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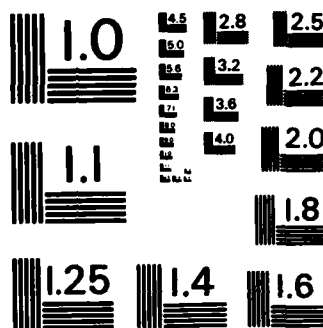
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DISTRIBUTED DECISION AND COMMUNICATION PROBLEMS
 IN TACTICAL USAF COMMAND AND CONTROL

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 Ms. Elizabeth R. Ducot
 Prof. Michael Athans
 July 30, 1982

Annual Technical Report for Period: July 1981 - June 1982

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1. INTRODUCTION

The inherent complexity of C^3 systems and the rapid implementation of technological changes in the acquisition, processing, storage, and dissemination of data, present problems that existing theory and available tools do not address adequately. The analysis of generic aspects of C^3 systems represents an area of research that requires the integration of diverse concepts and theories, if progress is to be made toward the development of a theoretical basis of their analysis and design. Furthermore, while many of the generic problems are relevant to the C^3 systems of all services, the unique missions of each service introduce constraints that need to be understood and design considerations that must be exploited to produce more effective systems.

During the second year the technical effort continued to be directed toward generic, long range, basic, unclassified research. The emphasis was on general methodological and technical issues, but from the perspective of the unique needs and requirements of the Air Force. Four research areas were specified. They were:

- (a) C^3 System Structure and Organizational Forms
- (b) Decentralized Estimation
- (c) Information Storage and Flow in C^3 Systems
- (d) Distributed Decision Problems in Dynamic
Missile Reassignment Strategies.

Progress achieved in each of these areas is summarized in the next section. The list of documents resulting from research carried under this project is included in Section 2. Section 3 contains a list of professional personnel that were supported by this project.

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MATTHEW J. KERPER
Chief, Technical Information Division

2. STATUS OF RESEARCH EFFORT

2.1 C³ System Structure and Organizational Forms

Research in this area has been focused on the development of a mathematical theory for the modeling and analysis of information-processing and decisionmaking organizations. The specific organizational structures considered and motivated by tactical Air Force C³ systems, perceived as support systems for the decisionmakers.

A number of interrelated research problems have been addressed; each problem is described below in the following format: (a) problem statement and research objective, (b) achievements to date, and (c) publications.

2.1.1 Model of Interacting Decisionmaker (Dr. A. H. Levis, Mr. K. L. Boettcher)

The first problem addressed was the development of a model of the decisionmaking process applicable to human decisionmaking in tactical situations.

A model was developed using the analytical framework of n-dimensional information theory. The interactions with other decisionmakers were modeled in terms of sharing situation assessment information and issuing or receiving commands that restrict the selection of outputs or responses.

Publications:

- (a) K. L. Boettcher and A. H. Levis, "Modeling the Interacting Decisionmaker with Bounded Rationality," IEEE Trans. on Syst. Man and Cybernetics, SMC-12, No. 3, May/June 1982 (Attachment I).
- (b) Earlier versions of the paper appeared in
 - Proc. of the 4th MIT/ONR Workshop on C³ Systems, LIDS-R-1159, Vol. IV, MIT, Cambridge, MA, October 1981.

- Proc. Bilateral Seminar on Control Systems, Science Press, Beijing, PRC, April 1982.

(c) K. L. Boettcher, "An Information Theoretic Model of the Decision Maker," S.M. Thesis, LIDS-TH-1096, MIT, Cambridge, MA June 1981.

2.1.2 Design of Decisionmaking Organizations with Acyclical Information Structures. (Dr. A. H. Levis, Mr. K. L. Boettcher)

The objective of this research task was to extend the theory developed for the single interacting decisionmaker to teams of decisionmakers forming an organization. There are three parts to the formulation of the design problem: (a) analytic characterization of the task the organization is to perform, (b) Specification of the interactions between organization members and the environment, i.e., who receives what external inputs and who produces the organization's outputs, and (c) Specification of the interactions between organization members. These include the sharing of situation assessment information and the issuing and receiving of commands.

The theory has been developed for organizations with acyclical information structures, i.e., organizations whose digraphs depicting information flow do not contain loops. The conventional workload-performance plane for the single decisionmaker has been extended to $n+1$ dimensions with the n dimensions corresponding to the workload of each one of the n members of the organization and the $(n+1)$ st dimension to the performance measure for the organization. The theoretical development has been illustrated by designing and evaluating two three-person organizations assigned to carry an abstracted air defense task.

Publications:

(a) A. H. Levis and K. L. Boettcher, "Decisionmaking Organizations with Acyclical Information Structures," LIDS-P-1225.

- submitted for publication to IEEE Trans. on Systems Man and Cybernetics.

- To appear in

- a) Proceedings of 5th MIT/ONR Workshop on C^3 Systems, Monterey, CA, August 1982
- b) Proc. 21st IEEE Conference on Decision and Control, Orlando, FL, December 1982. (Attachment II)

2.1.3 Information Theoretic Models of Storage and Memory
(Dr. A. H. Levis, Ms. S. A. Hall)

In previous work, the internal structure of the decisionmaking systems has been modeled as memoryless. In order to develop more realistic models in the context of the command and control process, it is necessary to introduce memory so that inputs that are statistically dependent may be considered. The objective of this research task, therefore, is to develop analytical models of different types of data storage using the information theoretic framework.

Three types of storage have been modeled: buffer storage, temporary storage (short term memory) and permanent storage (long term memory). Since this analysis addresses the processing of sequential inputs that are dependent on each other, information rates and the partition law for information rates are used. Consequently, inputs are modeled by discrete stationary ergodic sources. The results are being used to enhance the model of the interacting decisionmaker.

Publications:

- a) S. A. Hall, "Information Theoretic Models of Storage and Memory," S.M. Thesis in the Dept. of Electrical Engineering and Computer Science. Expected completion date: 18 August 1982.
- b) Upon completion of the thesis, a technical paper will be prepared for submission to a journal and for conference presentation.

2.1.4 Non-Deterministic Algorithms in the Decisionmaking Model (Dr. A. H. Levis, Ms. G. Chyen)

The model of the decisionmaking process that was developed earlier (item 1) contains a set of algorithms in the situation assessment stage and another set in the response selection stage. In the existing theory the simplifying assumption was made that the algorithms were deterministic. The objective of this task was to extend the theory to include stochastic algorithms.

First, information theoretic models of stochastic algorithms were developed. Then, these models were incorporated in the model of the interactive decisionmaker and the total activity was evaluated. As expected, it was shown that the presence of non-deterministic algorithms increases the total activity by increasing the component of total activity that corresponds to internally generated information or noise.

Publications:

A technical paper is in preparation by G. Chyen and A. H. Levis for submission to a technical journal.

2.1.5 Information Structures for Single Echelon Organizations (Dr. A. H. Levis, Ms. D. A. Stabile)

The objective of this research task was to develop an analytical approach to the design of the information structure for decisionmakers who comprise the boundary between an information-processing organization and its environment. The environment was modeled as a source that generates symbols or messages that the organization members must process without being overloaded. Two basic information reduction strategies were considered: 1) creation of self contained tasks, and 2) creation of slack resources. The former led to the partitioning of the input signal and the parallel processing of the partition; the latter to alternate processing where each decisionmaker receives signals according to some stochastic or deterministic rule but is given more time to process them, i.e., a delay was introduced. These two strategies were then integrated to produce a variety of information structures

for special cases.

Publications:

- a) D. A. Stabile, A. H. Levis, and S.A. Hall, "Information Structures for Single Echelon Organizations," LIDS-P-1180, MIT, Cambridge, MA January 1982. Submitted for publication to a journal in operations research.
- b) D. A. Stabile, "The Design of Information Structures: Basic Allocation Strategies for Organizations," S.M. Thesis, LIDS-TH-1098, MIT, Cambridge, MA June 1981.

2.2 Decentralized Estimation (Dr. D. A. Castañon)

The classical problem of estimation involves two stochastic processes: a signal process, which is the quantity to be estimated, and an observation process on which the signal estimate is based. It is assumed that the entire past observation process is available instantaneously at a central location, which processes these observations to produce the signal estimate. The objective of this research task was to study a non-classical version of the estimation problem. In this case, it was now assumed that there are several data processing locations, called local estimates, which received parts of the observation process and produced estimates of parts of the signal process.

A team-theoretic approach was used to design linear decentralized estimation schemes. The local estimates were viewed as decisions which affect the information received by other decisionmakers (local estimators). Necessary conditions for optimality of these estimates were derived. For full decentralized structures, these conditions were shown to provide a complete closed-form solution of the estimation problem. Finally, the complexity of the resulting algorithms was studied as a function of the performance measure and in the context of some simple examples.

Publication:

- a) D. A. Castañon, "Decentralized Estimation of Linear Gaussian Systems," LIDS-P-1167, MIT, Cambridge, MA December 1981.

(submitted for publication to Large Scale Systems, North-Holland Publishing Co.)

2.3. Information Storage and Flow in C^3 Systems

The need to limit the flow of information in a C^3 system operating under stress, while preserving its effectiveness in the context of a changing situation, provided the motivation for this research activity. The proposed approach to this problem has been to examine how the notion of situation dependent information flow control can be incorporated in the design of C^3 networks. It has been concluded that a *user intermediary* must be developed that must perform two key functions:

- (a) monitor the network to estimate system response, conditioned on the environment and the user request issued;
- (b) assist the user in reformulating his request in the light of system parameters.

Each aspect was investigated in a subtask.

2.3.1 Testbed Design and Implementation (Ms. E. R. Ducot)

The potential volume of control information required to create local data and network models suitable for the network monitor is clearly a source of concern. How one deals with this problem may determine the success of the network monitor concept and the viability of the user intermediary. Since the interactions between activities in the network appear to be difficult to represent analytically, it was decided to develop a small expandable testbed facility to simulate the various activities.

TECCNET (Testbed for Evaluating Command and Control NETWORKs) has been designed and implemented on MULTICS at MIT. The TECCNET system is interactive and consists of the Conversational Interface and a number of blocks that are separated into basic user activities, or functions, as follows: Interactive Node, Simulation Generator, Scenario and Input Generator, and Information Network Simulator. The detailed description of the TECCNET system, the initial algorithm implemented, and the use of the system as a research tool are described in the report cited below (also Attachment III).

Publications:

- (a) E. R. Ducot, "TECCNET: A Testbed for Evaluating Command and Control Networks," Report LIDS-R-1227, Laboratory for Information and Decision Systems, MIT, Cambridge, MA August 1982.

2.3.2 Networks Parameters and the Development of Local Nodes

(Ms. E. R. Ducot, Mr. M. LaRow, Dr. A. H. Levis)

The problem addressed by this research was how to communicate current attributes of a network, i.e., network parameters, to a user. These parameters should provide each user with information about the network's expected behavior in response to the user's transaction. The parameters chosen for this analysis were expected delay and incremental expected delay.

The network control algorithm of Gallager and Golestaani is used in which the total buffer occupancy of the system is minimized by communicating the derivative of buffer occupancy with respect to injection of each user node. One direct approach is to communicate over the network the required quantities, expected delay and incremental expected delay, in the same way that control parameters are communicated. However, this procedure is not cost effective since it doesn't make use of information already available. Using queueing theory, approximations to the delay parameters are derived from the existing control parameters and one additional parameter: the ratio of the weighted average number of hops from node i to node j to the total number of links over which a message is transmitted from i to j . The results of the analysis have been demonstrated on a simple test network.

Publications:

A technical memorandum is being revised and edited.

2.4 Distributed Decision Problems in Dynamic Missile Reassignment Strategies

(Prof. M. Athans and Mr. Y. L. Chow)

Research was initiated for a class of generic air defense problems involving the dynamic stochastic assignment of N defense interceptors against M incoming enemy targets. Key constraints are generated by the assumption that an illuminating radar must reflect energy from each target for a specific amount of time so that the interceptor guidance law can lock on the target.

The modeling phase of this research has been completed. Equations have been derived that relate one-on-one kill probabilities and other system variables to the overall probability of destroying all incoming targets. Two stochastic strategies were developed: the shoot-look-launch strategy and the shoot-look-reassign strategy (these include the flexibility of launching a salvo of interceptors against a target possibly followed by another salvo after kill assessment). Numerical results for optimal stochastic dynamic strategies for simple scenarios were obtained.

The analytical results have demonstrated that to solve successfully this class of dynamic optimization problems one needs significant modifications of the available stochastic dynamic programming theory and algorithm. This topic will be addressed in the future.

Long range plans include the formulation and solution of the distributed version of the above problem. This represents challenging and relevant theoretical research.

Publications:

- (a) Y. L. Chow "Dynamic Missile Reassignment Strategies," S.M. Thesis, Dept. of Electrical Engineering and Computer Science, MIT (final version expected September 15, 1982).
- (b) Upon completion of the thesis a paper by M. Athans and Y. L. Chow will be prepared and will be submitted for publication to the IEEE Trans. on Aerospace and Electronic Systems.

3. PERSONNEL

Dr. Alexander H. Levis, Co-Principal Investigator
Professor Michael Athans, Co-Principal Investigator
Dr. David A. Castañon, Research Associate
Ms. Elizabeth R. Ducot, Research Staff

Mr. Kevin L. Boettcher, Research Assistant, Ph.D. candidate
Ms. Susan A. Hall, Research Assistant, M.S. degree candidate
Ms. Gloria Chyen, Research Assistant, M.S. degree candidate
Mr. Mark LaRow, M.S. degree candidate
Mr. Y. L. Chow, M.S. degree candidate