TSC-USCG-80-1

CG-D-54-80

SIMULATION OF COAST GUARD VESSEL TRAFFIC SERVICE OPERATIONS BY MODEL AND EXPERIMENT

SEPTEMBER 1980

U.S. DEPARTMENT OF TRANSPORTATION

RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER • CAMBRIDGE MA 02142

PREPARED FOR UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT • WASHINGTON DC 20593

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-54-80		

4. Title and Subtitle	5. Report Date
SIMULATION OF COAST GUARD VESSEL TRAFFIC SERVICE OPERATIONS BY MODEL AND EXPERIMENT	September 1980
	6. Performing Organization Code: DTS-532
7. Author(s): D.B. Devoe, J.W. Royal, C.N. Abernethy	8. Performing Organization Report No.: DOT-TSC-USCG-80-1
9. Performing Organization Name and Address: U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge MA 02142	10. Work Unit No. (TRAIS): CG013/R 1003
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, U.S. Coast Guard, Office of Research and Development, Washington DC 20593	13. Type of Report and Period Covered: Final Report, October 1978 - September 1979
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A technique for computer simulation of operations of U.S. Coast Guard Vessel Traffic Services is described and verified with data obtained in four field studies. Uses of the technique are discussed and illustrated. A field experiment is described in which Vessel Traffic Service watchstanders were tested in simulated operations at traffic loads well in excess of routine levels. The strategies adopted are identified and discussed with regard to their implications for operating procedures and appropriate recommendations are offered.

17. Key Words	18. Distribution Statement
vessel traffic service, model, simulation, human performance, system stress	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	68	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The Behavioral Systems Branch of the Department of Transportation's Transportation Systems Center (TSC) under the sponsorship of the U.S. Coast Guard's Office of Research and Development is conducting a series of studies of watchstander performance at Coast Guard Vessel Traffic Services (VTSs). This report describes efforts in Fiscal Year 1979 to simulate VTS operations by computer and experiment.

The authors wish to express their thanks to Mr. L. B. Kelley and LT P.R. Corpuz of the Office of Research and Development and to Dr. H.P. Bishop, Program Manager at TSC, for their contributions, guidance, and assistance. Special recognition is due Mr. B. Rothmel of Kentron of Hawaii, Inc., for assistance in data collection, to Mr. J.W. Royal of System Development Corporation for model development and programming, and to Mr. R. Rudich of TSC for assistance in data analysis. Finally, the authors are particularly grateful to CDR W.C. Park, III, LCDR R.F. Lutz, and the watchstanders of the Puget Sound VTS for their cooperation in planning and running the field experiment.

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Two major efforts are summarized in this report: (1) development and evaluation of a model of Vessel Traffic Service (VTS) operations based on rate of information processing, and (2) exploration of the effects of unusual situations on the normal operating performance of VTS watchstanders.

MODEL DEVELOPMENT

A model of VTS operations, based on the rate of information flow through the system and programmed to permit simulation of operations with a computer, is described (2.1)*. Use of the model to predict the effects of changes in workload, equipment, procedures or personnel is proposed and illustrated using a model of a hypothetical VTS (2.2). The procedures used to convert data on operations to a model of the operation are given in detail for each sector of each VTS (2.3), and the results of simulation runs of each model are presented in support of the conclusion that the models do yield descriptive functions that are representative of operations at the VTSs (2.4, 2.5).

WORKLOAD STUDIES

To evaluate alternative approaches to the estimation of effects of exceptionally heavy workloads and other unusual events on the operation of VTSs, four VTSs (Houston, New Orleans, Puget Sound, and San Francisco) were surveyed. Information was sought on available data on past incidents, anticipated future events that would create heavy work loads, procedures for conducting and recording post-incident critiques, and the feasibility of conducting on-site simulation studies.

The results of the survey led to the conclusion that the kind of information required could only be obtained through on-site simulation (3.1). Consequently, an experiment was run at Puget Sound VTS in which ten subject watchstanders at a simulated communicating position were subjected to increases in vessel traffic load well in excess of normal operating conditions (3.3). The results of a one-hour run with each of the ten subjects demonstrated clearly that they were all forced to adopt strategies for effecting a tradeoff between the time spent communicating with vessels and the time spent plotting vessel positions, and that every watchstander adopted a different set of strategies (3.4.5). There was some evidence of increasing physiological stress during the course of the experiment, and the results showed a tendency for those subjects showing the least stress reaction to cope most effectively with the workload (3.4.6). This variability in response to unusual conditions and the desirability for a calm reaction were interpreted as evidence for a need for more stringent standing operating procedures (SOP) for unusual conditions and more initial and refresher training in such SOP (3.5).

Short interviews with the ten subjects yielded data suggesting that job satisfaction had improved over the previous year at PSVTS, but that some watchstanders still feel that a VTS assignment does not advance a career as a radarman or quartermaster (3.5.3.2).

RECOMMENDATIONS

The efforts described in this report, combined with information derived from earlier studies, suggest several efforts that warrant consideration. The feasibility and desirability of implementing these recommendations cannot be determined by TSC; however, the ideas seem worthy of note and further study.

1. Validate the procedure for modeling VTS operations by creating a preoperational model of operations using a new input/output terminal at Houston-Galveston VTS, exercising this model on a computer to derive operational descriptions, and comparing these descriptions with data collected on-site at HGVTS after the system has been in operation for three months or more.

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*Numbers in parentheses refer to sections of this report.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

1.1.1 Purpose

The United States Coast Guard (USCG) operates six Vessel Traffic Services (VTSs), located at San Francisco, CA, Seattle, WA, Houston-Galveston, TX, New Orleans, LA, Valdez, AK, and New York, NY. At each VTS, enlisted watchstanders operate a 24-hour watch over vessel traffic within their assigned VTS area, maintaining an up-to-date plot of traffic conditions, informing each vessel of anticipated traffic situations, and adding such cautionary or directive advice as the situation warrants. The purpose of this operation is to reduce the probability of vessel collisions, groundings and rammings by informing mariners, particularly vessel masters and pilots, of impending traffic and other hazards in time for the mariners to take appropriate actions for safe passage. Such services are expected to reduce shipping-related hazards to environment and safety.

Since the effectiveness of VTS operations is highly dependent on the performance of VTS watchstanders, the USCG Program Office, Office of Marine Environment and Systems (G-WLE-2), authorized the Office of Research and Development (G-DST-3) to manage a program of study of VTS watchstander performance. In turn, the Behavioral Systems Branch of the Department of Transportation's Transportation Systems Center (TSC) was commissioned to conduct the studies, beginning in the second half of Fiscal Year 1977 (FY77).

The ultimate objectives of this program are:
(1) to develop models of VTS watchstander performance and effectiveness for use in analyzing and evaluating current operations and predicting future personnel and equipment needs;
(2) to determine requirements and make appropriate recommendations on personnel selection and training, and
(3) to employ research results as soon as they are developed to improve current operations and assure that future system designs are responsive to the needs of the people who must operate them.

The purpose of this report is to document the studies completed under this program during FY79.

1.1.2 Scope

This report reviews briefly the basic nature of VTS operations (Section 1.2, below), the results of research on VTS watchstanders prior to FY79 (1.3) and highlights of the FY79 studies (Section 1.4). Section 2 summarizes the progress made in modeling VTS operations to reflect watchstander performance and describes potential applications of the models. Section 3 reviews efforts to estimate the effects of unexpected events, emergencies, and excessively heavy workloads on VTS operations, including the details of an experiment conducted at the Puget Sound VTS (PSVTS) simulating very heavy workloads. Section 4 summarizes the conclusions drawn from FY79 studies and offers appropriate recommendations.

1.2 VTS OPERATIONS

No two VTSs operate in exactly the same way. However, the watchstanders all perform the following functions: communicating, monitoring, and plotting. Although these functions often overlap in various activities, we have attempted to treat them separately for purposes of analysis.

Communicating involves two-way conversations between VTS watchstanders and mariners within the VTS area, conducted almost exclusively via VHF-FM radiotelephone. All VTSs have their own transceiver sites, and most have VHF-FM channels assigned exclusively for VTS use.

Monitoring involves the information processing conducted by VTS watchstanders to predict future traffic situations and to determine courses of action.

TABLE 1-1. CHARACTERISTICS OF CURRENT VTSs

VTS	H-G	NO	PS	SF	PWS	NY*
Assigned Radio Channel	12	11,12,14	14	13	13	11,12,14
SURVEILLANCE						
Radar Sites	1		4	2	2	2
Television Sites	4					5
Human Observers		X				
PLOTTING AND TRACKING						
Table and Board			X			
Board and Radar	X**		X**	X	X	
Computer	X	X				X
Data Cards	X		X	X	X	
VESSEL MOVEMENT						
Reporting Mandatory			X		X	X*
Reporting Voluntary	X	X		X		
Traffic Separation (TSS)			X	X	X	

H-G: Houston-Galveston VTS, Houston, TX
NO: New Orleans VTS, New Orleans, LA
PS: Puget Sound VTS, Seattle, WA
SF: San Francisco, VTS, San Francisco, CA
PWS: Prince William Sound VTS, Valdez, AK
NY: New York VTS, New York NY

*NYVTS was not operational during the period of study.
**Radar backup to plot.

2. MODELING VTS OPERATIONS

2.1 BACKGROUND

2.1.1 Introduction

This section describes the development and verification of the completed computer models of typical VTS operations at San Francisco, Puget Sound, New Orleans, and Houston-Galveston. It also contains an explanation of the entire modeling process -- development and output, verification, validation, and applications -- illustrated by a simplified example of VTS operations.

The description of the development and verification procedures are contained in two subsections: Method of Development and Results. The methods employed in gathering field data, preparing it for the model, and construction and computer programming of each model are covered in the first section. The second describes the results of the development of these computer models in terms of data base size, computer requirements and comparisons of simulation output with field data to verify each. Discussion and conclusions follow.

2.1.2 VTS Operations

A VTS is a system of equipment and personnel which receives information about vessel traffic in a defined area, processes the information, and informs vessels in the area of conditions affecting safety and efficiency of transit. Detailed descriptions of VTS operations at each center can be found in References 1 through 4 and summarized in Reference 5.

Each reference presents a sound description of VTS operations for a different waterway. These reports document not only the equipment, procedures and personnel at each VTS, but also the duration and relative frequencies of the major watchstander activities performed at each VTS. These reports, then, provide the basic information for development of the models and should be referred to for information on VTS operations, the methods employed in gathering the field data, their analysis and results.

2.1.3 Modeling Requirements

To accomplish his task, the watchstander interacts with equipment according to established procedures or sequences of steps. Each step takes time with an accompanying delay until the next step begins. Some steps generally take longer than others. In any given hour a watchstander may do more of some activities and less of others depending, mostly, on the frequency and type of mariner requests.

Obviously human behavior is highly variable. Timing a person's performance of the same task several times will produce a series of task durations, and timing a second person's performance at the same task will yield a different series of durations. Consequently, each of the durations required for a watchstander to perform each step of a procedure and the delays between steps will probably differ from instance to instance.

The modeling technique employed should be capable of reflecting the procedures, the steps comprising the procedures, the variabilities in durations for each step and the accompanying delays between steps, and the relative frequencies of activities as determined by mariner requests. To be fully useful to the U.S. Coast Guard, the completed models should be amenable to rapid modification for the study of increased vessel traffic workload and changes in equipment, procedures and personnel. Therefore, they should be suited to computer programming and simple, accurate simulation.

Finally, the output obtained from the computer simulation of a model must be sensitive to changes in system inputs to be indicative of VTS system and watchstander performance.

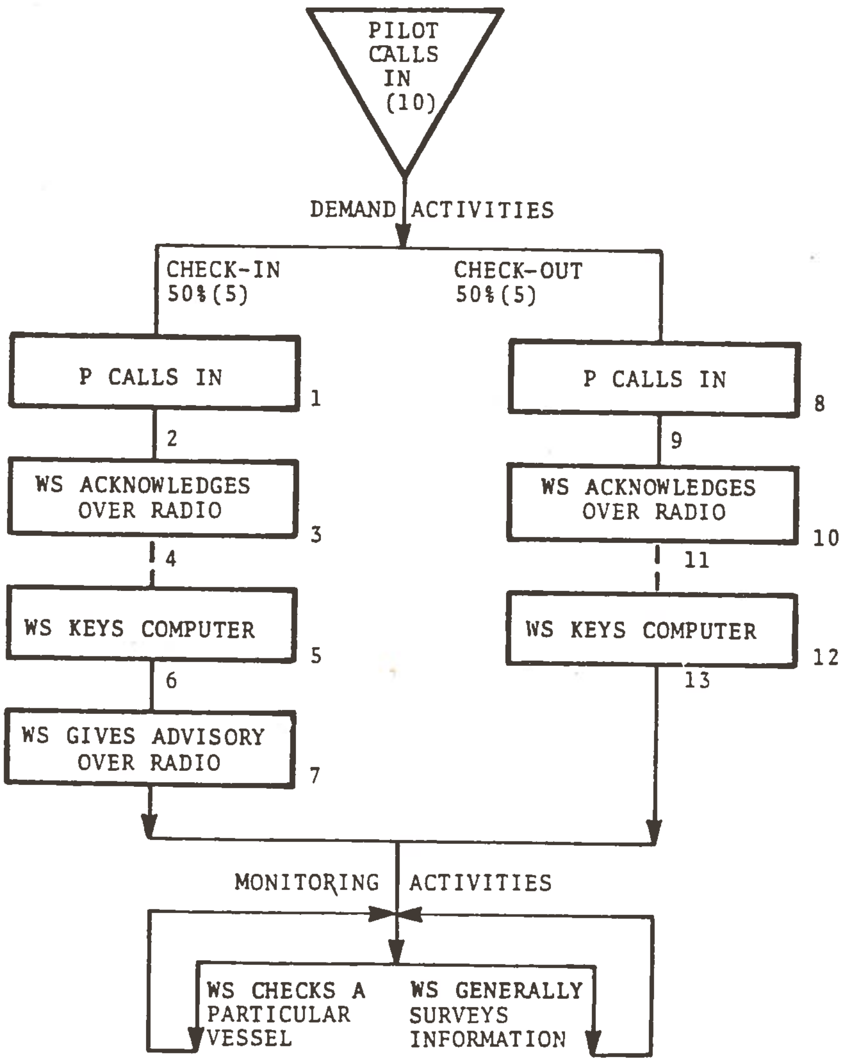

FIGURE 2-1. SIMPLIFIED EXAMPLE OF VTS OPERATIONS

TABLE 2-1. TYPES OF TRANSACTIONS AND INTERINITIATION TIMES FOR EXAMPLE VTS

NO.	TYPE	TIME (SEC)
1	Check-in	360
2	Check-in	300
3	Check-out	420
4	Check-out	340
5	Check-in	380
6	Check-out	330
7	Check-out	310
8	Check-in	390
9	Check-out	410
10	Check-in	--*

*Since the hour ends before the next radio transaction begins, this interinitiation time is indeterminate.

Similar data for check-outs are recorded in the bottom of Table 2-2. Again, each step in the procedure for this type of demand activity is assigned a number and the duration of each instance is tabulated.

For the first check-out call, the observer records 4 seconds for the pilot to make the call over the radio (Step 8). There is a 2-second delay until the watchstander responds (Step 9). The watchstander takes 3 seconds to acknowledge the pilot's call over the radio (Step 10). Other times are recorded (Step 11). The watchstander takes 7 seconds to key in the information required to check the vessel out of the computer system (Step 12). There is a 7-second delay before the computer displays the confirmation that the vessel is checked out.

At this point, we know the relative frequencies of the two different types of demand activities, check-ins and check-outs. We also know the time required for performance of each step and the delay until the initiation of the next step for each call-in. Finally, we have determined how often pilots call into this example VTS.

When demand activities are completed the watchstander has time available for both monitoring activities: checking upon a particular vessel and generally surveying the available information. Both of these types of monitoring activities can be interrupted by a pilot calling in. Observation of what the watchstander does when not responding to calls indicates that 20% of monitoring activities involve checking a particular vessel, 80% involve general surveillance. To keep this example uncluttered, no steps descriptive of the two types of monitoring activities are included.

The data gathering for the model is complete. The activities and the procedural steps to accomplish each have been determined. The relative frequencies of types of activities and the durations of each step in the procedures have been recorded for each instance. The intervals between arrivals of radio calls by pilots have been recorded again for each instance. Now the model can be constructed, programmed and computer simulated.

2.2.3 Model Construction

The model of VTS operations has already been presented in the block diagram in Figure 2-1. This diagram shows the types of activities and the procedural steps required to accomplish them in numbered blocks. The lines connecting the blocks indicate the sequence and interconnections of these steps. As noted above, the data have already been recorded and a table is prepared for each numbered block or interconnecting line. Each such table contains the times listed in one column in Table 2-2. The relative frequencies at branch points have been determined from the field data and entered onto the block diagram. The input to the VTS operation, the time intervals between incoming radio calls and their types, have been tabulated in Table 2-1.

This block diagram and the supporting data base constitute the model of VTS operations. This model describes the flow of information through the VTS in terms of watchstander interactions with both the pilots and the available equipment in accordance with observed operating procedures. To be useful, however, this model must be programmed for computer simulation.

2.2.4 Computer Entry

The block diagram and its supporting data base are turned over to the programmer for entry into the GPSS computer package. The programmer redraws the block diagram using the GPSS symbology. This new diagram permits easier step-by-step entry of the blocks and their interconnections into the program. The programmer then translates this new block diagram into the required GPSS listings, enters the relative frequencies at branch points, and tabulates the data for each block or interblock interval. The intervals between radio calls are also tabulated. These listings are then checked for errors and edited. The model can then be simulated in the computer.

2.2.5 Simulation

The computer simulates VTS operations by a Monte Carlo technique. This technique employs a random number generator built into the GPSS program to select values from the

TABLE 2-3. SAMPLE SIMULATION OUTPUT FROM EXAMPLE VTS INPUT

INPUT	
No. of Call-ins Per Hour: 10	
OUTPUT	
Average Utilization	
Demand Activities	10.4%
Monitoring Activities	89.6%
Average Processing Time per Demand Activity	37.5 sec
Number of Interruptions of Monitoring Activities	6.
Call-ins Delayed	
Check-in	2.
Check-out	3.
Total Number of Call-ins Delayed	5.
Average Delay Time	30.0 sec

Demand Activity Durations (sec)

Activity	Number	Mean	Std. Dev.	Total Duration
Check-in	5	45.00	6.221	225
Check-out	5	30.00	10.114	150

2.2.8 Validation

The overall technique, however, should be validated; that is, tested on an independent data base. This testing can be accomplished in either of two ways: The model can be constructed based on one set of data gathered at a field site, simulated, and the results compared to a separate set of field data gathered at the same site. Or a complete model can be constructed for a new site based on documented procedures and experience and data gathered at other sites. Computer simulation results for this new model should agree with actual data collected later at the site.

Validation is another method of assuring that the modeling technique employed is really descriptive of VTS operations.

2.2.9 Applications

Modeling VTS operations is useful in its own right as a way of describing those operations. The process of constructing these models brings out the processes which occur at a VTS and indicates the magnitudes involved in terms of time, frequency, and percents. Knowledge of both the processes and their magnitudes is useful in coming to understand the inner working of VTSs. However, significant further use can be made of these models.

By making changes in the rate at which radio calls come in to a VTS we can use computer simulation results to study the effects of increased workload. The effects of changes in equipment can be simulated by adding, moving, or changing the data base of particular equipment-related blocks in the flow diagram. Similarly, procedural and personnel changes can be simulated. The following paragraphs use our example VTS to illustrate how this technique of computer simulation of the models of VTS operations can be so applied.

a. Workload

Actually there are two questions concerning the effects of increasing workload due to traffic buildup:

1) What happens to VTS operations as the workload increases?
2) What workload can a watchstander safely handle?

Answers to the first question indicate potential weak points in a VTS operation by determining which system elements fail to keep up. Answers to the second question aid in determining safe workload limits for watchstanders and therefore, when further sectorization, with its increased costs in labor and equipment, is required. Increased workload, as far as a watchstander is concerned, means an increased rate of radio calls coming into the VTS from vessel and tug pilots initiating transactions. This increased rate imposes increased demands and decreases the amount of time available for monitoring activities. Some minimum level of monitoring activities is necessary for safe VTS operations.

An increase in the number of radio calls could be due to a specific incident such as increased traffic congestion at a particular location, or an overall increase in the number of vessels in the harbor. Regardless of the cause, the end result is an increase in watchstander workload.

The following paragraphs discuss how the computer modeling and simulation technique is employed in answering questions about system and watchstander limits under increasing workload.

The computer model of our example VTS is based on field data gathered during typical, everyday operations, but the computer model can be used to simulate atypical, abnormally high workloads in the following manner. A wide range of radio communication loads is generated by expanding or contracting the interinitiation interval (Table 2-1) obtained from the field data. Expansion is accomplished by multiplying each interinitiation interval to obtain fewer radio calls per hour; contraction is accomplished by dividing the same distribution to obtain more radio calls per hour. In this manner, the basic distribution of increasing radio calls is preserved while the effects of various communication loads are explored.

As the radio communication load increases from the 10 per hour of our example VTS, several output measures (Table 2-3) change: both the number of calls delayed and the associated average delay time per call increase. These two measures indicate that some system element (or step in Figure 2-1) is failing to keep up with the increasing workload thereby delaying more and more pilot calls longer and longer.

The raw GPSS output (not included in this report) can be examined to determine which system element creates the backup. For our example, as the radio communication workload increases, the simulation output indicates that the number of delays increase while the watchstander is checking-in another vessel. The raw GPSS output further indicates that the watchstander is most often occupied keying data into the computer (Step 5, Figure 2-1) when other pilots call in. Consequently this weak step or system element should be examined as a possible candidate for change. Possible changes might be the elimination of keying through use of other equipment, changes in procedure to bypass that step (second person responsible for keying and checking information), or reducing keying time (by requiring minimum keying speeds by watchstanders). These kinds of candidate changes are discussed in subsections b, c, and d below.

These paragraphs have illustrated, with the example VTS, how this computer handling and simulation technique can be employed to explore system limitations under increasing workload. The technique for explaining the second question, watchstander limits under increasing workload, is described in the following paragraphs.

An index employed in studies of system operator response to increasing workload is spare capacity (Reference 7). The assumption is that if an operator has some spare capacity he has not yet reached his workload limit. In our case the proportion of time a watchstander has available for monitoring activities is an indication of his spare capacity. However, some monitoring is required for safe VTS operations. How much may be determined from measures of watchstander performance decrements in an experiment simulating actual VTS operations. Experimental simulation of actual VTS operations permits accurate measures of watchstander performance during very high, controlled radio communication loads. Multiple computer simulations of the model can be used to relate the number of radio calls to the proportion of time available for monitoring.

For our hypothetical VTS, the number of radio calls is manipulated as described earlier. The results of these simulations of a wide range of radio communications loads is presented in Figure 2-2. Each data point relates the number of radio calls for one simulated hour to the proportion of time the simulated watchstander has available for monitoring activities as indicated on the computer monitor. For this example, the range of incoming radio calls extends from a low of 8 to a high of 114 calls per computer simulated hour. The corresponding proportion of time available for monitoring extends from 93.1% to 8.5%. A best-fit curve is plotted through the thirty data points in Figure 2-2.

In an experimental duplication of actual VTS operations, watchstanders at our example VTS were able to handle an average of up to 55 radio calls per hour before their performance (as measured by errors, delays, and inaccurate tracking) deteriorated significantly.

This number of radio calls, 55, translates, from the graph in Figure 2-2, to 40% of an hour available to the watchstander for the monitoring required for safe operations. We also know from the field data that the 10 radio calls recorded (Table 2-1) originated from the 4 vessels in the harbor at the time; so there was an average of 2.5 radio calls per vessel in an hour. Therefore a limit of 55 radio calls per hour implies, for this harbor, a limit of 22 vessels per hour for each watchstander.

In the study of the effects of candidate changes discussed below in subsections b, c and d, this criterion proportion of an hour available for monitoring, 40%, must be maintained. However changes in equipment, procedures and personnel will change the shape of the curve in Figure 2-2, possibly permitting a greater number of radio calls per hour and consequently a greater number of vessels per sector watchstander.

b. Equipment Change

Suppose that during the field data gathering trip to our example VTS, the data indicated long delays (up to 12 seconds) between the time the watchstander finished keying information into the computer and the time the new information was displayed. This long duration is reflected in columns 6 and 13 on Table 2-2 and at the same numbered points in Figure 2-1. Suppose further that this delay is intolerable and that a 1-second delay is the limit on both technical feasibility and watchstander tolerance. What would be the effect of improving the system so that the computer delay is only 1 second?

The computer program for the model is easily altered to reflect this change. Each number in columns 6 and 13 of Table 2-2 is replaced by 1 second. Running several computer simulations will then show, for this example, that with the same radio traffic load, where originally the watchstander had 10.4% of his total time occupied by demand activities, he now has 7.4% of his time so occupied -- a savings of 3% per hour -- a useful savings. This technique gives the Coast Guard a reasonable idea of the magnitude of the time savings which can be expected. The Coast Guard can then decide, based on the dollar costs, whether to actually implement this equipment change.

c. Procedural Change

The effects of a procedural change can be similarly studied. Suppose for our example VTS in Figure 2-1, it is felt that the likelihood of a computer outage is high enough so watchstanders should have a backup system based on cards. Then the procedural steps are altered in Figure 2-1 by adding a block prior to step 5 and step 12 during which the watchstander fills out or makes a note on a card. Tables of durations are constructed for both of these blocks as shown in Table 2-4. The computer program is easily altered by the insertion of statements for the two new blocks and the addition of the two new data tables.

Computer simulations are conducted. Suppose they demonstrate that such a change in procedure adds approximately 6% to the time a watchstander is involved in demand activities. Most of this added time involves check-ins and contributes to a rise in the number and average duration of pilot radio calls delayed. Based on operational experience and these results, the Coast Guard can make an informed decision about the costs and benefits of changing these procedures.

d. Personnel Change

Actually a personnel change would be a change in requirements so that particular skills were developed through training, particular characteristics or backgrounds were sought, or particular physical abilities sought or excluded. Suppose, in our example, watchstanders were required, through either selection or training, to be able to key information into the computer at a specified rate, in contrast to the present situation of no minimum standards.

In Figure 2-1 only blocks 5 and 12 would be affected by such a requirement. Knowledge of the new rate would decrease the times shown in columns 5 and 12 in Table 2-2 to those shown in Table 2-5.

Computer simulations then indicate an average of 8 seconds decrease in the handling of a check-in call and 4 seconds for a check-out, increasing the time available for monitoring activities by 3% of an hour, every hour.

Based on this information about the magnitude of the gains they might expect and their experience in recruiting and training of VTS watchstanders, the Coast Guard must decide if the benefits warrant instituting such requirements.

Note that the VTS used throughout this section is an example based on a hypothetical VTS. The purpose of this section has been to illustrate the whole procedure involved in accomplishing the modeling task so that the program thus far can be put into perspective and so that the technique and some of its potential applications can be better understood. The rest of this chapter deals with the construction and verification of the actual models of VTS operations based on field data.

2.3 METHOD OF DEVELOPMENT

2.3.1 <u>Data Requirements</u>

Modeling of VTS operations at Houston-Galveston, New Orleans, Puget Sound and San Francisco require the following kinds of data:

1) The sequence of operations, i.e., the actual procedures.
2) The processing delay times of watchstanders and equipment at each procedural step.
3) The relative frequencies of the different operations at each branching point.
4) The time interval between incoming radio calls.

TABLE 2-6. TRANSACTION ILLUSTRATING THE DETAILED COMMUNICATIONS ANALYSIS

Duration (sec)	Message	Descriptive Label
Start of Transaction		
1	Vessel name, New Orleans Traffic	Pilot (P) calls in
2	--	Intermessage interval
2	Vessel name, this is New Orleans Traffic	Watchstander (WS) acknowledges
0	--	Intermessage interval
2	Vessel name is southbound	P gives position information, etc.
8	--	Intermessage interval
16	Vessel name, New Orleans Traffic, roger, sir. My display shows you should be meeting three reported southbound vessels up to your next checkpoint at Crescent Light: The first being the non-participant Vessel A; followed by Vessel B just underway from --- Island; followed by another non-participant Vessel C.	WS gives advisory
0	--	Intermessage interval
3	Roger, roger	P acknowledges and signs off
1	--	Intermessage interval
1	Traffic out	WS signs off
252	-----	Interval start of next transaction.

TABLE 2-7. SIZE CHARACTERISTICS OF VTS WATCHSTANDER SECTOR MODELS

VTS	HGI	HGII	HGIII	PS	SF	NOI	NOII	NOIII	TOTAL
DATA BASE									
No. of hours	5	5	5	6	10	4	4	4	43
No. of radio transactions*	205	123	194	245	200	68	59	70	1164
No. Vessel initiated	89	46	115	233	117	63	56	64	783
No. of WS radio messages and control actions	1768	1589	2162	3028	1576	1138	970	906	13,137
Total No. of data points	1857	1635	2277	3261	1693	1201	1026	970	13,920
BLOCK DIAGRAM									
No. of blocks	76	3	3	125	145	64	61	87	704
No. of branch points	6	5	5	10	16	17	13	19	91
No. of branches	16	12	12	26	31	36	30	37	200
COMPUTER PROGRAM									
No. of function tables	43	47	46	94	100	78	78	70	556
No. of program steps	214	215	223	397	362	342	308	372	2433
Total No. of lines	762	656	730	1294	957	805	733	815	6752

*Includes overlaps for HG.

are arranged into function tables. Some are duplicated throughout the model, so one function table may describe many blocks. The total number of function tables goes from 43 for sector one at Houston-Galveston to a high of 100 at San Francisco. The total number of program steps required to specify each model in GPSS ranges from 214 for sector one at Houston-Galveston to a high of 372 for sector three at New Orleans. The total number of lines includes those required to specify both the model and its supporting data base. This total goes from a high of 1,294 for Puget Sound to a low of 656 for sector two at Houston-Galveston.

The computer requires approximately 27K of 32 bit words of core memory space to simulate each sector model. Each simulated hour takes about 15 seconds of computer time to compile and up to 23 seconds to execute. The program and computer specifications are based on operating the GPSS V.10(60)* on TSC's DEC-10 computer. Some additional Fortran IV statements were written to select certain GPSS output for listing in a usable output format (see Table 2-3).

2.4.2 Verification

The verification method involved comparison of the results of multiple simulations with the field data on the basis of several important parameters. The use of multiple simulations insures statistical reliability, i.e., the results of one hour of computer simulation could be spuriously high or low but an average of several simulated hours will be stable. Verification is accomplished by comparing simulation and field data on the basis of parameters describing radio communications; the durations of watchstander responses to the following demand activities; check-ins, advisories and updates, check-outs, and others; and proportion of time available for monitoring.

In the paragraphs to follow, for each VTS, several simulated hours are compared with the average of several hours of field data. A VTS computer model is considered verified if its simulation data are equivalent to the field data according to the established criterion (see Section 2.2.7, Verification).

It is important to note that prior to this report such comparisons were made as a part of the development of this modeling technique without a criterion. Previous models were developed for only one sector at each VTS, based on only two or three hours of field data, and compared to only one hour of simulation results. The present verification comparisons are based on complete models; that is, all sectors are modeled, based on virtually all of the available field data including a full and detailed re-analysis of the radio communications data, and compared with a substantial number of computer simulation hours.

Comparisons between several computer simulation hours and several hours of field data are presented in Figure 2-4 through 2-7 for a number of parameters for each VTS. Figure 2-4 compares seven computer simulation hours with six hours of field data for verification of the Puget Sound VTS computer model. Figure 2-5 compares seven computer simulation hours with ten hours of field data for the San Francisco VTS computer model. These comparisons are presented in Figure 2-6 for the New Orleans VTS computer model with twelve hours simulated and twelve hours field data; and in Figure 2-7 for the Houston-Galveston VTS computer model with twenty-one hours simulated and fifteen hours field data.

The New Orleans and Houston-Galveston VTSs have three sectors each. For these comparisons both the field data and the simulation results have been combined.

In the left portion of each figure, radio communications activity is compared in terms of the average number of mariner-initiated radio transactions per hour and the range, or minimum and maximum number. For each VTS, several radio transaction levels falling within the range of the field data were selected for input to the simulation. As shown, their averages are virtually identical to those of the field data for all four VTSs. Consequently, in terms of this parameter, radio transactions per hour, the major input to both the computer model simulation and the actual VTS is the same.

VTS response to these mariner-initiated radio transactions is described in the central portion of each figure in terms of the average duration (plus or minus one standard deviation) required for completion of each of the four categories of demand

*M. David Martin, Department of Computer Science, University of Western Toronto, London, Ontario, Canada, author of this GPSS version.

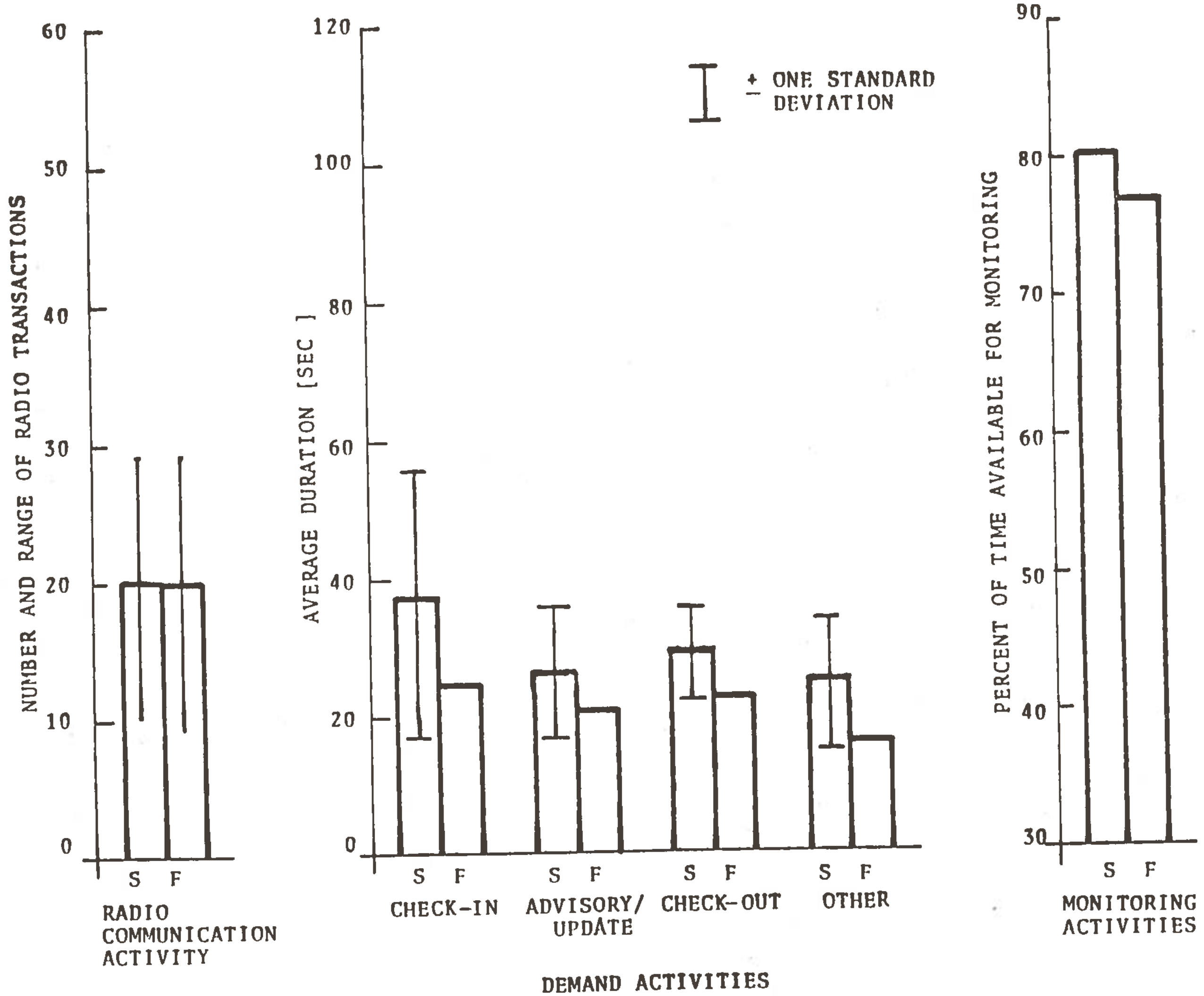

FIGURE 2-5. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF SAN FRANCISCO VTS COMPUTER MODEL

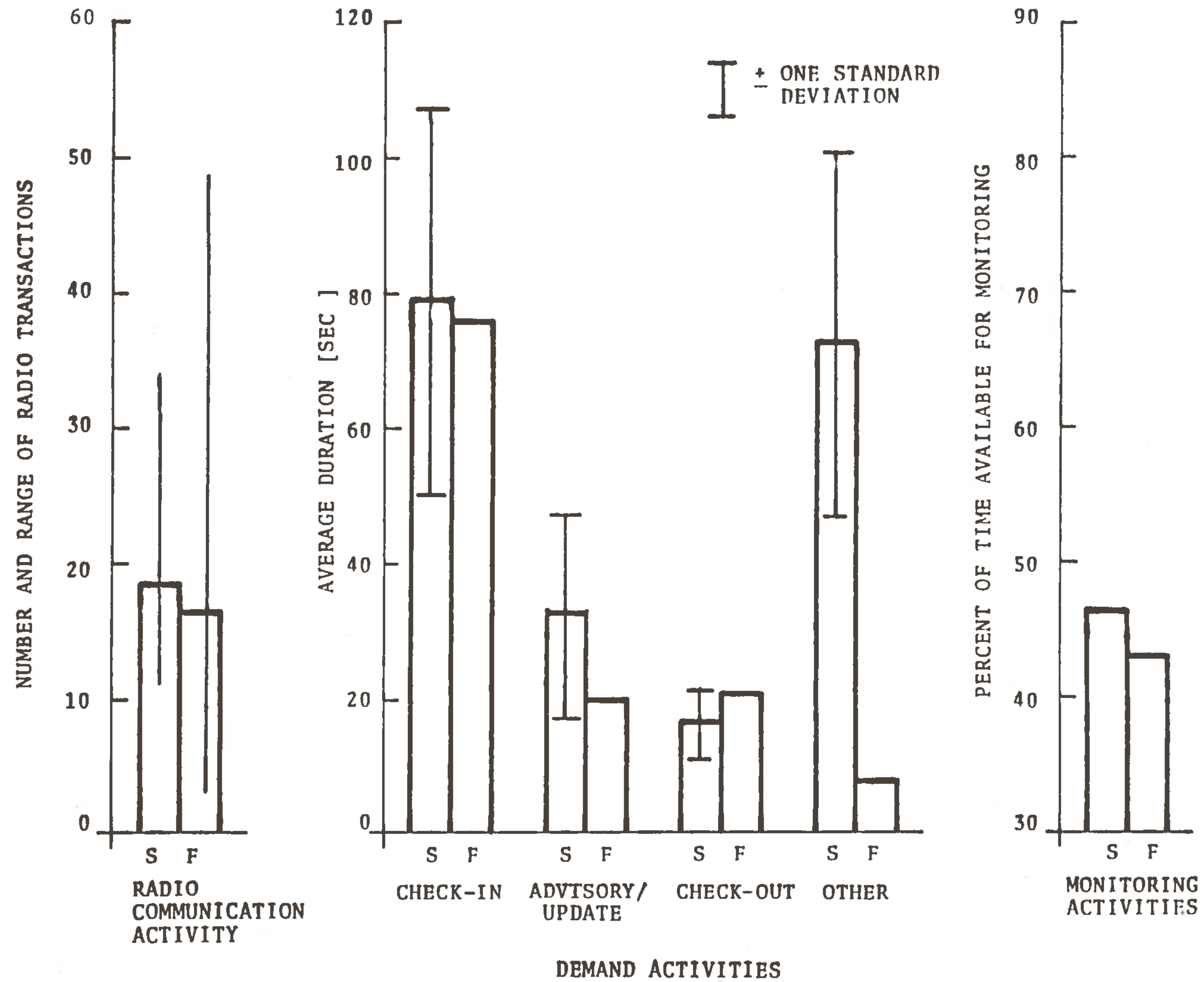

FIGURE 2-7. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF HOUSTON-GALVESTON VTS COMPUTER MODEL

3. STUDY OF EFFECTS OF WORKLOAD

The initial models of watchstander activity developed in FY78 were based on measurements and observations made during routine operations. It is well understood that watchstander performance changes considerably when the system is stressed by such events as accidents or incidents within the system, special events producing traffic congestion, failure of aids to navigation or traffic surveillance equipment, or severe weather conditions such as fog or storms. Moreover, a major criterion of system effectiveness is the manner in which the VTS functions in these stress situations. Thus it is imperative that models used to evaluate the system reflect activities during increased workloads as well as during routine operations.

3.1 SURVEY OF APPROACHES

Since it was realized that only in rare circumstances would it be possible to collect data at a VTS on an occasion of system stress and high workload, a survey was designed to evaluate the feasibility of several methods or approaches for collecting alternative data on workload effects.

3.1.1 Procedures

Personnel at each of the four VTSs previously studied were interviewed in depth to obtain information relating to problems of increased workload. Officers and enlisted men with at least one year's experience as a watchstander were asked to describe procedures in responding to emergencies and system overloading. They were also asked to describe actual experiences during specific incidents of system stress.

During the interview with the commanding officer of each of the centers three additional topics related to increased watchstander workload were discussed:

1) Whether or not there were any scheduled events which could be anticipated and would be expected to increase workload or create unusual or extreme working conditions (e.g., regattas or construction on shipping channel).
2) Post-emergency or post-incident critiques which could be attended by a TSC observer or recorded for later analysis.
3) The feasibility of using traffic simulations to examine this workload problem experimentally.

Each of these approaches would aid in understanding the operation of a VTS under conditions of system stress.

3.1.2 Results

Data gathered from interviews with key personnel led to the following general conclusions:

1) Available data from watchstander performance under stress are sparse and unquantified.
2) No stress situations could be anticipated that would permit the scheduling of data collection during the events.
3) There are no formal post-incident critiques held at any of the centers.
4) The active computer-based systems are not programmed for off-line simulations of traffic.
5) VTS commanding officers are firmly opposed to simulation studies that would interfere with operating watchstanders.

Based on this information it was decided that an experiment simulating operations on a non-interference basis at one of the centers seemed the most promising way to increase understanding of VTS operations under nonroutine situations.

Communication equipment included a head set and a console for the subject and for the experimenter. The subject spoke with the simulated vessels simply by talking into the microphone. The experimenter had a tape recording of all scheduled VITs which he would transmit at given intervals. The experimenter also had the capability of speaking directly with the subject via a microphone. The experimenter acting as a vessel master or pilot, was thus able to respond to specific questions and statements made by the subject.

3.3.3 Data Recording

There were three basic data records kept for each of the ten exercises: a voice recording of all communications, a frequency/duration count of the major activities performed by the subject, and a handwritten log of unscheduled events, such as problems the subject might be having or the subject's indicating that he would ask for assistance if this were an actual operational situation. Frequency and duration of activities were recorded on magnetic tape through a keyboard device; depression of a key coded for an activity created a record of which key was depressed and the time at which it was depressed.

Blood pressure and heart rate were measured immediately before and after the excercise in an attempt to evaluate the presence of physiological stress attributable to the simulation. Urine samples were collected for most subjects.

After the simulation each subject was interviewed to obtain his explanation for various actions which he made during the hour and to get his general impressions on the exercise.

3.3.4 Preliminary Procedure

The basic purpose of this study had been explained to all of the potential subjects in the days prior to the commencement of the simulation. They all knew that some of them were going to participate in a communications simulation, similar to one used by this center in their training program. All subjects of the study willingly participated.

After being ushered into the room, each subject was given a pre-simulation interview; his blood pressure and heart rate were recorded, and a urine specimen was taken. Then he was shown the simulated watchstander station while the experimenter explained the situation and what was expected of him. The elements of the situation were all familiar to the subject. The board, shown in Figure 3-2, contained the models for 16 vessels in their updated positions. There were eight vessels that had already given their pre-departure call awaiting entry and eight vessels currently transiting the system. Correspondingly, there were 16 vessel status cards in the active file rack.

Each subject was told that he was relieving another watchstander who had been working the station. The subject was to assume that everything was correct as he took over. All vessels on the board were checked in, each vessel knew about each other vessel, all the cards in the file were properly annotated, etc. In other words there was nothing required of the watchstander at the start of his watch. However, he was given one item of information that was not apparent on the board; one vessel, the Sea Wench, enroute to Bremerton, had apparently lost her radio and had not been heard from at her last check point. The subject was not asked to do anything in particular about this; he was simply notified of the situation. When the subject had had a few minutes to familiarize himself with the board, vessels, and cards and adjusted the equipment to suit himself, he indicated that he was ready to begin. At this point the hour simulation began. Clocks and tapes were started, and the first VIT came about 15 to 20 seconds later.

3.3.5 The Simulation

The first ten minutes of the simulation progressed at a speed more or less determined by the subject. The experimenter would proceed through the VITs at a pace

FIGURE 3-2. PLOTTING BOARD AT START OF SIMULATION

TABLE 3-1. DATA COLLECTED IN WORKLOAD EXPERIMENT

TYPE OF DATA	SUBJECT									
	1	2	3	4	5	6	7	8	9	10
Voice Tape	X*	X	X	X	X	X	X	X	X	X
Activities Tape	X	X	X	X		X	X	X	X	X
Manual Log Notes	X	X	X	X	X	X	X	X	X	X
Post - Experiments Plot Photo	X	X	X	X	X	X	X	X	X	X
Pulse Rate - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X
Urine Sample - Pre-Experiment		X	X		X	X	X	X	X	
Post-Experiment		X	X		X	X	X	X	X	
Stress Rating - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X
Interview - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X

*Incomplete data.

Urine specimens were analyzed by specialists under contract. The results were expressed as rate of secretion of adrenalin in nanograms per minute. Selected portions of communications tapes were analyzed for evidence of voice stress by a specialist under contract. Messages of innocuous content (e.g., "Seattle Traffic") were selected, six from the early part of the experiment (low stress situation) and six later (high stress). Tapes were sampled for two subjects, one who clearly was stressed, as evidenced by change in heart rate, blood pressure and adrenalin excretion as well as observed overt behavior, and another whose indications suggested low stress. All voice samples were rated as showing stress on a scale of 0 to 5.

3.4.2 General Allocation of Time

The driving force in the experiment was incoming communications, and as their frequency increased, either plotting functions were delayed or postponed, or strategies to control the time spent in communicating were adopted to permit keeping up the plot. The tradeoff between time allocated to communicating and time allocated to plotting is thus a focus of interest.

The percentage of time spent in communicating was determined for eight of the subjects* for each ten-minute interval during the experiment. Likewise, the percentage of time given to plotting functions (marking cards, marking tiles, and placing and moving tiles on the board) was determined. When plotting functions were performed while communicating, the time so spent was scored as communicating time. Average allocations of time for the eight subjects for each ten-minute interval are shown in Figure 3-3.

On the average, the group allocated 52 percent of their time to communications during the first 10 minutes, when the traffic load was light. An earlier study of routine operations at PSVTS (Ref. 2) showed the primary communicator spending 40 percent of his time communicating. Considering that the experimental situation included a ship without a radio and floating logs in the system, the first ten minutes of the simulation was probably representative of the watchstanders' regular performance. As the traffic load increased, communicating time also generally increased through the next 40 minutes, with a slight decrease in the last 10 minutes, when many subjects has reached a point of diminished traffic demand. A slight reversal of this trend in the third 10-minute period reflects the influence of three subjects who apparently cut back on communicating to catch up with plotting tasks.

The curve for time spent in plotting functions is essentially the mirror image of the communicating trends, clearly demonstrating the tradeoff between communicating and plotting and showing that, for the group as a whole, the plotting function suffered as traffic demands increased. Beyond this generalization, however, it is necessary to inspect the characteristic behavior of individual watchstanders and to compare this with their effectiveness before conclusions can be drawn about coping with heavy traffic.

3.4.3 Performance Effectiveness Measures

3.4.3.1 Performance Scores - For each subject, the experiment differed, since each subject's responses and strategies paced his run. Also, since the experiment was exploratory, there was no predefined criterion of "good" or "poor" performance. After considerable study of alternative scoring methods, two measures were judged to be related to effective coping with the heavy traffic situation. The programmed inputs (vessel-initiated transactions, or VITs) were 52 in number; so the number of the last VIT in each subject's run was selected as a measure of ability to keep up with communication demands. Keeping up, however, may not be desirable if it is accomplished at the expense of accuracy in the plot and advisories. Therefore the average error in the final positions of the six "constant" vessels (see Section 3.4.1) was adopted as an error index. Dividing the final VIT number by the average error yielded a performance index (PI) exponentially weighted for accuracy, reflecting the importance attributed to providing accurate advisories. These performance measures are shown for the ten subjects in Table 3-2.

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*Equipment problems resulted in inadequate data for this analysis for subjects 1 and 5.

The PIs in Table 3-2 can be grouped as follows: PI above 35, good* performance; PI between 25 and 35, average performance, and PI below 25, poor performance. We thus consider Subjects 2 and 3 as the best performers, Subjects 1, 4, 5, 7, 8, 9 and 10 as average, and Subject 6 as poor.

3.4.3.2 Critical Incidents - An analysis of each subject's reaction to the critical or unusual incidents in the simulation provides additional information on watchstander activity under workload stress. In interpreting their reactions, it must be remembered that the artificiality of the created incidents may have caused somewhat arbitrary reactions. That is, some subjects may not have accepted the importance or critical nature of these incidents enough to give responses equivalent to what would occur under operational conditions. These reactions are summarized in Table 3-2.

3.4.3.3 Loss of Radio Contact - As soon as the simulation started, there was an opportunity for the subjects to attempt to contact the Sea Wench, a vessel who had lost radio transmission capabilities. Although no instructions to do so were given, 7 of the 10 subjects did attempt to contact the Sea Wench.

Since the Sea Wench could not be raised on the radio, the question became one of whether the subjects would notify approaching vessels of the situation. During the course of the hour, three different vessels called the center (one vessel called twice) with a precall or an underway call from either Bremerton or Port Orchard. Each of these vessels would be meeting the Sea Wench enroute and, therefore, should have been told of the radio difficulty. The first VIT was from the Sea Witch getting underway from Port Orchard to Seattle and timed to meet the Sea Wench at the bend in Rich Passage. Only one subject told the Sea Witch about the radio problem with the Sea Wench.** The other two vessels who would be meeting the Sea Wench initiated VITs a total of 22 times to the 10 subjects. Of these 22 opportunities to inform the vessels of the Sea Wench's radio malfunction, a subject relayed this information only 6 times. In other words, there were 13 occasions (out of a possible 22) where a vessel was never told of the Sea Wench's problem.

3.4.3.4 Deadhead in Water - The next incident occurred when a vessel called in to the center reporting a deadhead (floating log) in the Possession Sound about half way between Possession Point and Elliot Point. In every case the subject reported the incident to the "watch officer" and eight subjects relayed the information to concerned vessels when the occasion arose. The two who did not report it were severely pressured and behind in their plot.

3.4.3.5 Communications Delay - Twice during the simulation, once in the first 20 minutes and again in the last 20 minutes, a pilot called the center and complained of an inability to get through on the radio. Seven subjects apologized for the inconvenience and two of the seven added that they had not heard any previous calls by that vessel. Three subjects did not apologize but carried on with the usual manner of communicating. In each case the subjects were courteous and professional in their demeanor.

3.4.3.6 Foundering Pleasure Craft - The only event which called for some action of the subjects was the notification of a pleasure craft foundering in the sound. In actual cases like this, it is the watchstander's duty only to inform the watch officer of the incident and the watch officer would take appropriate action; usually notifying SAR. In the simulation nine subjects notified the experimenter acting as watch officer, and one subject did not. Eight subjects asked for further description of the incident (color and description of the vessel, number of people on board, estimation of danger of sinking, etc.), and two recorded only the information provided by the calling vessel (number of people on board, estimation of danger of sinking, etc.). Two subjects, in addition to notifying the watch officer, attempted to contact other vessels in the vicinity of the sinking boat and request aid from them.

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*The PI will be used as an index of good or poor performance in subsequent discussion; it is important to keep in mind that it is an arbitrary index based on what the authors considered desirable performance.

**It may be unfair to criticize the subjects for not mentioning the radio problem to the Sea Witch since, in their initial instructions, they were told that each vessel on the board (including the Sea Witch) knew about every other vessel and there was no need to update anyone. Most of the subjects may have assumed that this meant the Sea Witch knew of the Sea Wench's problem and that no further notification was warranted.

It was noted by the experimenter that, although the next VIT immediately after the sinking vessel call was an underway call by a Coast Guard cutter, none of the subjects asked the cutter to offer assistance. When queried about this in the debriefing, they responded that they are not authorized to request anything from a Coast Guard vessel. All requests must go through proper channels.

3.4.3.7 Summary - In summary, those subject who were under the most pressure tended to leave out (forget?) information that should be passed to concerned vessels (e.g., information concerning the Sea Wench losing its radio), but all subjects remained courteous and professional in dealing with upset pilots and all but one handled the most extreme situation (the foundering boat) in at least a minimally acceptable manner.

3.4.4 Individual Time Allocations

In Figure 3-4, the individual time allocations are shown for the eight subjects (arranged in descending order of PI) who were combined in Figure 3-3, which is repeated under the heading "Group". It is apparent that the curves for Subjects 9, 4, 10 and 8, are similar and resemble the group curves. The curves for Subjects 2 and 3, the good performers, resemble each other, and the curves for Subject 6, the poor performer, and Subject 7, a special case, are unique. From these curves and the performance measures, it is possible to generalize that the average performers managed to avoid loss of plotting time during the early period of traffic buildup by controlling the amount of time spent communicating. The poor performer, Subject 6, and Subject 7 both talked a lot and plotted relatively little, yet Subject 7 maintained accuracy at the expense of falling behind and working from a plot that had not been updated in the last 30 minutes by the end of the experiment.

3.4.5 General Strategies

As communication demands began to interfere with plotting functions, the subjects adopted a variety of strategies to effect a tradeoff between communicating and plotting. Some techniques were aimed at reducing communicating time, others at reducing plotting time. Some people neglected plotting or asked for help in plotting. Other techniques involved temporary tradeoffs.

3.4.5.1 Reducing Communicating Time - Communicating time was reduced by shortening messages, or decreasing the number of messages. Messages were shortened by omitting superfluous words (such as repeated call signs) or information judged unessential and by issuing advisories only on traffic in a vessel's immediate vicinity. Messages omitted included advisories when there was no significant traffic, and advisories on meetings in traffic lanes. Sometimes the watchstander simply neglected to give any advisories while plotting. The number of messages was reduced further by issuing group advisories to several vessels at one time and minimizing center (subject)-initiated transmissions (CITs)--that is, advising only on vessel-initiated transactions.

3.4.5.2 Reducing Plotting Time - Plotting time was reduced by adopting efficient procedures ("streamlining"), omitting plots of some traffic, neglecting plotting, or asking for help in plotting. Techniques for "streamlining" included marking and moving cards and tiles while talking, using abbreviations on cards, grouping card marking and tile marking activities to minimize changing pens, or taping two pens back-to-back. One watchstander omitted the plotting of tugs without tows. There were several cases where updating the plotting board (regularly required every 15 minutes) was completely neglected.

In real-life operations, a heavy traffic condition is first met with assistance in plotting from another watchstander (the external communicator or the radar plotter). The subjects were asked to report to one of the experimenters at any time that they would normally request assistance, even though such assistance was not provided in the experiment. Six subjects either requested help or reported after the experiment that they would have requested help.

3.4.5.3 Temporary Tradeoffs - Time was bought both in communicating and plotting by assigning priorities to demands and attending only to urgent business, postponing low priority tasks until such time as the workload might become lighter. Finally, the most frequently used practice to gain time was to put incoming calls on "hold"--that is, to ask the caller to wait until the watchstander called back. Eight subjects employed "hold" from 4 to 19 times.

TABLE 3-3. SUMMARY OF STRATEGIES

STRATEGY	SUBJECT									
	GOOD		AVERAGE						SP	POOR
	2	3	9	4	1	10	5	8	7	6
REDUCING COMMUNICATING TIME										
Shortening Messages		X			X	X		X		
Omitting Messages					X	X		X		
Decreasing Number of Messages				X	X					X
Group Advisories			2			5	2	1	7	
REDUCING PLOTTING TIME										
Streamlining	X						X	X		
Omitting Traffic		X								
Neglecting Plotting			X		X					X
Asking for Help			L	M		L		M	E	L
TEMPORARY TRADEOFF										
Prioritizing Advisories								X		
Prioritizing Plotting	X				X					
Using "Hold"	7	12		5		5	7	8	19	4

X = Observed or reported.

E,M,L = Observed in early, middle, or late part of experiment.

Number = Number of times observed.

of his being behind. He admitted that he "...let the plot go..." In real life he felt that he would have used "hold" much sooner; (his first "hold" was at 39 minutes, and he used "hold" only four times.) His performance in the face of an increasing traffic load might be characterized as "business as usual" in communications with consequent neglect of the plot.

3.4.6.4 Special Case - Subject 7 ranked next-to-last in the PI in spite of an accurate plot. His top curve in Figure 3-4, his C, CIT and D values in Table 3-4, and other observations combine to characterize him as excessively loquacious. He gave long advisories, initiated many extra messages, asked numerous questions - and consequently fell far behind in handling communication demands, his last VIT being 11 behind the next slowest subject. His strategy was to employ "holds," using a total of 19. Thus he might be considered effective with regard to the traffic he did service, but it is doubtful that in real life he could avoid an eventual critical traffic backlog unless he shortened procedures somehow.

3.4.7 Stress Measures

Since the buildup of demands on the subject watchstanders during the experiment was greater than is normally encountered in operations, the experiment was considered as a potentially stressful experience. To determine whether such stress can be measured and whether such measures relate to the quality of job performance, several measures were taken on some subjects at the beginning and at the end of the experiment. These measures included heart rate, blood pressure, rate of excretion of adrenalin in urine, and ratings of stress made by the subjects. Also samples of voice recordings of two subjects were rated for stress. The changes in the first four measures and the scores of the voice analyses are summarized in Table 3-5. Again the subjects are arranged from left to right in order of decreasing PI.

3.4.7.1 Physiological Measures - The rate of excretion of adrenalin, as measured in urine samples, has been found to be a reliable indicator of psychological stress (Ref.8). This measure increased between the beginning and end of the experiment for every subject from whom specimens were obtained.

The other stress measures were compared with adrenalin excretion and among themselves by computing coefficients of correlation. These correlations are summarized and explained in Table 3-6. Because of the small number of measurements involved, there is a risk that some of these coefficients of correlation were obtained by chance in spite of no real underlying relationship. With the numbers involved, any coefficient less than .67 based on 7 cases, or .55 based on 10 cases, could be expected to occur by chance in up to 10 percent of similar experiments; thus we consider values below those given to lack statistical significance. Using this criterion, we note immediately that systolic blood pressure correlated almost perfectly with adrenalin excretion, but that heart rate and blood pressure did not vary together significantly. These correlations suggest that the change in systolic blood pressure was a good indicator of change in adrenalin excretion (and thus of psychological stress), but that heart rate changes were of less value for stress analysis.

In Table 3-5, the adrenalin measures suggest that Subjects 2,5 and 8 experienced relatively little stress, Subjects 3 and 9 showed some stress, and Subjects 6 and 7 were the most stressed by the experiment. Blood pressure results tend to confirm this grouping, with the low stress group showing a drop in systolic blood pressure after the experiment. This lowering of blood pressure probably represents alleviation of initial apprehension about participating in the experiment.

Observations of behavior of the subjects confirm these conclusions. Subject 2, with the lowest adrenalin gain and a large drop in blood pressure, reported that, when traffic built up, he kept calm. Subject 5 appeared tense at the beginning of the experiment, with a jiggling leg and twitching thumbs, and he showed the largest drop in blood pressure of all the subjects. Subject 6, on the other hand, was obviously disturbed by the experiment, making comments on the absurdity of giving advisories from a plot 30 minutes out of date. His blood pressure (and heart rate) had increased far more than any of the others by the end of the experiment.

3.4.7.2 Stress and Performance - Increase in adrenalin excretion yielded a correlation coefficient of -0.62 with the PI. Although, based on only 7 cases, this result could occur 14 percent of the time by chance alone, we can give it credence, because blood pressure and PI had a coefficient of -0.59 based on 10 cases, with significance at the 8 percent level. We conclude, then, that there was a tendency for greater stress to

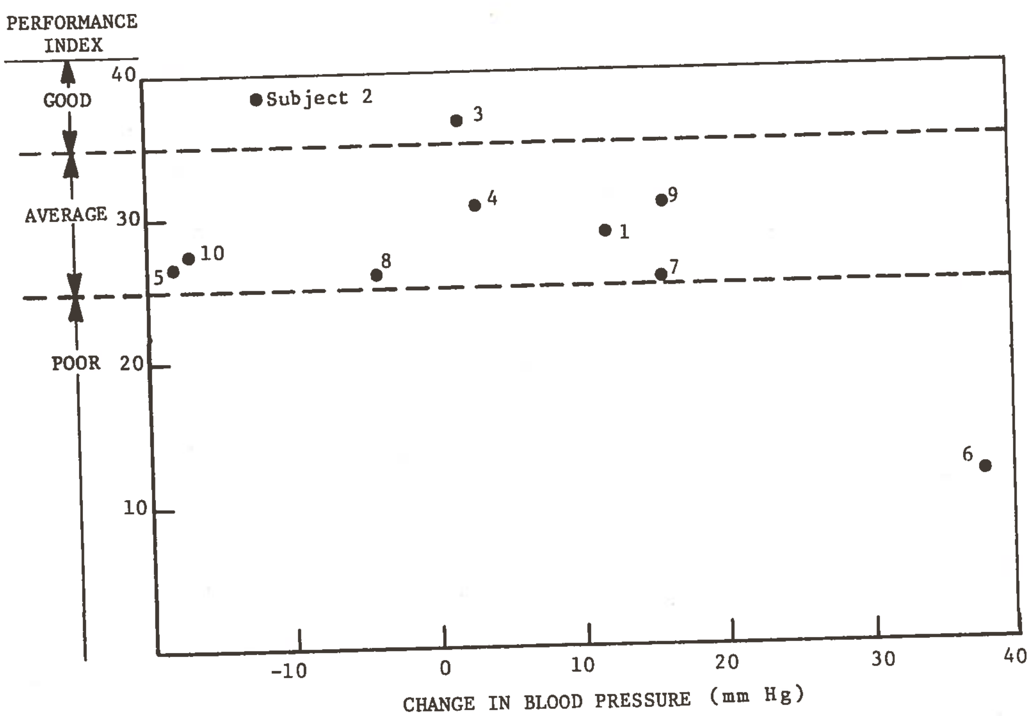

FIGURE 3-5. PERFORMANCE AND STRESS

EXAMPLE: Presently experiencing a headache:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe
X						

1. Presently experiencing aching or burning eyes:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

2. Presently feeling tired, drowsy, having difficulty staying awake:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

3. Presently experiencing stiffness or tenseness:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

4. Presently feeling anxious, on edge, irritable:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

5. Presently experiencing a headache:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

6. Presently being fidgety:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

FIGURE 3-6. STRESS RATING FORM

(Ref.5) and were repeated at this time to see whether attitudes had changed over the previous 16 months. The responses are summarized in Table 3-7 together with responses at Puget Sound and across four VTSs in 1978-79.

Obviously these watchstanders enjoy their work. Their reasons (the people, doing a unique and useful job, shore duty) are the same as those given previously in other VTSs. Although the number of cases in each sample is small (10 in 1979, 6 in 1978), the job attitude at Puget Sound VTS appears to have improved. In both 1978 and 1979 there were 3 watchstanders who would not want a second tour at Puget Sound, but there were 7 in 1979 who said they would like another tour as compared to 1 in 1978. Whereas in 1978, Puget Sound VTS had proportionately fewer watchstanders who said they would like a second VTS tour than did the four VTSs combined, the proportions in 1979 in favor of more VTS work was far higher than for the combined four in 1978. The question on a tour at another VTS yielded essentially the same results. This improvement in job attitude at Puget Sound VTS is probably the result of a combination of changes, including giving more responsibility to non-commissioned officers, simplifying the plotting, and changing watch and rotation schedules.

The highest number of negative replies was to the question of VTS as a career assignment. Although fewer than in the four VTSs in 1978, still 4 out of the 10 subjects felt that radarmen and quartermasters on VTS duty would have lost some proficiency in their career fields ("You get behind everybody else".) on returning to sea duty. Three of the 4, however, stated (as did many in other VTSs in 1978) that they could consider VTS a good career if it were a "rate".

3.5 DISCUSSION OF RESULTS

3.5.1 Representativeness of Results

Throughout the following discussion, it is important to make the following distinction: the performance of watchstanders in this experiment does not represent what might be expected to happen in real-life operations at the Puget Sound VTS, but does represent what might be expected under conditions like those of the experiment.

The simulation differed from real-life operations at Puget Sound VTS in at least five significant respects. First, there are always other people in the operations room who can help a watchstander in plotting when the workload is heavy. Our experiment denied this assistance, although we asked the subjects to request it, and six subjects did. Second, in spite of instructions to do what would be done in real-life operations, some of the subjects probably tried to guess what the experimenters were evaluating and assigned priorities to their tasks based on their guesses. For example, a subject expecting to be rated on thoroughness would initiate more requests for additional information than he would normally do in operations, to the neglect of the plot. Third, our lack of detailed knowledge of the realities of Puget Sound traffic introduced little discrepancies in the simulation that might disturb a watchstander's work pattern. For example, additional questions were raised by some watchstanders regarding a simulated cargo different from the one that a particular vessel regularly handled. Fourth, some of our initial reports omitted information that a vessel would normally provide, necessitating additional subject-initiated queries. Finally, the experimental situation was stressful in varying degrees to the individual subjects. In spite of assurances that they were not being evaluated as individuals, they were apprehensive at being closely observed and recorded. In summary, then, the simulated operation differed from real operations at the Puget Sound VTS, and the errors in plotting and in advisories that occurred during the experiment would not be expected under similar traffic loads in actual operations there.

On the other hand, the various ways in which the subjects reacted to the increasing traffic load are very likely indicative of how they would react under the same circumstances in real-life operations. The subjects appeared to be well-motivated. They were cooperative and seemed to be genuinely concerned with performing their duties well under trying circumstances. Their behavior was professional. Although some showed physiological indications of stress, they were all calm and courteous in their communications, even in response to annoying comments. We feel justified, then, in drawing some general conclusions about the strategies they adopted to cope with unusual conditions.

TABLE 3-7. RESPONSES TO INTERVIEW QUESTIONS

QUESTION		Number	Percent		
		PS '79	PS'79	PS'78	4 VTSs, '79-'78
Do you like working here?	Yes	10	100	50	59
	No	0	0	17	30
	No reply or unsure	0	0	33	11
Is VTS a good career assignment?	Yes	6	60	33	36
	No	4	40	67	52
	No reply or unsure	0	0	0	12
Would you like another tour at this VTS?	Yes	7	70	17	46
	No	3	30	50	41
	No reply or unsure	0	0	33	13
Would you like a tour at another VTS?	Yes	8	80	17	48
	No	2	20	50	40
	No reply or unsure	0	0	33	12

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