor
	A/F A/C A/C Status Munitions POL Manual TTY			Digital Network w/ RSI & Automated Logistics System

Table 2-2

SKELETON DESIGN MODEL FOR AIR DEFENSE

DATA BASE RED	LOC Logistics Order/Battle Rqmt 25% w/in 5mi. Transport R/R Trucks Installations 4000-30 day .2500 fixed .1500 mobile-300 combat 1200 other		100% 8000 .1000 w/in 20 mi. .1000 w/in 6 hrs. .1000 w/in 12 hrs. .5000 w/in 24 hrs.
DATA BASE BLUE	Same as Air Defense		
ANALYSIS	Manual		Monitor & Update: Data Bases Automatically, Simulators, & Decision Aids
COMM. & DISPLAY	NSA TTY AF Manually change data base		Electronic Links from sources (NSA, overhead, A/C, to data bases, Elec. Links from CP to recce units, strike units, NATO higher HQs)

Table 2-3

SKELETON DESIGN MODEL FOR INTERDICTION AND AIR SUPERIORITY

BLUE DATA BASE	Manual Updates		Digital Updates
RED DATA BASE			
COMM/ DSPY	Radio TTY		Wide band capacity to DASC for photos, maps

Table 2-4

SKELETON DESIGN MODEL FOR CLOSE AIR SUPPORT

DESIGN model was necessary. In building the Army model, two new variables, Environment and Survivability, were added to the list, comprised of Comms, Blue Data Base, and Red Data Base, used in all of the Air Force models. Some question arose as to the appropriate place in the model of Information Management/Analysis, and it was decided that this variable would be subsumed under the categories of *information* to be managed and analyzed. Table 2-5 shows the DESIGN model developed for Army C^2; the leftmost column contains information about functions for the variables, and the entities to the right are tools used to achieve these functions.

After the DESIGN model displayed in Table 2-5 had been built, the variables listed for C^3 and Surveillance/Fusion in the DIV 86 Blueprint of the Battlefield were classified according to their relationships to the variables in the model currently under discussion. This classification was undertaken with an eye towards using the DIV 86 variables in a future iteration of the current model; the taxonomy is shown in Figure 2-2.

2.3 Summary of Conference with Admiral William H. McLaughlin

Admiral McLaughlin began by defining C^2 as a commander

(1) making a decision,
(2) issuing a directive, and
(3) controlling the execution

in a dynamic, uncertain environment; he pointed out that the executor of a directive is also a decision maker, often performing the three tasks listed above. The dynamic, uncertain nature of the environment induces the need for a complete communication loop, as the commander must, besides conveying

COMMS	Higher, lower adjacent, supporting units	Secure Voice VHF Radio HF Radio Telephone TTY		Satellite Taccom Secure Higher-Bandwidth Data Video Telephone
BLUE DATABASE	Status-own people morale equipment location logistics pic. Status-adjoining Status-behind Status-support Avail. of reconn., intell.	Manual Voice Manual Plots Situation Boards		Automated CSS PLRS/JADS HYBRID Automated Net/ Plots
RED DATABASE	Status-red Indications of Red intentions Equipment types	Manual Reports Aerial Photog. Sensors Sigint Manual Filter, Collate		Satellite Photog. Auto Filter, Collate
ENVIRONMENT	Terrain Weather Roads Cities Obstructions	Manual Reports Maps Aerial Photog. Satellite Weather Weather Unit Data		CO_2 Laser for Wind Veloc. Automated Terrain anal. RPV
CP SURVIVABILITY	Dispersion Mobility	Camouflage Bulk Movement Radio Silence		Airborne CP Mobile Teleconferencing Improved Passive Counter-Measures MM-Wave Radio

Table 2-5

ARMY C^2 DESIGN MODEL

	BLUE		RED			
COMMS	DATA	DATA MGMT	DATA	DATA MGMT	ENVMT	SURVIV/MOBIL & MISC
SINGLE CH COMMO	JTIDS/PLRS	TOS	AGTELIS	ASAS		MPs
MULTI CH COMMO			QUICK FIX	SOTAS GD STNS		DIV/BDE HQS
SINCGARS			TRAILBLAZER			BDE TOC SUPPORT
HF VOICE			SOTAS			CI TEAMS
			GSR			COMSEC TEAMS
			REMBASS			TACSAM
			INTERROGATORS			TLQ-17A

Figure 2-2
TAXONOMY OF DIV 86 C^3 AND SURVEILLANCE/FUSION VARIABLES

information in the form of orders, receive current information for decision making.

The Admiral pointed out that, for modelling purposes, the appropriate C^2 context is that of a general war, with the goal of winning. As in the Army and Air Force sessions, the emphasis in this session was on information variables; however, rather than classifying C^2 systems and equipment according to the types of information to which they are relevant, the types of information were measured along various dimensions for a specific command, the Carrier Task Force. The resulting matrix is shown in Table 2-6; similar matrices could be developed for other commands.

BLUE

	DYNAMIC	STATIC	AGE/ TIMELINESS	ORIGIN	PRIORITIZATION	METHOD OF HANDLING	DISTRIBUTION
Operational Info							
Positioning							
Own	✓		Very recent	Internal	Very high	Exped.-auto visual dspy	TF members, own warfare GPs
Adjacent	✓		Very recent	Int/Ext	High	" "	" "
Status							
A/C							
AD							
Readiness Info							
Surface Operational Status	After Start of Battle	Prior to Battle	Up to date-- Prior Very current During	Internal (Indiv. ships)	High-Prior	Auto but lower priority	CTF WGC
Logistics - Fuel, Ordnance etc.	"	"	Reasonable-- Prior More Current During	Internal	Med-High	Auto, lower than op'l status	CTF, WGC, NPC, LOG CDR (SPT TF)

Table 2-6

INFORMATIONAL REQUIREMENTS--CARRIER TASK FORCE

RED

	DYNAMIC	STATIC	AGE/ TIMELINESS	ORIGIN	PRIORITIZATION	METHOD OF HANDLING	DISTRIBUTION
<u>Operational Info</u>							
Positioning	✓	If not immediate threat		Sensors Ext-Other Forces	As high as Blue data	Auto	CTF, WGC, Adj. TF
Status (#, Type)	✓	"		"	"		"
Order of Battle		✓	Up to date--Current	Resident, Ext Intel Agencies	Med Priority	Man/Auto	CTF, WGC, All ships in force (prev. distrib.)
<u>Readiness Info</u>							
Logistics							
Recent Engagements							

Table 2-6 (Cont'd)

INFORMATIONAL REQUIREMENTS--CARRIER TASK FORCE

3.0 A HIERARCHICAL EVALUATION MODEL AND CONCLUSIONS

The information gathered in conferences with C^2 experts was used to structure a Multi-Attribute Utility Analysis (MAUA) model for the evaluation of C^2 information capabilities. MAUA is a structured, logically defensible approach to the evaluation of entities which vary along more than one dimension. A MAUA model is hierarchical in nature, starting with the specified top-level factor for which an overall score is desired. This factor is successively decomposed into subfactors in descending levels of the hierarchy such that each successive level is more specific than the one preceding it. At the lowest level of the hierarchy are predictable or observable characteristics of the system under evaluation.

Figures 3-1 through 3-4 show the hierarchy built for the evaluation of C^2 information capabilities. C^2 INFORMATION is broken down into DATA and COMMUNICATIONS; DATA is divided into BLUE, RED, and ENVIRONMENT, each of which is further subdivided, and so on.

3.1 Importance Weights

To implement the model, it is necessary to obtain weights which reflect the relative importance of the evaluation criteria.

Two approaches to assigning weights are generally used in MAUA. One is a "top-down" approach, which begins at the top of a hierarchy, first establishing the relative importance between factors (level 1), between subfactors (level 2), and

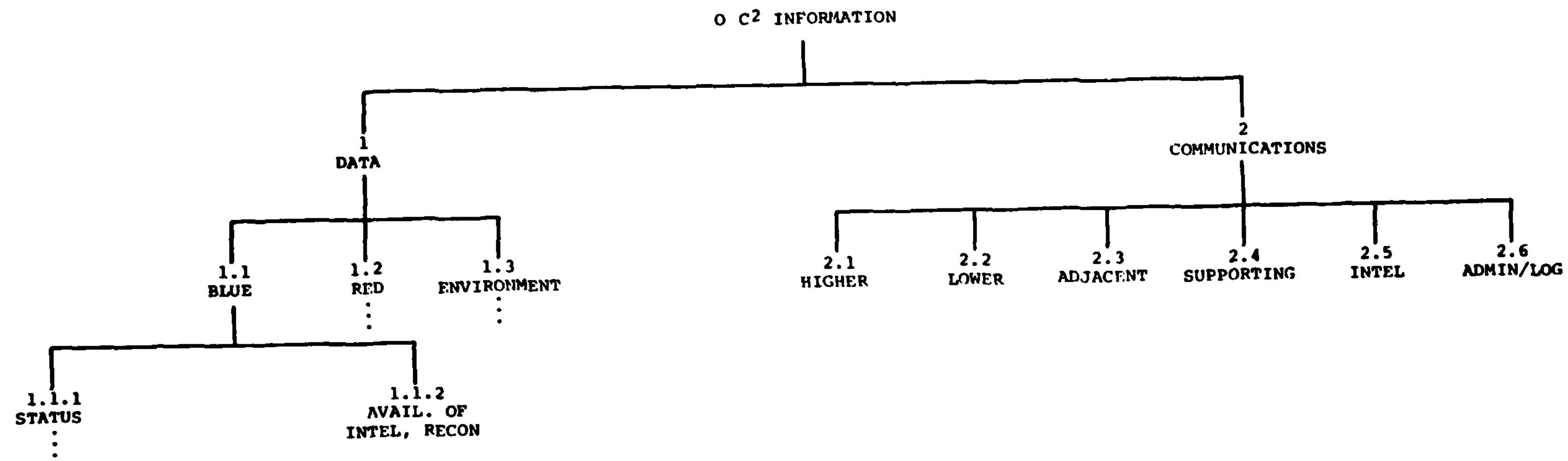

Figure 3-1

HIERARCHICAL EVALUATION MODEL FOR
C^2 INFORMATION CAPABILITIES -- TOP LEVEL

C^2 INFORMATION - DATA - BLUE - STATUS

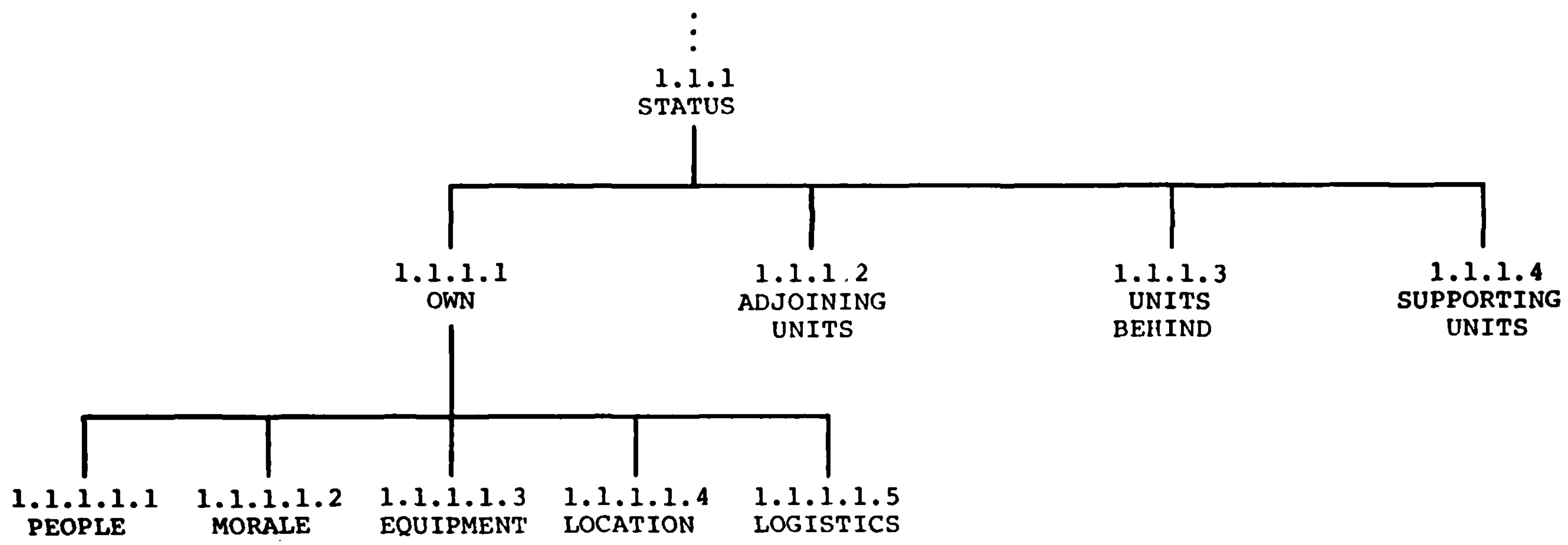

Figure 3-2

HIERARCHICAL EVALUATION MODEL FOR
C^2 INFORMATION CAPABILITIES -- BLUE STATUS DATA

C^2 INFORMATION - DATA - RED

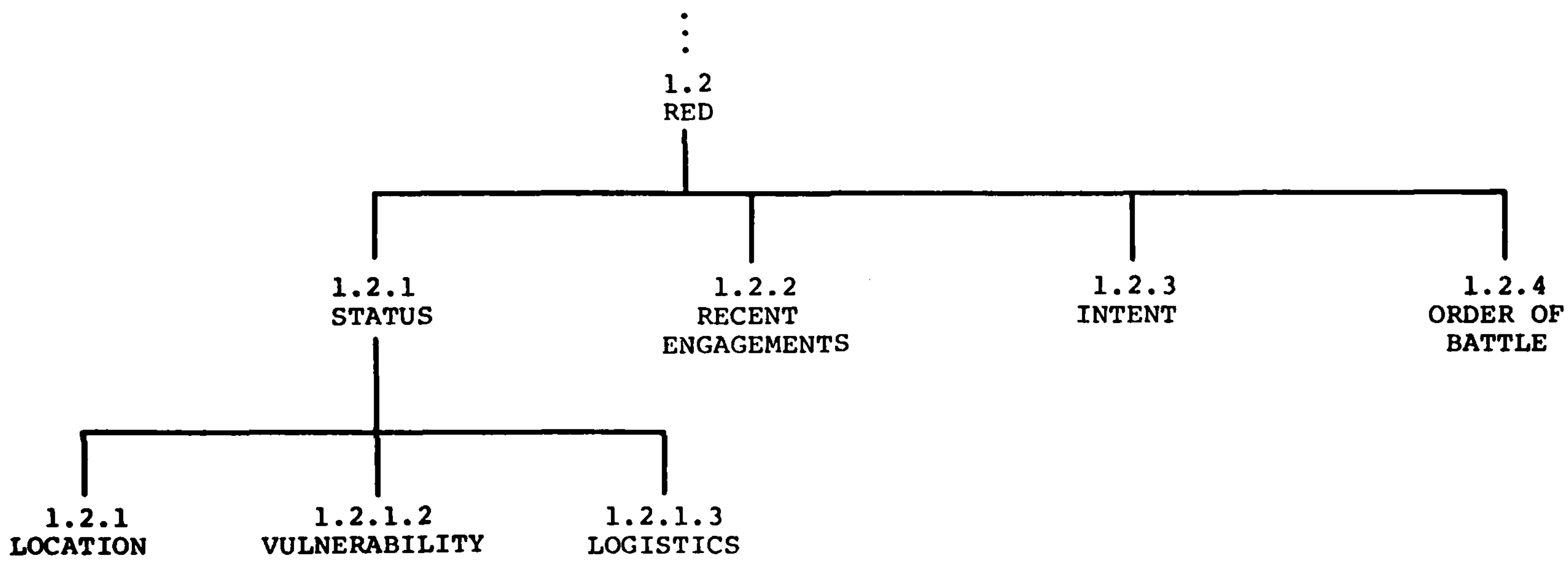

Figure 3-3

HIERARCHICAL EVALUATION MODEL FOR
C^2 INFORMATION CAPABILITIES -- RED DATA

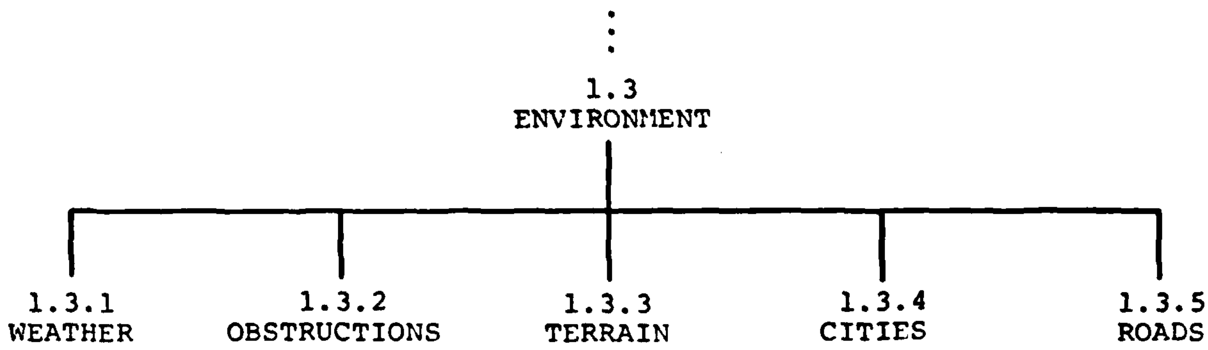

Figure 3-4

HIERARCHICAL EVALUATION MODEL FOR
C^2 INFORMATION CAPABILITIES - ENVIRONMENT DATA

than COMMUNICATIONS. Within DATA (i.e., level 2), one asks if BLUE DATA is more, equally, or less important than RED DATA or ENVIRONMENT DATA. The same approach is followed throughout the hierarchy. The relative weights assigned to the factors or elements that comprise each level of the hierarchy are normalized to sum to 1.0 (or 100) at that level of the hierarchy.

The second approach, referred to as the "bottom-up" approach, first establishes the most important of the subelements, e.g., within ENVIRONMENT DATA in our own hierarchy. This can be accomplished by asking questions about the relative value attained by changing each of the subelements from the worst to the best plausible performance of a C^2 center on the particular capabilities. For example, which provides the greater increase in the value of the ENVIRONMENT DATA--increasing the quality of the WEATHER DATA from the minimum to the maximum of its plausible range, or doing the same for OBSTRUCTIONS DATA? The relative importances of the ENVIRONMENT DATA subelements are thus established by successive paired comparisons. The same is done for the other subelements.

An important step then links the subelements. The most important subelement of ENVIRONMENT DATA is compared with the most important subelement of RED DATA. A similar comparison of the relative value of varying each subelement through its respective performance range establishes a link between the importances of the subelements of ENVIRONMENT DATA and those of RED DATA. The relative importances of all those subelements are then on the same scale. This procedure continues moving toward the top of the hierarchy. Once all subelements have been either directly or indirectly compared and consequently established on the same rating scale, each subelement is assigned a number between 0 and 1 (or 100%), called a cumulative weight. This is simply the relative importance assigned the subelement, divided by the sum of the relative importances of all the subelements in the hierarchy. The cumulative weight assigned any element in the hierarchy can then be established by simply summing the cumulative weights of all subelements that comprise the element in question. These cumulative weights are then normalized to sum 1.0 (or 100%) at each level of the hierarchy to yield the element weights.

3.2 Using the Hierarchical Evaluation Model

Using the hierarchical C^2 INFORMATION model to evaluate information capabilities of specific command and control centers requires a certain amount of tailoring. This tailoring may be as simple as merely assigning weights to the elements of the hierarchy in a way that reflects the relative importance of the various elements at the particular position in the command structure occupied by the C^2 center being evaluated; it may be as complicated as further breakdowns of the evaluation hierarchy to achieve lowest-level elements which are specific to the C^2 center to be evaluated. The simple case involves using one of the procedures discussed in Section 3.1. In the more complicated case, a large amount of further modelling is necessary. As an example, to adapt the model to use for evaluating the C^2 information capabilities of a Carrier Task Force, one might wish to include specific status information on the carrier, cruisers, submarines, logistic ship, any associated aircraft, and so on. After these kinds of information were attached at the bottom of the C^2 INFORMATION hierarchy, importance weights would be assigned to the elements using either the "bottom-up" or "top-down" approach.

When the C^2 INFORMATION model (applying either of the tailoring approaches described above) has been used to evaluate the information capabilities of a number of C^2 centers at various positions in the command structure, it should be possible to begin to extract some quantitatively stated principles about the importance of different information variables as a function of the positions of C^2 centers in the structure. This would be achieved by examining the variations in the relative importances assigned to the elements of the C^2 INFORMATION hierarchy as C^2 centers from different branches and levels in the command structure are evaluated. The set of principles extracted from these evaluation efforts would be an invaluable aid in C^2 center design, as they could be used not only to guide the planning of new C^2 centers, but would also provide logical rationale for the allocation of scarce resources among various existing C^2 centers.