LEVEL II

12

REPORT NO. CG-D-44-79

VESSEL TRAFFIC SERVICE WATCHSTANDER PERFORMANCE IN ROUTINE OPERATIONS

AD A076066

D.B. Devoe et al.

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

DDC
RECEIVED
NOV 2 1979
E

DDC FILE COPY

OCTOBER 1979

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington DC 20590

79 11 02 102

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-44-79		

4. Title and Subtitle
VESSEL TRAFFIC SERVICE WATCHSTANDER PERFORMANCE IN ROUTINE OPERATIONS.

5. [redacted]
Oct[redacted]79

6. Performing Organization Code
DTS-532

7. Author(s)
D.B. Devoe, C.N. Abernethy, J.W. Royal, K.J. Kearns, [redacted] R.A. Rudich

8. Performing Organization Report No.
[redacted]TSC-USCG-79-5

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)
CG 913/R0002

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 20590

13. Type of Report and Period Covered
Final Rep[redacted]t
Apr[redacted]977-Sep[redacted]978

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Human factors specialists observed and measured the performance of watchstanders at four Vessel Traffic Service (VTS) centers: Houston-Galveston, Puget Sound, New Orleans, and San Francisco. Analysis of the data yielded results amenable to mathematical modeling for generalized evaluation and prediction of VTS watchstander performance. The report discusses implications of the data for the design and use of equipment (including computers), communications facilities, operational procedures, and personnel selection and training methods. Fourteen recommendations are offered for consideration in the operation of current VTS's and the planning of future systems.

407082

17. Key Words
Vessel Traffic Service, Watchstander Performance, Human Factors, Performance Models

18. Distribution Statement
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	84	

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

PREFACE

The Human Factors 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 observed, recorded and analyzed the activities of watchstanders at four Vessel Traffic Service (VTS) centers. Results of the analyses and recommendations for each VTS were published separately in four interim reports. This report compares the operations at the four centers and derives additional conclusions and recommendations of more general relevance for all VTS's.

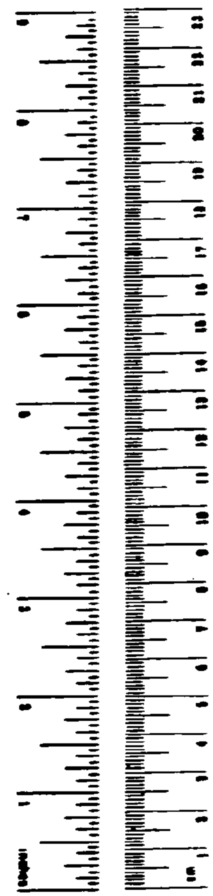
The authors wish to express their sincere thanks to LCDR C.T. Johnson and LT P.R. Corpuz of the Office of Research and Development for their guidance and assistance in the accomplishment of this study. We also gratefully acknowledge the guidance and contributions of Dr. H. P. Bishop, Program Manager and Chief, Human Factors Branch (DTS-532), at TSC.

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or special
A

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

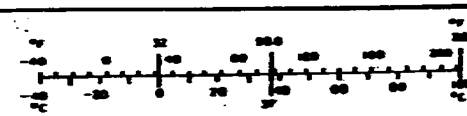


TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

TABLE OF CONTENTS (CONT.)

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

The first phase of an evaluation of watchstander productivity in U.S. Coast Guard Vessel Traffic Service (VTS) operations involved the observation and recording of watchstander activities under routine conditions in four operating VTS's: Houston-Galveston, Puget Sound, New Orleans and San Francisco. Analyses of the frequency and duration data for a variety of tasks in the general areas of communicating, tracking, monitoring and miscellaneous activities were performed. The results showed both similarities and differences in watchstander activities among the four VTS's. From the results, implications were noted for the design and use of equipment (including computers), communications facilities, operational procedures, and personnel selection and training methods.

The VTS's were found to be alike in that they receive data on vessel traffic through VHF radio reports, integrate the data into a model of traffic flow, predict future traffic situations from this model, and advise individual vessels by radio as to what traffic situations they will encounter in the near future.

The VTS's differ in the ways in which additional information on traffic is sensed and processed (particularly in the use of radar, television and computers). They differ also in organization of communications facilities, scheduling and division of duties, operational procedures, and selection and training of personnel.

In general, the results show that as traffic load increases, the time required for communicating with vessels and tracking them increases, with consequently less time available for monitoring the overall situation and responding to emergencies. This situation in turn leads to an uncritical reliance on computer-based advisories when they are available. These problems may be alleviated by shortening communications formats, simplifying tracking procedures, dividing the VTS area into more (smaller) sectors, and assigning additional watchstanders to each sector.

The feasibility of developing computerized models of VTS watchstander performance as an aid in predicting the impact of changes in system design on operational safety and efficiency was explored. The flow of information in at least one sector of each of the four VTS's was modeled using the data recorded on site. Testing of these tentative models showed that they do provide a useful simulation of actual operations and merit further development.

Analysis of all of the information obtained at the four VTS's led to the following recommendations:

1. Continue the effort to model and generalize VTS operations by collecting data on operational characteristics when the system is stressed by such occurrences as unusually heavy traffic loads, unexpected incidents (including accidents and emergencies) on or near the waterways, sudden loss of communications or surveillance equipment, sudden reduction in manpower, and the like.

2. Adopt as soon as feasible basic physical fitness criteria for the selection of personnel for watchstander duty, and initiate development of psychological selection tests.

3. Develop specifications for future VTS processing and display systems that will assure responsiveness of the system to watchstander needs, giving particular attention to:

a. Integration of data in displays, particularly a situation display that shows location, movement and identification of traffic on a map-like background.

b. Accessibility to supplemental data with a minimum of keying and a minimum of delay.

4. Develop specifications for a standardized communications console with integrated displays and controls.

5. Equip every VTS with surveillance systems.

6. Maintain illumination in VTS operations rooms at as even a level as is feasible, and shield displays from bright spots.

7. Provide ventilation at each watchstander duty position adequate to carry off tobacco smoke.

8. Rotate watch periods at least every 4 days with liberty time between watch periods. Rotate duty positions during a watch every 2 hours.

9. Study duty performance late in 12-hour watches to determine better the degree of fatigue, particularly with regard to speed and effectiveness of response to unexpected situations.

10. Develop a VTS watchstander training program based on an evaluation of options and techniques for minimizing on-the-job training time.

11. Institute at every VTS a formal program for career-advancement study and training.

12. Develop a general Standard Operating Procedure for all VTS's, allowing flexibility for adaptation to local conditions.

13. Institute at every VTS a continuing program of refresher training, to include understanding of SOP, simulation of emergency procedures, and check-rides on vessels in the VTS area.

14. Institute at every VTS a continuing public relations program so that, through watchstanders' visits to pilot and to tow master groups and visits of pilots and tow masters to the VTS, a mutual appreciation of one another's needs and problems is developed.

ABBREVIATIONS

CPO - Chief Petty Officer
GPSS - General Purpose Simulation System
HOU-GAL - Houston-Galveston
NOLA - New Orleans LA
PPI - Plan-position indicator
PS - Puget Sound
SF - San Francisco
SOP - Standard operating procedure
TSC - Transportation Systems Center
TSS - Traffic separation scheme
VHF - Very high frequency
VMRS - Vessel Movement reporting system
VTC - Vessel Traffic Center
VTS - Vessel Traffic Service

1. VESSEL TRAFFIC SERVICES

1.1 INTRODUCTION

In order to reduce the probability of vessel collisions and groundings in crowded waterways, and to keep individual vessels apprised of the total traffic situation, the U.S. Coast Guard is operating several Vessel Traffic Services (VTS's). To profit from the experience gained in operating these VTS's, both to improve present services and plan future services, the Coast Guard's Office of Research and Development has undertaken a broad program of analysis of VTS operations.

Human performance is basic to the operation of a VTS. The principal product of a VTS is a traffic advisory communicated by a watchstander to a vessel master or pilot via VHF radio. The value of the advisory is dependent on the skills of the various watchstanders in acquiring and monitoring traffic data, in integrating the data into a coherent picture of present and anticipated traffic, and in composing and delivering a clear, concise and accurate traffic advisory. Therefore the Coast Guard has recognized that any model of VTS operations and productivity must include the influence of watchstander performance on system performance. The Coast Guard's Office of Research and Development has commissioned the Human Factors Branch of the Department of Transportation's Transportation Systems Center (TSC) to obtain and analyze data on watchstander performance and to integrate the results into models of watchstander activity and productivity.

For its first year's work on this study of VTS watchstanders, TSC undertook the collection and analysis of data on watchstander activities in routine operations in four operating VTS's: Houston-Galveston, Puget Sound, New Orleans and San Francisco. The analysis of each of the four VTS's was reported in an Interim Report*, which included identification of problems related to the

*See References, p. 66.

specific VTS with appropriate recommendations. The present report summarizes the findings of these studies as they apply to VTS's in general.

In the rest of Section 1, VTS's are described first in terms of their similarities with regard to inputs, information processing, and outputs; then the salient differences between individual VTS's are described.

Section 2 summarizes the data collected on performance of watchstanders in terms of utilization of time and utilization of communications facilities.

In Section 3, a number of specific operational problems are discussed in terms of their implications for improving VTS operations in general.

In Section 4, the performance data are fitted to the General Purpose Simulation System as a preliminary model of watchstander productivity. The strengths and weaknesses of the model are discussed, and possible applications of the model are illustrated.

Section 5 presents a summary of what has been learned about VTS watchstander performance during this first year of study and offers appropriate recommendations.

1.2 GENERAL DESCRIPTION OF VESSEL TRAFFIC SERVICES

1.2.1 Traffic Management

Vessel Traffic Services are characterized as traffic management systems. However, their operational philosophy emphasizes self-management by the vessels rather than control by VTS's, with the VTS's providing information to assist the vessels. This concept is reflected in the name: Vessel Traffic Service.

In providing traffic management services, VTS's interact with two important traffic management aids; Channel 13 on VHF-FM radio and Traffic Separation Schemes. Channel 13 has been reserved for bridge-to-bridge communications, and most vessels are required to maintain a continuous listening guard on it. A Traffic Separation

Scheme (TSS) requires traffic to move only within defined traffic lanes, usually restricted to one direction of movement. These lanes may be defined by federal regulation, are marked by buoys, and are indicated on standard navigation charts. When one or more TSS's lie within a VTS area, the VTS may be responsible for assurance of traffic compliance.

Basically, then, a VTS is a system of equipment and people 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. Only when it is necessary to avoid or resolve an unusual situation (generally an emergency), will a VTS exercise direct control of traffic flow.

1.2.2 Information Flow in a VTS

The basic pattern of information flow in a VTS is:

Input-Information Processing-Output

Inputs -- Inputs consist of all the data relevant to every traffic movement, including:

Vessel identification
Vessel type and characteristics
Vessel load
Vessel intentions
Vessel location
Vessel speed and direction of movement.

This information may be received via VHF radio, automatic sensing equipment, or miscellaneous printed information. VHF radio reporting is formalized in the Vessel Movement Reporting System (VMRS), which requires a vessel to radio to the VTS relevant data on entering or leaving the VTS area, on passing specified reporting points, or on changing status. A radio channel is specified for VTS communications, and participants are required to guard this channel continuously. Participation in a VMRS is sometimes required by law, sometimes voluntary.

Automatic sensing equipment at present includes radar and low-light-level closed-circuit television.

Information Processing - Information processing at VTS's includes logging, tracking, and predicting. Logging may involve entering relevant data on each vessel into a handwritten log, onto vessel data cards, into a computer memory by keyboard action, or some combination of these.

Tracking involves keeping track of the location of each vessel in the system. Tracking may be accomplished by monitoring radar and television returns, moving vessel traffic cards through a series of storage positions, moving vessel models on a plotting table, calculating and displaying position in a computer-based processing and display system, or some combination of these. When exact positions are not directly sensed or reported, traffic is periodically moved through the tracking system in accordance with positions dead-reckoned from the latest reported position and speed of each vessel. The calculations may be performed by watch-standers or by a computer.

Prediction of future traffic situations involves extrapolation of tracked and plotted data. Vessel meetings, overtakings and crossings are predicted and integrated with other data to forecast hazardous situations, such as dense traffic, passings in constricted locations, and interactions with unusual events (for example, fishing fleets, sailing regattas, accidents and the like). Prediction is fundamentally a mental function of the watchstander. Formulas, plotting devices, and radar cursors may sometimes be used as aids, but their use is infrequent. Where computers are available, they are programmed to predict and display future traffic listings, but the watchstander may modify these predictions if the computer program is judged to be inadequate.

Outputs -- Traffic advisories are the principal output of VTS's. A traffic advisory is generally a message directed to a single vessel via VHF radio, telling that vessel what traffic and channel conditions it can expect to encounter during a specified time period. When the occasion requires it, an advisory may include cautionary warnings that the vessel is exceeding a speed limit, straying away from a traffic lane, or similar admonitions. When it is judged necessary for safety or to resolve a complicated traffic situation, a VTS may issue a command to a vessel; however, great care is exercised to limit control advisories as much as possible.

VTS's may record traffic summaries for automatic playback to telephone enquiries or for broadcast by the Captain of the Port's Office (when not in conflict with commercial sources). When the operational load and commercial restrictions permit, VTS's will provide message relay services both for Coast Guard organizations and for participating vessels.

1.2.3 VTS Functions

The principal functions performed by VTS watchstanders include monitoring, information processing, and communicating.

Monitoring involves keeping track of what is happening. It always involves maintaining a guard on the VTS assigned radio channel as well as Channel 13. It may involve watching traffic as displayed on radar and television scopes, on plotting tables or card racks, or on computer display devices. Activity may be at a low level, although radio channel selection and tuning, radar and television adjustments, or computer display request-keying may be involved.

Information processing has been described in Section 1.2.2. Activities involved include writing or keying new information, marking vessel positions on radar scopes, moving cards or models on plots, keying display requests or operating calculating devices. The considerable amount of mental activity involved in predicting future situations can not be distinguished from monitoring by an observer.

Communication involves speaking and listening on VHF radio equipment, including receiving information and issuing advisories. Communicating is observable and may also be tape-recorded for detailed analysis.

1.2.4 VTS Duty Positions

In most VTS's, the area of responsibility is divided into sectors. A sector watchstander duty position is defined for each sector. The watchstander operating the position performs all functions (monitoring, processing, communicating) required for that sector. At Puget Sound VTS, however, duty positions are defined by function (Primary Communicator, Plotter, Radar Operator). The watchstander operating the position performs the assigned function for the entire system.

At all VTS's a duty position (External Communicator) is recognized for handling incoming and outgoing communications other than direct radio contact with vessels in the system. However, the External Communicator position is not always formally manned; often all personnel on duty informally share the external duties.

A VTS is always under the direction of a commissioned officer, given the position of Watch Officer. At some VTS's, the Watch Officer is assisted by a Chief Petty Officer (CPO)* in the duty position of Watch Supervisor. The combined team of persons manning a VTS's duty positions for a given watch period is termed a Watch Section. Generally one or more trainees may be assigned to a Watch Section for on-the-job training.

1.3 CHARACTERISTICS OF INDIVIDUAL VTS's

The preceding general description of VTS characteristics encompasses the four VTS's that were the subject of this study: Houston-Galveston (HOU-GAL), New Orleans LA (NOLA), Puget Sound (PS), and San Francisco (SF). Specific characteristics of the individual VTS's, however, vary considerably. As a background for subsequent discussion of operations, the individual characteristics of the four VTS's have been summarized in Table 1-1. The values shown are as of the dates when TSC personnel observed operations for this study.

---

*Enlisted pay grade E7, E8 or E9.

TABLE 1-1. CHARACTERISTICS OF INDIVIDUAL VTS's

VTS Location and Date of Data Collection	HOU-GAL SEP '77	NOLA APR '78	PS JAN '78	SF JUL '78
Assigned Radio Channel	12	11,12,14	14	13
Inputs				
Vessel Reports (VMRS)	Volun.	Volun.	Mand.	Volun.
Sensing - Radar Sites	1		4	2
- Television Sites	4			
Miscellaneous Printed Material	X	X	X	X
Information Processing				
Logging - Log Sheets	X			X
- Vessel Data Cards	X		X	X
- Computer	X	X		
Tracking - Plot Update Period	15 sec.	30 sec.	15 min.	
- Monitoring Radar	X		X	X
- Moving Cards	X			X
- Plotting Table			X	
- Computer	X	X		
Prediction - Mental	X	X	X	X
- Radar Cursor	X		X	X
- Computer	X	X		
Outputs				
Traffic Advisories (VHF Radio)	X	X	X	X
Telephone Tape Recording			X	
Operations				
Sectors	3	4	1	1
Ship Channel Characteristic	Narrow	Narrow	Open	Open
Traffic Separation Scheme			X	X
Manning				
Basic Watch Section	5	8	5	4
Positions - Watch Officer	1	1	1	1
- Watch Supervisor (CPO)		1		
- Sector Watchstander	3	4		1
- Primary Communicator			1	
- Plotter			1	
- Radar Operator			1	
- External Communicator	1		1	

1.3.1 Communications

Houston and Puget Sound each operate on one reserved VHF channel. Transceivers are so located in the HOU-GAL area that each sector's radio traffic can be distinguished at its sector position. However, Puget Sound has been unable to sectorize its operation because of communications overlap. The three channels at NOLA are generally adequate for the four sectors except near sector boundaries. However, having to share Channel 14 with operators of canal locks raises some serious interference problems on that channel. San Francisco's traffic load is light enough to permit use of the bridge-to-bridge channel (13) without serious interference.

1.3.2 Inputs

All four VTS's rely basically on a VMRS, but only in Puget Sound is participation mandatory, and only in part of that system. Houston has radar coverage of the Galveston area and four television sites to add to the information obtained from the VMRS. Puget Sound has less versatile radar equipment but a broad area of coverage; periodic radar checks are made of the positions of vessel models on the plotting table. San Francisco bases its monitoring on the excellent coverage afforded by its two radar sites. Only New Orleans has no traffic sensing equipment to permit verification of its traffic plot.

1.3.3 Information Processing

Having a computer to assist in logging, tracking and predicting distinguishes HOU-GAL and NOLA from the other two VTS's. However, display limitations and excessive keying requirements have caused HOU-GAL to maintain both a manual logging of vessel departures and a parallel card-tracking system that result in considerable duplication of effort. Tracking accuracy at HOU-GAL is relatively high, because of frequent position updating and of radar and television verification; however, the computer produces a display of much poorer resolution than is available in the data.

The NOLA computer-generated plot has adequate resolution and frequent updating, but the lack of sensors to verify computed positions constitutes a serious problem in system accuracy.

Puget Sound's plotting table has far poorer position resolution and lower position update frequency than the computer-generated displays. Part of the system can be monitored by radar, but the Primary Communicator bases advisories mainly on what the plotting table shows, since the radar scopes are not visible to him. On the contrary, San Francisco's radar coverage and resolution is excellent, and its traffic load is light. So one Sector Watchstander can generally handle the whole system, doing tracking by watching the radar, with an array of data cards mainly as reminders of vessel data. A plotting board is maintained for a channel outside the area of radar coverage, but traffic is relatively light there and easily tracked with the cards.

For prediction, both computer systems will display on demand a listing of time, place and nature of future encounters for any specified vessel. This display is always used in giving advisories at NOLA, but, because of keying requirements and display delay, is seldom used at HOU-GAL. At both locations, the watchstander may modify these predictions on the basis of his understanding and judgment. Predictions are made by mental extrapolation from the plot at PS, from the radar at SF.

1.3.4 Outputs

There are systematic variations between VTS's in the format of advisories (see 3.3.3), but all are similar messages, spoken over the VHF radio. PS also prepares a voice-tape listing commercial traffic, available to the general public by telephone.

1.3.5 Operations

The two VTS's serving traffic on a narrow, winding waterway (HOU-GAL and NOLA) are sectorized, with one watchstander performing all required functions for his sector. Because of communications overlap on the one channel, and because of the efforts required in maintaining a manual plot of high-volume traffic within a large, open area of seaways, PS has divided its operation by functions rather than sectors. On the other hand, because of low traffic volume, SF is essentially a one-sector one-man operation.

1.3.6 Staffing

The number of positions staffed at each VTS is roughly proportionate to the volume of traffic handled. At HOU-GAL and PS, the number of positions is the same as the basic number of people in the Watch Section, implying that everyone is assigned to some position throughout a watch. In these two VTS's the External Communicator position functions partially as a rest or relief assignment. At NOLA and SF, two members of the Watch Crew are always assigned to rest breaks, although they help the supervisors handle external communications. Watch Sections usually have additional personnel assigned for on-the-job training. Every Watch Station has a Section CPO, but only at NOLA is there a duty position exclusively for the Watch CPO.

2. WATCHSTANDER ACTIVITIES

Because of the many differences among the four VTS's (see Table 1-1), variations were found in the way watchstander time was utilized and in the use of communications facilities.

2.1 TIME ALLOCATIONS

The data collected at each VTS on the frequency and duration of activities were combined to determine the percentage of time devoted to each major function. Operating differences and changes in data recording techniques made it necessary to adopt some simplifying assumptions, the principal one being the averaging of the three duty positions related to vessel traffic management (Primary Communicator, Plotter and Radar Operator) into an equivalent sector watchstander function at Puget Sound. Table 2-1 summarizes these results, with each column representing the way a typical sector watchstander's time was utilized during the periods of observation. Also in Table 2-1, the average number of vessels per hour in a sector (or equivalent sector at Puget Sound) is shown as an indicator of workload. Although an average of 27 vessels per hour were tracked in New Orleans, only 19 (participating vessels) communicated with the VTS. A high proportion of ferries were in the systems at Puget Sound and San Francisco (74 and 50 percent, respectively). Since communications with ferries were few and very brief, the traffic loads at those two VTS's have been adjusted by eliminating ferries.

2.1.1 Communications Time

The communications effort roughly reflects the traffic load. The Houston-Galveston figure may be spuriously high, because measurements from sector communications tapes were confounded by some transmissions picked up from adjacent sectors. Nevertheless, a somewhat higher percentage of communications would be expected, because reporting points are more numerous on the Houston channel than in the other systems. In interpreting communications time

TABLE 2-1. TIME ALLOCATION OF AN AVERAGE SECTOR WATCHSTANDER

PERCENT OF TIME ALLOCATED TO:	HOU-GAL	NOLA	PS	SF
Communicating with vessels	18	22	13	12
Communicating with others	3	7	5	7
Monitoring	40	30	41	45
Computer/radio/plot	12			
Radar/TV	28			
Tracking	39	34	24	11
Computer	16			
Plot			15	
Cards	23		3	
Radar			6	
Miscellaneous		7	17	25
HOURLY AVERAGE				
Number of vessels in sector	10	27(19)	13*	5*

*Less ferries

for New Orleans, it should be noted that New Orleans watchstanders do not communicate with non-participating vessels, although they do monitor and track them. The average number of participating vessels per sector per hour at New Orleans was 19. Generally, between 35 and 70 seconds per hour is spent communicating with each vessel in a sector.

2.1.2 Monitoring Time

Despite differences in types and amount of surveillance equipment and plotting aids, Houston, Puget Sound and San Francisco watchstanders all devoted about 40-45 percent of their time to monitoring the traffic situation. New Orleans watchstanders appeared to have less time for monitoring, presumably because the heavier traffic load kept them busier at other tasks.

2.1.3 Tracking Time

Activities that were considered tracking functions varied considerably in frequency among the VTS's. Although sector traffic was not heavy, Houston watchstanders spent 39 percent of their time tracking. However, they were maintaining a data-card tracking system in parallel with the computer-based tracking, because they could prepare advisories faster and easier from the cards than from the computer displays. The data suggest that if they could do without the cards (as was done at New Orleans), tracking time would be reduced to about 16 percent. Of course, New Orleans watchstanders spent 34 percent of the time tracking, but their traffic load was considerably heavier than Houston's. The card-plot-radar system at Puget Sound required more tracking time for the same tracking load than did the two computer-based systems. The light, well-dispersed traffic load combined with high-quality radar displays and good area coverage by radar, permitted simplified tracking at San Francisco; taking only about 11 percent of the watchstander's time.

2.1.4 Miscellaneous Time

The routine operations observed at these VTS's did not overload watchstanders. When the system did not demand communicating, when the plot was up to date, and when the traffic situation was well understood, there were periods of "free" time which watchstanders filled by conversing with other watchstanders or supervisors, reading notices, references, or other material, and a variety of other activities not directly related to traffic management, all of which have been combined in Table 2-1 under "Miscellaneous" time. Because of the extra work involved in maintaining the double tracking system, the Houston watchstanders had relatively little of this time. If they could rely only on the computer system for tracking, however, an estimated 23 percent of their time would be freed, comparing well with the 25 percent observed under an equivalent traffic load level at San Francisco. Miscellaneous time was not evenly divided among the three functions at Puget Sound that were averaged for an equivalent sector watchstander. The Plotter had 33 percent miscellaneous time, the Radar Operator 15 percent, and the Primary Communicator only 2 percent.

Miscellaneous time is not wasted time. The data under review were all collected during periods of routine operations. A variety of unusual or emergency situations may occur from time to time to stress the system. Stress conditions include heavy traffic concentration, special events (such as regattas), accidents or incidents within the system, and loss of surveillance or communication capabilities. Since these occurrences are generally unpredictable, the VTS must be ready to respond to them at all times. The miscellaneous time in an operation, then, can be considered buffer time -- insurance of readiness to respond to system stress.

2.1.5 Generalized Model of Time Utilization

As a first step toward generating a generalized model of watchstander time utilization, the data for the four VTS's were combined. Several assumptions and corrections were made to render the data comparable for a hypothetical general system, as follows:

Houston-Galveston -- Only computer tracking time was assumed; time now being used for card tracking was considered miscellaneous time.

New Orleans -- Communications time was based on assumed communications with all vessels being carried (including non-participants).

Puget Sound -- The time allocations for 3 watchstanders were averaged for a single hypothetical sector watchstander. Ferry traffic was removed from traffic load.

San Francisco -- A correction was applied to traffic load to account for the low communications requirements of ferries.

Following these adjustments, percentage of time given to each function was plotted against average number of vessels per hour per sector, and function curves were drawn. The resulting model is shown in Figure 2-1.

This admittedly oversimplified picture does disclose some trends that might logically be expected. Since each vessel in the system requires separate communications and tracking activity, the proportion of time allocated to these two functions increases with traffic load. Job-related additional communications are relatively unaffected by the traffic load. To balance the extra time devoted to communicating and tracking, watchstanders spend less time monitoring and have less miscellaneous time available with heavier traffic loads.

Two critical points can be anticipated with increasing sector loads. First, the requirements for communicating, tracking and monitoring will combine to 100 percent, leaving no residual miscellaneous time. Operation at this level can continue for an indefinite period of time with no dramatic consequences, but a sudden incident could suddenly overload the watchstander when his services are most critically needed. Operating at a zero or low-

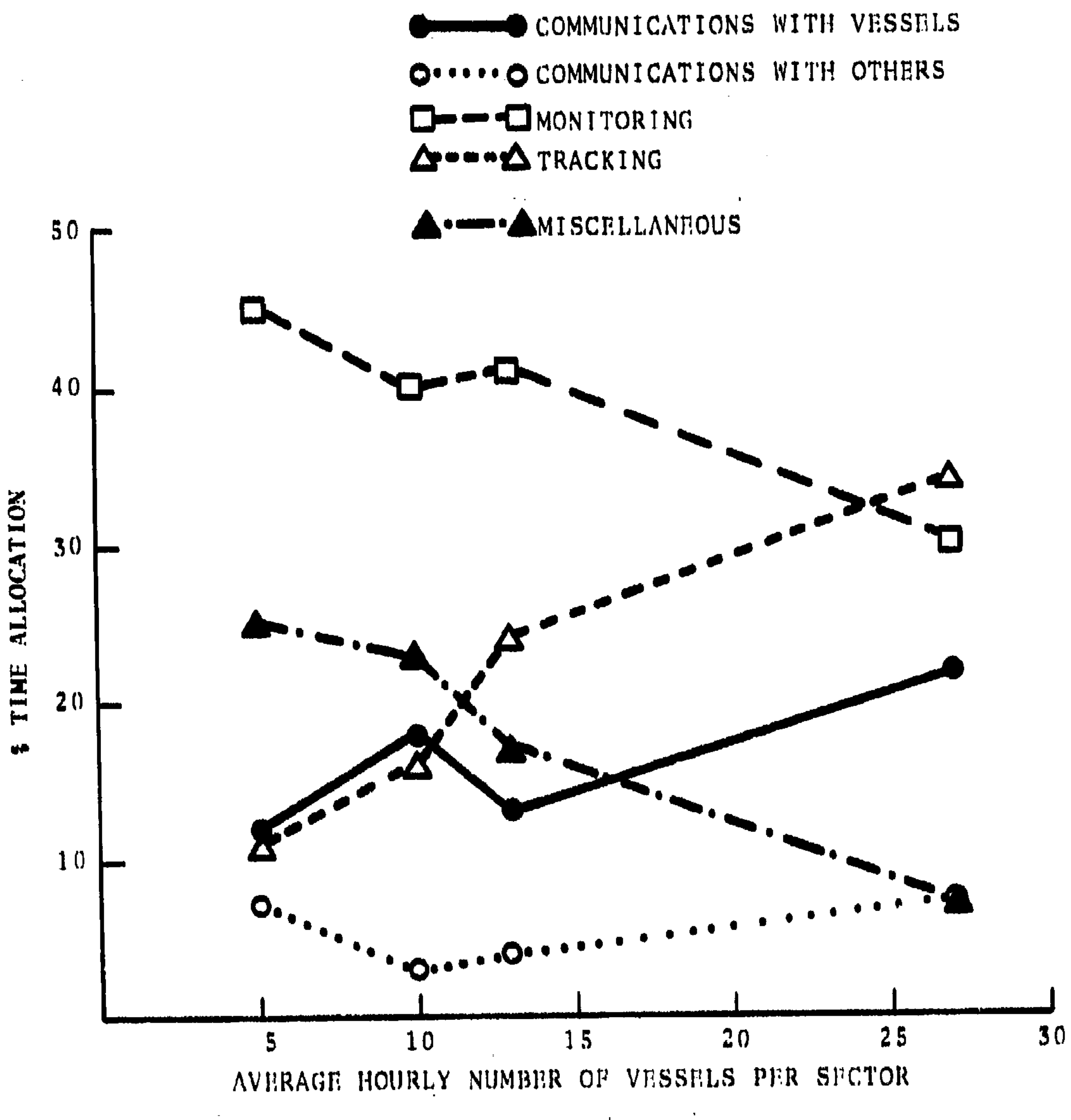


FIGURE 2-1. EFFECT OF TRAFFIC LOAD ON TIME ALLOCATION

level miscellaneous time mode, therefore, involves risks associated with inability to respond adequately to emergencies. New Orleans is operating now at close to this mode; should mandatory participation be imposed at New Orleans, the increased traffic workload might well overload watchstanders under present operating conditions.

The second critical point that Figure 2-1 suggests is at the traffic load where communicating and tracking requirements add to 100 percent, leaving no time for monitoring. In a manual tracking system, we might expect that some critical loss of monitoring time short of total loss would affect all functions enough to warn that operational risks were serious. However, in a computer-based system, operations could continue with the watchstander having complete, uncritical reliance on computer-prepared advisories.

Extrapolating the functions in Figure 2-1 to predict these critical points must be done with caution. First, the functions are based on sparse data and several simplifying assumptions. Second, there is no guarantee that the functions are linear -- they might curve sharply or become discontinuous at higher load levels. Third, the number of vessels in the sector is only an approximate measure of actual workload. The functions do provide a conceptual model of VTS workload dynamics, however, and support the following general conclusions:

a. As traffic load increases, time required for communicating with vessels and tracking them will increase.

b. As workload increases, residual time for response to emergencies will decrease.

c. As workload increases, time available for monitoring the traffic situation will decrease, with a consequent increase in uncritical reliance on computer-based advisories.

Possible remedies for the consequences of increased sector workload include:

a. Reduction of communication time through less frequent check-in transactions and shorter advisories.

b. Reduction of tracking time through less frequent check-ins, automatic data inputs, and more efficient manual inputs.

c. Addition of sectors in the operating area.

d. Functional sharing of sector watchstander duties among two or more watchstanders.

2.2 COMMUNICATIONS USE

2.2.1 Channel Utilization

At each of the four VTS's studied, communications at sector watchstander positions were tape recorded. Each tape was analyzed by a computer programmed to measure the time during which voice transmissions were occurring. These transmissions included both VTS-to-vessel and vessel-to-VTS transmissions as well as any other transmissions picked up by the VTS receiver. Corrections were applied to these measurements as follows:

a. At Houston-Galveston, three sectors shared Channel 12. Different receivers are located so that each picks up transmissions mainly from one sector. However there is some overlap (reception at one sector of transmissions from others). A detailed analysis of some of the data showed 18 percent overlap in one sector. This correction was applied to the measurements for the entire system, yielding an estimate of 23 percent channel utilization per sector, or 69 percent for the three sectors. This figure is high to the extent that different sectors were transmitting at the same time without interference at the sector receivers. Since total communications time was estimated independently at 18 percent for an average sector watchstander, 54 percent seems to be a reasonable upper limit for channel utilization across the three sectors.

b. At New Orleans, each of the three sectors analyzed had a different channel. Two sectors averaged 19 percent utilization; the third averaged 51 percent, but it shared the channel with canal locks radio traffic, which caused considerable interference. Allowing for the higher vessel traffic load in the third sector, a value of 20% utilization was estimated as a representative figure for each channel in the system.

c. At San Francisco, the VTS shared Channel 13 with bridge-to-bridge communications, which were measured as occurring 4 percent of the time; so the measured 16 percent channel utilization was reduced to 12 percent as the VTS utilization figure.

Table 2-2 summarizes these channel utilization figures. Houston-Galveston makes the heaviest use of available communications capacity, which is adequate for routine operations. New Orleans and Puget Sound are putting even less stress on their capacity, and San Francisco is having no problem sharing Channel 13 with the bridge-to-bridge communications. Only rarely does traffic bunch up enough to require a vessel to wait an unduly long time to communicate with these VTS's in routine operations.

2.2.2 Communications Characteristics

In Table 2-3, some of the outstanding characteristics of communications practices at the four VTS's are summarized. The term "transaction" was adopted to describe a complete two-way conversation from initial call to sign-off. A transaction may include several transmissions plus pauses ("dead time"). Some pauses occur when a watchstander looks up data or calls up computer displays; such time has been charged as part of transaction time in our summaries. These average transaction times are useful for gross comparisons between VTS's. However, it should be noted that there is considerable variance behind each average -- many routine reports take only a few seconds, while a check-in transaction may take several minutes.

The average amount of time devoted to each vessel in the system per hour shows that, despite great differences in equipment and procedures, New Orleans, Puget Sound and San Francisco provide essentially the same amount of communications time per vessel. The Houston-Galveston VTS appears to spend up to twice as much time

TABLE 2-2. VHF RADIO CHANNEL USE

	HOU-GAL	NOLA	PS	SF
Percent channel utilization	54	20	30	12
Number of channels	1	3	1	1

TABLE 2-3. COMMUNICATIONS CHARACTERISTICS

Average Hourly Characteristic	HOU-GAL	NOLA	PS	SF
Number of transactions	96	45	46	20
Number of transactions per vessel	3.2	0.8	1.2	2.5
Time per Transaction (sec)	22	53	30	21
"Dead time" per transaction (sec)	12	29	6	5
"Dead time" per transaction (%)	55	55	20	24
Communication time per vessel (sec)	70	42	35	53
Percent vessel-initiated transactions	90	91	73	76

as the others in communicating. Although this estimate may be spuriously high because of sector overlap in our measurements, two factors would lead us to expect Houston to communicate more. First, reporting points are closer together in the Houston system, reflecting a need for more frequent advisories, particularly in the narrow, winding, busy upper channel. Second, both the vessels and the VTS observed more rigid standard requirements for report frequency in the Houston system. Participation of vessels was more haphazard at New Orleans; advisories covered longer time periods at Puget Sound, and advisory frequency and length were both purposely minimized at San Francisco. The San Francisco figures here included ferry transactions, which were very short.

Other characteristic values in Table 2-3 point up interesting operational differences. New Orleans is characterized by transactions that are relatively infrequent (on the average of one per hour with each participating vessel) but fairly long (an average of 53 seconds). The "dead time" percentages show that New Orleans and Houston communications are characterized by long pauses within a transaction. Observations showed that the pauses often occurred while the watchstander keyed data into or out of the computer. Substituting cards for some computer use at Houston did not reduce the overall proportionate amount of dead time, but communicating time was less because of shorter transactions. Apparently, reading directly from a plotting table (Puget Sound) or a radar scope (San Francisco) is more efficient than calling up computer assistance. The data can not show which mode is more accurate; presumably the computer is less vulnerable to tracking error. However, the results do show that the value of computer assistance in VTS's is highly dependent on the ease and speed with which the data needed for advisories can be retrieved.

About 90 percent of the transactions were vessel-initiated at Houston and New Orleans, indicating more frequent passing points and more frequent requests for information than at the other two VTS's, which averaged about 75 percent vessel-initiated transactions.

Table 2-4 shows the average length and relative frequency of four types of transactions; advisories, check-ins check-outs, and other (including requests for information , updates without advisories, and incomplete calls). At Houston and New Orleans, the majority of transactions were advisories, with New Orleans taking more time per advisory than Houston, partly because of time required to call up the traffic summary display (Houston used the cards for advisories) and partly because Houston provided shorter advisories. Puget Sound issued advisories covering a period of 30 minutes (sometimes longer) but averaged fewer advisories per vessel. For example, tows with log booms were generally contacted only once per watch. San Francisco had relatively little traffic to report and thus could issue short and infrequent advisories. Also, a special effort was made there to eliminate unnecessary wordiness.

Check-in transactions involved entering a basic set of data on a vessel, either directly into a keyboard (New Orleans), or into a data card. Apparently, it takes about three times as long to key in information as to write it on a card. The Houston entry time lies in the middle, probably because sometimes the watchstander would key in the data during the transaction; at other times he would let several cards accumulate, and key the data while not communicating. The effect of the computer is not necessarily to lengthen data entry time, but it can lengthen the amount of communication time tied up for data entry. At San Francisco, ferries check in with the VTS at the beginning of each run but often require no advisory, accounting for the high proportion of check-ins there.

Average check-out time was in the range of 17 to 24 seconds at all VTS's. Relative frequency and length of miscellaneous transactions varied considerably, reflecting specific characteristics of each VTS area as well as unscheduled demands for special services. These miscellaneous transactions averaged 16 percent of communications time over the four VTS's.

TABLE 2-4. CHARACTERISTICS OF TRANSACTION TYPES

TYPE	AVERAGE LENGTH OF TRANSACTION (SEC.) HOU-GAL	NOLA	PS	SF
Advisories	20	56	34	21
Check-ins	76	88	27	25
Check-outs	21	24	17	23
Other	8	34	46	16

	FREQUENCY OF TRANSACTION TYPES (%) HOU-GAL	NOLA	PS	SF
Advisories	77	58	33	15
Check-ins	5	13	37	42
Check-outs	7	9	18	7
Other	11	20	12	36

3. ISSUES AND PROBLEMS

3.1 EQUIPMENT

3.1.1 Surveillance Equipment

Vessels maneuvering through a narrow, twisting, crowded waterway can not proceed at a steady pace. Even in more open waters, currents and tides can affect speed of advance. Therefore, a tracking system based on dead reckoning of position is sure to have some error of position, which generally increases with time. Tracking errors are compounded by the uncertainty and errors inherent in position reports. As a remedy, independent sensors of vessel position provide invaluable checks, from time to time, of the true location of vessels in a tracking system.

Table 3-1 summarizes the relative advantages and disadvantages of surveillance and computer devices in use at VTS's. Details are discussed in the following paragraphs.

Radar is the basic surveillance aid for VTS's. It is accurate, precise, independent of time of day, relatively independent of weather, and provides a wide area of coverage. However, the VTS radar systems do not provide vessel identification, nor do existing computer-generated displays provide integration of identification with radar returns. Therefore, radar tracking alone can be used only when there are few enough vessels in the system for the watchstander to keep track of their identities by memory. San Francisco is the only VTS studied where the traffic load permits the watchstander to prepare advisories from the displayed radar returns. All other VTS's require a separate traffic plot. Puget Sound VTS maintains a low-resolution, infrequently updated, manual plot; HOU-GAL and NOLA have high resolution, frequently updated, computer-generated plots. Where radar is available in these systems, it is used to check the plot rather than as the reference for advisories.

TABLE 3-1. REMARKS ON VTS EQUIPMENT

EQUIPMENT	ADVANTAGE	DISADVANTAGE
<u>Surveillance</u>	Real-time, real-world feedback	
Radar	Accurate and precise Broad area of coverage Independant of time-of-day Relatively independent of weather Relatively little adjustment needed	No identification information Susceptible to ground clutter Use requires training Display requires low brightness environment
Television	Familiar, realistic display Accurate Some identification information Some information at night	Restricted field and range Frequent adjustments needed Susceptible to weather (fog and precipitation)
<u>Computer</u>	Rapid update of data Rapid integration of data Versatile display of data Preparation of records	Manual inputs required in present systems
HOU-GAL		Plot display unrealistic Plot resolution 0.25 mile No data tags on plot Excessive keying needed Inadequate number of concurrent listings Display delays
NOLA	Realistic plot display Plot resolution 0.10 mile Rapid response Lists and plot on one display	Inadequate number of concurrent lists Excessive keying needed

Radar as used in VTS's has other weaknesses. It is susceptible to ground clutter, making it more suitable for open seaways than for narrow channels lined with many reflective targets. Interpretation of radar imagery requires special training. Finally, the basic CRT display is of low brightness, requiring operation in a dimly-lit room and frequent changes in visual adaptation by users.

Television, currently in use only at HOU-GAL, has some distinct advantages. It presents images like those a human observer would see at that location, thus requiring a minimum of image interpretation. It contains many cues to identification of vessels and shows positions with respect to known landmarks. The low-light-level system at Houston provides considerable detail even at night. Disadvantages of television include a restricted field of view (requiring the operator to select cameras, pan, zoom, and focus frequently) and loss of visibility in fog and precipitation.

The selection and location of surveillance aids must be determined for each VTS individually. However, their use at all VTS's is strongly recommended. Without this feedback there is virtually no check on the accuracy of a traffic situation plot between vessel reports, nor on the accuracy of the reports themselves. This uncertainty in the data undermines the confidence of the watchstanders in their own advisories, which is sensed by vessel masters and pilots, who in turn lose confidence in the service and become reluctant to participate and careless in reporting. This situation was clearly evident at NOLA, the only VTS without surveillance aids.

3.1.2 Computers

The two computer-based VTS data processing and display systems (at HOU-GAL and NOLA) were designed independently. Basically they perform the same functions; they accept and store vessel status information entered by keyboard; they plot the traffic situation on a map-like display, and they display, on demand, summary lists of information, including a prediction of future encounters for any designated vessel. In detail there are some significant differences, however. The HOU-GAL computer generates a situation display of limited information, requires excessive keying, and responds slowly to keyed requests. The NOLA computer presents a map-like situation display with vessel position and identification, requires somewhat less keying than the HOU-GAL system, and responds faster. Both systems should be modified to demand less keying and to display a greater amount of data at one time.

The differences between the two systems are clearly reflected in watchstanders' procedures. At HOU-GAL, a secondary card tracking system is maintained that duplicates many of the computer functions but is considered easier and faster to use. This redundant activity occupies an estimated 25 percent of the watchstanders' time. The special display for a traffic advisory is slow to call up at Houston and requires erasure of basic traffic data on one of the display surfaces. Therefore, the watchstanders rarely use it. On the other hand, New Orleans operators readily interpret the situation display without any backup tracking system and always call up their special display for traffic advisories.

The implications for design of future systems of these and other problems noted at the VTS's with computers have been reported to the USCG Research and Development Center in support of their development of specifications for the second generation processing and display subsystem.

3.1.3 Room Illumination

Two major problems in operations room illumination were identified: the rooms were generally maintained at too dim a level of illumination, and the illumination level varied considerably within some VTS's. A dim room is difficult to move around in, and, because some tasks will require higher light levels, it is generally unevenly illuminated. Uneven illumination requires continual adaptation and pupil adjustment of the eyes as they scan different areas and can cause discomfort and fatigue. Aching or burning eyes were among the top complaints checked on the stress questionnaire at every VTS visited. There is no simple solution to illumination problems, but the following procedures may be helpful when feasible:

a. In general, maintain an even level of illumination within the visual work area at each duty station.

b. Where the major displays are all dim (radar PPI's and equivalent), maintain the room illumination at or slightly above the display level. Shield all displays from glare sources, and eliminate glare sources when feasible by sealing off light leaks at windows and doors, dimming bright panel indicator lights, and the like. Where higher levels of light are needed (as for reading print or writing), limit the illuminated areas through use of spot lights. Be sure that light sources are not reflected in display face plates.

c. Where relatively bright (such as television) and dim (such as radar) displays must be used in the same room, maintain the general room illumination level at or slightly above the level of the bright displays and shield the dim displays.

3.2 COMMUNICATIONS FACILITIES

At the time the study was conducted at the four VTS's, the communications facilities were adequate to handle routine operational communications loads (see 2.2). However several problems related to communications should be noted:

a. The requirements for communications channels involve traffic load, sectorization, and the location of transceiver sites. Houston, with a moderately heavy traffic load but good siting was able to tolerate some overlap and operate three sectors on one channel. Puget Sound had attempted to sectorize, but, in spite of having four transceiver sites for its one channel, experienced too much overlap in some areas. New Orleans, with three channels, still had severe problems in sharing one of its channels with canal lock radio traffic. New Orleans also had some reception problems, most of which can be solved by relocating sector boundaries to match site transmission patterns better. When vessel traffic loads suggest division of a VTS area into additional sectors, transmission patterns and possible communications overlap must be given great weight in determining the number of radio channels required and the location of transceivers.

b. At New Orleans, the Watch Supervisor had to attach his headset to a sector communications console in order to take part in transactions (to resolve a problem, for example). Every VTS should provide the Watch Supervisor with a communications console versatile enough to permit him to monitor or take over the transactions at any position.

c. Communications noise was both annoying and fatiguing at some VTS's. These effects should be minimized by providing high quality receivers and headsets. Inter-position interference will be reduced if good equipment permits operation at low volume. In addition, sound shielding could be installed to reduce noise and interference.

d. Communications consoles were observed to vary considerably among the VTS's, but all appeared to be essentially a group of individual units stacked together. This resulted in considerable redundancy in selection and tuning controls and indicator lights, a waste of space, and an undue amount of selecting and reaching by the watchstanders. Consideration should be given to designing an integrated communications console, with simplified displays and controls.

3.3 OPERATIONS

3.3.1 Participation

The Vessel Movement Reporting System (VMRS) is the basic source of traffic information at every VTS. Sophisticated surveillance systems may show vessels that have failed to report, but only through the vessel's report can its identity be established. Likewise, computer displays are generated from data originating in reports from vessels. If a vessel master or pilot decides not to participate in the VMRS, his vessel may not appear at all in VTS traffic plots and advisories, or at best, appear with incomplete information.

At the time that TSC observed operations at the New Orleans VTS, lack of full participation in the VMRS was at the heart of a vicious circle of consequences (see Figure 3-1): Poor participation led to inadequate advisories which caused masters and pilots to lose confidence in the VTS advisories, which led to poorer participation. Two secondary effects aggravated the circle further. (1) Some masters and pilots, disillusioned with the value of the VMRS, became careless in giving position reports, thus adding errors to the VTS data base and the resultant advisories. (2) Some watch-standers betrayed a lack of confidence in their advisories by voice and manner of speaking, which was detected by the masters and pilots, further increasing their reluctance to participate.

One approach to assuring full participation in the VMRS is to make it mandatory. In Puget Sound, vessels are required by law to report to the VTS. Although participation is nearly 100 percent in Puget Sound, so is it in Houston-Galveston and San Francisco, where participation is voluntary. Puget Sound participation increased when it became mandatory, but increased even more when radar surveillance was activated. The radar could be interpreted as having a coercive effect, increasing the chances that a non-participant would be caught, but this does not explain the success of the voluntary systems.

The basic key to obtaining participation in the VMRS is for the VTS to provide a useful service. Position reporting then becomes a reasonable price to pay for receiving the service. There were problems of non-participation at Houston-Galveston in its early days of operation, but once it proved itself as a reliable, desirable service, these problems lessened considerably. The present problem at New Orleans, however, is not simply a case of "growing pains". There, the fundamental problem is the uncertainty in the information provided; thus the VTS is likely to find it much more difficult to demonstrate its value until surveillance aids are installed and operating, providing the extra measure of reliability needed to create a demand for the advisory service.

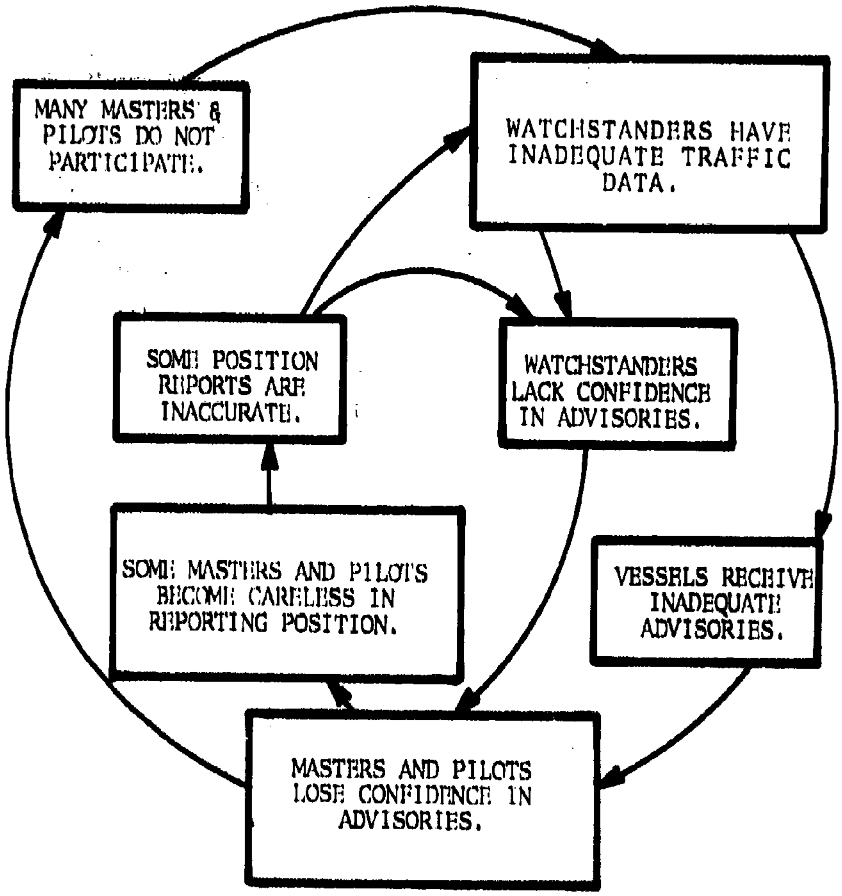


FIGURE 3-1. THE VICIOUS CIRCLE OF NONPARTICIPATION

3.3.2 Schedules of Work

Puget Sound VTS operates an 8-hour watch; the other three VTS's are on 12-hour watches. The 12-hour watch is generally preferred whenever it is in operation. By combining duty time into longer periods, off-duty time can also be in longer periods. The only way to avoid the stresses associated with frequent changes in time of day for work and sleep and still maintain a continuous watch, is to assign people to permanent shifts, an alternative which is completely unacceptable to the VTS personnel. Therefore watch-standers must cycle through watch periods and vary their work-sleep pattern, creating a cumulative fatigue. Since a 12-hour watch leaves a watchstander only 9-10 hours at home between watches, including time for sleep, liberty time is particularly precious. If liberty time is too short, too much of it is spent in catching up on sleep, with too little time left for the watchstander's family and social life.

In spite of their favoring a 12-hour watch, many watchstanders admit that they feel tired and less efficient during the latter part of the watch. This raises a serious question as to the increased risk of forgetfulness, carelessness and poor judgment during the last 4 hours of a 12-hour watch. The existence of such risk can not be demonstrated -- indeed, the general level of response to such items in the stress questionnaire as feeling tired and drowsy was higher at Puget Sound that at the VTS's with 12-hour watches. However, the possibility that 12-hour watches involve a higher risk of watchstander errors than 8-hour watches can not be ignored and warrants further evaluation.

Rotation of watch sections through watch periods differed at the four VTS's because of manpower constraints and local preferences. They all involved cycles of 2-4 days on/2-4 days off, with several days off when changing from one watch period to another. Watch-standers generally were satisfied with the schedule in effect at their VTS. An extensive survey of industrial shifts in a number of countries* disclosed a wide variety of rotation schedules but no

* Maurice, M., "Shift Work: Economic Advantages and Social Costs." Geneva: International Labour Office, 1975.

data favoring any particular schedule. Fairly frequent change of watch periods seemed desirable.

At Puget Sound, watch teams were not formed. Watchstanders were continually regrouped when they changed watch periods to avoid departures from standard procedures, which had been found to be characteristic of teams. This regrouping led to difficulties for watchstanders in learning and adapting to the personal operating preferences of individual Watch Officers, but it is felt that a well-defined standard operating procedure (SOP) can minimize such problems. All other VTS's had essentially permanent watch teams. At all centers, the watchstanders generally were satisfied with their particular team policy.

At all VTS's, watchstanders rotated from one duty position to another on a 2-hour cycle (variable at the Watch Supervisor's option). At Houston, watchstanders were cycled through the sector positions sequentially, then to External Communicator, an easy assignment. At Puget Sound, cycling was similarly through the functional positions with External Communicator equivalent to a rest. At New Orleans, a watchstander worked the same sector throughout the watch, cycling between duty and rest, but helping with external communications duties during rest periods. At San Francisco, cycling was between the one sector position and rest. At many VTS's, additional rest breaks are possible when all personnel are present, or when trainees can relieve a watchstander, but when a watch section is short-handed, rest breaks are less frequent. Because of variations in manpower and types of duty, duty cycling must be flexible and left to local option.

Rest periods are necessary for relief from continuous display monitoring, for eating and for attention to bodily needs. They are also used for study and for performance of routine duties. Even though a VTS may have one or two watchstanders resting at any time, they must be on hand to permit quick and effective response to emergency situations.

In Table 3-2, the highlights of the preceding discussion have been summarized with recommendations where appropriate.

TABLE 3-2. SUMMARY OF SCHEDULE ISSUES

ISSUE	ADVANTAGE	DISADVANTAGE	RECOMMENDATION
Watch length - 8 hours	Less tiring	Shorter liberty periods	
12 hours	Longer liberty periods	Possible loss of effectiveness	Further study
Watch period - Short	Few consecutive night watches	Frequent readjustment required	
- Long	Time to adapt	Long sequence of night watches	Not more than 4 days
Watch section - Team	Smooth operations	Cliques Get tired of each other	
- Non-Team	Flexibility of section scheduling	Frequent adjustments in work habits	Leave to local option
Duty rotation	Relief		Every 2 hours

3.3.3 Procedures

Operating procedures in the four VTS's varied considerably. In three of the VTS's, there was a Standard Operating Procedure (SOP) in the form of a watchstander's manual; in the other there was a set of operating directives. These guidelines for operations differed in organization, emphasis and detail.

A clear set of instructions on operating procedures and policies is essential for effective operations. Equally important is a program to assure that all personnel understand and follow the SOP. Within a VTS, varying ways of doing essential tasks can cause confusion both within and outside the organization. Where the SOP was vague, the pattern observed during this study was for each watch section to operate in accordance with the preferences of the Watch Officer. To the extent that personnel were assigned to specific watch teams, this variability did not affect the watchstanders except for replacements for ill or vacationing team members. The situation was more serious where personnel were regularly rotated through different watch sections; an individual could never be certain that the way he had been doing things would please his present supervisor. Variability among Watch Officers in requirements for vessel reporting, in format and frequency of advisories, in leniency in permitting variances from traffic rules, and in other procedures can confuse and irritate pilots and vessel masters, who expect a VTS to provide a uniform service. For all of these reasons, a uniform SOP is necessary at every VTS.

A VTS SOP should include as a minimum: radio communications procedures, message formats, procedures for operating and calibrating equipment (to the extent that the work is performed on watch), limitations of authority, policy on variance in traffic rules, procedures for watch relief, and emergency procedures.

Where manual data input into a computer is required, care should be taken to minimize the amount of data entered while communicating -- that is, release the radio channel before doing extensive keying.

Uniformity of SOP across all VTS's is a more complex problem. The VTS Commanding Officer must have enough flexibility in requirements to permit him to adapt his operation to the specific needs of his VTS area. On the other hand, a vessel master traveling from port to port should not have to learn a different set of rules and expect a different set of services at each VTS. Although the bulk of VTS transactions are with local pilots and tow masters, check-ins may be with vessel masters, and some masters are qualified pilots for several ports.

A uniform SOP for all VTS's, then, appears desirable with regard to those procedures not directly affected by local conditions. Such procedures include: standard radio communications procedures, information to be reported at check-in and check-out, and restrictions on VTS radio channel usage. Local variability should still be allowed for information from vessels at reporting points, frequency of update reports, contents of update reports, variances from traffic rules, and emergency procedures.

Additional advantages in a standardized SOP include centralized publishing and training and ease of transition of watchstanders between VTS's.

3.4 PERSONNEL

3.4.1 Personnel Selection

Some people are simply not suited for VTS duty. Both physical and psychological characteristics may be involved. Every VTS had had experience with such people. Some of the disadvantages of malassignment include: danger of causing accidents and incidents through inept duty performance, undermanning of the VTS while a billet is occupied by a person who can not perform the duty (up to a year's time lost before a trained replacement is on duty), and negative impact on the individual's Coast Guard career.

Physical fitness criteria for VTS duty can be readily established, and should include freedom from problems in hearing and vision and from speech defects as a minimum. Psychological characteristics, such as lack of capability to integrate and operate with complex data, inability to communicate clearly, concisely and comfortably, and psychiatric disturbances may be indentifiable through screening before tests. It is recommended that adoption of physical fitness screening before VTS assignment be given high priority. Research on psychological screening tests is also highly recommended.

A further recommendation is for the provision of adequate lead time in assigning replacement personnel to allow a transferee to continue on duty at the VTS until the replacement is on hand and qualified for duty. Without such a provision, the transfer of several persons at about the same time leaves a VTS running short-handed. This situation has a negative effect on morale and motivation and increases the risks of inadequate VTS response to (or even aggravation of) critical traffic incidents. Such a situation should be avoided in any safety related operation.

3.4.2 Training

The locally developed training programs for watchstanders differ in detail but all produce qualified watchstanders, generally after 2 to 4 months of individual study and on-the-job training. Computer operation poses no special training problems.

All VTS's require some experience riding the bridges of various vessels within the system. Although this requirement is generally unpopular with the watchstanders (it takes up liberty time, and pilots and masters are not always hospitable), its importance can not be over-emphasized. Only with a realistic understanding of what work is like on a vessel's bridge can a watchstander provide a service that meets the user's real needs with a minimum of interference with his other duties. Ship rides should be required periodically, not only during qualification training but throughout a watchstander's VTS assignment.

The problem of understaffing during qualification training might be alleviated by shortening on-the-job training in two ways. First, a basic watchstander course might be established at a Coast

Guard training center, covering such general subjects as rules of the road, communications procedure, traffic management, and operation of equipment (radio, radar, television, and computers). Second, this preliminary training might be shortened by selection of personnel for VTS duty whose previous assignments had provided some of this training. Such processes would limit on-site training to learning the characteristics of the specific VTS area and riding ships. It is recommended that further study be conducted to define training requirements for VTS duty and to determine the most efficient way of meeting them.

Some watchstanders indicated in their interviews that the VTS duty does not exercise the skills they developed during prior assignments and will use in future assignments. Therefore, they feel that a VTS assignment may have a negative effect on career progress. A remedy for this situation is practiced at San Francisco, where efforts were made to place VTS personnel in Coast Guard and Navy refresher courses being run at installations in the San Francisco area. The San Francisco VTS Training Board shows great concern for encouraging enlisted personnel to maintain a program of study and for acquiring study manuals and training aids. Career-advancement studies should be an integral part of every VTS's training program.

3.4.3 Stress

At each VTS, some watchstanders filled out a questionnaire at the beginning, middle, end, and three hours after the end of the watch period for four successive days. The questionnaire asked them to rate how they felt with respect to 30 descriptive words (items) by placing a pencil mark on a line with the words "none" and "severe" at either end and "moderate" in the middle. The questionnaires were scored by measuring the distance of each mark from the "none" end of the scale.

Responses to these questionnaires yielded a consistent pattern at all VTS's of increasing stress throughout the watch period that is still felt 3 hours after coming off watch. Although the level of stress felt is not high on the average (generally rated less than halfway between "none" and "moderate"), individual ratings at the "severe" level did occur.

Table 3-3 shows the items getting the highest median* ratings at the end of the watch at the four VTS's. The table entries are ranks (1 is highest, 2 next highest, etc.). Items with medians at or near "none" are not ranked. Items with a median rating greater than halfway between "none" and "moderate" are marked with an asterisk; the one median rating at the "moderate" level is marked with a double asterisk.

The most characteristic feeling at the end of the watch is tiredness. It received the highest median rating at all four VTS's and was at or approaching the "moderate" level at three of the four. The related feeling of drowsiness was also generally rated high. We can not ascribe these feelings to the 12-hour watch period, since the highest rating was at Puget Sound, where they stand an 8-hour watch. In general, watchstanders are moderately tired and are feeling drowsy at the end of the watch.

At three VTS's, the second highest median rating was given to aching or burning eyes. There are two possible contributors to this problem. First, uneven room illumination (see 3.1.3) may have induced visual fatigue. Second, tobacco smoke in the room may also have been a factor. At Puget Sound and San Francisco, some watchstanders complained about the smoking by others. Aching, burning eyes received lower ratings at New Orleans than at the other VTS's, and New Orleans had the least variability in illumination and the best ventilation of the four. We recommend additional effort at all VTS's to reduce uneven illumination and to improve ventilation at each operating position.

Tension and related feelings (such as on edge and irritable) were more characteristic of Houston and New Orleans than of Puget Sound and San Francisco. Very likely, the tension at Houston was related to inadequancies in the computer assistance (see 3.1.2), while at New Orleans it was clearly related to the lack of

*The median rating is the middlemost; half the ratings fall above it, half below.

TABLE 3-3. HIGHEST RATED STRESS ITEMS AT THE END OF A WATCH

ITEM	HOU-GAL	NOLA	PS	SF
Tired	1*	1*	1**	1
Aching/burning eyes	2*	9	2*	3
Tense	3	3*	10	
Fidgety	4	12		
On edge	5	4*	11	
Irritable	6	5*	8	
Anxious	7	17	13	
Stiffness	8	16	9	
Drowsy	9T	2*	3	2
Difficulty staying awake	10T	14	6	4
Loss of temper	11	6		
Poor appetite	12			
Headache		7	4	
Uncomfortable		8	12	
Worry		10T		
Depressed		11T		
Upset		13		
Bothered by noise		15	5	
Backache			7	

Entries show rank ordering of median ratings.

T = Tied score

* = Over halfway between "none" and "moderate"

** = "Moderate"

surveillance information (see 3.1.1 and 3.3.1). In fact New Orleans shows a higher level of stress in general and more stress items with median ratings approaching "moderate" than the other VTS's.

Fatigue seems to characterize the Puget Sound operation (tired, tense, drowsy, and the like). Possibly part of the problem is the requirement to work standing for extended periods of time. On the other hand, at San Francisco, with a generally low level of stress, watchstanders showed a pattern of responses resembling boredom, very likely induced by long duty periods with virtually no activity.

3.4.4 Job Satisfaction

During visits to the various VTS's, interviews were conducted with a total of 6 officers and 31 enlisted personnel. Included in the interviews were 5 questions bearing on job satisfaction at VTS's. These questions and the responses to them are summarized in Table 3-4.

Although there were more favorable than unfavorable responses with regard to liking VTS work, and more interviewees favoring another VTS tour than not wanting one, the negative responses warrant further consideration. Of even greater concern is the fact that a majority of the interviewees felt that VTS is <u>not</u> a good career assignment. The comments elicited by these questions highlight some problems.

The principal reasons given for liking VTS duty were:

a. It is a break from sea duty.
b. It is a challenging job.
c. It is a rewarding job.

The principal reasons given for <u>disliking</u> VTS duty were:

a. It is boring; there is no challenge or satisfaction.
b. It involves pressure.
c. The service is unnecessary.
d. It is not conducive to family life.

TABLE 3-4. RESPONSES TO QUESTIONS RELATED TO JOB SATISFACTION

		TOTAL	RANGE OVER VTS's
Do you like working here?	Yes	22	3-9
	No	11	1-5
	No reply or unsure	4	0-2
*Is VTS a good career assignment?	Yes	9	2-4
	No	13	3-6
	No reply or unsure	3	0-3
Would you like another tour at this VTS?	Yes	17	1-7
	No	15	3-6
	No reply or unsure	5	0-2
*Would you like a tour at another VTS?	Yes	12	1-7
	No	10	3-4
	No reply or unsure	3	0-2

*Question not asked at one VTS.

The principal reasons given for considering VTS duty a poor career assignment were:

a. You are not advancing in your rate; you are at a disadvantage in your next assignment .

b. You are not doing the kind of work chosen as a career.

c. CPO's are not utilized to their potential; they are doing the same tasks as lower grades.

Additional comments of interest were;

a. VTS duty is a good final assignment before leaving the service -- a chance to settle in to shore life.

b. VTS should be a "rate."

Patterns of responses varied among the VTS's, reflecting operational conditions. Favorable comments on the challenge and satisfaction inherent in VTS work came from a VTS that was well-equipped, well-established and providing a needed service. Unfavorable comments on lack of challenge, appreciation and necessity for the service came from a VTS where surveillance equipment was lacking and where the watchstanders were subjected to harassment and abuse from the users. Comments on monotony and boredom came from a VTS where the traffic load was light. Comments on problems with family life came from a center operating on a 12-hour watch schedule and located at some distance from desirable residential areas. Such operational factors have been discussed (see 3.3). Other site-specific factors that could lead to job dissatisfaction could include geographical location, cost of living, and personal dislike of commanders, supervisors or crew mates.

At the three locations where VTS as a career assignment was probed, there were enough negative responses to suggest that this problem is more general. Since VTS is not a separate Coast Guard career field, it is inevitable that VTS's must be staffed by some people who have not selected that duty. The possibility that persons selected from other career fields might find VTS duty more acceptable than do Radarmen and Quartermasters should not be overlooked. The difficulty of advancement in a chosen field while on VTS duty can be relieved by maintaining a formal program for career advancement at each VTS (see 3.4.2). Effective utilization of CPO's can be helped by recognition of a Watch Chief position, with supervisory authority and duties. This is a matter of policy and procedure at each VTS.

4. MODELS

4.1 INTRODUCTION

4.1.1 Reason for Computer Simulation

The management of Vessel Traffic Services includes the prediction of requirements for changes in staffing, equipment and procedures early enough to assure their implementation when needed. A technique to predict and evaluate the effects of system changes before implementation could significantly improve the chances of selecting those changes most beneficial to the system. Simulation of future systems has proven to be a cost-effective technique for such predictions and evaluations, particularly simulation using computerized models.

Simulation"...is a form of imitation in which a problem...is represented by a model which... replaces the problem by a second problem that is easier to solve."* A computerized model is a simplified imitation of a system in the form of mathematical expressions that can be solved by a computer to predict the behavior of the system. One objective of the present study was to seek a computerized model, or models, of VTS watchstander performance that would yield useful operational predictions.

4.1.2 Criteria for Model Selection

Human behavior is highly variable. Timing a person's performance of a task several times will produce a series of different times, and timing a second person's performance of the same task will yield a second, different series of times. Any useful model of human performance should take account of this variability.

Modeling techniques have been developed that handle variability by describing performance in terms of the distribution of

*Gordon, G., The Application of GPSS V to Discrete System Simulation, Prentice-Hall, Englewood Cliffs NJ, 1975, 398 p.

probabilities of occurrence of values. Such a probabilistic, or stochastic, model was judged necessary to describe VTS watchstander performance. The assumptions made in averaging values and the limited usefulness of the model of average watchstander time utilization (Section 2.1.5) emphasized the desirability of progressing to a stochastic model.

Since staffing requirements depend on how much each individual can accomplish in a given period of time, it was necessary to select a model that would reflect a sequence of activities on a time scale.

A third criterion for our model was adaptability. VTS's were found to vary significantly in equipment and procedures (See Section 1.3). This fact established the need for a model to be adaptable to these differences and still yield comparable results for the different VTS's.

4.1.3 The General Purpose Simulation System

Fortunately a modeling technique was available that not only met the three criteria but also was programmed for immediate use on a variety of digital computers. The General Purpose Simulation System (GPSS) is a set of computer programs developed specifically for the simulation of systems characterized by sequential series of events or processes. Any system whose operation can be described as a sequential flow of processes in time can be modeled on the GPSS.

The data flow at each of the four VTS's studied was fitted to the GPSS, and each model was exercised to explore its potential utility. This procedure will be described in more detail in the following paragraphs.

4.2 MODEL CONSTRUCTION

4.2.1 A Simplified Example

The GPSS consists of a series of "blocks" representing flow of informati:ı ʰthrough the system in terms of a series of specific processes. Each process is considered to impose a delay in the flow of information described by a distribution of possible delay times. The flow of processing from block to block is statistical in nature -- that is, there may be branching points where different processes may follow with differing degrees of likelihood.

As an example of fitting a VTS to the GPSS format, let us describe a very simple system. We will assume that a watchstander's time is occupied either in communicating or monitoring -- that is, we define monitoring time as all of the time not spent in communicating. Communications are either vessel-initiated (75 percent) or VTS-initiated (25 percent). Vessel-initiated calls are either vessel reports (80 percent) or requests for information (20 percent) A vessel report is followed by an advisory prepared by the VTS watchstander. A request for information is followed by the process of retrieving the required information, followed in turn by issuance of an advisory. A VTS-initiated call leads to a report by the vessel and issuance of an advisory by the VTS watchstander. This oversimplified operation is diagrammed in Figure 4-1, where a box identifies each process, a time delay (t) value is associated with each process, and probabilities are assigned at branching points. Data required for the model include the probability values for the branching points, and a set of time delay values for each of the 10 processes $(t_1 - t_{10})$.

This model is exercised through the "random walk" procedure. A value for t_1 is selected randomly from the set of values stored for t_1 and stored separately. A branch of the path is then selected by a process set to yield the left branch 75 percent of the time, the right 25 percent. Let us suppose that the right-hand branch is selected. Then values for t_8, t_9, and t_{10} are selected at random and stored, completing a run. The process is then repeated, starting with the random selection of another value of t_1, a random selection from the branching pathways, and so on for another run. Runs are continued for as long as the simulation requires. For example, runs would continue until the accumulated t values reached a total of 3600 seconds to simulate an hour's operation of the VTS.

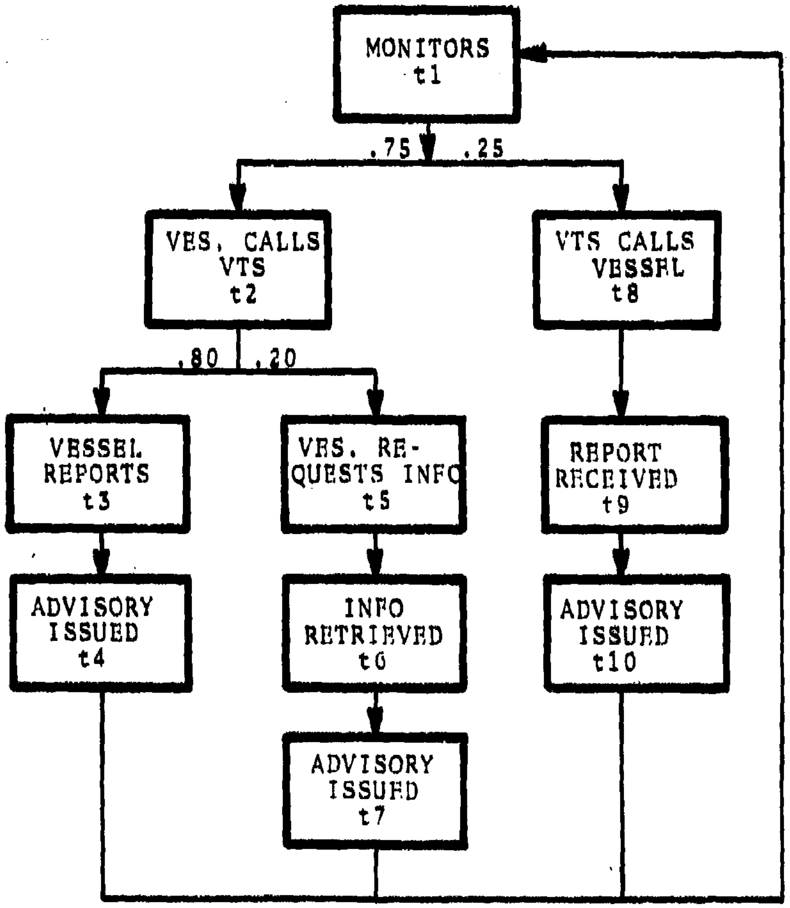


FIGURE 4-1. SIMPLIFIED EXAMPLE OF GPSS MODEL

If the various selected t values are stored individually, it is clear that a series of runs through the model will yield the distribution of t values, the average t value, and the percentage of time utilization for each process. The more runs there are in an exercise, the closer the results should match the total data base being sampled. This process yields no new information but is a test of the degree to which the model resembles the system from which the data came.

Of more interest is the use of the model to predict the effects of changes in the system. For example, in the simple model, an increase in communications load could be simulated by changing the sampling distribution for t_1 to contain shorter (non-communicating) time intervals. A change in the format of advisories (say a longer advisory format) could be simulated by substituting larger values in the sampling distributions for t_4, t_7 and t_{10}. A change from manual to automatic retrieval of data through use of a computer could be simulated by substituting smaller values in the sampling distribution for t_6. In short, such a model can be used to predict the effects on watchstander time utilization of any proposed change that can be described in terms of its effects on process times.

4.2.2 Procedure for Modeling VTS's

Use of the GPSS computer package to simulate the flow of information through a VTS required:

a. The logic of the flow of information through the VTS.
b. The processing delay times of VTS personnel and equipment.
c. The relative frequencies of the different watchstander activities at each branching point.

For each of the four VTS's, an information flow diagram was developed, based on procedures described in the operating manual, observed on site, and reported in interviews with watchstanders. Measurements made on site provided the sampling distributions of processing times and the frequencies of alternative processes at each branching point.

The basic flow diagrams were necessarily far more complicated than the simple example of Figure 4-1, incorporating multiple branching points and such processes as monitoring, operating, and adjusting various items of equipment as well as conducting various types of communications. An example of a flow diagram for the operation of one sector position at the Houston-Galveston VTS is given in Appendix A along with the probabilities of each branching point and a description of each processing delay.*

4.3 USES AND LIMITATIONS OF THE GPSS MODELS

4.3.1 System Functions

As noted above (4.2.1), each model may be tested by running it to generate data for comparison with the field measurements. One simulated hour of the model for one sector in each of the four VTS's was run. Tables 4-1 and 4-2 summarize some of the results of this test.

Table 4-1 compares the measured and simulated proportions of time watchstanders spent performing other than demand activities for an hour of average traffic load. The simulation results agree within a few percent with the measured data obtained in the field. Table 4-2 compares the measured and simulated duration times of basic communications activities. In general, the simulated results are consistent with the measured data; most are within the same order of magnitude. Discrepancies (such as in check out time in New Orleans) may simply mean that the sector modeled was not representative of all sectors; they may reflect differences between definitions of functions, or they may signal a need to modify the model. However, the general agreement between measured and modeled results gives us confidence that the GPSS is a useful and valid instrument for modeling VTS watchstander performance.

---

*Detailed flow charts and time and frequency data for the four VTS's are on file at the Transportation Systems Center.

TABLE 4-1. PROPORTION OF TIME SPENT PERFORMING OTHER THAN DEMAND ACTIVITIES

	HOU-GAL	NOLA	SF	PS
MEASURED*				
Monitoring	40%	64%+	45%	41%
Talking with others	3%	7%	7%	5%
Miscellaneous	0%	7%	25%	2%**
Total	43%	78%	77%	48%
SIMULATED				
Monitoring	46.6%	82.6%	79.1%	44.7%

*From Table 2-1.

**For Primary Communicator

+Includes 34% computer use time performed when the watchstander was not involved in radio communications with a vessel.

TABLE 4-2. COMMUNICATIONS ACTIVITY DURATION TIMES (seconds)*

TYPE	HOU-GAL	NOLA	PS	SF
MEASURED**				
Check in	76	88	27	25
Advisories/Update	20	56	34	21
Check out	21	24	17	23
Other	8	34	46	16
SIMULATED				
Check in	62	85	45	43
Advisories/Update	50	46	57	17
Check out	20	0	28	36
Other	70	17	36	43

* Presented as a gross comparison. The measured times are averages of several hours' observation while only one hour is simulated. The measured data covered the period from the time a radio transaction started until that transaction finished while the simulation data started at the beginning of a radio transaction but ended when the watchstander finished dealing with the information involved in that transaction.

** Taken from Table 2-4.

Since our data bases represent several hours of observation at each VTS, the one-hour simulation test reflects a partial sampling. Longer simulation tests should yield results in closer agreement with those measured. To estimate the rate of stabilization of model outputs as the number of runs increases, the cumulative average of one process measured (proportion of time between transactions) was recorded after each hour of simulation for one sector at one VTS. Figure 4-2 shows that the model output stabilized fairly well after 2 simulated hours.

At the time of writing this report, the models are in the process of continued testing, the addition of more data, and the combining of sectors for a more generalized model of each VTS.

4.3.2 Simulating Changes

To illustrate the predictive utility of the GPSS model for VTS operations, the sampling distributions of intertransaction time intervals were varied to simulate various radio communications loads at the four VTS's. Multiplying a distribution of intertransaction intervals by a constant yields larger intervals between communications, thus simulating a lighter communications load. Conversely, dividing the distribution by a constant simulates less time between communications and thus a heavier communications load.

The effects of varying communications load on the functional processes of the model were determined by running a one-hour simulation for each of a series of different sampling distributions of intertransaction times. This exercise was performed on a one-sector (or equivalent) model of each of the four VTS's, generating a set of processing times for each hour's simulation. These results permitted an analysis of the effect of communications load on each basic process.

Figure 4-3 shows the results of this simulation for one process -- monitoring. Despite inter-VTS differences in equipment and procedures, the results suggest that the Houston, New Orleans and Puget Sound VTS's are alike with regard to loss of monitoring time as a function of increasing communications load. San Francisco

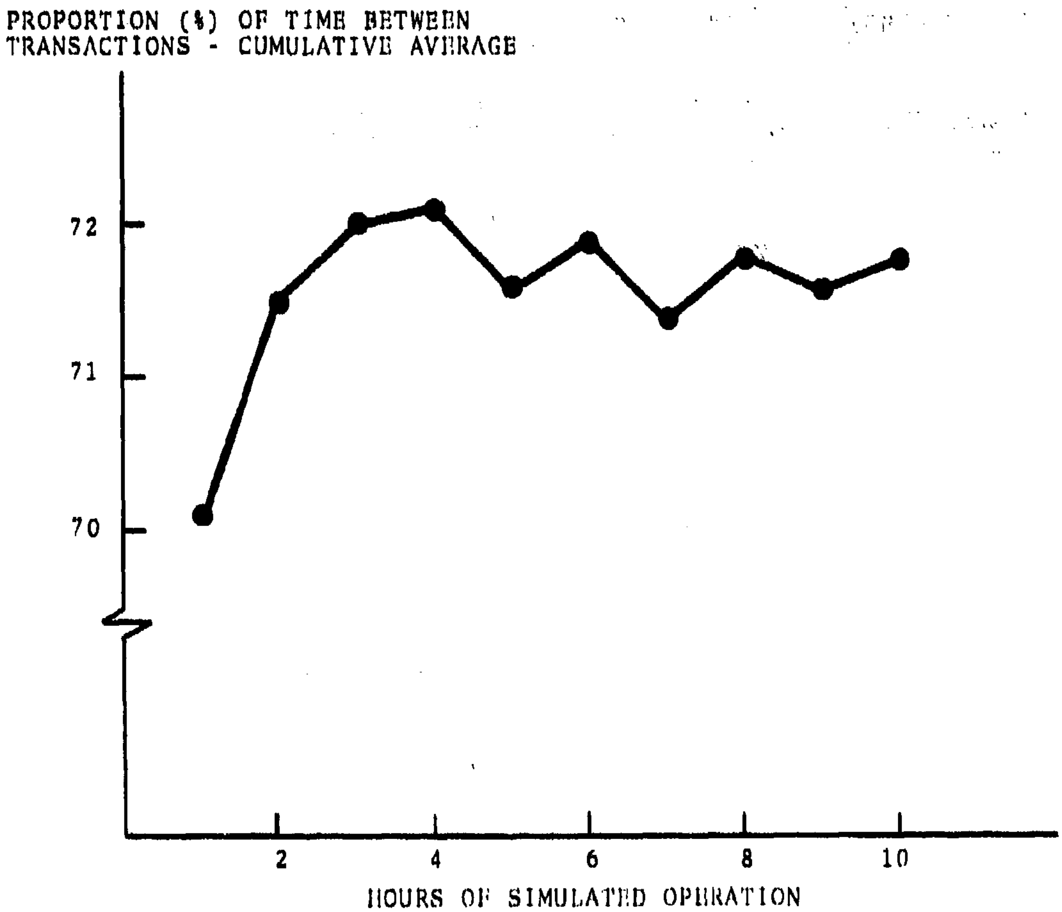


FIGURE 4-2. MODEL STABILIZATION DATA

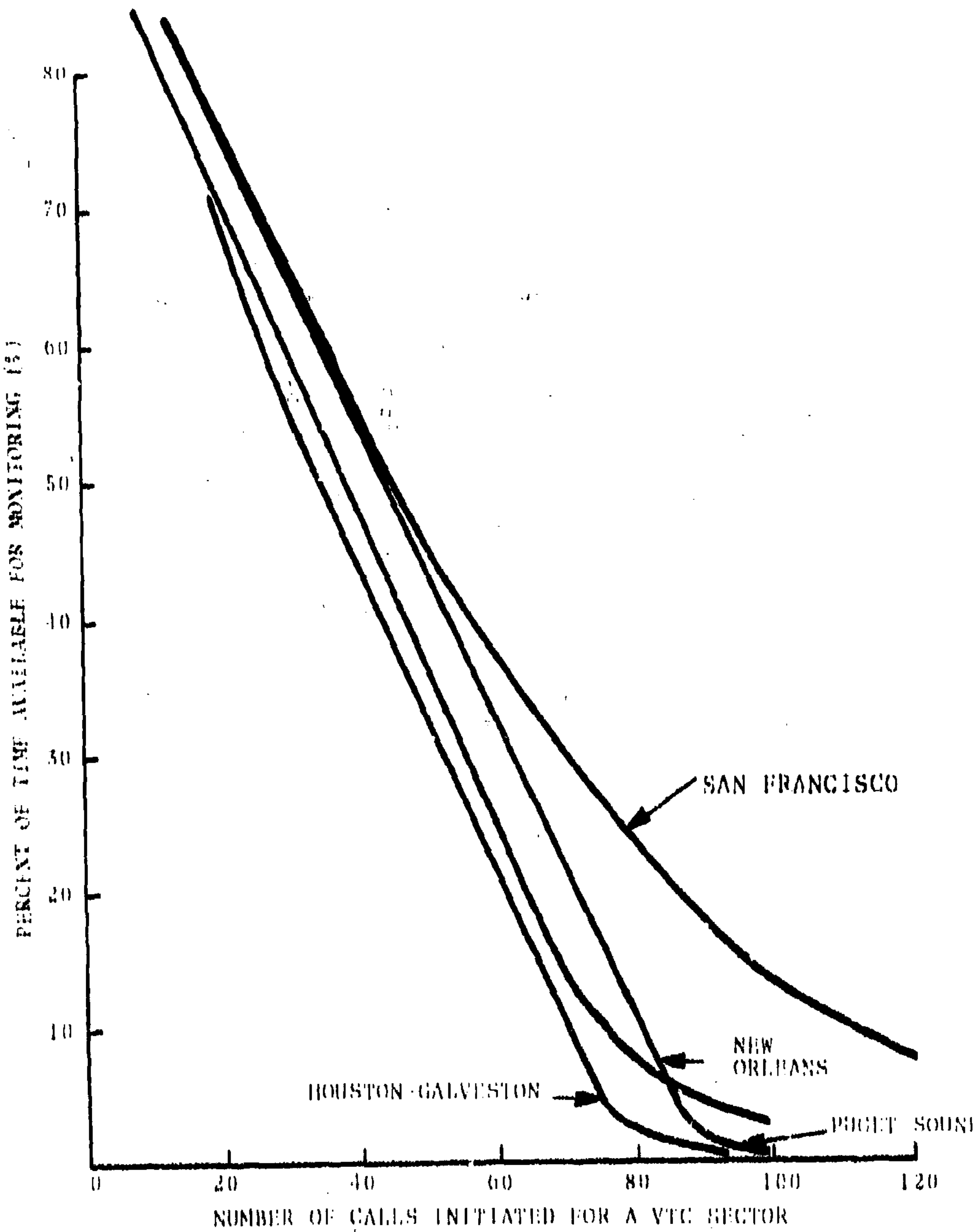


FIGURE 4-3. PERCENT OF TIME AVAILABLE FOR MONITORING AS A FUNCTION OF THE NUMBER OF CALLS INITIATED FOR A MODEL VTS WATCHSTANDER AT EACH OF THE FOUR CENTERS

has more time available for monitoring than do the other VTS's, probably because of the smaller proportion of time devoted to tracking. The operational significance of loss of time for monitoring, leading to an uncritical reliance on situation displays, has been noted in Section 2.1.5.

Care must be taken not to overinterpret the results of this exploratory exercise. The models are based on a small amount of data; only one sector is represented for multi-sector VTS's; only one-hour simulations were run to generate the data points (note the desirability for longer simulations illustrated in Figure 4-2), and communications traffic loads were extrapolated well beyond the limits sampled in the actual data. However, the consistency of this crude simulation with our observations of operations leads us to conclude that it is desirable to continue our efforts at fitting VTS data to the GPSS model for predictive purposes.

4.3.3 Model Limitations

The GPSS model of VTS operations has a wide variety of possible uses; however, it also has limitations, particularly with respect to its dependence on the accuracy of the logic of information flow and on the representativeness of its data base and also its restriction to time data.

Since a model is a simplification of the real world, the way in which it is simplified limits its applicability. The conversion of an operating VTS to a sequence of processes risks the omission of significant functions. The initial tests of applicability (4.3.1) have given us confidence that our information flow logic is a valid and useful representation of VTS operations. Continued refinement of the models is recommended, however, as additional data become available.

The representativeness of the distributions of process times is probably the most critical limiting factor of our models. The definitions of functions to be observed, the accuracy of function timing during observations, the representativeness of the operations at the time of observation, and the representativeness of the watchstanders observed all affect the degree to which the results of model simulations will predict actual operations. Similarly, the accuracy and representativeness of process frequency data affect the validity of model results. Initial testing of the models has given us confidence in their general representativeness of the conditions during the time of observation. However, we cannot be certain at this time that extrapolation of the models to simulate high levels of system workload will yield valid results. Additional data and background information on emergency operations at the four VTS's are currently being sought.

A more general limitation on the use of the GPSS-based models to predict VTS operational processes is their restriction to data on time flow. An efficient operation may not necessarily be effective, and a VTS system designed to optimize watchstander time utilization will not necessarily produce accurate advisories. Thus, while we make as much use as possible of the GPSS to help design time-effective systems, we must continue to seek methods of determining system accuracy and modeling techniques suitable for predicting system effectiveness.

4.4 SUMMARY AND RECOMMENDATIONS ON MODELS

4.4.1 Summary

The data and information obtained in field studies of four VTS's have been used to model the utilization of time by watchstanders at those VTS's. The programs of the General Purpose Simulation System (GPSS) have been shown to be suitable for this purpose within the limits of the data that have been analyzed. These GPSS models show potential value for the prediction of the effects of changes in VTS system design, provided that the changes can be expressed in terms of changes in the time flow of data processing.

4.4.2 Recommendations

It is recommended that the development of GPSS-based models of VTS watchstander time utilization be continued by:

a. Continuing to fit all available data to the models.

b. Collecting additional data, particularly on VTS procedures under emergency conditions.

c. Reviewing and refining the logic flow charts for each VTS.

d. Combining sector models into total VTS models.

e. Deriving a generalized model for future VTS's.

f. Testing the accuracy of model predictions.

It is further recommended that methods be sought for estimating or measuring the accuracy and effectiveness of VTS products and that appropriate techniques be developed for modeling the effectiveness of these products.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

Analysis of data on watchstander performance during routine operations at four VTS's permitted some generalizations about VTS operations to be drawn.

5.1.1 Similarities and Differences

VTS's are alike in that they receive data on vessel traffic through VHS radio reports, integrate the data into a model of traffic flow, predict future traffic situations from this model, and advise individual vessels by radio as to what traffic situations they will encounter in the near future (1.2).*

VTS's differ in the ways in which additional data on traffic are obtained (radar, television), the ways in which the information is integrated and the situation is modeled (computer generated displays, plotting table), and the ways in which advisories are prepared (mental preparation, computer generated advisory). They differ in organization of communications facilities, division of labor on duty tasks, duty scheduling, operational procedures, selection and training procedures, and in other ways (1.3).

5.1.2 Allocation of Watchstander Time

Despite the differences among VTS's there are some underlying dynamics of a sector watchstander's time utilization as a function of traffic load that can be summarized as follows:

a. As traffic load increases, time required for communicating with vessels and tracking them will increase.

b. As traffic load increases, residual time for response to emergencies will decrease.

*Parenthetical references are to relevant sections of this report.

c. As traffic load increases, time available for monitoring the traffic situation will decrease, with a consequent increase in uncritical reliance on computer-based advisories.

Possible remedies for the consequences of increased sector workload include:

a. Reduction of communication time through less frequent check-in transactions and shorter advisories.

b. Reduction of tracking time through less frequent check-ins, automatic data inputs, and more efficient manual inputs.

c. Addition of sectors in the operating area.

d. Functional sharing of sector watchstander duties among two or more watchstanders. (2.1)

5.1.3 Communications

On the average, VTS's spend about 30-60 seconds per hour communicating with each vessel in the system. Where a watchstander must operate a computer terminal while communicating, transactions are characterized by pauses that sum to about half of the total time of transaction. Transactions tend to be shorter and more frequent in narrow winding channels than in open waterways. (2.2.3)

In routine operations, present communications channel allocations appear to be adequate, with channel utilization varying from 10 to 50 percent, depending on area sectorization, traffic load, and number of channels assigned. (2.2.1)

Some problems were noted with respect to communications facilities:

a. Realignment of sector boundaries to make better use of radio transmission patterns is needed in some VTS's.

b. At some VTS's channel sharing caused interference.

c. Radio reception is too noisy at some VTS's.

d. Communications consoles are generally redundant in controls and indicators, wasteful of space, and require too much selection and reaching by watchstanders. Some lack the capability and flexibility required by the users. (3.2)

5.1.4 Equipment

Surveillance equipment is necessary at any VTS to supplement the traffic data received by vessel reports. Radar and television have differing advantages and disadvantages, but an appropriate combination can be found for any waterway situation. Lack of surveillance backup can lower watchstander confidence and traffic participation in the Vessel Movement Reporting System (3.1.1, 3.4.3).

Computer equipment shows promise in assisting watchstanders in data processing, situation plotting, and prepartion of advisories. However, failure to match computer performance to watchstander requirements (such as rapid data retrieval and integrated data display) can lead to increases in the time required to perform some functions and even the adoption of alternative methods (3.1.2).

5.1.5 Operations

Every VTS should have formal Standard Operating Procedures (SOP). To a certain extent, a general SOP can be defined for all VTS's, but flexibility for local VTS's to adapt procedures to local conditions must be provided (3.3.3).

Participation of vessels in a Vessel Movement Reporting System (whether mandatory or voluntary) depends basically on the provision of a service by the VTS that meets users' needs with a minimum of interference with user activities. Such service can not be provided without the backup data provided by surveillance systems (3.3.1).

Twelve-hour watch schedules are popular with watchstanders, but the risks associated with fatigue late in the watch period are not well understood and require further study (3.3.2).

Division of duties by function rather than by sector appears to be less efficient, resulting in a severely uneven distribution of workload (2.1.4).

5.1.6 Personnel

There are very few criteria currently used for selection of personnel for VTS duty, resulting in occasional malassignments that result in potentially dangerous operational situations and overloading of VTS personnel (3.4.1).

Qualifications for VTS duty are established by on-the-job training, which results in well-trained personnel but which is time-consuming (3.4.2).

Stress questionnaires filled out by VTS watchstanders showed that VTS duty is moderately tiring. The characteristics of stress varied from VTS to VTS and may be summarized as follows:

Houston -- frustration with a non-responsive computer.

New Orleans -- insecurity for lack of surveillance backup.

Puget Sound -- fatigue from varying workload and considerable standing.

San Francisco -- boredom from light traffic load.

Stress levels consistently increased throughout the watch period and had not returned to the pre-watch level 3 hours after the end of the watch (3.4.3).

5.1.7 Models

The purpose of development of generalized models of VTS operation is to provide an inexpensive technique for understanding the impact of changes on equipment, procedures and personnel on safety and operating costs.

Several steps are required to develop such models: A modeling technique adaptable to computer simulation must be chosen, operations modeled, available data fitted to that model, the model checked and verified, and the model used to determine the effects of changes in VTS operations. The General Purpose Simulation System (GPSS), a computer package program was chosen to model information flow through VTS personnel and equipment. The report describes the models developed, simulated, checked, and used for a sector at Houston-Galveston, and for the Puget Sound, New Orleans, and San Francisco VTS's (4.2,4.3,4.4,4.5).

The models depict the flow of information through the VTS system, using a data base of processing delays and frequencies of activities at each branching point of the flow. Observation and measurement of watchstander performance at the 4 VTS's provided the data base for those models.

Trial simulations of each of these four models were successfully conducted using the GPSS computer package. The results of those simulations describing the duration of watchstander activities and the proportion of time devoted to them were both logical and agree with the data gathered and observations made in the field. Certain parameters of watchstander activities, especially the proportion of time available for monitoring, show promise as indicators of workload limitations. The process of developing each of these models revealed areas which could benefit from refinements in the data base and suggested further simulations.

5.2 RECOMMENDATIONS

VTS-specific recommendations were included in the individual interim reports issued on the systems studied (see Appendix B). The more general findings (5.1) have led to some additional recommendations offered below for consideration in the operation of current VTS's and the planning of future systems:

1. Continue the effort to model and generalize VTS operations by collecting data on operational characteristics when the system is stressed by such occurrences as unusually heavy traffic loads, unexpected incidents (including accidents and emergencies) on or near the waterways, sudden loss of communications or surveillance equipment, sudden reduction in manpower, and the like (2.1, 4.5).

2. Adopt as soon as feasible basic physical fitness criteria for the selection of personnel for watchstander duty, and initiate development of psychological selection tests (3.4.1).

3. Develop specifications for future VTS processing and display systems that will assure responsiveness of the system to watchstander needs, giving particular attention to:

a. Integration of data in displays, particularly a situation display that shows location, movement and identification of traffic on a map-like background.

b. Accessibility to supplemental data with a minimum of keying and a minimum of delay (3.1.2).

4. Develop specifications for a standardized communciations console with intègrated displays and controls (3.2).

5. Equip every VTS with surveillance systems (3.1.1).

6. Maintain illumination in VTS operations rooms at as even a level as is feasible, and shield displays from bright spots (3.1.3, 3.4.3).

7. Provide ventilation at each watchstander duty position adequate to carry off tobacco smoke (3.4.3).

8. Rotate watch periods at least every 4 days with liberty time between watch periods. Rotate duty positions during a watch every 2 hours (3.3.2).

9. Study duty performance late in 12-hour watches to determine better the degree of fatigue, particularly with regard to speed and effectiveness of response to unexpected situations (3.3.2).

10. Develop a VTS watchstander training program based on an evaluation of options and techniques for minimizing on-the-job training time (3.4.2).

11. Institute at every VTS a formal program for career-advancement study and training.

12. Develop a general Standard Operating Procedure for all VTS's, allowing flexibility for adaptation to local conditions.

13. Institute at every VTS a continuing program of refresher training, to include understanding of SOP, simulation of emergency procedures, and check-rides on vessels in the VTS area.

14. Institute at every VTS a continuing public relations program so that, through watchstanders' visits to pilot and tow master groups, and visits of pilots and tow masters to the VTS, a mutual appreciation of one another's needs and problems is developed.

REFERENCES

Devoe, D.B., C.N. Abernethy and K.J. Kearns, "Houston-Galveston Vessel Traffic Service Watchstander Analysis," CG-D-24-78 (May 1978).

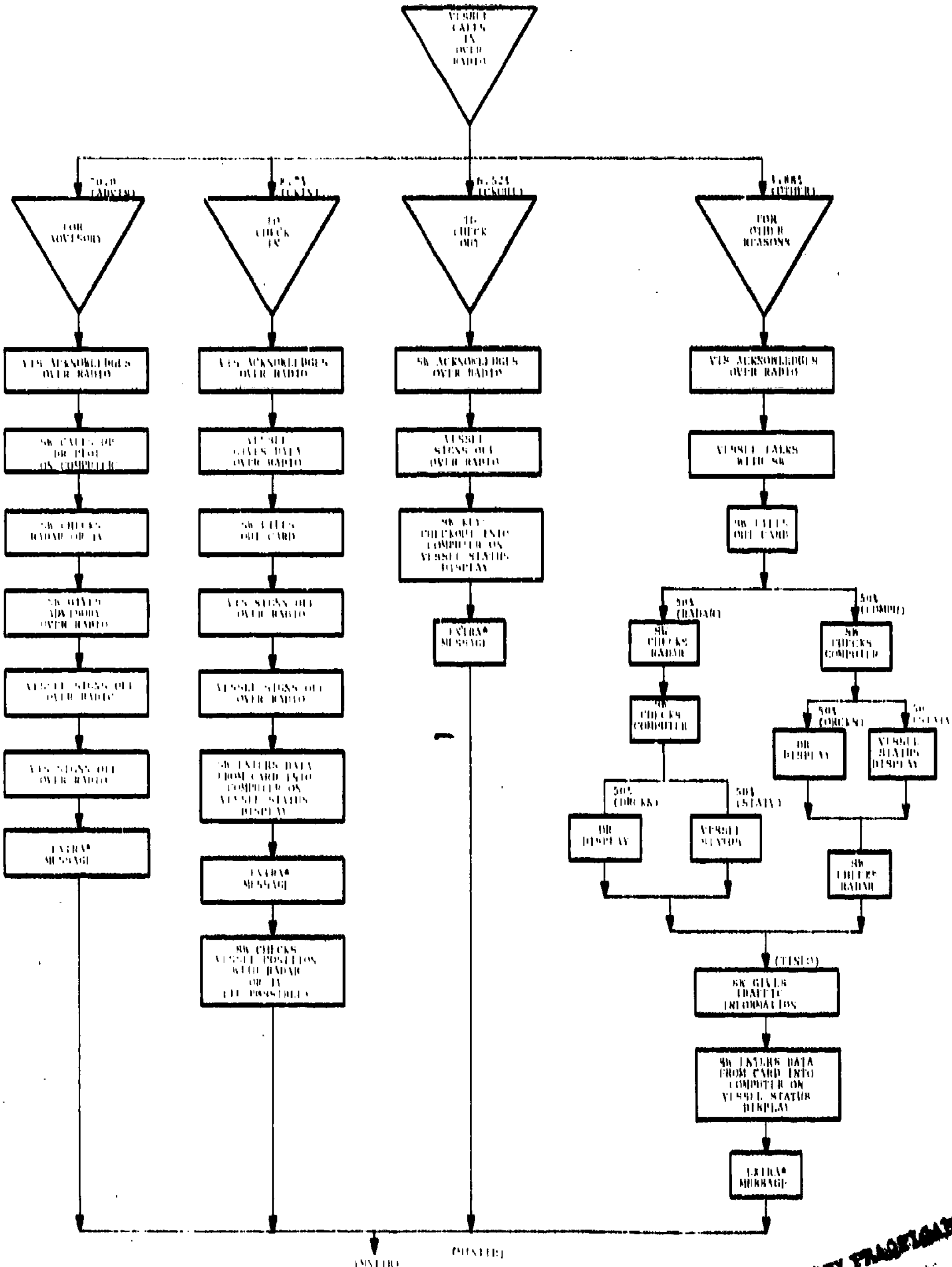
Devoe, D.B., J.W. Royal, C.N. Abernethy and K.J. Kearns, "Puget Sound Vessel Traffic Service Watchstander Analysis," CG-D-82-78 (November 1978).

Devoe, D.B., J.W. Royal and C.N. Abernethy, "New Orleans Vessel Traffic Service Watchstander Analysis," CG-D-17-79 (May 1979).

Royal, J.W., D.B. Devoe, C.N. Abernethy, K.J. Kearns and R.A. Rudich, "San Francisco Vessel Traffic Service Watchstanier Analysis," (In preparation, DOT-TSC-USCG-79-4).

APPENDIX A

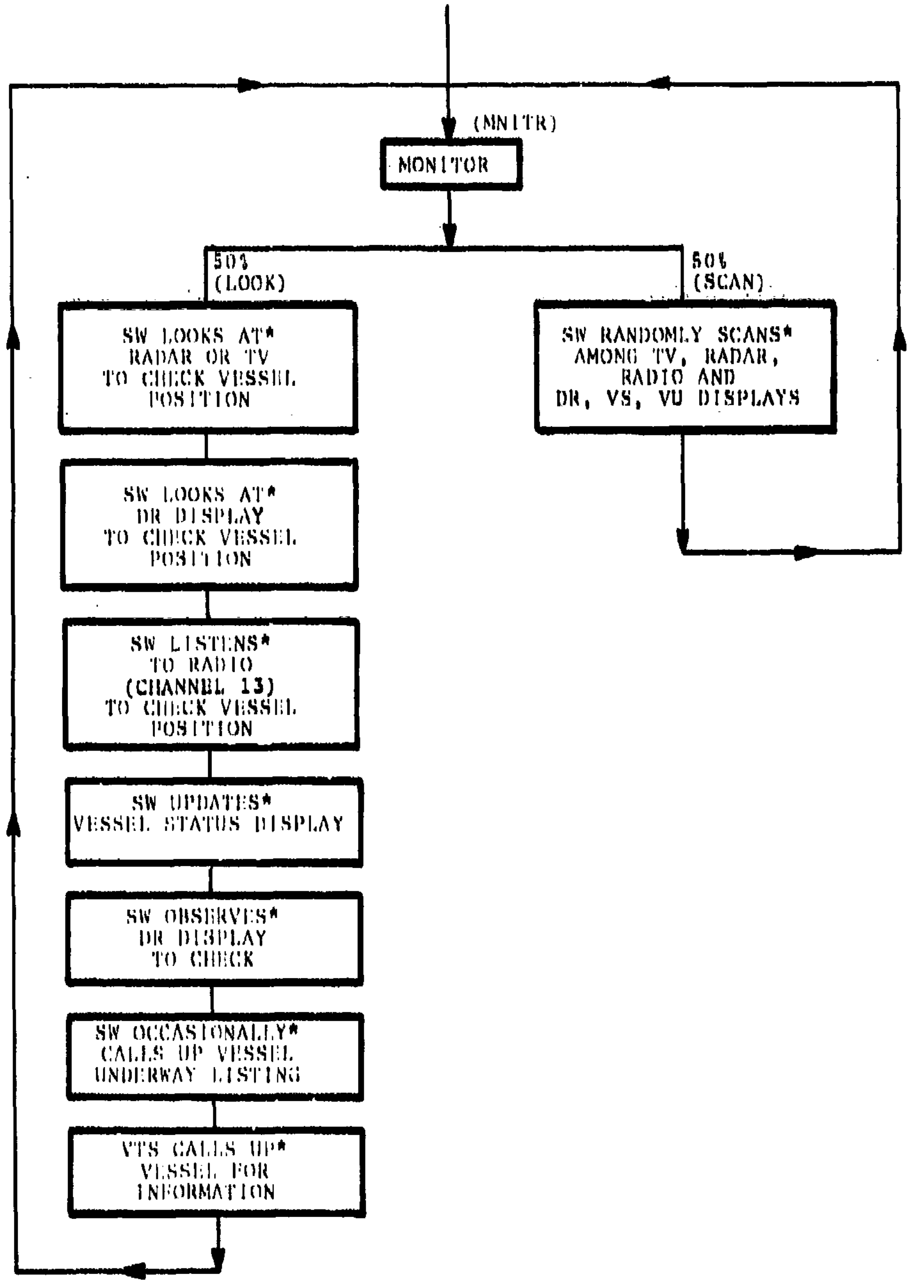
HOUSTON-GALVESTON VTS COMMUNICATIONS FLOW



THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

APPENDIX A (CONTINUED)

HOUSTON-GALVESTON VTS COMMUNICATIONS FLOW



* WILL BE INTERRUPTED BY A VESSEL CALLING IN

APPENDIX B

RECOMMENDATIONS FOR INDIVIDUAL VTS's

B.1 HOUSTON-GALVESTON VTS

1. Add additional television sites to Sector III.

2. Add a radar site to Sector II.

3. Provide additional computer display scopes at Sector Watchstander positions.

4. Reprogram the VTS-DACS display formats to eliminate unnecessary displays, to add entry time to the Vessel Departures Sheet, and to allow expansion and off-centering of the Dead Reckoning Sheet.

5. Increase the computer memory capacity to permit reduction in display delay times.

6. Add more function keys to the keyboard to reduce the number of keystrokes required for requests and commands.

7. Provide a trackball or joystick for cursor control on the VTS-DACS displays.

8. Extend the tracking algorithm to include predictions of changes in vessel speed.

9. Obtain a more stable power supply for the VTS-DACS.

10. Reorient and shield the radar PPI's to reduce glare.

11. Increase room illumination to the level of television and computer displays.

12. Mask down the brightness of self-illuminated panel buttons.

13. Conduct follow-on stress evaluations as an aid to evaluation of the twelve-hour watch schedule.

14. Study the relative merits of grouped versus segregated sector positions.

15. Provide at least one position for a full-time training instructor.

16. Establish a set of criteria for selection of personnel for VTS duty.

B.2 PUGET SOUND VTS

1. Adopt as standard procedure a complete radar update before each 15-minute dead-reckoning update.

2. Review and standardize all operating procedures.

3. Study ways to reduce the number of advisories and to shorten their contents.

4. Consolidate the Primary Communicator's communications equipment into a smaller and more conveniently located position.

5. Elevate the Primary Communicator and Radar Operator positions if feasible.

6. Move the Radar Operator closer to the plotting table, if feasible.

7. Rearrange radar equipment to make the scopes visible to the Plotter, if feasible.

8. Substitute a tinted transparent plastic curtain for the window drapes.

9. Continue efforts to reduce glare spots.

10. Seek ways to improve light-shielding and sound-shielding of radar equipment.

11. Improve sound-shielding of teletype equipment and relocate at External Communicator position.

12. Divide the Primary Communicator function into two or more Sector Watchstander positions.

13. Further consolidate the communications console.

14. Provide each Sector Watchstander with a radar display covering his area.

15. Plot radar traffic at the Sector Watchstander positions; eliminate the Radar Operator position.

16. Design a consolidated radar-communications console for the Sector Watchstander.

17. Use a computer for tracking and plotting; eliminate the Plotter position and plotting table.

18. Use a computer to predict and display future traffic situations.

19. Integrate the radar data into the computer for automatic radar tracking.

20. Design an integrated computer-radar-communications Sector Watchstander console.

21. Redefine VTS duties to give more responsibility and authority to CPO's.

22. Continue efforts to develop selection criteria for VTS duty.

23. Modify assignment practices to permit overlap of incoming and outgoing personnel for a training period.

B.3 NEW ORLEANS VTS

1. Give highest priority to the acquisition of surveillance aids, particularly radar and CCTV.

2. Redesignate sector boundaries to conform better to transmitter receptivity.

3. Reassign communications channels to sectors and/or locks to reduce interference between VTS and lock radio transactions.

4. Provide for longer vessel identification word in the computer.

5. Provide a capability for displaying two simultaneous lists in the status tabular area of the CRT.

6. Continue effort to define personnel selection criteria.

7. In training, stress the fact that the symbolic representation of vessels on the dynamic display is merely a representation of their general direction and degree of progress and never of their actual position and orientation in the waterway.

8. Sound-shield individual sector position .

B.4 SAN FRANCISCO VTS

1. Study the efficacy of the present work schedule, both shift hours and day/night rotation.

2. Improve heating/cooling/circulation of air in operations room.

3. Explore methods to light-shield radar displays.

4. Standardize SOP for all watch sections, with special emphasis on exceptions to basic traffic patterns.

5. Examine training procedures to ease introduction to new watchstanders.

6. Continue and expand emphasis on career training and education for VTS personnel.

7. Examine effects of reorienting radar consoles in an arc around central watchstander position.

140 Copies