ADA027931

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

(19) (2) (18)

1. REPORT NUMBER: AMRL-TR-75-25

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): (6) SAINT MODEL OF A CHOICE REACTION TIME PARADIGM

5. TYPE OF REPORT & PERIOD COVERED: Oral Presentation

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): (10) Reuben L. Hann; Gilbert G. Kuperman (Systems Research Labs, Inc.)

8. CONTRACT OR GRANT NUMBER(s): (15) F33615-74-C-0127

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Aerospace Medical Research Laboratory
Aerospace Medical Division, AFSC
Wright-Patterson AFB OH 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62202F, 7184-04-28

11. CONTROLLING OFFICE NAME AND ADDRESS: (12) 7p.

12. REPORT DATE: (11) Jul[illegible]76

13. NUMBER OF PAGES: 7

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (16) AF-7184 (17) 718404

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:

Proceedings of the Human Factors Society meeting, Dallas TX, 13-16 Oct 75

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

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

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

340 400

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

S..INT MODEL OF A CHOICE REACTION TIME PARADIGM

Reuben L. Hann
Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio

Gilbert G. Kuperman
Systems Research Laboratories, Inc.
Dayton, Ohio

INTRODUCTION

The primary mission of the Air Force Aerospace Medical Research Laboratory, Systems Research Branch (AMRL/HEB), is to develop quantitative techniques, methods and models of operator performance and man/machine systems to specify system design criteria and effectiveness. The major thrust of this development has been through the use of the Human Engineering Systems Simulator (HESS)--composed of an IBM 370 (Model 155) computer with attached IBM 2250 graphic display units and extensive software developed by AMRL and the IBM Corporation.

The HESS has made possible simulation of relatively complex activities such as multi-operator remotely-piloted vehicle (RPV) missions, using live subjects as operators. Another area under investigation has been the assessment of performance in the operation of a multi-function keyboard (MFK) within a digital avionics framework. See Hoffman (1975) for a more detailed description of the Digital Avionics Information System (DAIS).

Although man-in-the-loop real-time simulations are a necessary part of this research, they can be time-consuming and expensive--especially when a large number of variables are of interest and numerous experimental runs are required. A potential solution to this problem has been the development of simulation techniques which model the operator as well as the system processes and parameters. One of these techniques, called SAINT (Systems Analysis of Integrated Networks of Tasks), will be used in this paper.

The objectives of this paper are twofold. First, it is intended as a demonstration of how SAINT can be used to model psychological theory. Once a basic model is constructed, candidate processes can be added or deleted and parameters may be varied by simply adding or altering cards in the basic input deck. In this way test and development of theory can proceed quickly with minimum cost. The second objective is to serve as an initial investigation of performance assessment metrics. The process to be modeled here is being studied by AMRL as a method of measuring the interaction between a primary task and some secondary loading task. Successful modeling of these tasks and the cognitive processes underlying them could greatly facilitate the development of such performance metrics--specifically in terms of estimating the operator's reserve capacity in a complex task environment.

SYSTEMS ANALYSIS OF INTEGRATED NETWORKS OF TASKS (SAINT)

The SAINT modeling technique and computer program were developed to aid in the design and performance evaluation of complex man/machine systems. Systems are created as graphical networks of task activities with which one or more operators interact. Each task in a network is described as to how its performance affects the overall system and how it is related to other tasks within the system. The graphical operator/task analysis system description is entered into the SAINT computer program for automated performance assessment. Employing Monte Carlo techniques, SAINT permits the simulation of probabilistic and conditional task performance descriptions and precedence relationships. It also permits the collection of statistical estimates of system performance. The SAINT program is capable of simulating continuous or discrete system state variables and their response to discrete control task execution. Another major capability of the program is the modification of operator and system characteristics in response to system-internal or external simulated "events." SAINT III is used in this demonstration (see Seifert, 1975).

THE ITEM RECOGNITION PARADIGM

Much of the earlier research into assessing pilot performance has been accomplished by means of various secondary psychomotor tracking tasks. While motor performance is extremely important, the fact remains that a great deal of the pilot's workload is composed of internal, higher-level, cognitive processes; he has a vast amount of information to process and act upon in the course of a mission which has an impact on flight performance. The problem has been: How can the effects of mental work upon the primary flight task be measured in the laboratory? The solution to this problem must also deal with the objection often heard regarding secondary tasks used as metrics; i.e., unless stringent prioritization of task and metric is maintained, confounding will result. The measurement technique, therefore, should not disrupt performance on the primary task.

One possible approach has been adopted for investigation by AMRL; this is the use of an item recognition paradigm. Sternberg of Bell Telephone Labs extended this methodology in the late sixties; since then well over a hundred experiments have been done using the technique. Basically, the procedure consists of presenting to the subject a short list of items to be remembered. This is called the positive or memory or--as we prefer to label it at AMRL--the critical set. After presentation of the critical set a single test stimulus is presented; the subject must decide as quickly as possible whether the test item is or is not a member of the critical set. He then depresses one of two response keys which have been designated in advance as "critical" or "non-critical." The dependent measure is the total reaction time (RT) from onset of the test probe to the activation of one of the keys. The critical set can be presented in one of two procedures, fixed- or varied-set. The fixed-set procedure involves presentation of the critical set for memorization just once; the subject learns the items and they are used over a long series of trials. The varied-set procedure, conversely, changes the critical set stimuli on every trial. Theoretically, the fixed-set stimuli are thought to be stored in long-term memory, while the varied-set items must be accessed within a few seconds after presentation and are therefore thought to be located in short-term memory.

The subject is encouraged, sometimes by means of a pay-off scheme, to respond as quickly as possible while still maintaining a high level of accuracy. Typically, the error rate is in the range of 3-5%, depending upon the nature of the stimuli. The item recognition paradigm is rather unique in this respect; most other methods of examining memory and information processing have used accuracy as the primary measure--that is, they have studied the failure to remember. Since it is difficult to discern in which part of the memory storage and retrieval operations the failure has occurred, little insight into the memory process can be gained. By studying cognitive processes under a condition in which memory is functioning successfully, the item recognition technique can induce some of the mechanisms at work to reveal themselves by studying the time they require to operate.

RT's yielded by application of the item recognition technique are decomposed and analyzed by assuming the total RT to consist of separate, non-overlapping stages. These hypothetical stages have been used by Smith (1968) as a framework for his review of the choice RT literature and were used as a guide in this demonstration. Briefly, the stages are: (I) the test stimulus is sensed and then preprocessed (encoded) in some manner to put it in a suitable format for comparison with the critical set items already in short term or active memory; (II) the representation of the test item is compared to the critical set representations, one at a time; the output of this stage is either "match" or "no-match"; (III) based on the output of Stage II a binary "yes" or "no" (critical or non-critical) decision is made and the appropriate "left-hand" or "right-hand" signal is produced; and (IV) the actual motor response occurs. These events are shown in Figure 1.

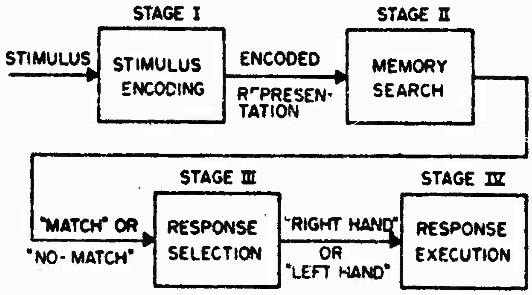

Fig. 1. Theoretical Stages of a Choice Reaction Time Task (after Smith, 1968)

It should be noted here that not all investigators agree with the assumption of non-overlapping stages; however, a discussion of this controversy is beyond the scope of this paper. Suffice it to say, a great amount of evidence has been accumulated supporting the additive-stage model and it will be the approach adopted for the development of this demonstration.

Typically, Sternberg obtains the following results. When RT is plotted as a function of critical set size (designated M), curves similar to those in Figure 2 are the result. RT's are a linear function of M, with the functions for critical and non-critical responses being parallel to, and separated from each other by a constant 40 milliseconds (ms); critical RT's are faster. (Sternberg [1975] has noted that this difference disappears when a critical test stimulus occurs with a probability of approximately 0.25.) Some investigators have obtained a logarithmic RT function (e.g., Briggs and Blaha, 1969) in which linear functions result only when M is stated as $\log_2$ of the critical set size, in the manner of the H_c information measure established by Shannon and Weaver (1962). Kristofferson (1975) has shown these discrepancies to be a function of the nature of the positive set (e.g., whether the item in M=1 is also contained as one of the two items in M=2--i.e., "nested") and the amount of practice with the task.

The RT functions are interpreted as follows. The y-intercept of the curve contains the total time for Stages I, III, and IV as described above. The slope of the line (in ms/item) is thought to be an indicator of central processing (memory scanning) rate in Stage II. Sternberg interprets the data as evidence that memory scanning is a serial, exhaustive search. It is serial (i.e., items in memory are checked one-at-a-time) rather than parallel (all items examined simultaneously), since the critical and non-critical RT functions would have been of zero slope, parallel to the x-axis, if the latter were true. The scan is exhaustive because the two functions are of the same slope. If the search

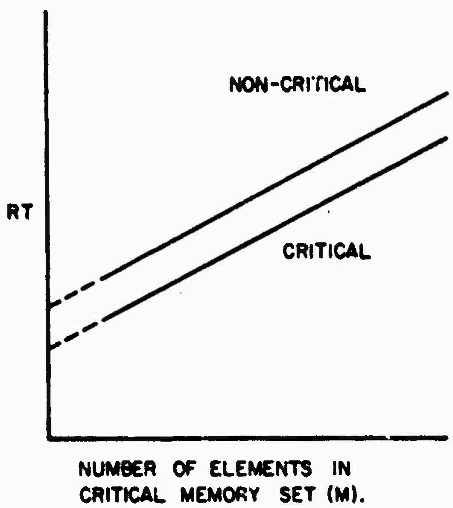

Fig. 2. Theoretical RT-Function; Serial-Exhaustive Search

had been self-terminating, the critical curve slope would have been 1/2 the slope of the non-critical curve, since, on the average, the scan could be terminated half-way through the memory set on critical trials.

THE ITEM RECOGNITION PARADIGM AS A SECONDARY TASK

Under contract to AMRL, Briggs and his associates (Briggs, Fisher, Greenburg, Lyons, Peters, and Shinar, 1971) performed the first experiments in which the item recognition technique was used as a method for measuring workload. It is based on the widely-accepted assumption that central processing capacity is finite. Furthermore, whenever a primary, first priority task is being performed simultaneously with some secondary task, the measured performance on the second task will start to deteriorate as the primary task becomes more difficult, thus indicating greater demand on central processing space and time. That is, this methodology enables one to measure <u>reserve capacity</u>.

The ability to assess cognitive workload is of real importance as man/machine systems, such as increasingly sophisticated aircraft, place greater and greater demands upon the operator. The item recognition secondary task technique is being applied presently in the DAIS manned simulation; future plans call for its incorporation into a SAINT simulation of generalized man/machine tasks.

APPROACH TO MODELING THE ITEM RECOGNITION PARADIGM

Task Durations

The four stage representation of a choice reaction time task provides what is essentially a flow diagram of a cognitive/psychomotor process. Each of these stages must then be represented in the SAINT network. (The stages are: (I) Stimulus Encoding; (II) Memory Search; (III) Response Selection; and (IV) Response Execution.) The basic equation to be modeled is

$$RT = I + II(M) + III(PC) + IV$$

where

RT = total time from stimulus onset to response execution

I = duration of Stage I

II = duration/iteration product for Stage II

M = number of critical elements in memory set

III = duration of Stage III (depends on both the criticality of a stimulus and the ratio of critical-to-total stimulations, PC)

PC = ratio of critical-to-total stimulations

IV = duration of Stage IV

Table 1 presents a summary of the data and their respective sources which were exploited in developing the SAINT network. The most directly applicable data were provided by Sternberg (1966). He gave values for II and for (RT - II). These values are: II is equal to 38 ms per critical element in the memory set and (RT - II) is equal to 370 ms. Kristofferson (1975) employed both one- and two-choice RT designs in implementing the Sternberg paradigm. The single-choice RT data are apparently unique[1] and afforded us an opportunity to estimate the duration of Stage III by inference. We arbitrarily (lacking any other

TABLE 1. [illegible]

[illegible]

[illegible]

Assumptions	Protocol	Data
Fixed Set Procedure	Critical set changed/ block	I + III + IV = 370 ms
[illegible]	Critical sets independent	II = 38 ms/element
Response Incompatible	Critical and non-critical elements change blocks	
2 Responses	Choice RT	
[illegible]		

[illegible]

Fixed Set Procedure; [illegible]; Response [illegible]; 2 Responses	(Same as Sternberg, 66)	III = [illegible] ms
1-Response	[illegible]	
[illegible]		

[illegible]

[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible] ms	[illegible] ms
[illegible]	[illegible] ms	

[1] "One-choice" here does not refer to a simple RT procedure. The experimental procedure was the standard item recognition paradigm, but the subject had a single response key and depressed it only if the test stimulus was critical. Non-critical stimuli required no response.

guidance) chose to take the mean of the intercepts of the critical and non-critical double-response cases and compared that value to the intercept for the single-response case. This produced an estimate for III of approximately 50 ms. Sternberg (1975) pointed out that for equally probable critical and non-critical stimulations, the non-critical response times exceed the critical responses by approximately 40 ms. Based on the definition of the process represented by Stage III, this time difference must be represented in this response selection phase. Since this artifact does not manifest itself for unequal probabilities of critical and non-critical stimuli, two distinct representations of Stage III are required in the network. For the equal probability case, these representations (tasks) will have a mean duration of 50 ms for a critical stimulation and 90 ms for a non-critical stimulation; if the probabilities are sufficiently unequal, the duration will be 50 ms independent of the stimulus. This interpretation differs from Sternberg (1975), but is consistent with the binary decision process represented by Stage III.

Woodworth and Schlosberg (1954) provided the data used for estimating the duration (and distribution) of Stage IV. Under our definition, Stage IV encompasses both nerve conduction and the resultant muscle movement. Data from tasks requiring simple response to visual stimulation suggest that the range of 45 to 55 ms is reasonable for this stage.

The mean duration of Stage I is estimated by subtraction. Using the estimates presented above, we have

$$I = 370 - III - IV = 370 - 50 - 50 = 270 \text{ ms}$$

The values developed from the literature are used in the network as arithmetic means. The distributions of stage durations are estimated; Stages I and II are normally distributed, Stage III is weighted by a Gamma distribution to reflect the skewness typically found in psycho-physical reaction time data. Stage IV, essentially physiological, is uniformly distributed. Similarly, minima, maxima, and standard deviations are estimated. Table 2 presents a summary of the stages and their respective time distributions.

TABLE 2. STAGE/TASK DURATIONS (MS)

Stage	Task	Distribution	Mean	Minimum	Maximum	St. D.
I	1	Normal	270	150	400	8
II	2	Normal	30	20	36	6
III*	3	Gamma	50(90)	40(80)	75(110)	5
III	5	Gamma	50	40	70	2
IV	4**	Uniform	--	45	55	--
IV	6	Uniform	--	45	55	--

* Task 3 is realized for non-critical stimuli. The values in ( ) apply for equally probable critical or non-critical stimuli. Task 5 is realized for all critical stimuli and is identical to Task 3 (when PC ≥ .25, PC ≤ .75)

** Task 4 is the successor to Task 3, Task 6 is the successor to Task 5.

SYSTEM ATTRIBUTES

In deriving the time estimates representative of the item recognition paradigm, a total of six logical blocks were found to be required to correspond to the four stages. Additionally, it was implicitly noted that the model must take the size of the critical memory set, whether the test is critical or non-critical, and the probability of a critical stimulation into account. These are modeled as system attributes of the network. (For actual execution of the SAINT computer model, a fourth system attribute, a counter or the number of times Task 2 is realized during an iteration, must be introduced.) Table 3 presents the system attributes of the SAINT/item recognition paradigm model.

TABLE 3. SYSTEM ATTRIBUTES

Attribute	Meaning
1	M, the number of elements in the set of critical stimuli
2	PC, the probability of a critical stimulus
3	Counter on execution of of Task 2
4	Index of criticality on current stimulus

THE SAINT NETWORK

In order to create a SAINT network model, the mathematical model of the item recognition paradigm, developed above, is translated into SAINT symbology. The basic SAINT entity is the task, which is a goal directed activity, consuming a finite amount of time. Tasks may have special connotations. A source task serves to initiate a sequence of related activities. A successor task to an activity is one for which logical on mathematical relationships have been satisfied. These relationships define the inter-task branching of the SAINT network.

A logical sequence of tasks is implicit in the four stage model of the item recognition paradigm. The duration of each task and the branching between tasks also follow from this model, as do the system attributes. Two additional tasks, both source tasks, complete the model. One is used to generate the stimuli and the second facilitates the collection of statistics on the task corresponding to Stimulus Encoding (Stage I). The completed network is presented in Figure 3.

In automating the network, time distribution data sets are defined, system attributes are specified and initialized, and tasks are described as to their characteristics, information assignments, and successor tasks and branching procedure. Use of the model is facilitated in that only two independent variables need be specified: the size of the critical set and the probability of a critical stimulus.

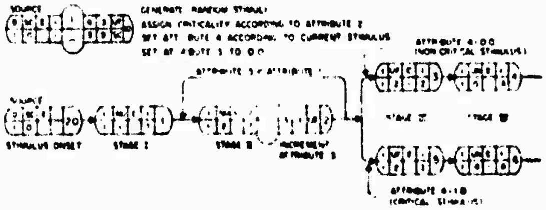

Fig. 3. SAINT Network for Sternberg Paradigm

OUTPUT OF THE SAINT/ITEM RECOGNITION MODEL

Although the network used in the automated simulation is rather simple, the true power of this modeling approach resides in the capability to rapidly perform and analyze large numbers of iterations. An iteration, in a very strong sense, corresponds to a single trial in an experiment employing live subjects. All model runs executed in performing the effort reported on in this paper employed 500 iterations.

The SAINT model permits the collection and analysis of timing data at the individual task level. Figure 4 is an example of the graphic output for all iterations of Task 2 (Memory Search). Both histographic and cumulative representations are output. It should be noted that 2000 samples of this task are treated. This occurs because the example was drawn from the iteration of a case in which there were four critical stimuli possible and, therefore, task 2 was cycled four times in each iteration.

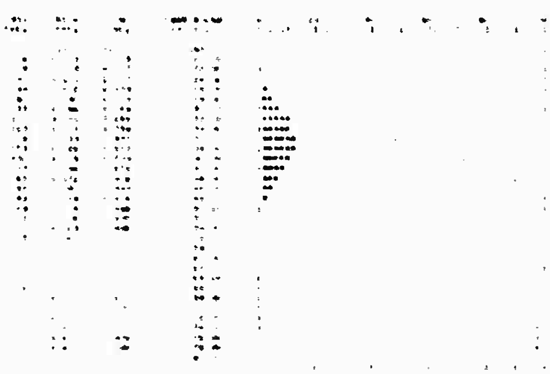

Fig. 4. Statistics Histogram for Task 2 (M = 4)

Detailed output data are also provided (if needed) for individual iterations of the network. Table 4a through d presents such data. In this table, the size of the critical set is held equal to four elements while both critical and non-critical stimuli are studied at two probabilities of occurrence. In this format, the sequence of task releases is explicitly recorded and the discrete duration for each task release sample is also provided.

TABLE 4. DETAILED OUTPUT FOR SINGLE ITERATIONS

(a) Detailed Output (M=4, PC=.50) Non-Critical

Task	Duration
1	272
2	39
2	36
2	33
2	38
3	87
4	54
	559

(b) Detailed Output (M=4, PC=.50) Critical

Task	Duration
1	275
2	38
2	47
2	45
2	41
5	49
6	48
	543

(c) Detailed Output (M=4, PC=.25) Non-Critical

Task	Duration
1	273
2	[illegible]
2	40
2	35
2	32
3	47
4	46
	516

(d) Detailed Output (M=4, PC=1.25) Critical

Task	Duration
1	275
2	38
2	47
2	45
2	41
5	54
6	49
	549

Summary statistics, over all iterations, are also provided for each task. Table 5 presents these data for both probabilities of critical stimulus occurrence. Note that these data are independent of the number of elements in the critical set. This effect is shown in the number of samples used in estimating the duration for Task 2.

TABLE 5. SUMMARY RESULTS FOR 500 ITERATIONS (PC = .25) PC = .50

Task	Stage	Mean	N
1	Stimulus Encoding	(270)270	(500)500
2	Memory Search	(38)38	(2000)2000
3	Response Selection (Non-critical)	(49)92	(374)250
4	Response Execution (Non-critical)	(50)50	(374)250
5	Response Selection (Critical)	(50)50	(126)250
6	Response Execution (Critical)	(50)50	(126)250

Figure 5 presents the most general statement of the simulation results. RT is shown as a linear function of the size of the critical stimulus set. The case depicted is for PC equal to 0.50. The least squares fit for the mean critical stimulus data is given by the equation RT = 38(M) + 375 ms and for the non-critical stimuli by RT = 38(M) + 415 ms. These equations are in agreement with the data produced by Sternberg (1966;1975). (The equations for both critical and non-critical stimulations at PC = 0.25 are collinear with the critical stimulus line for PC = 0.50, which is in agreement with Sternberg [1975].)

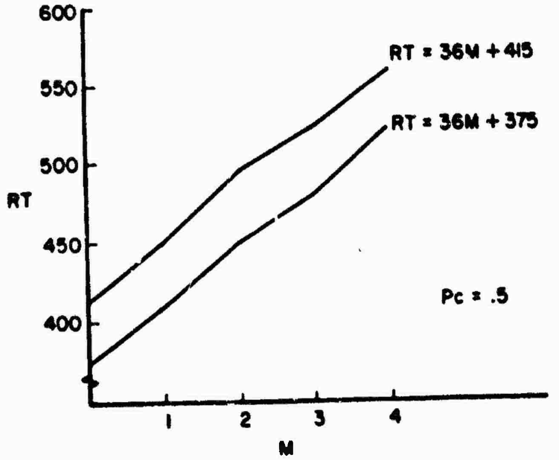

Fig. 5. Reaction Time (RT) as a Function of Set Size (M)

CONCLUSIONS

1. The two objectives of this SAINT application were satisfied. The use of SAINT modeling techniques in the context of psychological theory was demonstrated. Specifically, a choice reaction time metric was simulated with close agreement to the available literature.

2. To create a network which represented the logic and interrelationships of the item recognition paradigm, it was necessary to make assumptions which offer promising opportunities for experimental confirmation or refutation.

3. Because of the power afforded by the iterative capability of the model, it appears possible to study subtle variations of the paradigm which might have confounding effects if applied in the laboratory.

4. Because of the modular structure of the SAINT network, new data and interpretations can be readily incorporated into the model to improve its accuracy and sensitivity.

REFERENCES

Briggs, G.E., Fisher, R.P., Greenberg, S.N., Lyons, J.J., Peters, G.L., and Shinar, D. Multi-task time-sharing requirements (AMRL-TR-71-105). Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, August, 1972.

Briggs, G.E. and Blaha, J. Memory retrieval and central comparison times in information processing. Journal of Experimental Psychology, 1969, 79, 395-402.

Hoffman, M.S. A methodology for evaluating advanced DAIS concepts in terms of the human operator's performance requirements (Interim Technical Report on Contract No. F33615-72-C-0235). Dayton, Ohio: Systems Research Laboratories, Inc., Jan. 1975.

Kristofferson, M.W. On the interaction between memory scanning and response set. Memory and Cognition, 1957, 3, 102-106.

Seifert, D.J. SAINT III, manuscript in preparation, Wright-Patterson Aerospace Medical Research Laboratory, 1975.

Shannon, D.E. and Weaver, W. The mathematical theory of Communication. Urbana, Ill.: University of Illinois Press, 1962.

Smith, E.E. Choice reaction time: An analysis of the major theoretical positions. Psychological Bulletin, 1968, 69, 77-110.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Memory scanning: New findings and current controversies. Quarterly Journal of Experimental Psychology, 1957, 27, 1-32.