AD-A178 600

DTIC FILE COPY

(12)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Command and Control Theory		5. TYPE OF REPORT & PERIOD COVERED 1 December 1986 to 28 February 1987 6. PERFORMING ORG. REPORT NUMBER LIDS-IR-1658
7. AUTHOR(s) Alexander H. Levis Michael Athans		8. CONTRACT OR GRANT NUMBER(s) N00014-85-K-0782
9. PERFORMING ORGANIZATION NAME AND ADDRESS Laboratory for Information and Decision Systems Massachusetts Institute of Technology Cambridge, Massachusetts 02139		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 564-001
11. CONTROLLING OFFICE NAME AND ADDRESS Life Sciences Technology (Code 1211) Office of Naval Research Arlington, Virginia 22217-5000		12. REPORT DATE March 25, 1987 13. NUMBER OF PAGES i+15
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) CDR. T. Jones Code 121 Office of Naval Research 800 N. Quincy Street Arlington, VA 22217-5000		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Command and Control, Distributed Decisionmaking, Organization Theory, Petri Nets, Distributed Battle Management

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

Progress on 4 research problems in Command and Control Theory is described.

DD FORM 1473

LABORATORY FOR INFORMATION AND DECISION SYSTEMS

Massachusetts Institute of Technology
Cambridge, Mass., 02139, U.S.A.

OSP NUMBER 96833

LIDS-IR-1658

QUARTERLY PROGRESS REPORT

for the period

1 December 1986 to 28 February 1987

for

COMMAND AND CONTROL THEORY

Contract Number N00014-85-K-0782

Work Unit NR 564-001

Submitted to:

CDR T. Jones, Code 121
Mr. J. G. Smith, Code 1211
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000

Submitted by:

Alexander H. Levis
Michael Athans

March 15, 1987

COMMAND AND CONTROL THEORY

1. PROJECT OBJECTIVES

The main goal of this research is to start bridging the gap between mathematical theories of command and control and empirical studies. More specifically, the goal is to develop theories on the one hand and to model experimental paradigms on the other, so that realistic problems in command and control (C^2) can be studied prior to the design of experiments and the collection of relevant data.

The research program undertaken for this project has three main objectives:

(a) The extension of a mathematical theory of C^2 organizations so that it can be used to design an experimental program;

(b) The further development of an analytical methodology for measures of effectiveness, and

(c) The investigation of organizational architectures for distributed battle management (many weapons on many targets resource allocation problems).

The unifying theme of this research is the concept of distributed information processing and decisionmaking. The emphasis is on the development of models and basic analytical tools that would lead to the design of an experimental program as contrasted to ad hoc experimentation.

The project draws upon and contributes to the theoretical developments on naval distributed tactical decisionmaking (DTDM) being pursued in parallel under ONR Contract No. N00014-84-K-0519. The co-existence of these two programs has made it possible to undertake long-range, basic research on fundamental issues and problems in command and control.

2. STATEMENT OF WORK

The research program has been organized into five tasks, four that address the research objectives and a fifth that addresses the question of disseminating the results of this project both directly to the members of the Basic Research Group of the Technical Panel on C^3 of the Joint Directors of Laboratories and to the C^3 community at large through publications and presentations.

2.1 RESEARCH TASKS

<u>TASK 1:</u> <u>Development of Computer-Aided Design System</u>

1.1 Develop the specifications for the Computer-Aided Design System. Specifically, design the data base, the architecture generator, the performance-workload locus module, and the analysis and evaluation module. The system should be able to handle a generic five member, three echelon organization.

1.2 Implement the design developed in Task 1.1. Design the graphics module to be used in presenting the performance-workload locus and its projections as well as the loci obtained from the analysis and evaluation module.

1.3 Design and implement the user interface. Use the Petri Net formalism for the specification of the interactions between organization members and the design of protocols.

<u>TASK 2:</u> <u>Command and Control Organization Design and Evaluation</u>

2.1 Develop and implement a set of tasks, as well as sets of information processing (situation assessment) and decisionmaking (response selection) algorithms for use with the decisionmaker models. These tasks and algorithms should be appropriate to future experimental efforts.

2.2 Use organizations with up to five members to exercise and test the CAD system developed in Task 1.

2.3 Analyze and evaluate command and control organizational architectures using the CAD system. Begin developing hypotheses that can be tested through experimental efforts.

2.4 Incorporate in the design system and in the analysis module the theoretical results obtained from parallel research projects.

TASK 3: C^3 Organizations and Architectures for Distributed Battle Management

3.1 Develop a unified theory for complex engagements of several weapons against several targets. Assume imperfect defensive weapons systems so that the elemental "one-on-one" kill probability is non-unity. Also assume imperfect defensive surveillance so that the target/decoy discrimination probability is non-unity.

3.2 Develop several "many-on-many" engagement strategies and evaluate their impact upon decentralized C^3 system requirements and architectures. Develop the necessary tools so as to design distributed C^3 architectures compatible with the engagement strategies.

3.3 Illustrate the tactical doctrine and C^3 interface requirements via computer simulations. Develop hypotheses that could be tested in the field.

TASK 4: Measures of Effectiveness

4.1 Conceptual Development. Develop and refine the concepts and definitions of measures of effectiveness (MOEs), measures of performance (MOPs), and system/mission parameters. Interpret the concept of measure of force effectiveness (MOFE) as a global effectiveness measure in the context of C^3 systems.

4.2 Implementation of the Methodology. Develop a quantitative framework where models of various types can be used to estimate measures of performance (MOPs). Develop analytical, computational and graphical tools for measuring effectiveness (MOEs). Begin the implementation of these techniques on the same workstation used for Task 1 with the objective of developing a system based on MOE evaluation that can be used as an aid in system development and selection. Note that many of the software utilities to be developed are common to Tasks 1 and 4.

4.3 Application of the Methodology. Illustrate the various conceptual and technical developments with examples drawn from actual or planned C^3 systems. Apply the methodology to an evolving C^3 system. While motivated by real systems, the applications will be described in generic terms.

TASK 5: Information Dissemination

5.1 Participate in technical sessions of the Basic Research Group to be held approximately once per calendar quarter.

5.2 Present the research results at technical conferences and meetings and publish articles in archival journals.

3. PROGRESS REPORT.

During this quarter, the research effort was directed (a) to the integration of the computational and graphical tools to be used in the design of organizations, and (b) the design of the first experiment involving human subjects.

3.1 Development of Computer-Aided Design System.

The computer aided design system being developed has been named CAESAR, for Computer-Aided Evaluation of System ARchitectures. It consists of four major components:

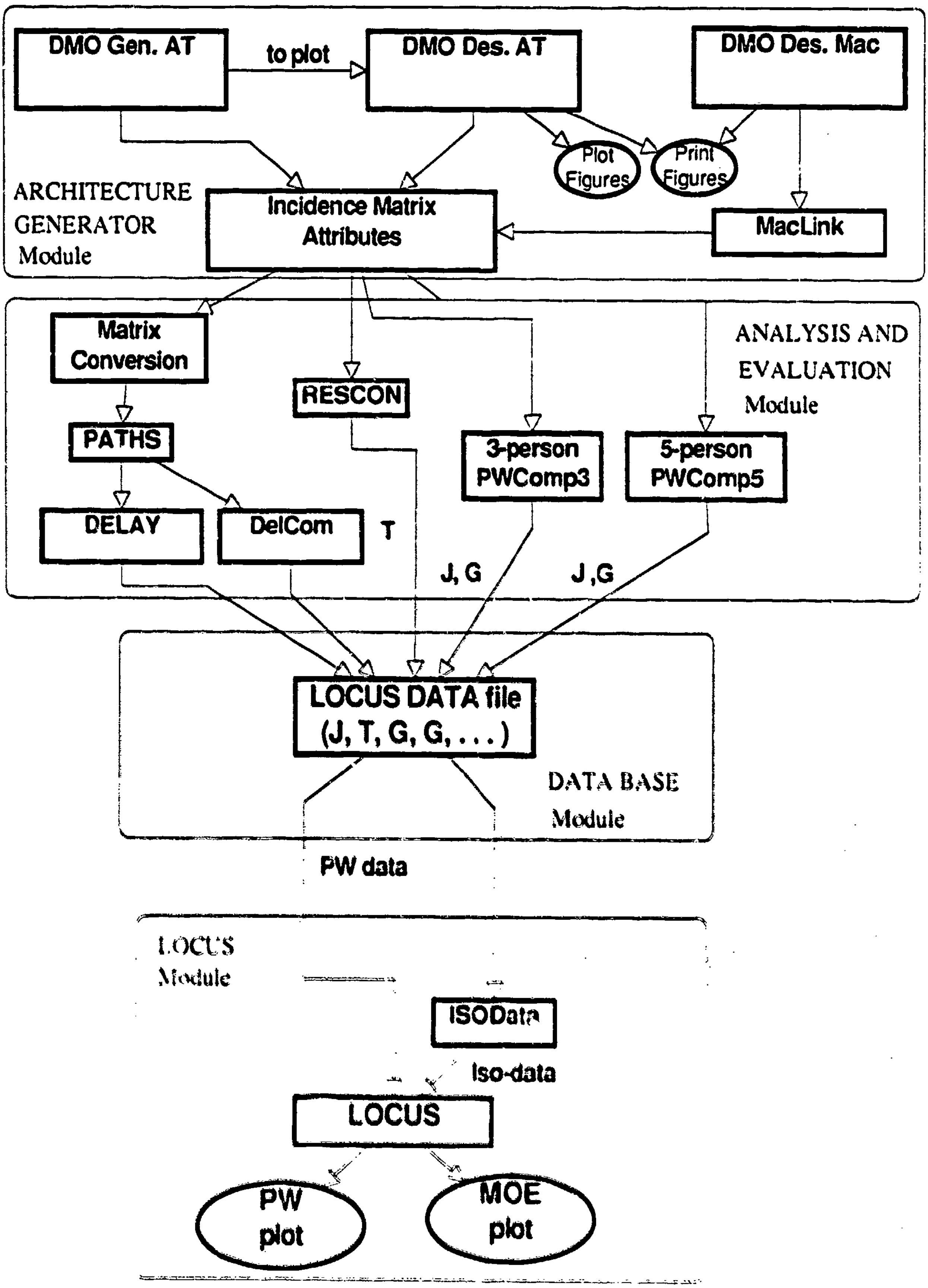
The Architecture Generator which constructs feasible organizational forms using the Petri Net formalism.

The Analysis and Evaluation Module contains algorithms for the analysis of organizational architectures and their evaluation.

A Data Base which is used to store the results of the analysis of organizational architectures.

The Locus module that constructs the performance-workload locus of an organizational form that is carrying out given task and computes and presents graphically selected measures of effectiveness (MOEs).

The structure of the software system is shown in Figure 1. All the modules and their status are described in the table that follows. It should be pointed out that CAESAR incorporates theoretical and computational developments obtained over a period of seven years through more that ten completed theses and six more in progress. Some modules are being developed explicitly under this contract; others are being developed with support by the Distributed Tactical Decision Making initiative of the Office of Naval Research.



CAESAR: Computer - Aided Evaluation of System ARchitectures [illegible]

LIST OF MODULES IN CAESAR

A. ARCHITECTURE GENERATOR

DMO Gen.AT

Program that generates the Petri Nets of Decisionmaking Organizations that satisfy a set of structural constraints, as well as constraints imposed by the user. The algorithm is based on P. Remy's thesis (1986) and has been implemented in DOS 3.0 © IBM, using Turbo Pascal 3.01A ©Borland International and Screen Sculptor ©Software Bottling Company.
Status: Program operational.

DMO Des.AT

Interactive graphics program for the construction of the Petri Nets of arbitrary organizational architectures. It can be used to create and store subsytems and to combine them to form large organizational structures. Program, developed by I. Kyratzoglou, also creates the analytical description of the Petri Nets. Implemented in DOS 3.0, Professional Fortran, Graphics Tool Kit, and Graphic Kernel System, all ©IBM.
Status: To be completed by June 1.

DMO Des.Mac

Interactive graphics program for the construction of the Petri Nets of arbitrary organizations. It can be used to design organizations of arbitrary size through the use of nested subnets. Program developed for the Apple Macintosh by the Meta Software Corp. using the Design Open Architecture System ©Meta Software Corp. Program being enhanced by J. L. Grevet. The program creates the analytical description of the Petri Net, as well as store functions and attributes represented by the transitions, places, and connectors.
Status: Program operational.

MacLink ©Dataviz

Commercial software for for converting and transmitting files between the DOS machines and the Macintosh.
Status: MacLink has been installed and is operational.

Incidence Matrix / Attributes

Standard form for the analytical description of Petri Nets. The files contain the incidence matrix or flow matrix if the Petri Net and the attributes and functions associated with the elements of the net.

Status: Standard version of incidence matrix has been implemented; the specifications for the attribute file are being developed. Expected completion date: May 1.

B. ANALYSIS AND EVALUATION MODULE

Matrix Conversion	Simple algorithm that transforms the incidence matrix into the interconnection matrix used in Jin's algorithm. Algorithm in Turbo Pascal 3.01A. **Status:** Algorithm is operational.
Paths	Algorithm developed by Jin in her thesis that determines all the simple paths and then constructs the concurrent paths in an organizational architecture. This is an efficient algorithm that obtains the answers by scanning the interconnection matrix.Algorithm in Turbo Pascal 3.01A. **Status:** Program is operational.
Delay	Simple algorithm that calculates path delays and expected delay when processing delays are constant. Algorithm in Turbo Pascal 3.01A. **Status:** Algorithm is operational.
Del Com	Algorithm developed by Andreadakis that calculates measures of timeliness when the processing delays are described by beta distributions. It also accounts for the presence of jamming and its effect on timeliness. Algorithm in Turbo Pascal 3.01A. **Status:** Problem specific version operational; general version to be completed by September 1.
Res Con	Algorithm developed by Hillion in his thesis that calculates the maximum throughput in a Timed Event Graph, a special class of Petri Nets. It also determines the optimal schedule in the presence of resource and time constraints. The procedure incorporates an algorithm proposed by Martinez and Silva for determining simple paths through the calculation of s-invariants. **Status:** Independent version of algorithm is operational; integrated version in workstation to be operational by June 1.
PW Comp 3	Algorithm for the computation of a three-person organization's performance measure J (Accuracy) and

the workload of each one of the decisionmakers. The algorithm computes the accuracy of the response and the workload for each admissible decision strategy. This version was developed by Andreadakis in Turbo Pascal. **Status:** Program is operational.

PW Comp 5

A variant of PW Comp 3, but for a five-person organization modeling the ship control party of a submarine. Algorithm developed by Weingaertner as part of his thesis. Implemented in Turbo Pascal.
Status: Program is operational.

C. DATA BASE MODULE

LOCUS Data File

Data file in which the results from the evaluation of a decisionmaking organization are stored. The file, as currently structured, can accommodate five measures of performance - accuracy, timeliness, and workload for three persons. It also contains four indices that specify the decision strategy associated with each record.
Status: Three-person organization version operational. General structure to be implemented by June 1.

D. LOCUS MODULE

LOCUS

Graphics plotting program that generates two or three dimensional loci or two- and three-dimensional projections of higher dimensional loci. This is the basic program used to construct the Performance - Workload locus of an organization. Basic version developed by Andreadakis and Bohner and described in latter's thesis.
Status: Version using professional graphics controller is operational. Revised transportable version adhering to the VDI standard and with improved user interface is being implemented by Jin. Expected completion date is May 1.

ISO Data

Algorithm for obtaining some measures of effectiveness from the measures of performance stored in the Locus Data file. Specifically, it finds isoquants: e. g., locus of constant accuracy, of constant workload.
Status: New version for microcomputers being implemented by Azzola using a design by Weingaertner.Expected date of completion is May 1.

E. INPUT / OUTPUT

Output:

By adopting the Virtual Device Interface (VDI) standard and the Enhanced Graphics standard, it is possible to develop a version of the CAESAR software that is transportable to other IBM PC ATs or compatibles and to drive a wide variety of output devices: various monitors, printers, laser printers, and pen plotters.

Input:

A uniform user interface with windowing capability is needed to make the system useable by analysts and designers. Commercially available software are being investigated to select the most appropriate one. Expected completion date is September 1.

3.2 Organizational Designs --

Experimental Investigation of the Bounded Rationality Constraint*.

In this experiment, a simplified air defense task is being used to establish the existence of the bounded rationality constraint. This constraint is defined as a point value and expressed in terms of a bit rate of processing using the information theoretic surrogate for workload developed by Boettcher and Levis. If such a point is found to exist for a sufficient proportion of our experimental subjects, and the point is sufficiently stable within individuals, then the experimental data will provide specific parameter values needed for the analytical evaluation of alternative organizational architectures.

During the past quarter (1) the experimental design has been implemented on an IBM PC/AT, (2) analytical and empirical techniques have been used to determine appropriate initial settings of the experimental parameters, (3) pilot experimentation has begun (4) analytic tools for analyzing the experimental data have been developed.

All stimulus presentation and data collection/reduction is controlled by the microcomputer. Incoming threats are displayed on a simplified radar screen and subjects attempt to select the threat with the earliest time of arrival. Time pressure is varied incrementally. The minimum and maximum task interarrival times differ by roughly a factor of three. A clock face and second hand beside the radar screen indicate the total window of opportunity as well as time remaining.

Setting critical experimental parameters, such as the minimum and maximum task interarrival times, requires an iterative "honing-in" process. Proper setting of these parameters is critical, because the psychophysical

---

*This experiment was first discussed in the 12/86 progress report.

procedures necessary to derive accurate threshhold estimates (of, in this case, the bounded rationality constraint) typically require large numbers of experimental trials. Mathematical analysis was used initially to determine appropriate relative settings as the number of threats is varied. "Pre-piloting" was then used to determine absolute interarrival times. The pilot data (currently being collected) will yield the final parameter values to be used in the actual experiment. In addition to fixing parameter values, the pilot results will indicate how much practice is necessary for subjects to become "expert" in the task — that is, to reach asymptotic performance.

The necessary mathematical/statistical tools have been developed-identified for addressing the following questions: (1) For what proportion of people (if any) does a bounded rationality constraint exist as defined above? (2) Is this constraint stable within individuals over time? (3) Is this constraint stable across individuals? (4) What is the numerical value of the constraint (in bits per unit time) for each individual and, if possible, aggregated across individuals?

3.3 C^3 Organizations and Architectures for Distributed Battle Management

Project Objective: The long-range goal of this research is to understand basic issues associated with Battle Managament/C3 (BM/C3) architectures associated with many weapons engaging several targets. The defensive weapons are assumed imperfect, and the targets may have a finite probability of being decoys. Thus, the problem is one of wise Weapon-to-Target (WTA) assignment strategies, and their interface with other BM/C3 functions. We also seek the evaluation of centralized, decentralized, and distributed BM/C3 architectures that support such "many-on-many" engagements.

Problem Definition: The major emphasis of the research to date has been in the area of problem definition. We have studied the problem of optimizing the Weapon-to-Target (WTA) function which is at the heart of the "many-on-many" problem. Several formulations of the problem are possible. Suppose that we have a total of M weapons which we are willing to commit against the total of N targets. At that most general level, the effectiveness of each weapon can be different against each target; this can be quantified by having a different kill probability p_{ij} for weapon j assigned against target i (j=1,2,...,M); i=1,2,...,N). The WTA function should allocate the right weapons against the correct targets so as to minimize some cost function.

The simplest cost function is leakage, i.e., the expected number of surviving targets. Thus, if we adopt an optimization framework, we wish to minimize the leak L which is given by

$$L = \sum_{i=1}^{N} \prod_{j=1}^{M} (1-p_{ij}x_{ij}) \tag{1}$$

by selecting optimally the M.N allocation decision variables x_{ij}, each of which is either 0 or 1. Thus, $x_{ij} = 1$ if the j-th weapon is assigned to the i-th target and 0 otherwise and

$$\sum_{i=1}^{N} x_{ij} = 1 \quad , \quad j = 1,2,\ldots,M \tag{2}$$

which simply states that each weapon can only engage a single target.

The solution of such optimization problems for the WTA function is very difficult, because it has a strong combinatorial flavor; in fact, it has been proven to be NP-complete by Lloyd and Witsenhausen in 1986. Part of the complexity relates to the fact that the kill probabilities p_{ij} are different. If the kill probabilities are the same, i.e., $p_{ij}=p$ for all i and j, then the optimal solution (to minimize the leakage) is easy and it requires the maximally uniform assignment of the weapons among the targets.

The problem is inherently hard even in the special case that the kill probabilities depend only on the weapons but not the targets, i.e., p_{ij} is independent of i.

More realistic versions of this problem can be formulated in a similar manner. For example, each target indexed by $i = 1,2,\ldots,N$ can be assigned a value V_i reflecting the importance of that specific target to the defense. In this case, the defense may wish to minimize the expected total surviving value associated with all targets, i.e., minimize the cost function

$$C = \sum_{i=1}^{N} V_i \prod_{j=1}^{M} (1-p_{ij}x_{ij}) \tag{3}$$

again by selecting optimally the M.N allocation variables x_{ij}, subject to the constraints of Eq. (2).

Another, still more complicated, problem that we have been studying recently couples the WTA problem to that of preferential defense. In this framework we explicitly take into account the value of the defense assets. So let us suppose that the defense wishes to protect a total of Q assets, indexed by $q=1,2,\ldots,Q$, and that each asset has a value denoted by D_q. Each one of the defense assets can be attacked by one or more enemy targets. Let π_{qi} denote the probability that the i-th target can kill the q-th asset. Note that the π_{qi} captures such important attributes as target yield, asset hardness, targeting accuracy etc. In this case we can form a utility function which the defense wishes to maximize. This utility function takes the form

$$U = \sum_{q=1}^{Q} D_q \prod_{i=1}^{N} (1-\pi_{qi} \prod_{j=1}^{M} (1-p_{ij}x_{ij})) \tag{4}$$

The above formulation allows for optimal selective defense of the defensive assets. It may be worthwhile to leave a low-value overtargeted defense asset undefended in order to direct the defensive weapons against other targets.

Description of Recent Progress: This research is being carried ou by two doctoral students, Mr. J. Walton and Mr. P. Hossein, under the supervision of Prof. M. Athans. Mr. Walton joined the project in June 1986, while Mr. Hossein joined the project in January 1987. Both students are attempting to define Ph.D. thesis topics in this area. Most of the recent effort has been in the area of developing efficient computational algorithms for solving the centralized WTA problem. The development of such algorithms is highly nontrivial in view of the generic NP-complete nature of the optimization problem. We are also examining additional tradeoffs that arise from decoy considerations, vulnerability of BM/C3 to enemy countermeasures, and delays in decision execution. We foresee highly nontrivial tradeoffs as we move from centralized to distributed and then to purely decentralized (or autonomous) BM/C3 architectures. In particular, we are working on developing analytical models and quantitative approaches to study the following issues:

- Optimal weapon resource utilization deteriorates with increased distribution; however, such degradation will be strongly dependent upon the effectiveness of one-on-one engagements (the kill probabilities p_{ij} defined above).
- The overall vulnerability of the BM/C3 functions will reduce as the degree of its distribution increases.
- The communications requirements for coordination will increase as we distribute the BM/C3 functions more and more.
- The complexity of the coordination strategies will increase as the degree of distribution increases.
- The delay in executing a local BM/C3 function will decrease in distributed architectures, simply because each subfunction will have to handle fewer targets and weapons.

To what extent the improvement in survivability and reduced delays are counterbalanced by increases in communication/coordination and resource misutilization remains a problem for future research.

Documnetation: No formal documentation exists as yet.

3.4 Measures of Effectiveness

4.0 RESEARCH PERSONNEL

Dr. Alexander H. Levis, Principal Investigator
Professor Michael Athans
Dr. Jeff T. Casey

Mr. Patrick Hossein,	Research Assistant	(Ph.D. Candidate)
Mr. John Kyratzoglou,	Research Assistant	(ME Candidate)
Mr. Didier Perdu,	Research Assistant	(MS Candidate)
Mr. James Walton,	Research Assistant	(Ph.D. Candidate)

5.0 INFORMATION DISSEMINATION

The following documents were issued as Laboratory Technical Reports or as Technical Papers. There were submitted to ONR, to the Basic Research Group of the JDL Panel on C^3, and to the distribution list specified in the contract. Some aspects of the work contained in these reports were supported by other related projects, such as the one from the Office of Naval Research on Distributed Tactical Decisionmaking (N00014-84-K-0519).

5.1 Theses/Technical Reports

1. C. M. Bohner, "Computer Graphics for System Effectiveness Analysis," LIDS-TH-1573, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA, July 1986.

2. P.J.F. Martin, "Large Scale C^3 Systems: Experimental Design and System Improvement", LIDS-TH-1580, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, August 1986.

3. H. P. Hillion, "Performance Evaluation of Decisionmaking Organizations Using Timed Petri Nets," LIDS-TH-1590, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA, August 1986.

4. S. T. Weingaertner, "A Model of Submarine Emergency Decisionmaking and Decision Aiding," LIDS-TH-1612, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA, September 1986.

5. P. A. Remy, "On the Generation of Organizational Architectures Using Petri Nets," LIDS-TH-1630, S.M. Thesis, Laboratory for Information and Decision Systems, MIT, Cambridge, MA, December 1986.

5.2 Technical Papers

1. P. Remy, A. H. Levis, and Y.-Y. Jin, "Delays in Acyclical Distributed Decisionmaking Organizations," LIDS-P-1528, Laboratory for Information and Decision Systems, MIT, January 1986. To appear in Proc. 10th World Congress of the International Federation on Automatic Control, Munich, FRG, July 1987; revised version to appear in Automatica, 1987.

2. A. H. Levis, "Modeling the Measuring Effectiveness of C^3 Systems," LIDS-P-1608, Laboratory for Information and Decision Systems, MIT, September 1986. Proc. Seventh Annual AFCEA European Symposium, Brussels, Belgium, October 1986.

3. M. Athans, "Command-and-Control Theory: A Challenge to Control Science" LIDS-P-1584, Laboratory for Information and Decision Systems, MIT, September 1986; also IEEE Transactions on Automatic Control, Vol. AC-32, No. 4, April 1987.

4. P. A. Remy and A. H. Levis, "On the Generation of Organizational Architectures Using Petri Nets," LIDS-P-1634, Laboratory for Information and Decision Systems, MIT, January 1987. To appear in Proc. Eighth European Workshop on Applications and Theory of Petri Nets, Zaragoza, Spain, June 24-27, 1987.

5. H. P. Hillion and A. H. Levis, "Timed Event-Graph and Performance Evaluation of Systems," LIDS-P-1639, Laboratory for Information and Decision Systems, MIT, January 1987. To appear in Proc. Eighth European Workshop on Applications and Theory of Petri Nets, Zaragoza, Spain, June 24-27, 1987.

5.3 Technical Interactions

On January 5-7, Dr. Levis participated in the 1987 Modular Command and Control and Evaluation System (MCES) meeting and presented current research problems and issues.

On December 2, 1986, two representatives from the Navy Personnel Research and Development Center (NPRDC), Dr. D. Nebeker and C. Tatum, visited the Laboratory to be briefed on our research and discuss possible joint experimental efforts in the future.

Dr. Levis presented an invited lecture on Measures of Effectiveness at the 7th Annual AFCEA European Symposium on October 30, 1986.

Dr. Levis presented the results of the work on Measures of Effectiveness in a Seminar at the SHAPE Technical Center on October 29, 1986.

On August 11 and 12, 1986, 8 faculty and students from the C^3 Curriculum of the Naval Postgraduate School visited the MIT Laboratory for Information and Decision Systems where they had an in-depth presentation of the research results in anticipation of joint efforts in carrying out the experimental program.

In June 1986, Dr. Levis presented the first results on the generation of alternative organizational forms at the 9th MIT/ONR Workshop on C3 Systems.

Dr. Levis attended four meetings of the Basic Research Group in accordance with contractual requirements in which he briefed the Group on the progress of the research effort. The meetings were held at the Naval Ocean Systems Center, At Ft. Monmouth, and at the National Defense University.

Dr. Levis participated in the second workshop on Measures of Effectiveness for Command and Control Systems held at the Naval Postgraduate School in January 1986. His involvement in this workshop led to the use of the IFFN testbed as the illustrative example in Martin's thesis.

Dr. Levis and Mr. P. Martin participated in a meeting organized by Studies and Analyses, USAF, to discuss the applicability of the work to the experimental program of the IFFN Joint testbed (US Army, US Air Force).

These interactions are considered essential for presenting the results of basic, fundamental research to the C^3 community and for receiving feedback -- comments and suggestions -- that increase the relevance of the work.