Research Report 1261

A SAINT MODEL OF THE AN/TSQ-73 GUIDED MISSILE AIR DEFENSE SYSTEM

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The SAINT model of the AN/TSQ-73 system demonstrates the ability to incorporate the human element into a digital simulation model of a complex command and control system. The model is extremely versatile and can be used to evaluate the effect of both human performance characteristics and system operating policies on overall system effectiveness for a wide range of mission scenarios. Continuing refinement and expansion of the model will enhance its ability to address complex issues associated with operator training as well as the design and operation of the AN/TSQ-73 system.

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In its present form the model can be used to systematically vary battlefield scenarios and study the resulting effects on operator error rates, response times, and task performance sequences. Potential uses for an expanded version of the model include the identification of critical tasks based on simulated combat performance, resource or resupply bottlenecks, and optimal use of automatic or semiautomatic operational modes. A second year effort is presently under way to develop improved psychological models of target identification, track hooking operations, and fire unit message handling.

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FOREWORD

This research conducted in 1977 is part of an ongoing effort within ARI to improve human operator modeling for use in Army tactical system evaluations. The paper presents an implementation of the Systems Analysis of Integrated Networks of Tasks (SAINT) simulation language within a complex air defense system called the AN/TSQ-73 Missile Minder.

The unique aspects of the model concern the dynamic capturing of human operator behaviors within a changing battlefield environment and the subsequent ability to trace operator task performance in terms of both time dependent and error dependent modes. The report will be of particular interest to analysts who are planning or conducting research related to complex man/machine interactions in dynamic environments.

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A SAINT MODEL OF THE AN/TSQ-73 GUIDED MISSILE AIR DEFENSE SYSTEM

BRIEF

Requirement:

Increasing problems with evaluation of the human contribution to overall effectiveness in linked air defense systems required the development of improved human performance modeling techniques. Because of the heavy man/machine mixture of task functions in developing missile control systems, the AN/TSQ-73 was chosen as a test case within which realistic problems of operator loading, scenario difficulty, and operational policy could be examined

Procedure:

Three stages of model evaluation were developed with the present paper representing the feasibility stage. Feasibility consisted of translating available system task and hardware information into SAINT code, the development of independent submodels corresponding to operator, system computer, battlefield air space, and HAWK missile batteries. Human psychological processes included perceptual scanning, short term memory, and decision making. Scenario input was formatted based on menu selections including operational policy, aircraft flight paths, missile number and effectiveness, and number of HAWK batteries.

Findings:

The SAINT model provides an effective and time efficient method to capture complex man/machine relationships for analysis. It also serves as a conceptual matrix within which diverse psychological models of human capabilities can be fused together.

Utilization of Findings:

The model has currently been updated to include advanced human psychological characteristics. Along with a joint effort between ARI and the Institute for Defense Analysis, the model will be applied as a planning tool for the development of system models within the NATO Identification Study (NIS) test bed. Anticipated uses for the expanded model include identification of critical tasks based on simulated combat performance, resource or resupply bottlenecks, and optimal use of automatic or semi-automatic operational modes. A major contract effort is now underway to develop generalizable human operator models for High and Medium Altitude Air Defense (HIMAD) and Short Range Air Defense (SHORAD) air defense systems utilizing the lessons learned form this research.

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CONTENTS

A SAINT MODEL OF THE AN/TSQ-73 GUIDED MISSILE AIR DEFENSE SYSTEM

THE AN/TSQ-73 SYSTEM

The AN/TSQ-73 Missile Minder is a lightweight mobile automatic data processing command and coordination system for Nike-Hercules and Hawk Army Air Defense units (1, 2, 3). The AN/TSQ-73 integrates radar and identification of friend or foe (IFF) data from local and remote radars for console display. Through programming of the automatic data processing alphanumerics, track and site symbols, map symbols, coordinates, and lines are generated. These data are integrated with radar and IFF data to provide the operator with a CRT display of aircraft and missile targets identified by track symbols and alphanumerics, as well as alphanumeric site and map symbols. Target data, fire unit profile data, and defended point characteristics are processed and analyzed automatically in order to select primary and secondary fire units and weapons type.

Tactical operation of the system is accomplished by one tactical directions officer and two operator/repairmen (enlisted personnel). The system can be operated in a number of manual or automatic modes. Some of the possible modes are:

1. Air Track Identification
    a. Automatic and sector scan
    b. Manual

2. Tracking
    a. Automatically initiated automatic tracking
    b. Manually initiated automatic tracking
    c. Manual, by operator

THE SAINT SIMULATION LANGUAGE

SAINT, Systems Analysis of Integrated Networks of Tasks, is a unique and powerful technique that is both a systems modeling vehicle and a computer analysis tool. It is the only available technique that allows engineers and human factors specialists to develop system models in which men, machines, and environmental conditions are represented as elements of a network (4, 5, 6, 7, 8). SAINT models permit an analyst to investigate the impact of component characteristics on overall system performance without a major investment in equipment and time, and without necessitating a commitment to prototype hardware development. A further description of SAINT may be found in the Appendix.

THE AN/TSQ-73 MODEL

The SAINT model of the AN/TSQ-73 system is designed to simulate the tasks performed by a single operator/repairman involved in monitoring and operating the AN/TSQ-73 display console during a simulated mission.

It is comprised of four submodels: operator control, aircraft control, fire unit control, and systems control. These four submodels operate relatively independently of one another. They communicate through the use of messages and their common environment. Messages are represented as transactions that flow among the four submodels. The environment is represented by the current values of a number of FORTRAN variables.

The environmental variables are further divided into two groups: those which are apparent to the operator viewing the radar screen, or the system environment; and those which represent actual, or total, environment. The transfer of some information from the actual environment to the system environment is regulated by the system's operating modes and the activity of the operator. Other information is common to both of the environmental variable groups. Figure 1 illustrates the interaction of the four submodels and the environment.

Missions may be simulated in any of the operating modes identified previously. In addition, if the automatic system becomes overloaded and the processing of data is delayed, the model has the capability of simulating the operator manually updating the environmental data even though the system is operating in an automatic mode.

OPERATOR CONTROL SUBMODEL

The operator control submodel is divided into nine operational components. Each of these components is composed of a series of tasks that represent a distinct set of operator actions. The operator is modeled as a single transaction, or information packet, that moves from task to task throughout the submodel. The routing of the operator is determined by a set of task branching parameters. Figure 2 illustrates the precedence relationships controlling the movement of the operator among the components.

The search component triggers all subsequent operator activity. It represents a visual scan of the display screen by the operator to determine which of the tracks or sites requires his attention. The selection of a track or site is accomplished probabilistically, where the probability of selection is proportional to the visual stimulation that is presented by an object on the radar scope, a threat evaluation of that specific symbol, and the time since the symbol was last processed. For example, the operator would be more likely to react to a hostile target a few miles from his site than to a friendly target that is a great distance from his site.

There are six possible actions that the operator can initiate as a result of scanning the display screen and selecting a symbol. They represent the processing of video data; unknown, friendly, and hostile tracks; and fire unit sites within the system environment. Tasks that represent both specific operator actions (e.g., pushing a button, reading a message) and operator decisions (e.g., should processing of a symbol begin now or be delayed) are included in these components. Further, user-written moderator functions are used to represent variations in reaction and decision times as well as errors in judgment and mechanical act-- throughout the operator control submodel.

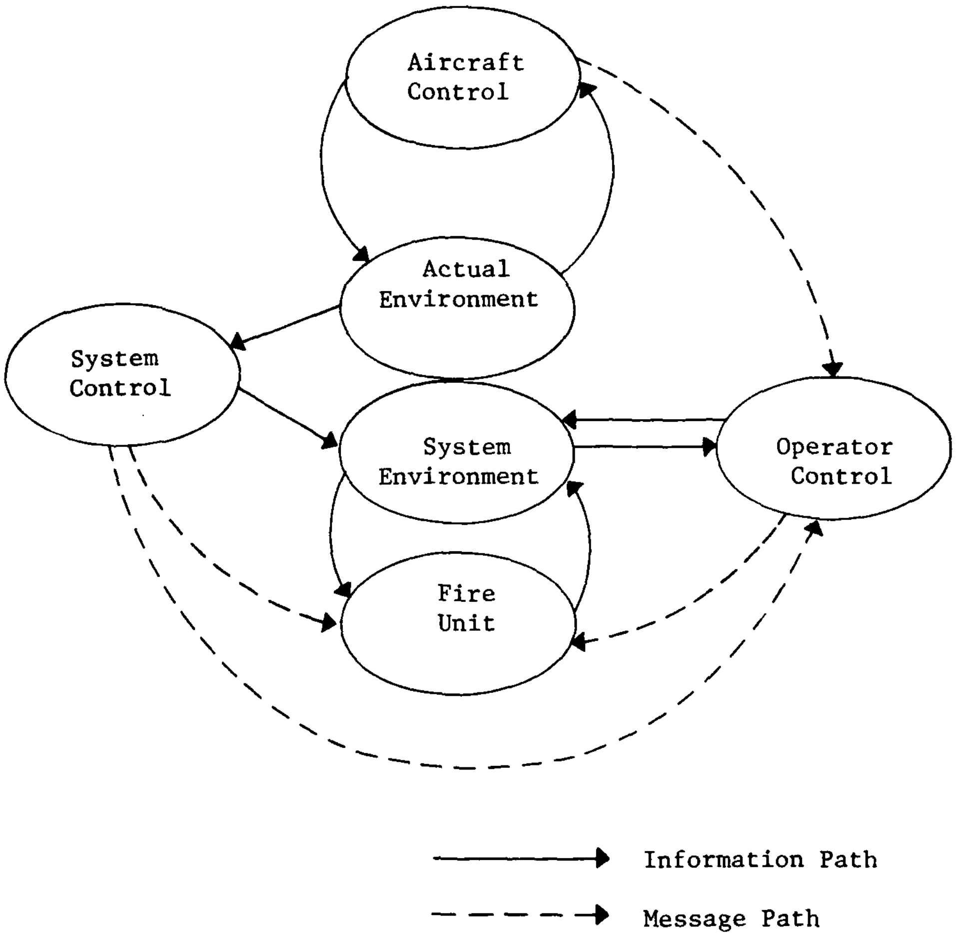

Figure 1. Interaction of the Four Submodels and the Environment

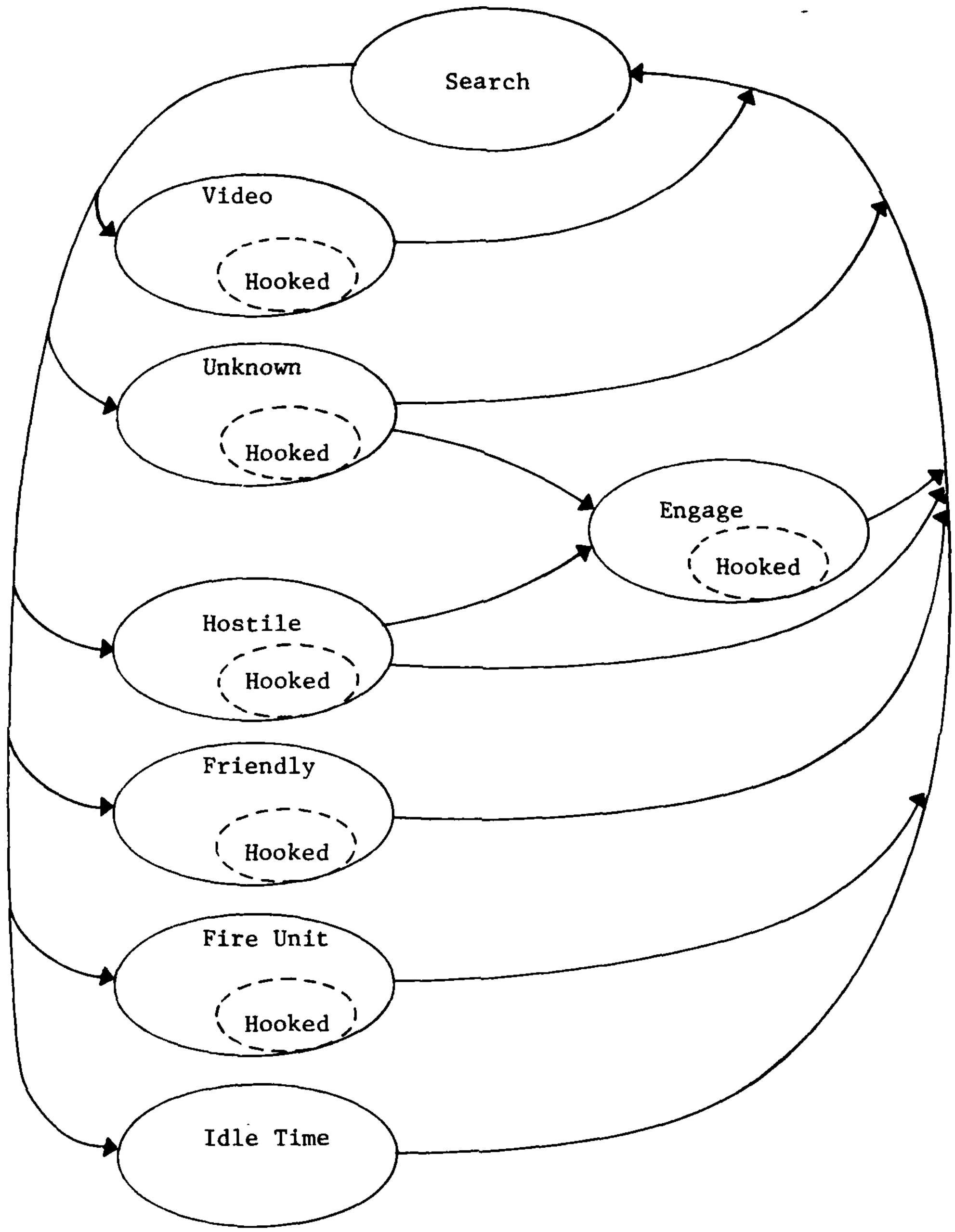

Figure 2. Operator Control Submodel

The video component of the operator control submodel handles operator processing of the video data that appears on the display. The operator must first recognize and identify the symbol. Then he must decide if this video data is a track and, if so, whether the track requires manual initialization. If it does, the environment is updated to reflect the change in status.

The processing of tracks that are currently classified as unknown is modeled in another component. This procedure requires the operator to observe and recognize the symbol as an unknown track and then decide if any action should be taken. If action is taken, the operator attempts to establish the identification of the track as either friendly or hostile. Upon completion of this process, the new status of the track may necessitate further action by the operator, i.e., the operator is routed directly to the component processing friendly or hostile tracks. This is accomplished without the operator returning to the search task and reflects a continuous processing of the track by the operator. As operator actions change the status of the system, the environment is updated accordingly.

Another component of the operator control submodel represents the operator observing and processing a hostile track. In this component, the operator checks to see if the track is currently being engaged by a fire unit. If it is not and the current operating policy indicates that the track should be assigned to a fire unit, the operator is directed to the engagement component.

The assignment of a fire unit to a track is accomplished within the engagement component and is simulated in any of three possible modes: manual, semi-automatic, or fully automatic. The operator or system is required to choose a valid fire unit to be assigned to the given track, that is, the track that initiated the action in this component. Once the assignment is made, a message is sent to the fire unit submodel to begin processing the track.

Friendly tracks that appear on the scope may also require processing. In the component that processes friendly tracks, a check is made to determine if a friendly track is currently being engaged by a fire unit. This would be a result of a previous classification of the track as hostile. If so, the operator informs the fire unit control submodel of this situation through the generation of a cease-engagement message.

The effectiveness of the fire units during their engagement process must be regularly monitored by the operator so that he may continue to process tracks correctly. The fire unit component of the operator control submodel models the two-way communication link between the operator and the fire units involved in the mission.

Another component is accessed repeatedly by the operator control components described above. It represents a series of tasks performed by the operator to "hook" a displayed symbol. Hooking is used to identify a specific track or fire unit to the system's computer. There are four methods in which hooking can be accomplished (tab, sequence, symbol number, or coordinates), and the capability to simulate any of these is included in the model. Hooking involves the operator positioning a computer-drawn circle over the specified symbol on the display screen. The four methods reflect the alternative mechanical processes that are available to the operator to accomplish this task.

The last component of the operator control submodel represents the time spent by the operator in the idle state. When in this state, the operator gives no attention to the radar system or its environment. The time spent by the operator in this component is dependent upon the current status of the overall threat environment of the system.

AIRCRAFT CONTROL SUBMODEL

Aircraft tracks are generated, controlled, and identified in this distinct submodel. The flow of information in this submodel is illustrated in Figure 3. The number of aircraft as well as their headings, speed and IFF classifications are provided as data input to the model. During the simulation, this submodel maintains the current status of these variables.

SAINT has the capability to model variables whose values change continuously over time. Aircraft position and distance from a site are represented by these continuous variables. The values of the state variables are updated continuously by evaluating algebraic equations involving the aircraft's current position and speed. These quantities are then available to be used as parameters in both policy and environmental decision-making throughout the model.

SAINT also provides the capability, through the use of monitors, to continually compare the values of specified state variables against prescribed threshold functions. A monitor will automatically locate the time that a state variable "crosses" the threshold value of the reference function, compute the values of the state variable at that time, and initiate a specified action. Thus, monitors provide a convenient method of updating the display parameters that are used in the search task. These parameters reflect the priority or threat value assigned to a hostile track as it approaches a target.

The initial processing of identification Friend or Foe (IFF) data is also controlled by this submodel. If an identification change is processed, the submodel checks to see if both the actual and system environments should be updated. If the system is in a manual mode, only the actual status will be updated. This information is then used at a later time by the operator to manually update the system environment. If the system is operating in an automatic mode, both the actual and system environments are updated. New identification information would then be available to the operator. If the identification status of a track changes, an appropriate message is sent to the operator control submodel.

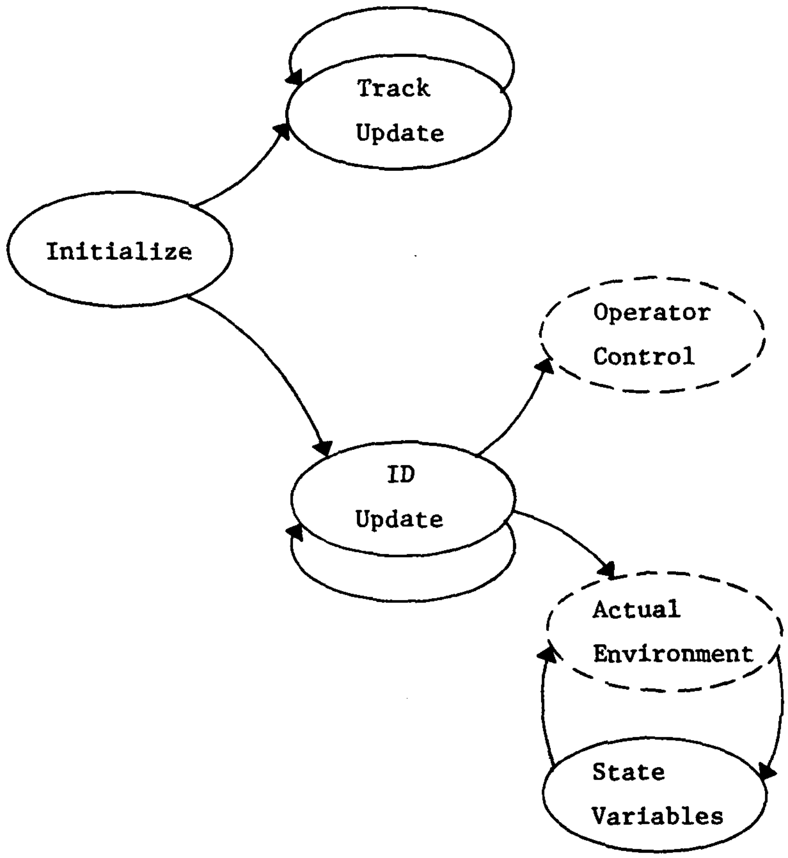

Figure 3. Aircraft Control Submodel

FIRE UNIT CONTROL SUBMODEL

The fire unit control submodel represents the activity of all fire units included in the model. Fire unit control processing is illustrated in Figure 4. Messages received from the operator and system control submodels are routed through the fire unit message processing tasks to the appropriate fire unit activity tasks. Messages are directed to a specific fire unit. Therefore, the fire unit submodel must interpret the message and initiate or terminate the proper activity for the specified fire unit.

The activities of the fire units are represented by five tasks. Current conditions are updated and checked at these tasks and procedures are initiated that continue the engagement process or terminate action. For example, the system will stop processing at the firing stage if the fire unit has received a hold fire message. This does not terminate the engagement of the fire unit to the track but only delays further action until the target moves within range.

SYSTEM CONTROL SUBMODEL

The system control submodel represents the activities of the AN/TSQ-73 system and fire unit computers. Figure 5 illustrates the information flow among these activities. At regular time intervals, this submodel monitors selected automatic procedures. The number of checks actually made is dependent upon the automatic/manual modes of operation selected.

When accessed, this submodel reviews all tracks to determine if their current status and the current system operating policies are reflected in the operation of the other submodels. For example, a review is made for changes in track classifications. It is possible that a track that was originally classified as hostile or unknown has been reclassified as friendly. If this track is currently assigned to a fire unit, a cease fire message is sent to the fire unit control submodel.

The system environment is also reviewed to determine if any of the existing unassigned tracks should be assigned to a fire unit. The assessment is made based on the track's identification (both hostile and unknown tracks may be engaged), distance to a target, and evaluated threat to a target. If an engagement is made, a message is sent to the fire unit control section.

This submodel also monitors the status of all fire units. It is possible that a fire unit may engage a track at a range that is outside its firing window. If so, processing of the track is interrupted until the firing window requirements are satisfied. Once the track has entered the firing window, the submodel signals the fire unit to continue with the engagement. If a change in the track's flight path indicates it will no longer fly within range of the assigned fire unit, a cease fire message is sent to the fire unit control section.

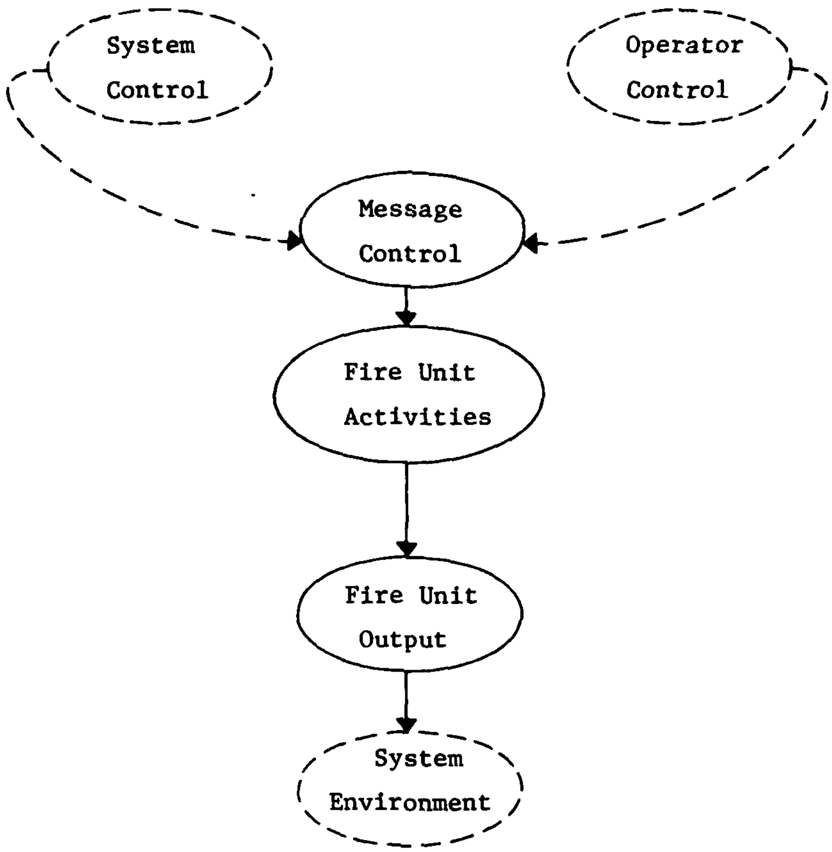

Figure 4. Fire Unit Control Submodel

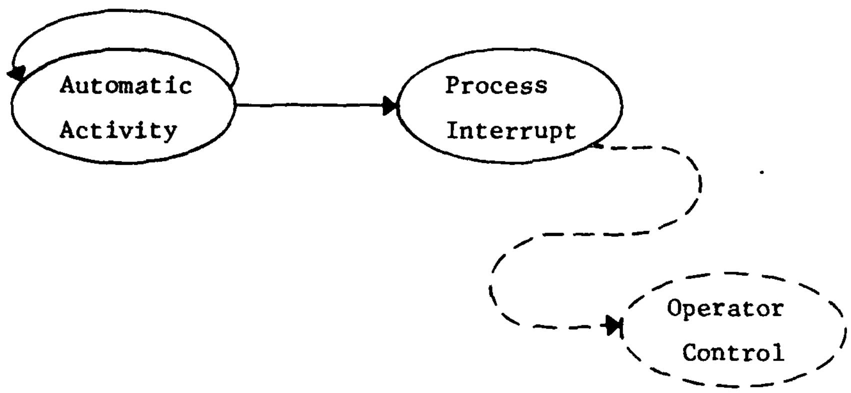

Figure 5. System Control Submodel

It is possible that the system control submodel will change the status/identification of the symbol that the operator is currently processing. This must be reflected by an immediate change in the activities of the operator. When such a change occurs, the system control component interrupts the operator and restarts his processing of the symbol under its new classification. This is accomplished by releasing the operator from the task he is currently performing and routing him to the appropriate task.

MODEL INPUT

The SAINT model is translated via specified formats into a set of data cards that are read by the SAINT simulation program. These data cards contain all of the information necessary to represent and analyze the model. As an example, consider the following data representing the observation of a hostile track by the operator:

```
TAS, 25, OBSHOST, 1, 1, DS, 9,
          (16) 1*
MOD, 25, 8, A,,
         10, A*
STA, 25 (5) BET, STA, 10, 0., 30.*
UTC, 25,,,50.,.8,0.*
ATA, 25 COM, SA, 0, 1, UF, 13,
              SA, 0, 7, SC, -1*
PRO, 25,SA, 0, 1, 1,
           15, 2,
           26, 3*
```

The data cards shown identify the time required for the operator to observe the track symbol, recognize the meaning of the symbol, and decide if further action is required. They are also used to control the resource required to perform the task, the preparation of detailed processing information, the collection of statistics related to the task, and the selection of the next task to be performed. Each task in the model is similarly described.

System operating policies are also specified on data cards. For example, one policy states that if a hostile aircraft is greater than 50 miles from the defended site, no operation action is required 80% of the time. However, if the track is within the 50 mile range, operator action is essential. This policy is reflected in the following data:

UTC, 25,,,60,50,.8,0.*

If the analyst wishes to evaluate a change in the above policy so that the operator will never take action if the aircraft is outside 60 miles, always take action if it is inside 40 miles, and possibly take action (proportional to its range within the interval) if the track is between 40 and 60 miles, the data card would read as follows:

UTC,25,,,50,40,1.,0.*

The majority of the operating policies included in the model may be altered in this manner, allowing a straightforward examination of policy options.

Mission information is also input on data cards. The data provided controls the attack scenario that is flown against the operator. The information required includes:

1. Initial automatic/manual operating mode selection

2. Fire unit characteristics

   a. Location

   b. Armament

   c. Effectiveness

3. Track characteristics

   a. Flight path information

      (i) Heading

      (ii) Speed

   b. Identification information

This information is varied in order to evaluate operator response to a wide variety of situations.

MODEL OUTPUT

The model provides two forms of output. The first is an operator activity trace. This trace includes the specific task being performed by the operator and the track number and/or fire unit number involved in this action. In addition, the current identification status of all tracks and the current activity status of all fire units is included. The tracing of any task is accomplished by the insertion of a single line of code in the SAINT input cards. For example, task 25 is traced as a result of including the following data card:

```
MOD,25,B,A,,
```

In this manner, the trace can be designed to satisfy changing analysis requirements.

Following the trace output is a series of statistical reports that represents a variety of system performance measures. These are divided into four categories:

1. SAINT-generated task statistics

2. User-generated statistics based on observation

3. User-generated statistics based on time

4. User-generated histograms

The statistics to be collected are also specified using data cards. For example, the following data card causes a statistical summary and associated histogram to be prepared for the time between performance of task 25 (observation of a hostile track):

```
STA,25,(5),BET,STA,10,0.,30.*
```

This data card, along with five other similar cards, causes the collection of statistics concerning the time between the execution of the submodels shown in Figure 1. These statistics are useful in establishing priorities and policies needed to improve operator performance.

The collection of user-generated statistics is controlled by a user-supplied FORTRAN function. Changes in the statistics to be collected require minor changes to the FORTRAN code and the addition of associated data cards. The observation statistics are currently being used to record the execution time of each task or selected groups of tasks performed by the operator as well as the time required by the fire units to react to selected system inputs. This information is displayed graphically in the user-generated histograms. The time-based statistics are used as the basis for evaluating the effectiveness of the operator. They represent the percentage of time that the operator is late in responding to system status changes. Time-based statistics are also used to record the amount of time that each fire unit is active.

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APPENDIX

SAINT has been designed, developed, and applied in modeling and analyzing systems in which resources (men and machines) perform tasks subject to physical and environmental constraints. It satisfies the need for a graphical approach to the modeling and analysis of systems which contain procedural, risk, and random elements. For engineers and human factors specialists, SAINT provides modeling capabilities similar to those provided by circuit diagrams for electrical engineers, signal flow graphs, and block diagrams for systems analysts, and PERT/CPM networks for project managers. Further, it provides automatic model analysis capabilities via the SAINT simulation program.

The SAINT philosophy is to separate the modeling process from the analysis process. A graphical approach to modeling is taken in which the system to be analyzed is represented by a network model. The network model facilitates communication regarding the characteristics of the system and also serves as the basis for subsequent system analysis. The SAINT approach to network modeling and analysis is depicted in Figure 6.

A SAINT network model is developed using symbols contained in the SAINT symbol set. The fundamental elements of SAINT networks are tasks, resources (personnel and/or equipment) required to perform tasks, relationships among tasks, and system status variables referred to as state variables. System performance is related to which tasks are performed, the manner in which they are initiated, utilization of the system resources, and the extent to which certain states of the system are achieved or maintained. The SAINT symbol set provides the tools required to build models of systems in which resources perform tasks to accomplish system objectives.

In addition to providing a flexible set of symbols which are integrated to form a network model of the system under study, the SAINT modeling approach allows for the specification of the conditions and constraints under which the system operates. These conditions and constraints may include such factors as time constraints on resources and the environment within which the tasks must be performed. By providing the means for specifying such conditions and constraints, SAINT allows the analyst to depict system performance in a variety of situations.

The application of SAINT is extending into many diverse areas, particularly in situations where the inclusion of the human component in a model is required to ensure valid analysis results. It is gaining a wide acceptance by systems modelers and analysts of many disciplines. The following are examples of modeling and analysis efforts involving the use of SAINT:

Analysis of a remotely piloted vehicle/drone control facility (9, 10, 11, 12)

Analysis of communication frequency utilization in a railroad switching yard.

Safety analysis of nuclear systems (13)

Investigation of psychological theory (14)

Analysis of multi-function switching and multi-purpose display concepts (15)

Analysis of process capacity and resource utilization in the steel industry (16)

Analysis of in-flight aircraft refueling operations (17)

Scheduling of experiments for the Spacelab

Determination of crew survivability/vulnerability in a nuclear environment

Evaluation of navigation and electronic warfare officer performance in B-52 missions

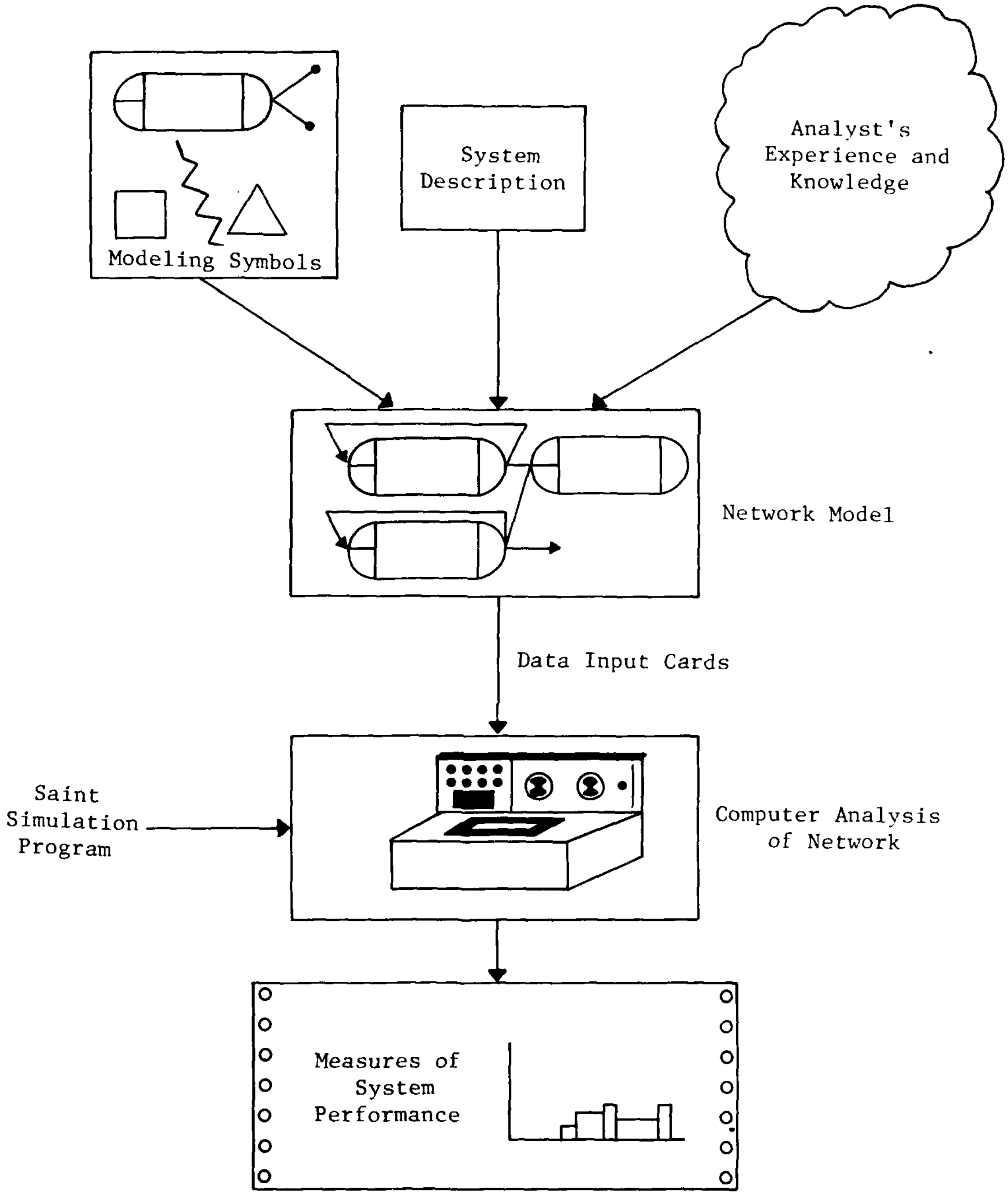

Figure 6. SAINT Approach to Network Modeling and Analysis

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