STRUCTURED ANALYSIS AND MODELING OF COMPLEX SYSTEMS

David R. Strome, Ph.D.
Systems Research Laboratories, Inc.
P.O. Box 35482
Brooks Air Force Base, Texas 78235

Mathieu A. Dalrymple
Systems Research Laboratories, Inc.
P.O. Box 35482
Brooks Air Force Base, Texas 78235

ABSTRACT

The Aircrew Evaluation Sustained Operations Performance (AESOP) facility at Brooks AFB, Texas, combines the realism of an operational environment with the control of a research laboratory. In recent studies we collected extensive data from Airborne Warning and Control Systems (AWACS) Weapons Directors subjected to low and high workload Defensive Counter Air scenarios. A critical and complex task in this environment involves committing a friendly fighter against a hostile fighter. Structured Analysis and Design techniques and computer modeling systems have been applied to this task as tools for analyzing subject performance and workload. This technology is being transferred to the Man-Systems Division of NASA/JSC for application to complex mission-related tasks, such as manipulating the shuttle grappler arm.

INTRODUCTION

Structured analysis and modeling are not new tools. They have been used for many years as aids in defining and analyzing systems, projects, products, and concepts. This paper discusses one application of these tools to a highly complex Air Force operational task, and the transfer of this technology to the Man-Systems Division of NASA.

Modeling focuses our attention on the processes and relationships of a system. It allows us both to describe a system as it is and to predict system behavior when conditions or constraints are altered. The accuracy of the prediction depends on the complexity of the question and the detail and validity of the model. Although often thought of as a research method, computer modeling is used in many forms: financial systems are modeled with spreadsheets; projects are modeled with program management software; motion is modeled with specialized graphics systems. Research models use specialized programs to explore neural function,communications, strategies and tactics, human performance, and task loading. These are only a few of the multitude of applications.

Creating a model is a simple concept but a demanding process. Using input from experts, the system being modeled must be broken down into detailed steps or processes, the relationships between the steps must be clearly defined, and the parameters that affect each process or relationship must be determined. The model is strengthened, verified, and validated by testing the real world system under a variety of conditions and comparing the data with the model's results. This iterative procedure continues until the model reaches a level of description and prediction that meets the demands of the research.

Structured analysis is a formalized process for developing the detailed information required to build the model. As a process, it is accomplished when any model is built, whether it is done formally or not. For simple systems models can be adequately defined with less rigorous methods. Complex tasks, on the other hand, benefit from a more structured technique that aids the analysis. Structured Analysis and Design Technique (SADT) [Marca and McGowan, 1988] is a widely recognized implementation of this concept. Originally a paper and pencil exercise, it is now appearing in software tools that provide basic consistency checks, easy modification, and presentation output. The basic building block of SADT is a box containing a descriptor of an event or process. This event has inputs, outputs, controls, and resources or mechanisms (Figure 1).
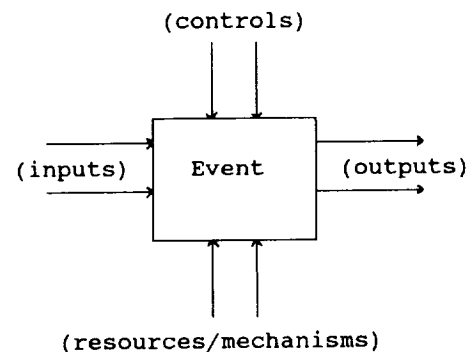
Figure 1

These blocks are linked together hierarchically in increasing detail until the model is sufficiently described. Structured analysis:

+ improves system definition.

+ improves problem understanding.

+ improves user/developer communication.

+ impacts system design.

+ smooths transition from analysis to design.

Technical developments in computer hardware and software have supported attempts to marry these two tools into a single integrated package of analysis and modeling. As separate tools, the information entered into the structured analysis program has to be re-entered into the modeling software. To overcome this duplication of effort, software engineers are developing integrated systems that automatically port the structured information into selected modeling systems.

AIR FORCE APPLICATION

The Aircrew Evaluation Sustained Operations Performance (AESOP) facility is located in the Sustained Operations Branch of the Crew Technology Division at Brooks Air Force Base, San Antonio, Texas. It is a research facility dedicated to the following goals:

+ Develop and apply individual and team performance measures to evaluate crew interactions under sustained operations.

+ Develop and integrate tools to support research and development.

+ Transfer technology to operational environments.

During 1989 the Air Force conducted a study in AESOP using 12 teams of Airborne Warning and Control Systems (AWACS) Weapons Directors (WDs). WDs provide control for Air Forces in their area of responsibility, committing friendly aircraft to missions such as: identification of unknown aircraft; engagement of hostile aircraft; search and rescue operations; mid-air refueling; and escort. Their operational environment is a complex combination of tactics and strategy, decision-making, and communication.

Each team of three WDs was subjected to three high workload and three low workload defensive counter air scenarios, each lasting three and one-half hours. Among the collected operational data were: switch actions, key presses, communication channel usage, audio traffic, microphone activations, target locations, and mission critical events. Video tapes captured non-verbal, non-console subject interaction. In addition to

operational measures, a battery of individual performance tests, surveys, and questionnaires was given throughout the course of the study. The resulting data is being continually analyzed to develop and test individual and team performance measures directly related to operational tasks.

Part of the ongoing development of tools to assist in this research involved selecting a complex WD task for structured analysis and modeling. The purpose was to evaluate several software systems while determining the applicability of the tools to our environment. The data from real subjects provided a testbed for the validity of the model.

Committing a friendly fighter to a mission against a potentially hostile, or known hostile, target is a primary WD task. The first two levels of the SADT analysis, created using Idefine (Wizdom Systems, Inc.), are shown below (Figures 2,3)
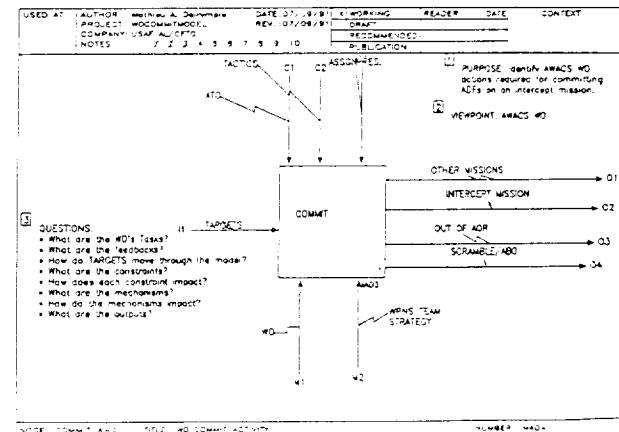

Figure 2

At the top level (Figure 2) we define the broadest description of the task. *Targets* on the computerized radar screen are the INPUTS to the task. The *WDs* and their *team strategy* are MECHANISMS for completing the task. The *Air Tasking Order (ATO), tactics,* and *assigned resources* are the CONTROLS (CONSTRAINTS) on conducting the task. When the task is complete the possible OUTPUTS include a target being *out of Area Of Responsibility,* a *scramble/airborne order* requesting additional resources, a commit of existing resources to an *intercept mission,* or committing to some *other mission* such as search and rescue or escort. The next part of the hierarchy (Figure 3) divides this broad analysis into the next level of detail.

This level has the same overall inputs, controls, mechanisms, and outputs; but the task is now subdivided into *identifying targets, sorting threats, sorting friendlies,* and *committing to a mission.* These tasks are connected functionally with outputs becoming inputs or controls to other steps as necessary. Each of these boxes is then subdivided in the same manner at the next
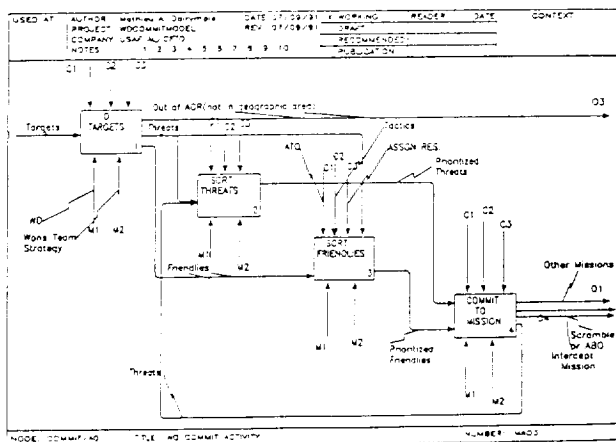
452

Figure 3

level of the hierarchy, and so on until reaching the required depth of detail.

The finest level of detail is entered into the modeling software. Time to completion, probability of a particular path, and other selected parameters are defined for each task to complete the definition of the model. Figure 4 is a typical output, graphing the frequency distribution of time required to complete the commit task.

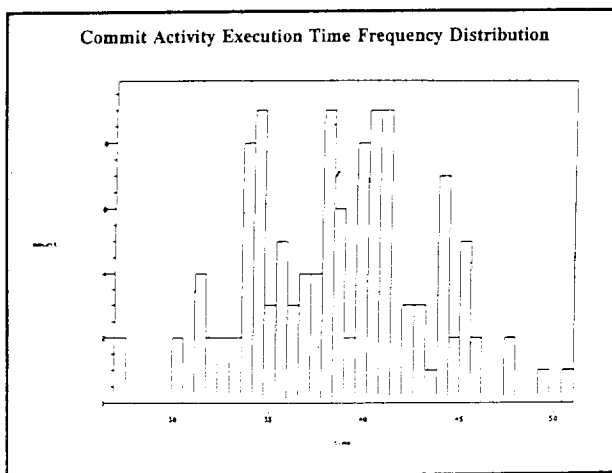Commit Activity Execution Time Frequency Distribution

Figure 4

The average completion time is around 37 seconds, which matches well the average time collected in actual scenarios. Changes in the model result in predictable shifts in this average time. However several aspects of the performance of real WDs are not accounted for by the current model. The model tends to have much less variation than human operators. It also does not account well for very slow or very fast times, which may be due to inattention, fatigue, anticipation, distraction, or other external causes. Finally it does not partition realistically between component phases of the overall task, such as a decision phase where the WD is

deciding what to do, and the action phase where switches and keys are pressed and information is communicated. Our experience suggests that the accuracy required to adequately describe and predict real world behavior will demand that these aspects be accounted for. To do so will require models that provide true parallel processing and accept algorithms for dynamics such as fatigue, anticipation, and distraction.

TECHNOLOGY TRANSFER

Working under the guidelines of a memorandum of understanding, the Sustained Operations Branch is working with the Crew Interface Analysis Section of the Man Systems Division at NASA/Johnson Space Center to integrate these tools into the space operations and research environment. The first task to be analyzed and modeled by NASA is the operation of the Remote Manipulator System at both normal and reduced gravity.

CONCLUSION

The application of these tools to both Air Force and NASA operational tasks has emphasized their usefulness in defining and understanding complex systems. Future use of structured analysis and modeling in the AESOP will aid in:

♦ Determining critical performance elements in complex tasks.

♦ Predicting performance effects of fatigue, decision aids, and drugs.

♦ Defining and testing new training strategies.

♦ Developing meaningful individual and team performance measures.

REFERENCES

Marca, David and McGowan, Clement, *SADT Structured Analysis and Design Technique*, McGraw Hill, New York, NY, 1988.

453