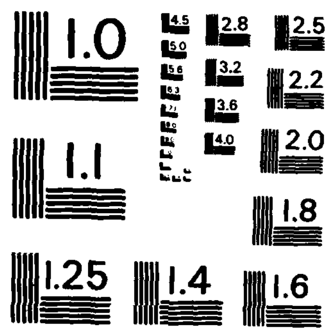
AD-A162 509 SPECIFICATION AND PRELIMINARY VALIDATION OF IAT (INTEGRATED ANALYSIS TECH..(U) ALPHATECH INC BURLINGTON MA J R KORNFELD MAR 85 TR-223 AFAMRL-TR-85-003 1/1

UNCLASSIFIED F33615-82-C-0509 F/G 17/2 NL



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS - 1963 - A

AFAMRL-TR-85-003

SPECIFICATION AND PRELIMINARY VALIDATION OF IAT METHODS: EXECUTIVE SUMMARY

JUDITH R. KORNFELD

ALPHATECH, INC.

MARCH 1985

Approved for public release; distribution unlimited.

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-83-003

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Air Force Aerospace Medical Research Laboratory

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A162 509

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): Alphatech TR-223	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFAMRL-TR-85-003
6a. NAME OF PERFORMING ORGANIZATION: Alphatech, Inc. / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Human Engineering Division, Air Force Aerospace Medical Research Laboratory
6c. ADDRESS (City, State and ZIP Code): 2 Burlington Executive Center, 111 Middlesex Turnpike, Burlington MA 01803	7b. ADDRESS (City, State and ZIP Code): Wright-Patterson AFB OH 45433-6573
8a. NAME OF FUNDING/SPONSORING ORGANIZATION / 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33615-82-C-0509
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT NO
62202F	7184	27	01
62202F	6893	04	63

11. TITLE (Include Security Classification) SPECIFICATION AND PRELIMINARY VALIDATION OF IAT METHODS: EXECUTIVE SUMMARY (U)

12. PERSONAL AUTHOR(S): Kornfeld, Judith R.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Technical	FROM ____ TO ____	March 1985	35

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Systems analysis; command, control, and communication (C3); human engineering

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

Since FY83 work has been conducted by Alphatech, Inc., under contract to the Air Force Aerospace Medical Research Laboratory, to develop a methodology for the description and analysis of complex Command, Control, and Communications (C3) systems. The methodology will explicitly consider the human role in such systems, as well as organizational and equipment constraints. The methodology developed under this effort will be a set of interrelated techniques, thus the title "Integrated Analysis Techniques" (IAT) has been chosen. This report outlines work to date, including the identification of requirements for IAT, development of an IAT conceptual framwork, and preliminary validation of IAT concepts. Planned work for FY85, including more extensive validation, is also described.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Capt David G. Leupp	(513) 255-7591	AFAMRL/HEC

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

SUMMARY

This Executive Summary describes IAT (Integrated Analysis Technique), its rationale, development history, and current status. Work done during FY84 is summarized and placed in the context of the overall development schedule (FY83-85). Technical achievements during FY84 are described and needs for further work (FY85) are elaborated.

The technical work presented here is described at a high-level, emphasizing what has been developed thus far, why it has been developed, and where we need to go to insure that a viable and usable product results. In the present document, tables and figures have been inserted to illustrate specific techniques that were developed during FY84; further details describing each technique can be found in TR-224, ALPHATECH FY84 Final Report [5].

PREFACE

This work was conducted by personnel of ALPHATECH, Inc. under contract F33615-82-C-0509, Task 84-0003, with the Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright Patterson Air Force Base, Ohio. The methods summarized in this report were developed under Program 62202F, Aerospace Biotechnology, Work Area 7184, Man-Machine Integration Technology.

Material for this Executive Summary has been derived from Interim and Final Reports submitted previously. Technical contributors include the following individuals: G.P. Chubb, J.C. Deckert, M.G. Gruesbeck, N.R. Sandell, Jr., and J.G. Wohl (ALPHATECH and ALPHASCIENCE personnel); D.L. Kleinman and R.A. Miller (consultants). Special thanks are extended to Mr. Donald Monk, Mr. Maris Vikmanis, and Capt. David Leupp, AFAMRL/HEC, for their support and sponsorship of the work reported here.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 5

1.1 Scope and Rationale 5
1.1.1 Objectives for Developing IAT 5
1.1.2 Technical Motivation 6
1.2 Development Background 9
1.3 Development Status 9

2.0 METHODS DEVELOPMENT: SUMMARIES OF CAPABILITIES DEVELOPED TO DATE 11

2.1 Structural Modeling 12
2.1.1 Dimensions for Analyzing C^3 System Structure 12
2.1.2 Recursive Decomposition 12
2.1.3 Derivation of MOPs, MOEs 16
2.1.4 Data Structures 19

2.2 Performance Modeling 21
2.2.1 Constraints on Building Performance Models 22
2.2.2 Specification of Analytic Methods 22
2.2.3 QNT Approaches to Modeling Human/System Performance . 22

3.0 VALIDATION (SIMCOPE-1) 24

3.1 Operator Scenarios 24
3.2 Data Flows (DeMarco) 24
3.3 Use of Frame Notation 26
3.4 QNT Representation 28
3.5 Use of Analysis Results for Changes/Redesign of C^3 Systems . 28

4.0 PLANS FOR FY85 29

4.1 Methods Development Strategy 29
4.2 Validation Based on Real-World C^3 Systems (NORAD Command Center) 29

REFERENCES 31

FIGURES

Number		Page
1-1	Matrix Showing Methods vs. Life-Cycle Phases [11]	8
1-2	IAT Developments: Required Capabilities	10
2-1	IAT Conceptual Framework - FY85 (FEO)	11
2-2	Recursive Nature of Decomposition	13
2-3	Primitives and Matrix Notation: Example Relations [3] . .	14
2-4	Relationship Between MOPs and MOEs in IAT	16
2-5a	Example of "Goal Hierarchy" - Tree of Objectives	17
2-5b	Example of Bennett's "Goal Hierarchy" Shown in IAT Framework	17
2-6	Example of Goal vs. MOP Matrix	18
2-7	Example of IAT Structural Description and Process Frame for the Process "Monitor for Enemy Missile Launch"	20
2-8	Definitions and Assumptions for Queuing Representation of Tasks	23
3-1	DeMarco Data Flow Diagram (Example)	25
3-2	DeMarco Diagrams Used in SIMCOPE Validation	25
3-3	Example of IAT Structural Description and Process Frame for the Process "Monitor for Enemy Missile Launch"	26
3-4	Monitor for Enemy Missile Launch: Tree Structure Hierarchy	27
3-5	The Queuing Representation of SIMCOPE	28

1.0 INTRODUCTION

This report reviews ALPHATECH progress to date in developing an Integrated Analysis Technique (IAT). Particular emphasis has been placed on technical capabilities developed during FY84, and their role within the context of the current three-year development period (FY83-85).

Development thus far has produced the component techniques and notational formats that together will comprise a comprehensive analysis and design tool. In order to see why these components have been developed and how they can be integrated effectively, we shall first review the scope and background of the current development effort [Sections 1.1 - 1.2]. After identifying what types of methods are required, and why, we outline the technical approach that ALPHATECH has taken in developing IAT [Section 1.3]. Finally, we describe the current status of methods development by summarizing technical accomplishments to date and showing where these achievements fit within the current development effort [Section 1.3].

Technical capabilities developed thus far are presented in more detail in Section 2.0. Section 3.0 describes a preliminary validation of IAT methods, based on those IAT components and techniques that have been developed during FY83-84. Section 4 re-examines development status and identifies work required during FY85 to insure the integration of all IAT components and their applicability to the analysis of C^3 systems performance.

1.1 SCOPE AND RATIONALE

1.1.1 Objectives for Developing IAT:

Why IAT is needed, and what requirements it must meet.

> IAT is being developed to provide quantitative information about C^3 human/system performance. This information can then be used to guide the analysis and design of new systems as well as the improvement or reconfiguration of existing ones.

IAT as an integrated methodology

To meet these objectives, IAT must provide techniques to predict and evaluate human/system behavior. Procedures are needed for analyzing and representing the dynamics of system behavior (in performance models). Because performance modeling depends on how well system structure can be described (in "static" models), techniques must also be developed to analyze and display structural elements and their interrelationships. In short, IAT must integrate: (1) descriptive methods for building structural and performance models; and (2) predictive methods, which can exercise these models to derive quantitative information. Decision-makers and operations personnel will then be able to use IAT to help answer questions about the structure and behavior of manned C^3 systems.

IAT is also envisioned as an integrated methodology in terms of its use for systems engineering purposes. In this context:

IAT as an analysis tool can --

1) Describe the structure of C^3 man-machine systems.

2) Represent the dynamics of human/system behavior.

3) Evaluate and predict human/system performance.

IAT as a design tool can be used to assess —

4) What aspects of a system should be improved and by how much. (Information from #2 and 3 will make it possible to compare achieved performance with desired levels of effectiveness, efficiency, and system adaptability.)

5) What parts of a system design should be altered to achieve the desired results. (The performance models from #2 can be used to run sensitivity analyses once the criterion of interest and magnitude of desired improvements have been identified.)

1.1.2 Technical Motivation

There are several important reasons why traditional systems engineering and engineering psychology methods are insufficient for deriving predictive performance data for C^3 systems:

1) The characteristics of manned C^3 systems are unique (e.g., timing constraints, authority/control in military organizations, nature of decision-making, mission objectives).

2) There is a need for organizing descriptive information about C^3 systems in a format that facilitates analyzing system structure and modeling system performance.

3) The complete range of system life cycle development stages must be addressed in analyzing existing systems and designing new ones.

Each of these issues is addressed below.

- Attributes of Manned C^3 Systems

  Manned C^3 systems have characteristics that are difficult to capture with traditional modeling tools. The activities associated with assessing threats and reacting effectively have unique attributes, in terms of time available (vs. time required) to make decisions. The role of military organization and communications connectivity must also be analyzed to understand their effects on functions like threat assessment and resource allocation.

Traditional descriptive methods may indeed be used to analyze physical composition (nodes) and connectivity, and to display the result graphically in block diagrams or tree structures [1,2]. Functional analysis methods can also help to trace the flow of data and processes (e.g., $IDEF_0$, Operational Sequence Diagrams [1]). And modeling languages like $IDEF_2$ [6] and SAINT [7] can represent system dynamics. However, none of these methods has been designed to analyze the effects that organizations, policies, plans, and goals have on human and system performance. These become critical when a C^3 system must respond to attrition or destruction of its elements, and must reallocate resources to maintain functional integrity.

There remains, then, the need for a descriptive method that can capture aspects of human behavior within C^3 systems (including, for example, decision-making, goal setting/evaluation, span of control, and task performance).

- **Need for Organizing Descriptive Information**

If quantitative information is to be used to help improve systems, mechanisms must be in place to insure traceability backwards and forwards, between high-level descriptions of system structure and representations of human/system performance. Analysts and planners need to see how quantitative changes in performance parameters impact specific tasks, resources, decisions, span of control, and authority. Unless a consistent syntax and semantics can be used as the basis for both static and dynamic analyses, such traceability cannot be guaranteed. Although many modeling techniques now available provide internally consistent formalisms, none that have been evaluated thus far [1,2] permit the desired linkage between structural and performance models (e.g., there is no automatic means for relating $IDEF_0$ function diagrams with PERT, SAINT, or $IDEF_2$ representations).

- **System Life-Cycle Development**

Few methodologies, if any, from the disciplines of systems engineering and engineering psychology can be used throughout the complete cycle of systems development — from concept of operations and needs analysis through design, implementation, test, verification and validation, user acceptance, maintenance and support. This limitation is a consequence, in part, of the split between structural analyses, which are especially useful for front-end planning and re-design; and performance analyses, whose results become most important for defining design alternatives and predicting their outcome. Organizing descriptive information in the manner outlined above for IAT will provide information relevant to a greater portion of the life-cycle than the portion covered by any single descriptive or predictive technique.

Figure 1-1 presents the limitations of representative systems engineering methods with respect to life-cycle applicability [11].

Methodology Purpose Designators

SYSTEM DEVELOPMENT PHASES

Phase								Designator
Needs Analysis								
Requirements Definition	$ID^1_{0,1}$ $PP^{2,4}$	$ID^1_{0,1}$ $PP^{2,4}$	$ID^1_{0,1}$ $PP^{2,4}$	$PP^{2,4}$, $ID^1_{0,1}$ $SR^{2,3,4}$	ID_0, SS	$SR^{2,4}$ $ID^1_{0,1}$	$ID^1_{0,1}$, SS $PP^{2,4}$	a
	QG	QG	QG	QG		QG, IS	IS	c
Requirements Specification	PP	PP	PP^2	SR^3, HS	ID_0, SS	SR, HS	PP	a
	$ID_{0,1}$, SS^2	$ID_{0,1}$, SS^2	$ID^1_{0,1}$	ID_0, SS^2	ID_0, SS	ID_0	ID_0, SS	b
Preliminary Design	SD, PD	SD, PD	PD	PD, HS	ID_0, SS, PD	PD, HS	PD	a
	$ID^1_{0,1}$, SS^2	$ID^1_{0,1}$	$ID^1_{0,1}$	$ID^1_{0,1}$, SS^2	ID_0, SS	$ID^1_{0,1}$	$ID^1_{0,1}$, SS	b
	QG	QG	QG	QG		QG, IS	IS	c
Detailed Design	WM, PD, MJ	WM, PD, MJ	PD	PD, HS	ID_0, SS, PD	HS^2, PD	PD	a
	SL, QG^2	SL, QG^2	SL, QG^2	SL, QG^2	SL, QG^2	SL, QG^2, IS^2	SL, IS^2	c
Construction and Verification Testing	HL	HL	HL	HL	HL	HL		a
	SL	SL	SL	SL		SL	SL	c
Integration and Validation Testing								a
	SL, QG	SL, QG	SL, QG	SL, QG		SL, QG	SL, QG	c
Implementation and User Acceptance								a
	SL	SL	SL	SL		SL	SL	c
Maintenance and Support								

Table Superscript Notation

1 – will later incorporate $IDEF_2$ to form an integrated modeling methodology $IDEF_{0,1,2}$

2 – recommended with reservations

3 – recommended for real-time systems

4 – will impose its own structure on the system

Methodology Purpose Designations

a – specify

b – describe and communicate

c – simulate

Methodology Designators

BA	Bachman
DA	Design Analysis System (DAS)
ER	Entity Relationship Approach (E-R)
GB	Graph Model of Behavior (GMB)
HL	High Level Language
HS	Higher Order Software (HOS)
ID_0	ICAM Definition ($IDEF_0$)
ID_1	ICAM Definition ($IDEF_1$).
ID_2	ICAM Definition ($IDEF_2$)
$ID_{0,1,2}$	$IDEF_0$, $IDEF_1$, and $IDEF_2$
IS	ICAM Decision Support System
MA	MASCOT
MJ	Michael Jackson Design Methodology (MJD)
PD	Program Design Language (PDL)
PP	Problem Statement Language/Problem Statement Analyzer (PSL/PSA)
QG	QGERT
SD	Structured Analysis/Structured Design
SL	Simulation Language
SR	SREM
SS	SIGS/SAMM
TR	Formal Decomposition and Allocation (TRW)
WE	Wellmade
WM	Warnier Mechanics

R-2309

Figure 1-1. Matrix Showing Methods vs. Life-Cycle Phases [11]

1.2 DEVELOPMENT BACKGROUND

IAT's development had its origin in a 1980 incident affecting operations at NCMC (NORAD Cheyenne Mountain Complex) MWC (Missile Warning Center). Because of the human factors involvement in that incident, AFAMRL initiated a field study to analyze function flow in NCMC operations. $IDEF_0$ was used as the descriptive analysis method [1], and its applicability to manned C^3 systems was compared with other systems engineering and engineering psychology methods [1,2].

None of the methods which were evaluated in the FY83 time frame was found adequate for describing either the structure or behavior of manned C^3 systems such as those at NCMC. Requirements were defined for a new method (IAT) that would integrate appropriate features from existing methods, yet go beyond the capabilities of any single method that was examined. In particular, IAT must address human engineering as well as system engineering aspects of C^3 system performance.

1.3 DEVELOPMENT STATUS

Methods development for IAT has followed a four-phased approach:

1) Identify needs & requirements for IAT.

2) Develop IAT conceptual framework.

3) Validate IAT methods.

4) Develop applications materials.

To date, work has been completed on 1. Portions of 2 and 3 have been completed during FY83-84, and are scheduled for completion during FY85.* The emphasis for FY85, however, will be on 3 and 4; viz.,

- Use techniques already in place to analyze human/system behavior in a real-world C^3 system (e.g., NCMC MWC).

- Develop guidelines and procedures for applying the techniques and insuring that the structural and performance modeling components of IAT are integrated.

Figure 1-2 summarizes the capabilities developed through FY84 and specifies what remains to be done in FY85. Further details about each accomplishment appear below in Sections 2 and 3. Section 4 will describe the approach to be taken for the FY85 effort.

*Preliminary validation of IAT methods was based on SIMCOPE-1. SIMCOPE-1 is a laboratory real-time simulation of a strategic Missile Warning Officer's crewstation in a hypothethical Command Warning Center (CWC).

[ ] indicate relevant documentation, primary source
"TBC" = to be completed during FY85

1.0 Identify needs & requirements for IAT	
Develop/defined:	
Questions about C^3 human & system performance (that IAT must address)	[1, 2 (revised)]
C^3 system performance measures useful in addressing questions	[1]
$IDEF_0$ description of function flow (NORAD NCMC/MWC)	[1]
Data requirements of $IDEF_0$ and other systems analysis & design methods	[1]
Comparative analysis and critique of systems analysis & design methods, to evaluate relevancy for addressing C^3 system performance	[1]
Set of desired capabilities for IAT	[1, 2 (revised), 4, 5 (TBC)]
2.0 Develop IAT Conceptual Framework	[2, 4 (revised)]
STRUCTURAL MODELING	
Review of systems engineering methods applicable for IAT structural analyses	[2]
Formal specification of: • Decomposition process • Dimensions for analyzing C^3 systems • Data structures (frames)	[2, 3 (revised)]
PERFORMANCE MODELING	
Review/taxonomy of analytic techniques relevant to IAT questions	[2]
Use of Queueing Network Theory (QNT) models	[2 (overview), 5 (detail)]
QNT approaches to modeling human performance	[5 (preliminary), TBC]
Specification of QNT with respect to data, functional usage requirements	[TBC]
Dynamic performance analysis from static descriptions	[5 (preliminary), TBC]
3.0 Validate IAT Methods	
SIMCOPE-1: STRUCTURAL MODELING	
• $IDEF_0$ functional decomposition	[2]
• SHOR decomposition	[2]
• Frame representations	[2, 5]
• Application of recursive formulae to - $IDEF_0$ Decomposition - SHOR Decomposition	[2]
SIMCOPE-1: PERFORMANCE MODELING	
• Data flow diagrams (DeMarco)	[5]
• QNT Representation	[5]
• Use of QNT to answer human/system performance questions	[5, TBC]
NORAD: STRUCTURAL & PERFORMANCE MODELING	[TBC]
4.0 Develop IAT Applications Materials	
Procedures & guidelines for applying IAT techniques	[2, 3, 5 (prelim.), TBC (revised)]
Documentation (user's manual)	[2 (planned), TBC]

R-2310

Figure 1-2. IAT Developments: Required Capabilities

2.0 METHODS DEVELOPMENT: SUMMARIES OF CAPABILITIES DEVELOPED TO DATE

<u>The Conceptual Framework: An Idealized Picture of IAT Use</u>

When fully developed, IAT will consist of a five-step analysis procedure:*

1) <u>Analyze the structure</u> of the system or subsystem of interest in terms of GOALS, ORGANIZATIONS, PROCESSES, RESOURCES, and their constituent elements; build a <u>structural model</u> to show the relationships among elements.

2) <u>Extract data</u> from the model in 1) and represent the derived information in appropriate formats (e.g., matrices or frames).

3) <u>Derive MOPs</u> (measures of performance) and <u>MOEs</u> (measures of effectiveness) using the structural model from 1) and the data representations from 2).

4) <u>Collect performance data</u> and construct a <u>performance model</u> (e.g., using a network of queues).

5) <u>Specify scenarios</u>, consisting of real-world events that activate or stop processes in the performance model from 4); <u>exercise the model</u> using appropriate methods (e.g., closed-form analysis, computer modeling and simulation, empirical tests with human subjects and mockups).

Figure 2-1, below, illustrates these steps and their outputs or products.

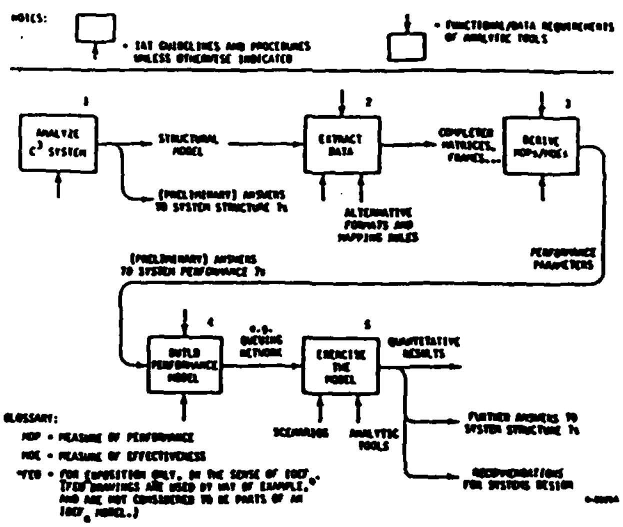


Figure 2-1. IAT Conceptual Framework - FY85 (FEO)*

*This procedure lists the logical set of activities that an analyst would carry out in analyzing an existing system to derive quantitative information. Steps 1-5 above are idealized -- in actual practice, an analyst must decide which steps to follow, and in what order, depending on the complexity of the system, difficulty in collecting performance parameter data, data requirements of the analytic tool, and intended use of the performance information that is generated.

The sections below treat the techniques and formalisms ALPHATECH has developed so far that support each of the five steps.

2.1 TECHNIQUES FOR BUILDING STRUCTURAL MODELS

2.1.1 Dimensions for Analyzing C^3 System Structure

Designers and planners need answers to questions about system structure to determine what changes need be made to improve human/system performance. Four perspectives are required for analyzing system structure in order to answer these questions:

1) GOALS — capture the requirements or constraints that mission objectives impose.

2) ORGANIZATIONS — site of control or authority; personnel play roles at different levels of organization, and have responsibilities allocated to them.

3) PROCESSES — activities carried out to fulfill goals.

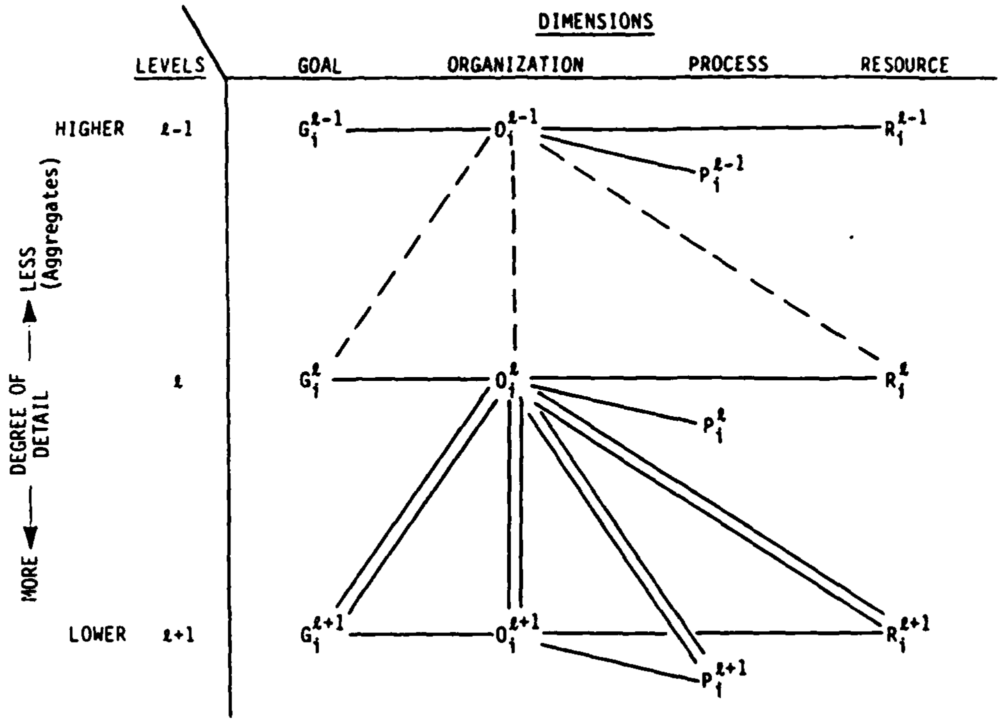
4) RESOURCES — agents (man or machine); equipment, materials, physical layout of components and their connections.

To answer specific questions and see the relationships among 1-4, it is necessary to break down each of these four dimensions into its constituent elements. Structured decomposition should proceed until specific tasks or transactions can be isolated: "tasks" and "transactions" are lower-level constituents of PROCESSES (i.e., subprocesses); tasks/transactions are carried out by agents (man or machine), who have been given responsibility, resources, and goals that they must meet.

2.1.2 Recursive Decomposition

Although many existing methods from systems engineering provide techniques to handle decomposition, none evaluated in [1,2] treat the relationships among GOALS, ORGANIZATIONS, PROCESSES, and RESOURCES in a systematic fashion. IAT uses set theory notation to describe levels of analyses within each of these four dimensions; i.e., one can keep track of GOALS/subgoals, PROCESSES/subprocesses, etc. And to specify relationships among elements across different dimensions, a recursive approach is used.

Figure 2-2 shows the four dimensions of decomposition and how relationships among elements can be described recursively. Figure 2-3 suggests how matrix notation can be used to capture additional relationships.



LEGEND

$X^{\ell} = \{X_i^{\ell}\}$ where i ranges over all elements at level-ℓ.

X_i^{ℓ} Denotes the i^{th} element of X at level-ℓ.

═══ ASSIGNMENT (from level ℓ) — An organizational element (O_i^{ℓ}) at a given level (ℓ) establishes goals for the next lower level (ℓ+1); O_i^{ℓ} (e.g., a commander) assigns goals ($G_i^{\ell+1}$), processes ($P_i^{\ell+1}$), resources ($R^{\ell+1}$), and organizational elements ($O_i^{\ell+1}$) (e.g., subordinates) to meet these goals.

- - - - ASSIGNMENT (from level ℓ-1) — O_i^{ℓ} has been assigned goals (G_i^{ℓ}), processes (P_i^{ℓ}), and resources (R_i^{ℓ}) from organizational elements at the next higher level ($O_i^{\ell-1}$).

──── RESPONSIBILITY — Exercise of responsibility within a level for meeting assigned goals.

R-2307

Figure 2-2. Recursive Nature of Decomposition

A. DECOMPOSITION MATRICES ("consists of/is part of")

$\begin{bmatrix} G_i^{\ell} & \times & G_i^{\ell+1} \end{bmatrix}$ = GOAL DECOMPOSITION: Describes partitioning of goals into subgoals for purposes of assignment (to organizational elements who are responsible for meeting these subgoals)

$\begin{bmatrix} O_i^{\ell} & \times & O_i^{\ell+1} \end{bmatrix}$ = ORGANIZATIONAL (AUTHORITY) DECOMPOSITION: defines lines of authority and responsibility

$\begin{bmatrix} P_i^{\ell} & \times & P_i^{\ell+1} \end{bmatrix}$ = PROCESS DECOMPOSITION: specifies constituency relations between higher-level processes and their components (subprocesses); describes what subprocesses are required (e.g., for producing a specific output at a higher level)

$\begin{bmatrix} R_i^{\ell} & \times & R_i^{\ell+1} \end{bmatrix}$ = RESOURCE DECOMPOSITION ("FAMILY TREE"): defines constituency of physical structure; e.g.,

```
      squadron
        /  \
      aircraft
       / | \
engine avionics ...
```

B. DEPENDENCY/CONNECTIVITY MATRICES ("connected to/flows to/depends on")

$\begin{bmatrix} O_i^{\ell} & \times & O_i^{\ell+1} \end{bmatrix}$ = ORGANIZATIONAL COORDINATION: describes which organizational elements can interact (e.g., exchange information, inform or coordinate-with)

$\begin{bmatrix} P_i^{\ell} & \times & P_i^{\ell+1} \end{bmatrix}$ = PROCESS DEPENDENCY: expresses what is required for process input and output (vs. what is actually available)

$\begin{bmatrix} R_i^{\ell} & \times & R_i^{\ell+1} \end{bmatrix}$ = RESOURCE CONNECTIVITY: specifies which resources can send/receive information (from each other)

(Continued)

Figure 2-3. Primitives and Matrix Notation: Example Relations [3]

C. ASSIGNMENT MATRICES ("is assigned to")

$$\begin{bmatrix} O_i^{\ell} \times G_i^{\ell+1} \end{bmatrix}$$ = GOAL-SETTING RESPONSIBILITY: represents partitioning of goals or objectives among organizational elements

$$\begin{bmatrix} O_i^{\ell} \times P_i^{\ell+1} \end{bmatrix}$$ = PROCESS ASSIGNMENT RESPONSIBILITY: assigns responsibility for processes to organizational elements (can be used for long-range planning)

$$\begin{bmatrix} O_i^{\ell} \times R_i^{\ell+1} \end{bmatrix}$$ = RESOURCE ASSIGNMENT RESPONSIBILITY: reflects issues of "ownership" and specifies site of control over resource disposition

$$\begin{bmatrix} O_i^{\ell} \times O_i^{\ell+1} \end{bmatrix}$$ = ORGANIZATION ASSIGNMENT RESPONSIBILITY: describes who can delegate responsibilities to whom

D. ASSIGNABILITY MATRICES ("can be assigned to/used for")

$$\begin{bmatrix} O_i^{\ell} \times G_i^{\ell+1} \end{bmatrix}^*$$ = Capable of having goal-setting responsibility

$$\begin{bmatrix} O_i^{\ell} \times P_i^{\ell+1} \end{bmatrix}^*$$ = Capable of taking responsibility for various processes

Where [ ]* indicates possibility-of-assignment. Each cell in these matrices is an index (numerical quantity) that represents relative capability; e.g., to show how well an individual could perform a given task. This notation can be used to specify capacity-for-change, or adaptability of a C^3 system with respect to its external environment.

(Concluded)

Figure 2-3. Primitives and Matrix Notation

2.1.3 Derivation of MOPs (Measures of Performance) and MOEs (Measures of Effectiveness)

MOPs are associated with PROCESSES and describe how well a specific process or subprocess has been executed — using quantitative data to specify factors like extent, duration, frequency, and currency.

MOEs are associated with GOALS and describe the extent to which requirements have been met; e.g., have mission requirements been satisfied? For C^3 systems, MOEs might include assessments of errors (type, number), target damage, efficiency counts (response time, kill ratios), and survivability estimates.

In terms of the IAT Conceptual Framework, shown in Figure 2-1, MOPs and MOEs can be defined according to levels and point-of-view:

At a given level (ℓ), appropriate quantitative measures (MOPs) will describe how well a particular process (P_i^ℓ) has been carried out. The organizational element (O_i^ℓ) responsible for this process will be interested in these measures to determine whether the goal (G_i^ℓ)has been met at this level. But since G_i^ℓ, O_i^ℓ, and P_i^ℓ have all been assigned from a higher-level organization ($O^{\ell-1}$), other measures (MOEs) will be needed to assess the extent to which goals at this higher level ($G^{\ell-1}$) have also been met.

Figures 2-4 and 2-5 illustrate MOPs and MOEs with respect to the IAT Conceptual Framework. Figure 2-6 shows how matrix notation can be used to describe Goal vs. MOP relationships.

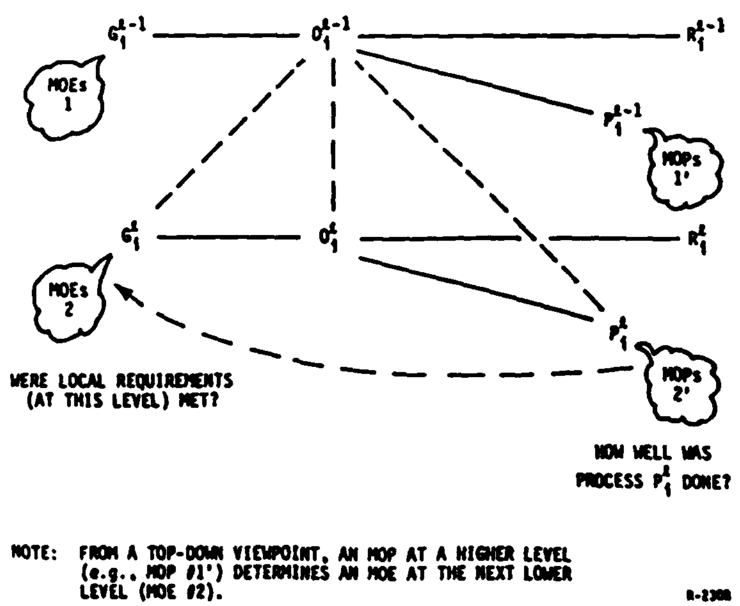


Figure 2-4. Relationship Between MOPs and MOEs in IAT

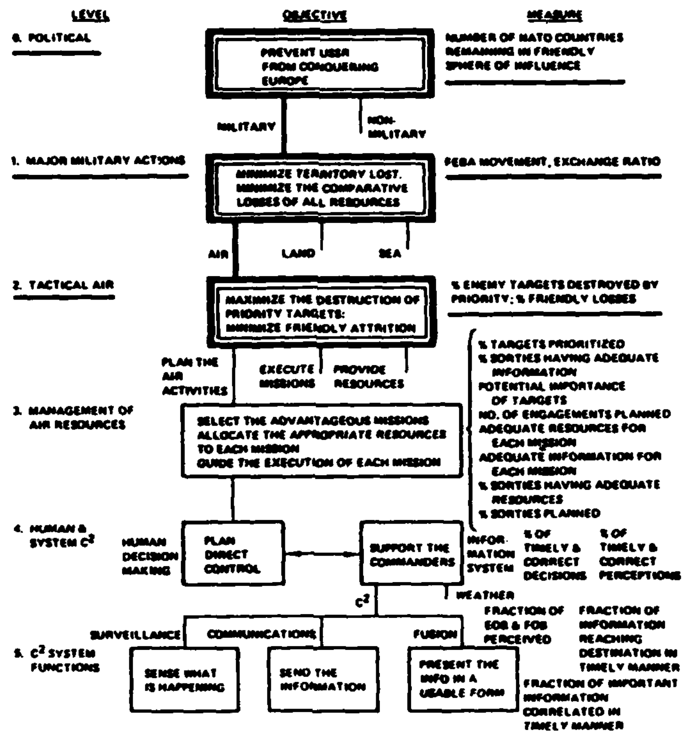


Figure 2-5a. Example of "Goal Hierarchy" - Tree of Objectives (from Bennett et al., 1979 [6])

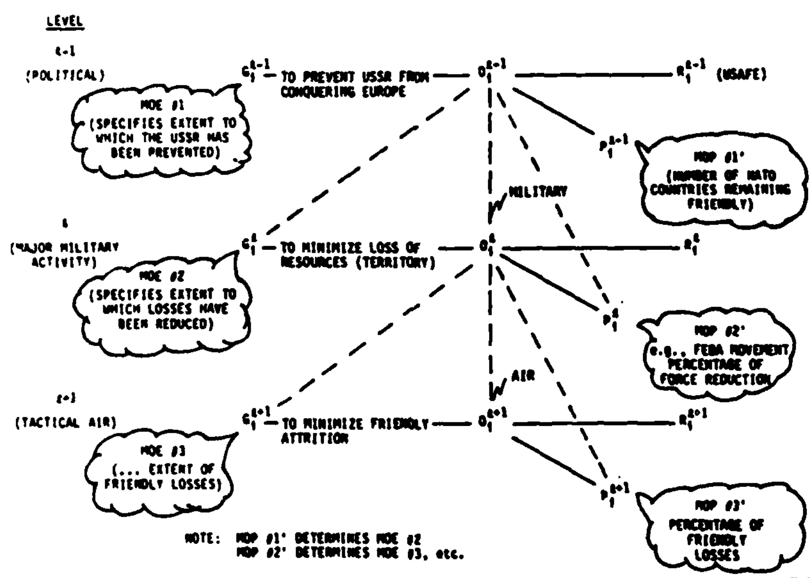


Figure 2-5b. Example of Bennett's "Goal Hierarchy" Shown in IAT Framework (Top 3 levels only from Figure 2-5a, above)

SIMCOPE-1 MOPs / SIMCOPE-1 GOALS: TO PROVIDE ...	TIME BEFORE ACCOMPLISHED	NUMBER OF OCCURRENCES	NUMBER CORRECT	% TIME OPERATOR BUSY	AVE. PROCESSING TIME/MESSAGE	AVE. TIME: MESSAGE ARRIVAL TO THREAT I.D.	AVE. NUMBER DISPLAYS TO PROCESS MESSAGE	AVE. NUMBER CONFERENCES TO PROCESS MESSAGE	ERROR CLASSIFICATION	AVE. NUMBER SIGNAL ERRORS/SHIFT
1 RAPID COMMUNICATION TO CDC*	X				X	X				
2 TIMELY/ACCURATE LAUNCH DETECTION	X		X		X	X			X	
3 TIMELY/ACCURATE THREAT I.D.	X		X		X	X			X	
4 INCREASED VIGILANCE (BRIEFS)		X	X					X		
5 RESOLUTION OF SENSOR CONFLICTS		X	X				X	X	X	X
6 STATUS ASSESSMENT	X		X	X			X	X		
7 DATA BASE UPDATE	X		X							

*Using IAT Conceptual Framework:

R-1656A

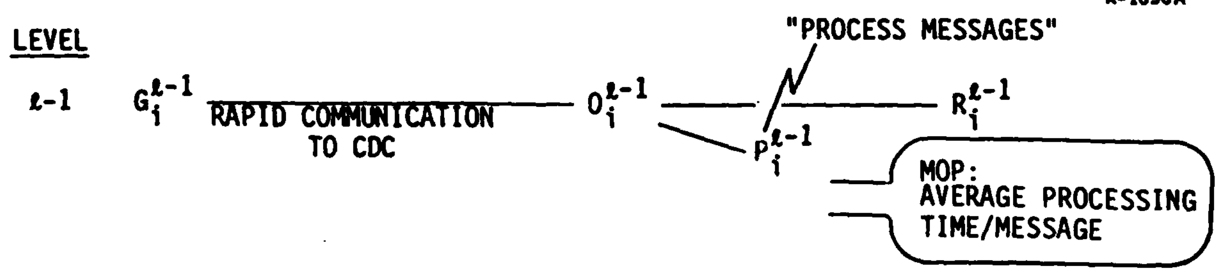


Figure 2-6. Example of Goal vs MOP Matrix. (From SIMCOPE-1 [5])

2.1.4 Data Structures

Set theory and matrix notations have been introduced in the previous sections to represent information about system structure and behavior. These notations should be viewed as the theoretical basis, or foundation, for step-by-step rules that will help users collect data and build structural and performance models.

Frame notation has also been developed by ALPHATECH for IAT applications [2]. Frames constitute major data sets for each of the four dimensions: GOALS, ORGANIZATIONS, PROCESSES, RESOURCES. "Slots" describe the data elements of a frame.

The advantages of using frames and slots are as follows:

1) Relationships that might be captured in several different matrices can be grouped together on a single frame.

2) Slots can be used with and without entries to indicate whether performance data are or are not available.

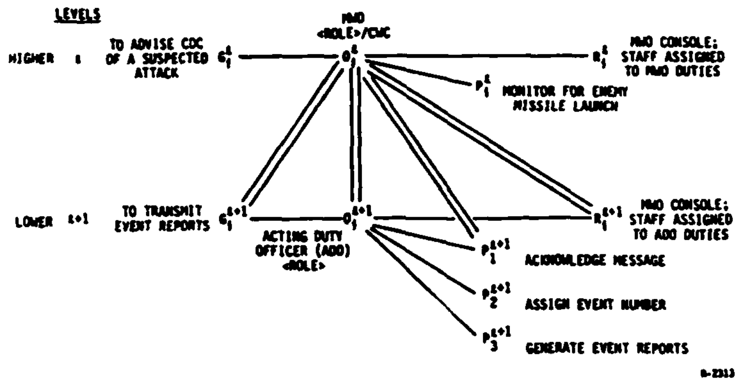
3) Default values can be defined in slots for carrying out sensitivity analyses and "zero-order" estimates of performance.

4) Cross-referencing can be handled by supplying pointers from frame-to-frame (indicated as entries on slots).

5) Slots can be added or deleted to specify attributes of the dynamic characteristics of a process.

6) The inherent nesting properties of frame and slot notation make it possible to capture information from structural models (recursive decompositions and matrices in IAT).

Figure 2-7 illustrates frame and slot notation.



PROCESS NAME:	MONITOR FOR ENEMY MISSILE LAUNCH
GOAL:	TO ADVISE CDC OF A SUSPECTED ATTACK
ORGANIZATIONAL ELEMENT:	MISSILE WARNING OFFICER (MWO) ... primary responsibility ACTING DUTY OFFICER (ADO) ... delegated responsibility
PARENT PROCESS:	ϕ
SUB-PROCESSES REQUIRED:	1) ACKNOWLEDGE MESSAGE 2) ASSIGN EVENT NUMBER 3) GENERATE EVENT REPORTS
INPUTS REQUIRED:	MESSAGES - (4 TYPES) 1) INTELLIGENCE 2) SYSTEM STATUS 3) ADS 4) BSS
OUTPUTS:	EVENT REPORTS - (3) 1) ADS1 2) ADS2 3) BSS
MEASURES OF PERFORMANCE:	TIMELINESS ACCURACY
RESOURCES REQUIRED:	MWO CONSOLE STAFF ASSIGNED TO MWO/ADO DUTIES

Figure 2-7. Example of IAT Structural Description and Process Frame for the Process "Monitor for Enemy Missile Launch" (Based on SIMCOPE-1 Analysis [5])

2.2 PERFORMANCE MODELING

> To generate estimates of human/system performance, predictive analysis methods from operations research and engineering psychology require information about system structure and system behavior.

Information about system structure can be derived from the hierarchical decompositions, matrices, and frames used in the IAT structural modeling component. Information about system behavior needs to be derived from a level of description that captures the dynamic properties of human and system performance. These properties will be represented in IAT performance models. Important properties of manned C^3 system behavior can be described in IAT performance models; e.g.,

1) Procedural Operations: processes in the system (identified as decomposed "P's" in the structural model) can be described by a sequence of steps to indicate the logic of each operation (i.e., "scripts").

2) Parallel Processing: any number of processes can be activated simultaneously.

3) Shared Resources: some processes require resources which are contended for by other resources.

4) Operational Loading: load on a system varies directly with the number of processes active and the number waiting on resources.

5) Process Communication: processes need to transfer data and/or materials to other processes: transfer may also include information about the process itself (i.e., copies of the process may be transferred). Note that actual transfer is carried out by resources (specified by the resource connectivity matrix $[R_i^\ell \times R_i^\ell]$, Figure 2-3).

2.2.1 Constraints on Building Performance Models

A performance model will be usable only in so far as it represents information with the right properties — "right" in this sense means that the data can serve as input to an analytic procedure. Different procedures exhibit different data needs, in terms of both structure and content. For example, statistical techniques like regression require inputs that specify observations of variables (x,y); whereas goal programming methods require coefficient data and goal values.

2.2.2 Specification of Analytic Methods

Since building usable performance models requires knowing the data requirements of an analytic method or methods, the tools used to carry out performance analysis in IAT must be well-specified, with respect to input/output requirements. Work done earlier on IAT [1,pp. 166ff.; 2] has addressed the task of describing data requirements of analytic methods. The results of these studies show that the types of information listed below will be required (minimally) as inputs to methods such as Queuing Network Theory (QNT):

1) Synchronous/asynchronous relationships between processes (derived from the IAT process dimension).

2) Description of actual data stores in the physical system (derived from the resource dimension).

3) Description of the actual data flows during event processing (derived from $[R_i^{\ell} \times R_i^{\ell+1}]$ connectivity matrices, shown in Figure 2-3).

2.2.3 QNT Approaches to Modeling Human/System Performance

Studies conducted during FY82-84 have selected QNT as a method appropriate for generating quantitative estimates of human/system performance in C^3 systems [1,2]. QNT was selected because its data outputs are time-related and capacity-related, and these relations are critical for analysts and designers to understand so that they can improve existing systems or design new ones.

However, traditional queuing methods are not designed to take account of human behavior at the level of complexity exhibited in C^3 systems. Modifications to standard QNT must be made to address factors like accuracy and error, associated with human operators who carry out specific tasks at workstations. Procedures have been developed during the FY83-84 efforts for using QNT to represent task flow and to capture the impact that errors can have on throughput [5]. Figure 2-8 summarizes the procedure to represent task flow.

1. Define any function or process as the processing of a given group of related problems, tasks, or jobs in some allowable sequence. Call these <u>tasks</u>, T.

2. Each task T has a set of attributes A. These attributes can be defined in terms of a variable set x and a relationship set f(x), where x is the set of all relevant variables.

3. Tasks can be clustered into classes based on common attributes via a simple clustering algorithm.

4. T_{ij} is the i-th task belonging to the j-th class.

5. T_{ij} has attributes A_{jk}.

6. There are assignable resources, or "servers" in a queuing theory sense, $(s_1, s_2, \cdots, s_\ell)$.

7. Each resource has a maximum processing capacity C_ℓ (for <u>any</u> task).

8. Each resource processes a class-j task at a rate $\eta_{j\ell}$, where $\eta_{j\ell}$ is the mean of an exponential distribution.

9. Arrivals are Poisson, and the arrival rate of class-j tasks is λ_j; i.e., average time between arrivals of $T_{1j}, T_{2j}, \cdots, T_{ij}$ is $1/\lambda_j$.

10. An external scenario drives the overall task arrival rate $\lambda = \Sigma\lambda_j$.

11. For simplicity, assume that all resources have identical <u>maximum</u> task processing capacities C, i.e., $C_1 = C_2 = \cdots = C_\ell = C$.

12. Assume that their <u>average</u> task processing rate $\mu_{j1} = \mu_{j2} = \cdots = \mu_{j\ell} = \mu_j$. (Note: We can relax assumptions 11 and 12 later in order to determine effects of individual differences among resources on system performance.)

13. $\sum_j \mu_{j\ell} < C_\ell$ (maximum capacity constraint).

Figure 2-8. Definitions and Assumptions for Queuing Representation of Tasks

3.0 VALIDATION (SIMCOPE-1)

The SIMCOPE facility at AFAMRL was chosen as a test case for illustrating the application of (preliminary) IAT methods. SIMCOPE was selected for several reasons:

1) It approximates the complexity of a node in real-world manned C^3 systems like those at NORAD MWC (even though its scenarios are fictitious).

2) Its operations are neatly circumscribed.

3) It permits the study of human performance within a controlled laboratory environment (which approximates a real-world operational setting).

4) The details of its design and operation can be analyzed and discussed openly (because of its fictitious nature).

The focus of SIMCOPE is on the Missile Warning Officer (MWO), whose main role is to monitor data to detect missile launches that may pose a possible threat. Performance predictions relevant for the validation address questions of system throughput — e.g., what happens as input message arrivals exceed operator service rates? what operating strategies best handle the work backlog? are there alternative designs that can alleviate the bottleneck?

For using SIMCOPE as a case study to validate IAT methods, several notational formats were required. These are reviewed in the sections that follow.

3.1 OPERATOR SCENARIOS

These specify the tasks and task sequences that MWOs would perform to carry out their responsibilities in a MWC. (Subject instructions were developed under the AFAMRL COPE Program for this purpose, and are described in [9].)

3.2 DATA FLOWS (DeMarco)

Because methods like QNT require explicit information about data flow, a formalism was needed that would capture this information in SIMCOPE. Of critical interest are the following data flow characteristics:

- Data Stores: sites, temporary repositories of data (e.g., computer files, blackboards, operator displays).

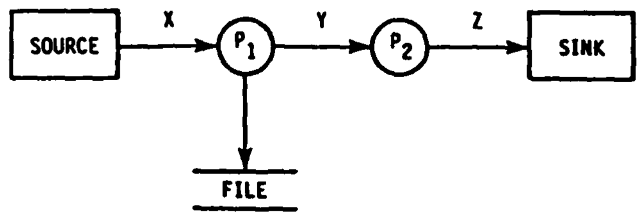
- Sources: points of origin.

- Sinks: points of destination.

- Processes: transformations that map input data to output data.

- Flows: "pipelines" through which packets of information of known composition may flow.

DeMarco diagrams [10] provide a simple syntax and semantics for capturing these characteristics. Figure 3-1 describes the components of a DeMarco diagram; Figure 3-2 presents an example of how these diagrams were used to portray data flow in SIMCOPE.



COMPONENTS

1. Data flows, represented by labeled arrows; (X,Y,Z)
2. Processes, represented by circles; (P_1,P_2)
3. Files or Data Stores, represented by straight lines; FILE
4. Data Sources or Sinks, represented by boxes.

R-2311

Figure 3-1. DeMarco Data Flow Diagram (Example)

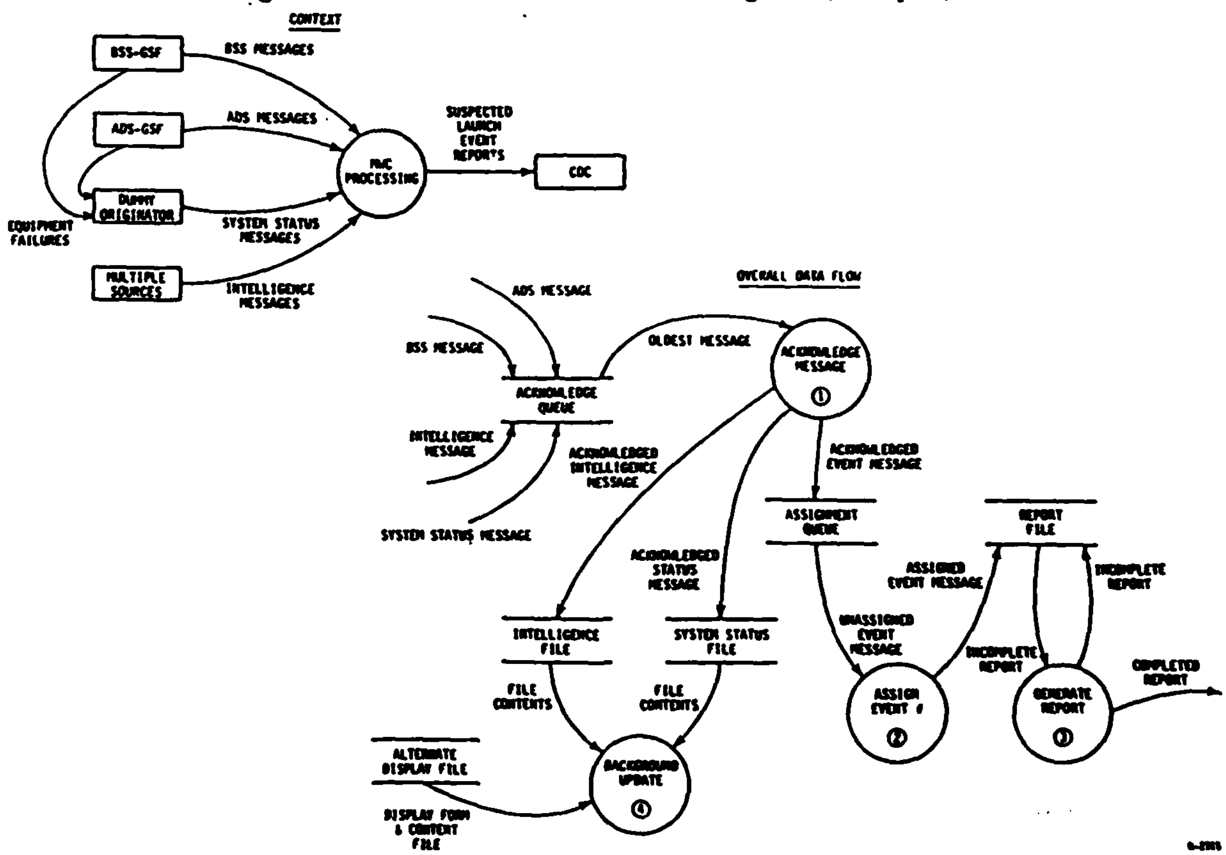
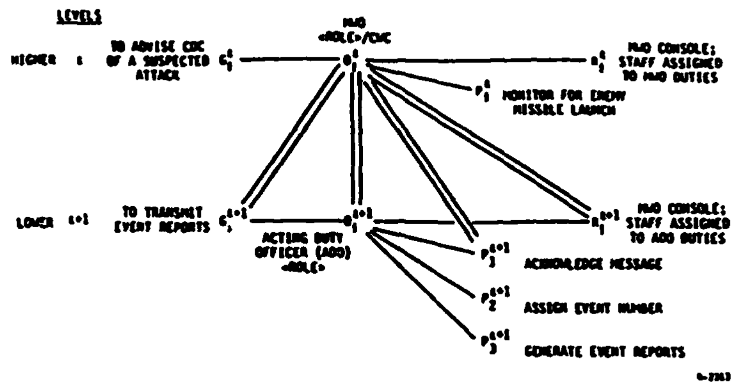


Figure 3-2. DeMarco Diagrams Used in SIMCOPE Validation [5]

3.3 USE OF FRAME NOTATION

Frames were used to describe aspects of information captured in the data flow diagrams. This was done to facilitate cross-referencing of data elements and provide traceability from data and processes (shown in DeMarco diagrams) back to components of system structure (GOALS, ORGANIZATIONS, PROCESSES, RESOURCES). Figure 3-3 (shown as Figure 2-7 presented earlier) is an example of a PROCESS Frame for the process called "Monitor for Enemy Missile Launch" in the SIMCOPE context; Figure 3-4 shows the hierarchical decomposition in terms of system structure.



PROCESS NAME:	MONITOR FOR ENEMY MISSILE LAUNCH
GOAL:	TO ADVISE CDC OF A SUSPECTED ATTACK
ORGANIZATIONAL ELEMENT:	MISSILE WARNING OFFICER (MWO) .. primary responsibility ACTING DUTY OFFICER (ADO) ... delegated responsibility
PARENT PROCESS:	ϕ
SUB-PROCESSES REQUIRED:	1) ACKNOWLEDGE MESSAGE 2) ASSIGN EVENT NUMBER 3) GENERATE EVENT REPORTS
INPUTS REQUIRED:	MESSAGES - (4 TYPES) 1) INTELLIGENCE 2) SYSTEM STATUS 3) ADS 4) BSS
OUTPUTS:	EVENT REPORTS - (3) 1) ADS1 2) ADS2 3) BSS
MEASURES OF PERFORMANCE:	TIMELINESS ACCURACY
RESOURCES REQUIRED:	MWO CONSOLE STAFF ASSIGNED TO MWO/ADO DUTIES

Figure 3-3. Example of IAT Structural Description and Process Frame for the Process "Monitor for Enemy Missile Launch" (Based on SIMCOPE-1 Analysis [5])

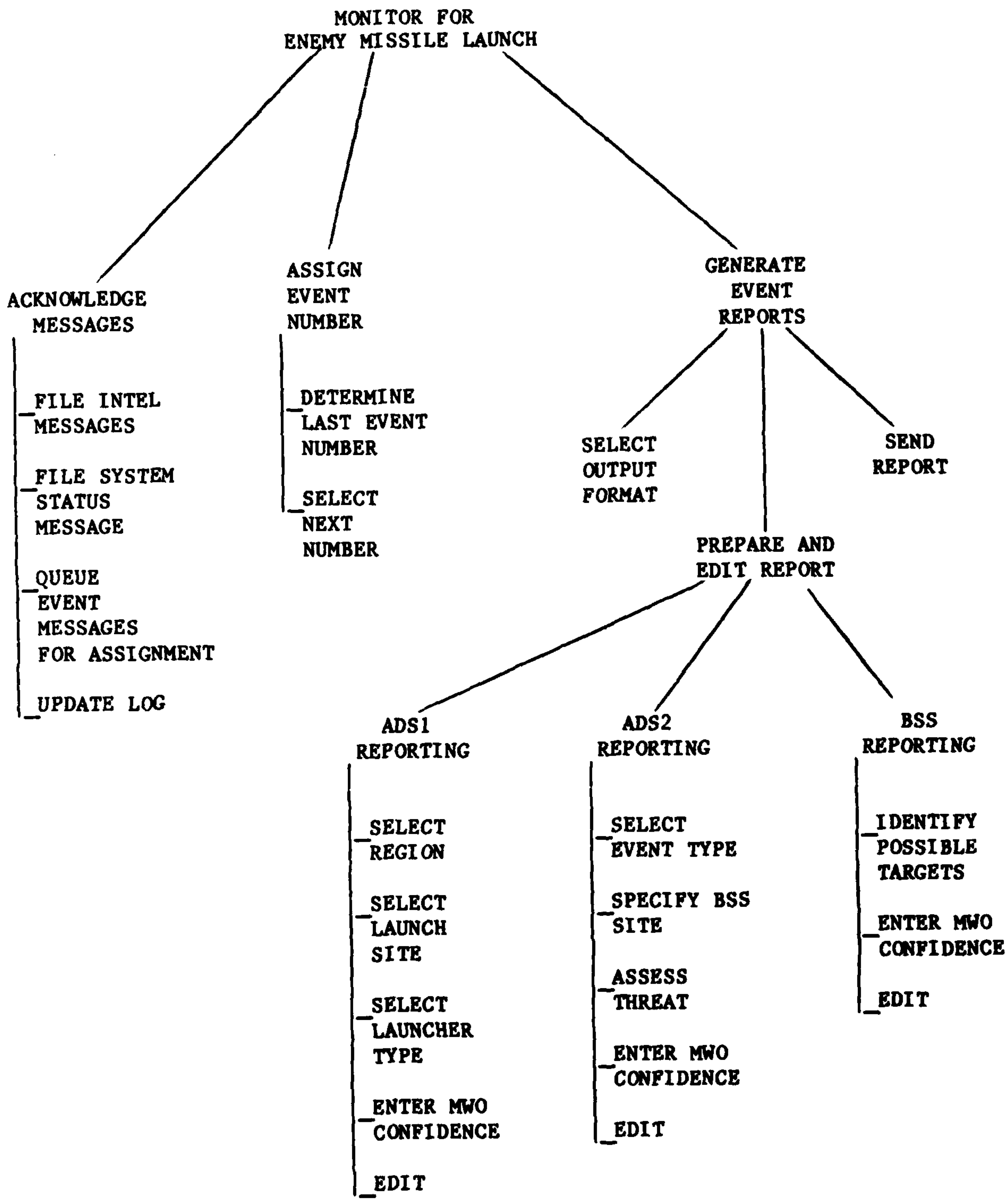


Figure 3-4. Monitor for Enemy Missile Launch: Tree Structure Hierarchy

3.4 QNT REPRESENTATION

Representing information about SIMCOPE structure and behavior with the formalisms described above made it possible to construct a queuing model (Figure 3-5). Arrival rates and service rates were specified, and conditional service times estimated. Estimates were then derived to describe the time required for completing report-processing. Further details are provided in [5] to explain how the model was constructed and the system performance parameters derived.

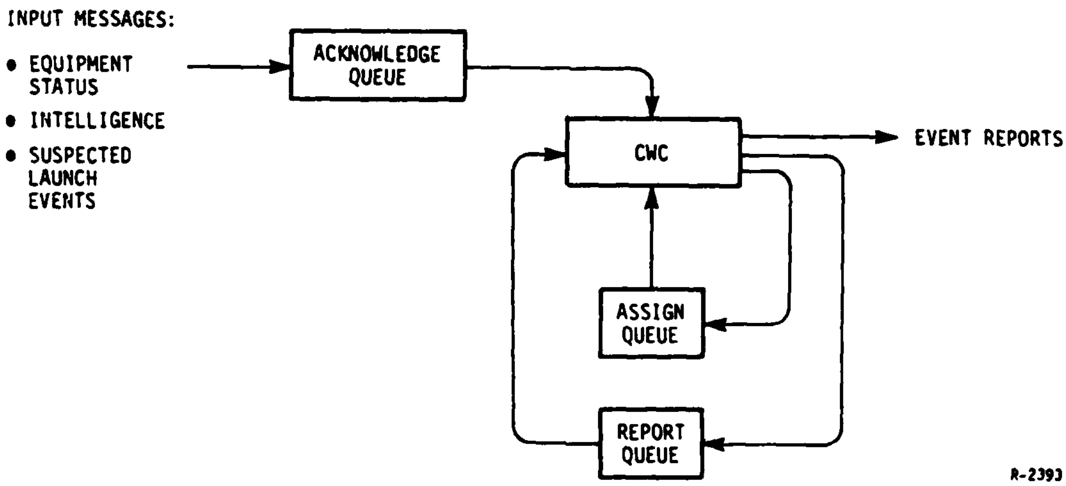


Figure 3-5. The Queuing Representation of SIMCOPE

3.5 USE OF ANALYSIS RESULTS FOR CHANGES/REDESIGN OF C^3 SYSTEMS

The queuing network model allowed investigators to pose "WHAT-IF" questions about human/system performance. For example, one could examine the benefits of adding one or more operators (MWOs) by adjusting the structure and the appropriate service time parameters in the model. In another case, one could examine what would happen if an excessive number of routine status or intelligence messages came in and overloaded the system [5].

4.0 PLANS FOR FY85

4.1 Methods Development Strategy

As discussed earlier, much of the work done to date has focused on developing the IAT conceptual framework and its component techniques and notations. Preliminary validation of these techniques on SIMCOPE has helped IAT methods developers identify areas of strength as well as needs for further development.

The most important tasks to be addressed in FY85 pertain to the use of IAT and its application to real-world C^3 systems. First, structural and performance modeling components of IAT must be integrated. Second, guidelines and procedures must be developed to insure applicability of the methods to actual systems.* The sections that follow summarize the work required to satisfy these needs.

Insuring Integration of Structural and Performance Modeling

Methods must be developed to specify the following activities:

1) Collecting data to build a structural model.

2) Carrying out recursive decomposition consistently across all dimensions (GOALS, ORGANIZATIONS, PROCESSES, RESOURCES).

3) Collecting data to build a performance model.

4) Using a consistent syntax and semantics to represent data in matrices and frames.

5) Using modeling tools such as QNT.

6) Extracting quantitative information appropriate to answer "WHAT-IF" questions.

7) Using results of performance analysis to change or improve C^3 systems.

4.2 Validation Based on Real-World C^3 Systems (NORAD Command Center)

Missile warning processing at the NORAD Command Center will provide a test of the validity of the methodology. This validation will provide direction for the methods development work that still remains to be completed -- insufficiencies will be spotted when the current set of methods is exercised in the field.

*The SIMCOPE validation provided a preliminary feasibility test for IAT use; this validation effort needs to be extended (and cross-validated) by applying IAT methods to other C^3 systems.

In particular, we would hope to: (1) determine the levels of difficulty associated with collecting data (#1,3 above); and 2) assess the degree to which quantitative information about human performance can be obtained by using IAT (#6,7). Once the utility of IAT as a human engineering technique has been demonstrated on real-world systems, we will be in a better position to insure that its use will improve the analysis and design of manned C^3 systems.

REFERENCES

IAT Development

1. Colter, M., Miller, R.A., and Wohl, J.G., "Integrated Analysis Techniques (IAT) for Application to Command, Control, and Communications Systems," TM-HU-566/000/00, System Development Corporation, Huntsville, AL, Sept., 1982.

2. Gruesbeck, M.A., Miller, R.A, Wohl, J.G., Kleinman, D.L. and Chubb, G.P., "An Integrated Analysis Technique (IAT) for C^3 Operator Performance Evaluation," TR-175, ALPHATECH INC., Burlington, MA, Feb., 1984.

3. Kleinman, D.L., Wohl, J.G., "A Hierarchical Method for Describing C^3 Systems," Working Paper, ALPHATECH INC., Burlington, MA, July 1984.

4. Kornfeld, J.R., "COPE/IAT Extensions for Supporting C^3 Systems Modeling and Analysis," SP-441, ALPHATECH INC., Burlington, MA, November 1984.

5. Kornfeld, J.R., "Specification and Preliminary Validation of IAT Methods," TR-224, ALPHATECH INC., Burlington, MA, (forthcoming).

Human/Systems Engineering Analysis and Design Methods

6. AF Wright Aeronautical Labs (AFWAL), "ICAM Dynamics Modeling Manual ($IDEF_2$)," UM 110231300, Wright-Patterson AFB, OH, June 1981.

7. Chubb, G.P., "SAINT, A Digital Simulation Language for the Study of Manned Systems," in J. Moraal, K. - F. Kraiss, (Eds.), Manned System Design: Methods, Equipment and Applications, New York: Plenum Press, 1981.

8. Bennett, A.S., Howen, E.D., Kasparian, K.D., Kistner, J.M., and Weingarten, A., "CONSTANT QUEST Modeling Group: Phase I Report," MTR-3757, The MITRE Corp., Bedford, MA, 2 April 1979.

9. ALPHASCIENCE, "SIMCOPE Instructions," WP-83-009, Dayton, OH, February, 1984.

10. DeMarco, T., Structured Analysis and System Specification, Yourdon Inc., New York, 1978.

11. Peters, L.J., Jumani, V.B., and Hull, H.B., "Alternate Architecture Display System Development Methodology Study, Vol. I, Part 2: Guidebook for System Development in a Manufacturing Environment," Boeing Computer Services Co., Seattle, WA, September 1979.

12. Samarov, A., Personal Communication, Higher Order Software, 23 February 1979.

U.S. GOVERNMENT PRINTING OFFICE: 1985 - 646-006/20229

END

FILMED

1-86

DTIC