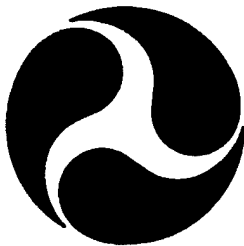


Report No. CG-D-05-97

Vessel Traffic Service (VTS) Digital Broadcasting

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FINAL REPORT
September 1996

DTIC QUALITY INSPECTED 2

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Prepared for:

U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental Protection, (G-M)
Washington, DC 20593-0001

19970218 042

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Technical Report Documentation Page

1. Report No. CG-D-05-97		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Vessel Traffic Service (VTS) Digital Broadcasting				5. Report Date September 1996	
				6. Performing Organization Code	
7. Author(s) David J. Pietraszewski				8. Performing Organization Report No. R&DC 27/96	
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, Connecticut 06340-6096				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
				13. Type of Report and Period Covered Final Report	
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection, (G-M) Washington, DC 20593-0001				14. Sponsoring Agency Code Commandant (G-MOV) U.S. Coast Guard Headquarters Washington, DC 20593-0001	
15. Supplementary Notes The R&D Center's technical point of contact is David Pietraszewski, 860-441-2676.					
16. Abstract The progress towards the introduction of electronic navigation equipment aboard the bridges of vessels that are required by law to participate in U.S. Coast Guard (USCG) operated vessel traffic services (VTSs) presents an opportunity to introduce cost-saving automation into the operation of the vessel traffic service itself. This report points out the need to either identify or develop the appropriate processes, standards, and methods needed to link the vessel traffic service data base with shipboard navigation systems. The necessary developmental steps are identified by applying the International Standards Organization Open Systems Interconnection Reference Model to the broadcast of digital marine navigation safety information. This is information contained in modern vessel traffic service computers. This report presents a breakdown of an approach that can be used to establish a proof-of-concept marine safety broadcast. This proof-of-concept system can be used to demonstrate and evaluate the concept. This report also raises issues concerning the potential shift in workload to marine pilots and resulting compromise in overall port security represented by this approach.					
17. Key Words vessel traffic service digital broadcasting vessel traffic services VTS automation VTS navigation safety broadcast voiceless VTS marine safety				18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) UNCLASSIFIED		20. SECURITY CLASSIF. (of this page) UNCLASSIFIED		21. No. of Pages	
				22. Price	

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

* 1 in = 2.54 (exactly).

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	0.125	cups	c
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

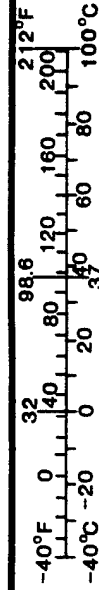


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Executive Summary

Today's vessel traffic services are being pressured to reduce implementation costs and annual operating costs. Both can be reduced by automating some functions of the vessel traffic service. Automation requires that new methods be used to provide navigation information more accurately and quickly to the new electronic navigation technology being installed aboard the ships of vessel traffic service participants. Over time, vessel traffic services can change the way waterways management is achieved. Change is difficult to achieve quickly in the marine world. Years of coordinated effort will be required to reshape the marine infrastructure to conform to a new vision. This report is a brief sketch of one possible course towards the automation of vessel traffic service (VTS) functions.

This report introduces and describes the concept of "voiceless vessel traffic services" and the part that wireless digital technology can play in future VTS automation. It also presents the engineering and implementation considerations that are needed to facilitate the introduction of a concept called "digital navigation safety broadcasting" into the marine community. The common thread, in both concepts, is the free and open distribution of vessel traffic service information using automated processes.

Automating VTS functions can reduce the cost of operating vessel traffic services. Automation is a way for the USCG to reduce the percentage of its annual budget supporting VTS systems, or as a way to make establishment and operation of VTS-like systems more attractive to potential partners in the private sector. The first benefit would occur through a reduction of the actual number of USCG staff needed to operate a USCG VTS. This represents direct cost savings. The second benefit would allow the USCG to avoid future implementation costs by encouraging alternative non-federal deployments of semi-automated VTS systems in ports needing VTS-like systems. Under suitable conditions, the USCG could also realize direct savings by adding automated VTS capabilities to existing VTS systems and transferring operation of these "reduced-operating-cost" services to willing partners.

The concept of voiceless vessel traffic services is based on two assumptions. First, that improving the flow of navigation information will improve the pilot's decision making process. Second, that information can flow automatically between the vessel traffic service computers and the computer systems aboard each ship. The existence of such a capability could significantly reduce the need for voice communications between the vessel traffic service operator and each ship's pilot or master. Removing the vessel traffic service operator from the immediate information flow significantly reduces the operator's workload. Introducing electronic automation increases the quantity and quality of information that can be provided.

Implementation of the voiceless vessel traffic service concept will require either the development of new or the identification and review of existing processes, standards, and methods that can be used to create the service. For example, a review of how information is presently entered into the vessel traffic service databases will be needed to affirm that the information in the database undergoes sufficient validation and that it

is suitable for automated distribution. Also, an assessment of the sensitivity of information in the database should be done to determine if open and automatic distribution of that information will compromise the present levels of port security.

The voiceless vessel traffic service model suggests the use of two complementary methods for the automated distribution of information, wireless digital communications and wireless digital broadcasting. Two factors favor the use of broadcasting for the distribution of navigation information. The first factor is the cost to the user. The user needs to make only a "one-time" investment in equipment. The second factor is the ability of broadcasting to simultaneously distribute all the information to an unlimited number of users. Broadcast capacity is independent of user demand. Wireless digital communication is sensitive to user demand. Communications channels can become saturated and fail as demand increases.

A simple model of a navigation safety broadcast system was developed and used to help identify areas requiring development. The following were found to be necessary to create a simple voiceless VTS navigation safety broadcast design; vessel traffic service database search process, broadcast site router process, broadcast scheduler process, and broadcast monitor process. Also, two standards describing the operation of the broadcast system are needed. The first standard would describe the internal system message and command structure of the system. This would be used to design and maintain the system. The second standard provides everything a potential equipment manufacturer would need to know about the broadcast signal in order to manufacture user equipment for voiceless VTS.

This report raises issues concerning the presentation of VTS information to the pilot. Automating the distribution of information reduces voice radio communications between the vessel pilot and vessel traffic service operator. This is viewed as a workload reduction for the operator, but it could represent a shift of the "vessel traffic service workload" to the pilot. The significance of this shift is not well understood. The impact of automation on the pilot as a result of this switch from aural distribution to visual display needs investigation. A future study is needed to investigate the change in piloting workload, impact on marine safety, and benefits of voiceless vessel traffic services. The pilot's views on the information content and shipboard presentation are needed to develop the most appropriate shipboard system.

Future USCG research should include a demonstration, "voiceless vessel traffic service test bed," conducted with the cooperation of an operating USCG vessel traffic service and the marine pilots association working in their vessel traffic service area. This demonstration would provide an opportunity to develop and evaluate the needed voiceless vessel traffic service processes and standards. It would also provide an opportunity to work with the pilots to develop the true information requirements for the content of the navigation safety broadcast. The demonstration would serve as a vehicle for standards and equipment development in cooperation with the industry that would support future operational deployment of voiceless vessel traffic services.

1.0 Introduction

Today's vessel traffic service managers are being pressured to reduce implementation costs and annual operating costs. Both can be reduced by automating some functions of the vessel traffic service. Automation requires that new methods be used to provide navigation information more accurately and quickly to the new electronic navigation technology being installed aboard the ships of vessel traffic service participants. Over time, vessel traffic services can change the way waterways management is achieved. Change is difficult to achieve quickly in the marine world. Years of coordinated effort will be required to reshape the marine infrastructure to conform to a new vision. This report is a brief sketch of one possible course towards the automation of vessel traffic service (VTS) functions.

Marine transportation is being reshaped by innovations made possible through the application of computers, communications, and other information-related technologies. The most direct benefits are measured in improved safety, reduced operating costs, increased capacity, and an improved environment. In view of the magnitude and potential impact of the benefits that are attainable through the introduction of advanced transportation technologies, the Department of Transportation (DOT) adopted the objective to "accelerate technological advances to make our transportation system more efficient, environmentally sound, and safe" in the DOT Strategic Plan of 1994.

This report introduces and describes the concept of "voiceless vessel traffic services" and the part that wireless digital technology can play in future vessel traffic service automation. It also presents the engineering and implementation considerations that are needed to facilitate the introduction of a concept called "digital navigation safety broadcasting (NSB)" into the marine community. Digital distribution will enhance the performance of vessel traffic services and reduce the costs associated with establishing, operating, and maintaining a VTS. The report also contains recommendations concerning areas needing further research and development. The principles of the digital navigation safety broadcast concepts presented in this report can be applied to any VTS or VTIS (vessel traffic information service) system presently in operation or planned for future operation in the United States. At the present time, none of the existing USCG VTS systems provide for the automated distribution of navigation information to marine users or to the shipboard systems they use.

The purpose of the NSB is to automatically provide vessel pilots with information gathered by the VTS. This would be accomplished by coding the information into a wireless signal that would be broadcast throughout the VTS "vessel traffic service area" (VTSA). Such information might include the position, course, and speed of large vessels in the VTSA, the actual water depth at key locations, or abnormal water current conditions. This automation is expected to significantly reduce the need for voice communications between vessels and the VTS operator, making more radio frequency time and conning time available for direct communications between ships.

The NSB service will need a number of operating features. For example, each discrete message will need type identification to allow automatic acceptance or rejection by each ship's navigation system. Mechanisms to clearly identify superseding information will need to be included. Measures to detect errors and correct errors are needed to prevent corrupted information from entering the ship's navigation system. Measures to guarantee the integrity and validity of information will protect the system from being degraded by unintentional or intentional interference sources.

General acceptance and implementation of VTS digital navigation safety broadcasts and the shipboard equipment that uses the broadcast information would significantly reduce the workload experienced by today's vessel traffic operators. This could be translated into reduced VTS operating costs, increased port efficiency, and increased safety. Automating timely VTS information flow and presentation should also reduce the marine pilot's workload, but, as this report suggests, this aspect of voiceless VTS requires more investigation.

Automating VTS functions can reduce the cost of operating vessel traffic services. Automation can be viewed as a way for the USCG to reduce the percentage of its annual budget supporting VTS, or as a relatively inexpensive approach to waterways management that would be more attractive to partners desiring to fund the establishment and operation of VTS-like services. The first option would occur through a reduction of the actual number of USCG staff needed to operate a USCG VTS. This represents direct cost savings. The second option would allow the USCG to avoid future implementation costs by encouraging alternative non-federal deployments of voiceless VTS systems in ports needing VTS-like services. Under suitable conditions, the USCG could also realize direct savings by adding voiceless VTS capabilities to existing VTS and transferring operation of these "reduced-operating-cost" services to willing partners.

Sections of this report contain an overview of the voiceless VTS concept and how digital broadcasting might be deployed. The reader interested in a quick overview of the voiceless VTS concept should read sections 2.0 and 2.1. A similar overview of the digital Navigation Safety Broadcast concept can be obtained by reading sections 3.0, 3.1, 3.1.1, and 3.1.3. The remaining sections of the report discuss specific issue, process, standard, or method details.

2.0 Background

In the United States there are a number of federally funded vessel traffic services (VTS). Vessel traffic services are established and operated to improve navigational safety and protect sensitive marine environments in areas of significant marine traffic. It helps determine the presence of vessels in and around ports, and it provides information to vessels on such matters as traffic, tides, weather conditions, and port emergencies. Under the authority of the Ports and Waterways Safety Act of 1972, as amended, the U. S. Coast Guard operates VTS in eight ports around the United States. Operations and maintenance costs for these systems, which totaled about \$19,000,000 in fiscal year 1995, are borne by the U. S. Coast Guard. The costs are not passed on to the ports or to the shipping industry.

Expansion of the nation's VTS facilities is now being considered as a result of the Oil Pollution Act of 1990 (P.L. 101-380), passed after the 1989 EXXON VALDEZ oil spill and subsequent spills in the waters of Rhode Island, the Delaware River, and the Houston ship channel. This act directed the Secretary of Transportation to prioritize the need for new, expanded, or improved VTS systems in U. S. ports and channels. The results of this study, Port Needs Study (Maio et al., 1991), were submitted to the Congress in March 1992. The U. S. Coast Guard presently has two major efforts underway to improve and expand VTS in the United States. The first is "VTS Upgrade." This is an effort to improve the existing VTS. The second is "VTS 2000." This is a large procurement designed to expand VTS to additional ports. In addition to federally funded and operated VTS, the private sector has started to invest in "VTS-like" systems in areas such as Los Angeles/Long Beach and Philadelphia/Delaware Bay. The VTS at Los Angeles/Long Beach is a demonstration of how a partnership between the U. S. Coast Guard and private sector can be formed to accomplish the goals of a VTS.

A primary function of a United States Coast Guard (USCG) vessel traffic service is to gather information that is of significance to marine navigation. The modern USCG VTS maintains much of this information in computer systems. The VTS operators use these computer systems to service information requests made by individual pilots over voice communications channels. The existing VHF-FM marine radio band is commonly used by the VTS operator to transfer information to the pilot.

While this approach is successfully used today to distribute navigation information, it does require knowledgeable and trained people. Voice communications do limit the amount of information that can be meaningfully distributed. The simultaneous processes of gathering and distributing information accurately create a challenging workload for even the most experienced VTS operator. A study of VTS operator workload (Smith et al., 1994) pointed out that attention to communications was the dominant factor that determined how the VTS operator scheduled activities.

The marine electronics industry continues to introduce products that should improve navigation safety and efficiency. The introduction of these products aboard vessels is expected to increase the demand for timely VTS information. For example, electronic

chart systems (ECS) graphically present the relationship of one's own ship with respect to the geographic surroundings. Pilots have expressed a desire to view the movement of other ships on the same display. This would provide the pilots with a display similar to the VTS operator display. It will not be possible for the VTS operator to satisfy the demand for this detail of ship information using the present voice communication's methods. Such a demand can only be satisfied by improving the way VTS navigation information is distributed.

2.1 Voiceless VTS - Concept Overview

Introduction - The concept of voiceless VTS is based on two assumptions. First, that improving the flow of navigation information will improve the pilot's decision making process. Second, that information can flow automatically between the VTS computers and the computer systems aboard each ship. The existence of voiceless VTS could significantly reduce the need for voice communications between the VTS operator and each ship's pilot or master. Removing the vessel traffic service operator from the immediate information flow significantly reduces the VTS operator's workload. Introducing electronic automation increases the quantity and quality of the VTS information that can be provided.

The voiceless VTS concept and the information it automatically provides are presented in this report primarily with the needs and operation of mandatory VTS participants in mind. Of course the service is expected to also service the needs of non-mandatory participants as well. The following are definitions for a few key terms used throughout the discussion of the voiceless VTS concept:

Vessel Traffic Service (VTS): Any service, implemented by a competent marine authority, which interacts directly with vessel traffic and in response to that traffic in real time in order to improve the safety and efficiency of traffic and to preserve the integrity of the environment.

Mandatory Participant: Vessel required by 33 CFR Part 161 to comply with VTS procedures and participate in a VTS.

Navigation: The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

Pilot: The pilot is responsible for safe navigation when exercising direction and control. The U.S. Supreme Court has described a pilot as the "temporary master" in regard to navigation. The pilot normally directs and controls the vessel's maneuvering and is subject only to the overriding command authority of the master. Under the federal system, a coastwise vessel may be piloted by its master or mate if the officer has an officer's license pilotage endorsement.

Four information flow models are used below to build and explain the voiceless VTS concept. Each of these models represents alternative methods for acquiring and presenting information to the ship's navigation process. The first model depicts traditional marine navigation in the absence of a VTS. The second model represents marine navigation when and where VTS information is available. The third model represents the change to marine navigation now underway. Some of the traditional

navigation tools are being automated and more timely information is being provided to the pilot. The technology needed to support the third model is being produced today. The fourth model is a general concept of how the navigation process could gain better access to VTS information in the future. The commercial components for the fourth model, which is called "voiceless VTS," do not exist today. They need to be developed and integrated.

Model 1 - The pilot uses a mix of shipboard sensory information, personal training, and experience to successfully complete the navigation of a vessel. Some sensory information is taken directly from shipboard instruments, such as a gyro compass, while other information, such as latitude or longitude, is more useful when a navigation tool is used. When navigating in coastal areas, a nautical chart provides the required backdrop upon which to present information. It contains the geographic information needed to support pilot decisions. The flow of sensor information directly, or through the traditional navigation tools, to the pilot are depicted in *Figure 1*.

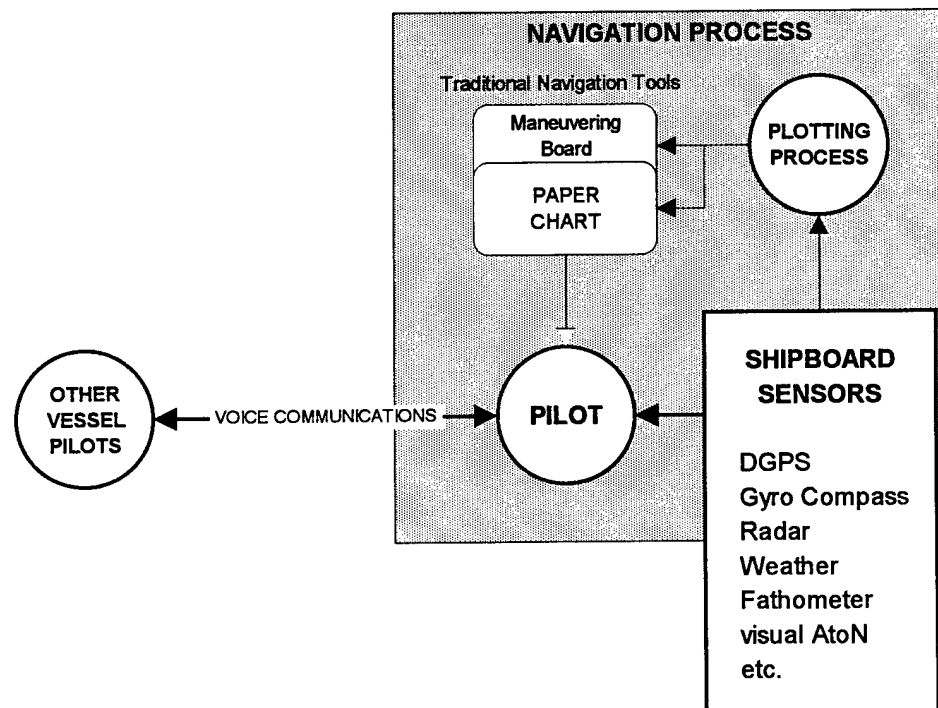


Figure 1- Simple model of traditional marine navigation process

The circles in *Figure 1* represent the human processes. These circles also represent training, experience, and knowledge that are critical to successful navigation, but that are not the subjects of this report. This report is primarily interested in the flow of sensor and database information. The arrows represent the general flow of information supporting the pilot's decision making process. The process boxes represent the tools that also play an important part in the pilot's decision making process. Notice that the "shipboard sensors" serve the pilot directly as well as the navigation process. The

arrow from the shipboard sensors directly to the pilot is shown heavier to represent the timeliness of the information. The arrow from the traditional navigation tools is less heavy. Sensor information processed by traditional navigation tools tend to give a very good record of where the vessel has been, but the information is not timely. The direct sensor output is more useful for making time critical decisions.

Voice communication is shown as the only real time information link used by the pilot to exchange information with other vessels. The use of voice communications has been a significant contributor to improved safety. However, it sometimes becomes difficult to establish and maintain good communications as the activity of the waterway increases. Organizing communications usage is one contribution made by a VTS to improved waterways management.

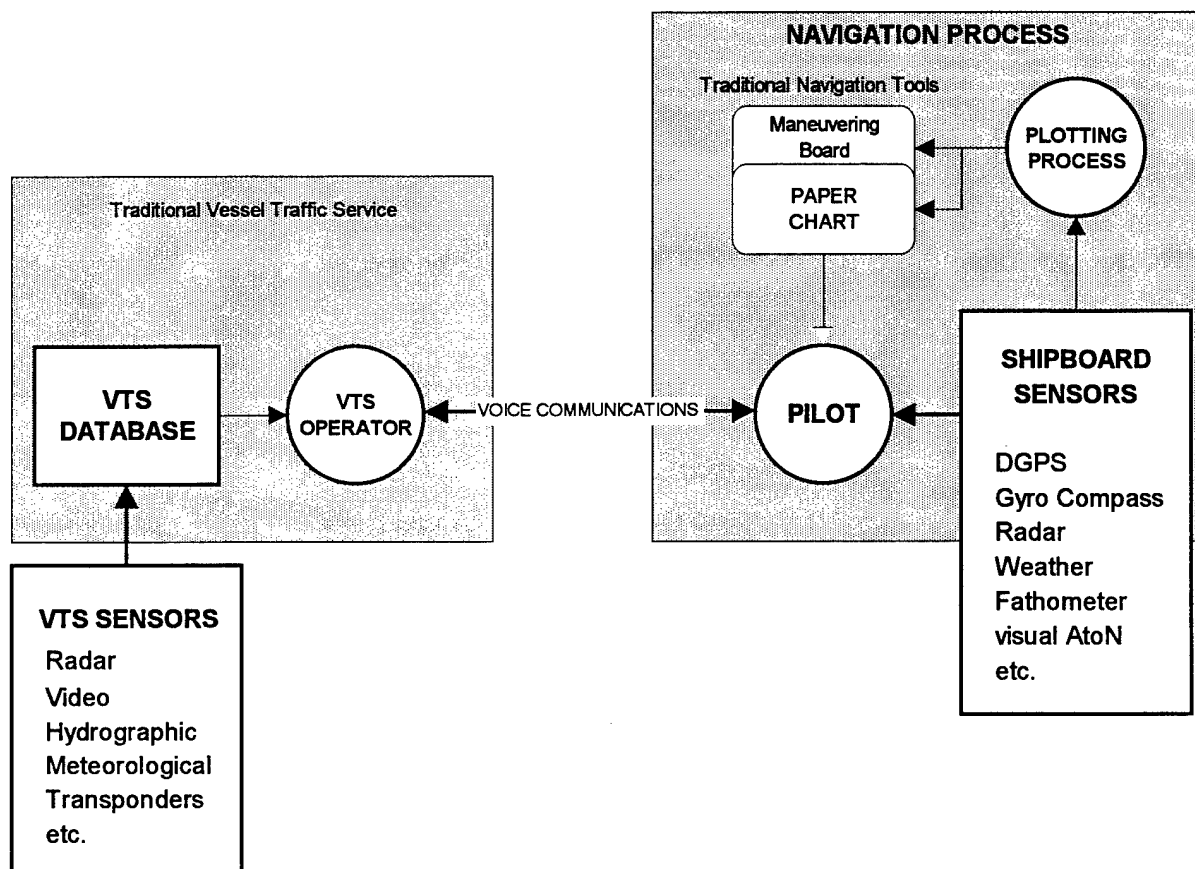


Figure 2 - Traditional marine navigation model augmented with VTS information

Model 2 - There are geographic areas where local conditions can complicate the traditional marine navigation process. A method, that has proved to be successful in recovering or improving performance, is a vessel traffic service. The vessel traffic service is staffed with operators familiar with the problems facing pilots navigating specific geographic areas. Using shore facilities, such as radar, video cameras,

hydrographic instruments, meteorological sensors, transponders, etc., the VTS operator is able to create, update, and maintain current information about a particular section of waterway. This is known as a vessel traffic service area (VTSA). In modern VTS systems, this information is maintained in a database located in a single computer. Larger VTS areas are subdivided into several VTSA's based on the amount of information one VTS operator can reasonably manage. In a modern VTS, VTSA information is exchanged with the vessel pilots using voice communications. A diagram of this augmentation is shown in *Figure 2*.

Like the pilot, the VTS operator performance can be improved by improving the sensors acquiring information for the VTS database. Sensors, such as transponders, can automatically report ship position and velocity information. Research conducted by the USCG R&D Center (Johnson et al., 1995 and 1996) shows that shipboard transponders, such as those use in the Valdez, Alaska VTS, are very effective for monitoring vessels. As new technologies, such as transponders, are added to VTS operations, the voice communications link becomes the limiting factor in moving information from the VTS database to the ship.

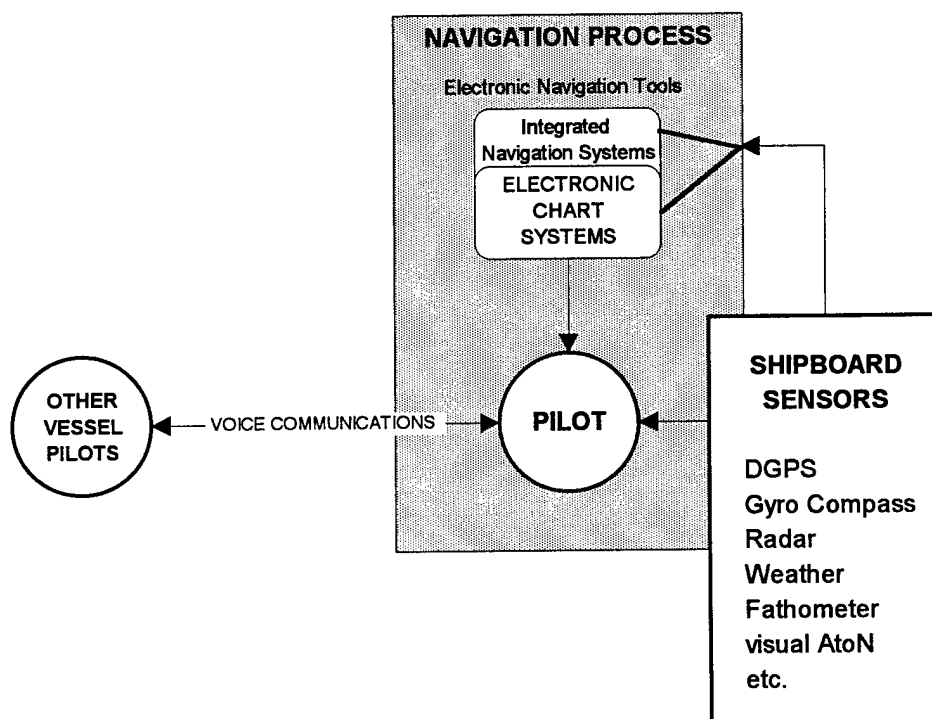


Figure 3 - Modern marine navigation with electronic navigation tools but without VTS information

Model 3 - The improvement of shipboard sensors, in particular, the introduction of Differential Global Positioning System (DGPS) technology and the creation of electronic chart replacements for the paper chart, is making it possible to automate the bulk of the "plotting process" shown in *Figure 1*. *Figure 3* depicts the impact that

electronic chart systems (ECS), and integrated navigation systems are and will continue to have on piloting. The introduction of these electronic tools has significantly decreased the amount of time it takes to give the pilot a graphical presentation of the shipboard sensor data. In fact, it is no longer necessary for the pilot to visit each sensor's display. All of the sensor information can be gathered, organized, and presented on a single display.

The automated presentation of information has also allowed the industry to improve the efficiency and effectiveness of the interface with the ship's pilot, and to offer new "navigation" features. Features, such as grounding warnings, can now be routinely provided when previously they were computationally prohibitive using traditional tools such as paper charts.

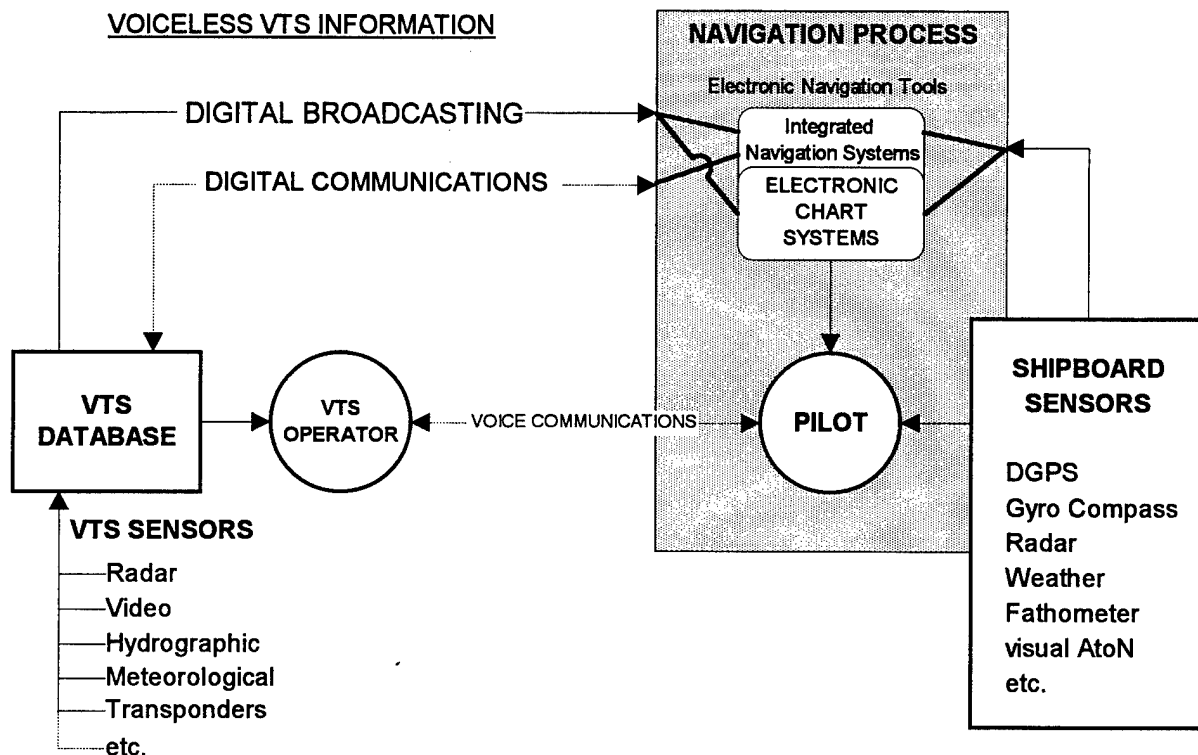


Figure 4 - Modern marine navigation with electronic navigation tools augmented with voiceless VTS information

Model 4, Voiceless VTS - With the introduction of computer-based navigation tools aboard every ship, it becomes reasonable to expect, that some time in the future these systems would accept and present information provided by a VTS. The use of voice communications between the VTS operator and the pilot would be the least desirable form of such a connection. The creation of a direct digital data path from the VTS database to the electronic navigation tools of the navigation process can be accomplished using either digital communications or an area broadcast. Wireless digital communications technology can be used to access the database using TCP/IP

internet-like solutions. At the present time, the telecommunications industry is investing heavily in wireless digital communications development. For this reason, the communications approach is not the primary subject of this report. This report concentrates on the concept of area broadcasting.

The linkage of the VTS database with the shipboard systems, represented by the electronic chart system, is shown in *Figure 4*. By automating the exchange of navigation information, the need for voice communications between the VTS operator and pilots should be reduced. This should significantly reduce the VTS operators communication responsibilities and allow more time for acquiring and validating information in the VTS database. It may also be possible to increase the size of a VTS operators VTSA thus reducing the total number of operators needed for a given waterway.

Voiceless VTS would provide the bulk of real time VTS information using digital broadcasting. This is indicated in *Figure 4* by the use of a heavier arrow. Besides being the least expensive approach, reception of digital broadcasts is also the simplest wireless method to incorporate into the navigation tools. It would be possible for inexpensive electronic chart systems to directly accept this type of information flow. While wireless digital communication is expected to be commonly available, it will be more complex to implement and more costly to use than a digital broadcast. Voiceless VTS would use digital communications for high speed or special data transfer capabilities as they are needed. Also, when inexpensive service and guaranteed access can be provided by digital communications, that option can be considered as an alternative to digital broadcasting.

Summary - A number of benefits would be realized with the deployment of voiceless VTS. First, the digital broadcasts would gradually become the primary source of VTS information. This would significantly reduce the amount of voice communications between pilots and the VTS operator. Second, the workload of the VTS operator would be reduced. Third, the quality of the VTS information would improve and the increased capacity would allow more types of information to be provided. Fourth, the VTS information would go automatically to the ship's computer systems and be immediately available for custom processing. Fifth, the ship's pilot would have immediate access to timely VTS information without the burden of requesting and handling the same information using voice communications. Finally, automated VTS technology may be viewed as an enhanced port facility.

2.2 Voiceless VTS - Database Issues

Automating the VTS database distribution using either the communication or broadcast approach should reduce the existing communications workload of the VTS operator and the pilot. However, voiceless VTS could shift some of the other VTS operator responsibilities onto the pilot. The net change in the pilot's workload is not clear and the full impact of the shift needs to be investigated further.

The voiceless VTS concept is based on the assumption that automatic distribution of the VTS database, or selected portions of it, improves port safety and efficiency from the navigation perspective. One cost of this navigation benefit may be the compromise of overall port security. The present manual method used to distribute VTS information, model 2, does limit outside access to the information contained in the database. The VTS operator is able to use experience, local instructions, and judgment to decide when and what information goes out over the airwaves. It needs to be recognized that easy access to VTS database information could compromise the existing level of overall port security.

Recognizing the potential for security problems, some precautions can be taken. The design of the broadcast format can provide for encryption that can be used to limit access to the content of the broadcast. In addition to coding the broadcast, the broadcast content should be selected to minimize the amount of compromising information that is broadcast. The accuracy of the information contained in the broadcast is also an important system design and operational issue. That is; should highly accurate port information be intentionally "dithered" for security reasons? This is similar to the selective availability added to the GPS signal. Similar information access issues also exist for the distribution of information using communications methods. Access to the VTS database will have to be controlled in order to maintain port security.

Another concern is the validity of the database. The voiceless VTS model, *Figure 4*, indicates that the information flows to the navigation process from the VTS maintained database. The information contained in the database is created using a number of sensors. The specific sensors and how the information is entered into the database is determined by the design and operation of a particular VTS. The VTS assumes some responsibility for the validity and accuracy of the database. Because of this responsibility, the database information that is distributed should be based on sensor information that can be validated using various cross checking mechanisms. This validation is necessary to protect the mandatory participant's navigation processes from false information that could enter the database due to equipment malfunctions or from sources intending to corrupt the data base. This validation of information is a significant security improvement over proposals to use single sensor systems such as the public use of ship-to-ship transponders.

Automating the distribution of information is going to speed up a process that is now limited by two people talking to each other over a radio. This is a public conversation that both people know can be received by anyone in the area. While voice radio may not be the most efficient method to exchange information from a navigation perspective, it does possess some characteristics that make people careful and sensitive to protecting the security of the port. These characteristics need to be recognized and integrated into the voiceless VTS design details.

2.3 Voiceless VTS - Digital Broadcasting Issues

Digital broadcasting is a one way flow of information, similar to radio or television broadcasting, using public frequencies. Direct digital communications is the use of a

two way channel, usually through a commercial service provider, to exchange information between two specific facilities. Two significant factors that favor digital broadcasting over direct digital communications for the distribution of VTS information are the costs to the user and the potential for unlimited and simultaneous distribution. Historically, navigation signals have been provided free of charge in the United States. This policy has resulted in widespread use of navigation signals by the general public. This has created a strong competitive market for consumer navigation electronics, and this in turn has supported the government's general desire to create a safe recreational and commercial marine environment. This has not been true in countries that charge for the use of navigation signals. If it satisfies their information needs, consumers generally favor public and free broadcasts. They view their primary cost for the information as the one-time purchase price of the receiver, and they appreciate avoiding the need for licensed radio equipment or the payment of usage fees.

Voiceless VTS information can be distributed using communications links as long as the communications capacity can expand to serve demand. As usage grows, providing timely access to all users becomes a communications capacity problem. This problem is similar to that being experienced by popular web sites on the Internet, today. Timely access to VTS information is very important. If it cannot be accessed quickly, it is of no use for navigation. Members of the marine community cannot be put in a position where they are competing with each other to access the information they all need.

A voiceless VTS broadcast supports the historic concept that the primary responsibility for the safe navigation of vessels rests with the vessel masters. Providing timely, accurate, and relevant navigation information simultaneously to all vessels will ensure that the independent navigation decisions of vessel pilots are based on common information. The vision of voiceless VTS digital broadcasting that this report represents is intended to be compatible with this idea. The following are overall design guidelines for this digital broadcast system:

- Information will be simultaneously provided to assist all vessels navigating the VTS coverage area.
- The information will be broadcast in discrete messages.
- Each message will be identified in such a way that reception equipment will be able to identify the message by type and accept or ignore it as appropriate.
- Equipment will be designed to hold information until it has been superseded.
- Messages will be encoded with error-detecting/forward error-correcting codes to guarantee shipboard systems either reject or correct corrupted information before use.
- The manner in which navigation safety information is displayed or otherwise utilized will be a function of different shipboard systems.

Broadcasting does not provide for any acknowledgment that what is being sent is being properly received. Information in digital broadcasts must be packaged and scheduled with the understanding that portions of the contents may never reach the user.

Although broadcasting does not provide directly for interactive error correction with each user, there are methods that can provide for some error reduction. These are

discussed later in the report. As long as users and providers can accept some lost information from the broadcast, digital broadcasting has been found to be a cost effective method for distributing information.

If there is concern about the reliability of broadcast signals, recall that essentially all radionavigation systems are themselves based on signal broadcasting. A unique practical example that combines broadcasting with computer based technology is the USCG implementation of the Differential Global Positioning System (DGPS) service. The success of this service operationally demonstrates that the automated creation and automatic distribution of digital information can safely and successfully improve the performance of shipboard navigation even without the benefit of interactive error correction.

2.4 Open System Interconnection 7-Layer Model

This report discusses the concept of broadcasting VTS navigation information by using a model developed by the International Standards Organization (ISO). The model is called the Open Systems Interconnection Reference Model (OSI model, for short). It was developed to provide a general structure for understanding and assisting in the development of digital links between computer based systems. This general structure was developed to help engineers create internationally standardized systems that use a number of different data and communication protocols. The OSI model is used in this report to help identify, define, and describe features that a digital broadcast service must possess. While designed primarily for communications systems, the OSI model was found to be satisfactory as an organizing framework for digital broadcasting.

The OSI model partitions the digital computer communications process into seven layers of services. The seven layers interconnect to provide the functions needed to move digital information. Each layer provides a service that ensures that digital information is transferred correctly. Standards and methods can be defined for each layer. Because broadcasting systems do not use a bi-directional communications path, the full features of each layer cannot be utilized. However, some methods can be introduced at the system level that could compensate for the lack of bi-directional layer connections.

The top three layers of the model are used to describe the process of exchanging information and the support functions needed. The bottom four layers of the model describe the processes needed to connect two systems and control information flow without errors, loss of information, or duplication of information. The following briefly describes the services provided by each layer in the OSI model, *Figure 5*.

Application Layer: This layer interfaces directly to, and performs common application services for, the application processes. It directly supports the exchange of information between application programs at both ends of the data path. This layer is not part of the applications that either generate or use the information. Specific applications are external to the OSI model.

Presentation Layer: Provides the process to transform information into a mutually agreed format. It relieves the Application Layer of concern regarding syntactical differences in data representation between the two "end-user" applications.

Session Layer: Responsible for managing the connection between cooperating applications. It manages such things as link termination and restart procedures.

Transport Layer: Manages the connection between the two end nodes in the information exchange. It provides the transparent transfer of information between the two "end-user" applications, thus relieving the upper layers from any concern with providing reliable and cost-effective data transfer.

Network Layer: Responsible for providing the functional and procedural means of transferring variable length data sequences from a source to a destination. It performs routing, flow control, and segmentation/de-segmentation functions.

Data Link Layer: Provides the reliable transfer of data frames over the physical layer. It can be used to detect and correct some of the errors that occur in the Physical Layer.

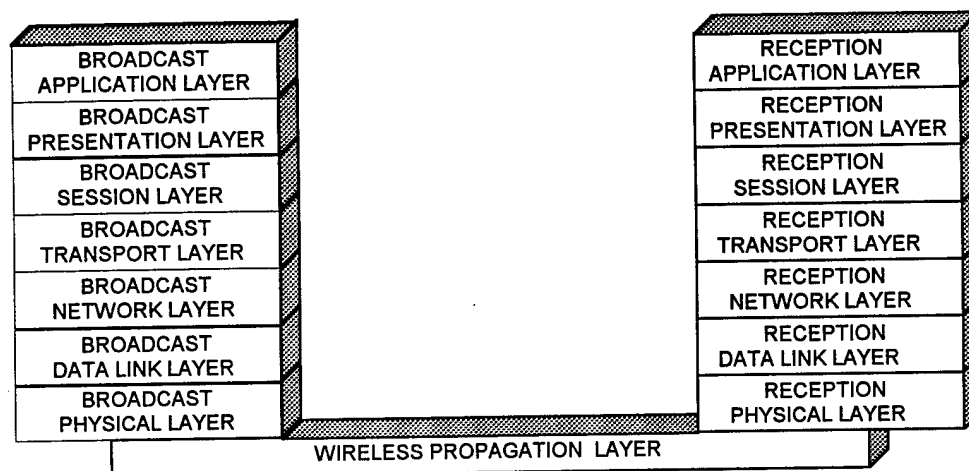


Figure 5 - General OSI model stack

Physical Layer: Responsible for the mechanical, electrical, functional, and procedural aspects of the data link between the "end-users". It establishes and terminates the communication medium connection, manages contention resolution and flow control, and converts the representation of digital data in the user equipment and the corresponding signals transmitted over the communications medium.

The details of the physical layer design are driven by the characteristics of the communications medium. In wireless broadcasting the communications medium characteristics are a significant factor in determining the overall design. In this report the communications medium is discussed as an "eighth layer" in order to draw attention

to signal propagation and electronic interference issues. In this report the eighth layer will be referred to as the "Propagation Layer".

Propagation Layer: This layer provides the connection between the information source and the destination. The uncontrolled characteristics of the propagation layer have a significant impact on the design and operation of the layers above it and performance of the overall system. Many of the precautions taken in higher layers are designed to combat problems that exist in this layer.

Each layer communicates with the layers above and below it. *Figure 5* shows how these layers can be organized into "stacks." Note that each layer exists at both the broadcast and reception side. Each layer in the reception stack must be designed with the detailed knowledge of what the corresponding layer in the broadcast stack is doing to the information passing through that layer. It is the detail of this type of information that makes it necessary to use clearly agreed upon methods and standards to implement a broadcast service. It is also important to keep in mind that an unlimited number of broadcast reception stacks can be simultaneously receiving the signal produced by a single broadcast stack.

The layers on the broadcast side may attach headers to the messages as they process them and pass them on to the next lower layers. Each lower layer treats the headers from the levels above it as part of the data that it is forwarding. On the receiver side, as a report is passed to successively higher layers, each layer examines the header applied at the corresponding level on the transmitter side to determine how the particular group of data is to be processed and routed and then removes that header before passing the data on to the next higher level.

3.0 Sample Design - VTS Navigation Safety Broadcast

In a vessel traffic service, such as the USCG VTS in New York, real time information is gathered using a variety of sensor technologies: radar, video cameras, voice radio reports, and, more recently, digital radio transponders. The information is entered into a common database. The database information is presented to a VTS operator using one of several display consoles. The VTS operator first "sees" the information on a console and then provides the information to marine pilots using VHF voice communications.

All of the information that is contained in the New York VTS computer system, Joint Maritime Command Information System (JMCIS), is organized and maintained in a common database. JMCIS already allows each operator's console at the VTS to independently display information stored in the database. The console information, and the way it is presented, is independent from the other operator consoles and the database itself. The existing capabilities of JMCIS imply that it would not be difficult to create a process that could provide the information needed for a VTS navigation safety broadcast without interfering with normal VTS operations. The simple design of a VTS navigation safety broadcast presented in this section assumes that such a capability can be created.

This section presents the technical details and issues surrounding implementation of the line in *Figure 4*, "Digital Broadcasting," that connects the "VTS Database" and "Electronic Chart System" blocks. This service of the VTS is referred to as a "VTS navigation safety broadcast (NSB)" in this report to distinguish it from some general digital broadcast. It is not the intent of this report to propose a specific broadcast design or a set of VTS broadcast services. However, this report does provide the background understanding needed to define a broadcast service. A definition of the broadcast service is needed to support the development of a broadcast performance standard and the creation or identification of the supporting technical standards and methods. Investigation of the issues that are raised by the performance standard requirements will be needed before implementation recommendations can be made. In this section a model of a broadcast system is suggested and then used to discuss the technical issues that should be considered while creating the performance standard.

The assumptions that have been implicitly made in selecting the range of options to be discussed are:

- The system makes information available, but does not require message-by-message confirmation of receipt.
- The information distributed must be made available to vessels in such a way that the marine pilot or master begins to obtain it before entering the VTS vessel traffic service area. This implies that for ports approached from the open sea, the broadcasts must be received some distance offshore.
- The content of the messages will change at varying rates. Some information may not change during the entire period of the port call of a vessel (e.g.,

announcements of some uncharted hazards to navigation), but would have to be broadcast frequently enough to make certain that arriving vessels receive it as they approach. At the other extreme, there may be information routinely updated at rates on the order of once per minute.

- The content of the broadcast will be used for a variety of purposes.
- Many, if not most, of the services will be provided by messages that are in totality quite short (equivalent to something on the order of 100 characters of text or less).

The remainder of this report describes the details of a VTS navigation safety broadcast design. A simple model of a VTS navigation safety broadcast is described and used to separate the broadcast details from standard communications details. The broadcast details are further discussed from the information flow perspective using the OSI model, and by introducing possible broadcast processes and system design techniques. The result of the investigation created a list of tasks that will need to be addressed during development of a performance standard and as a guide in assembling an actual system.

3.1 General Concept of the VTS Navigation Safety Broadcast

In point-to-point communications, the objective is to move information without error between two systems using a bi-directional communication channel. The processes at each end of the communications channel interact to eliminate any errors introduced by the connection. However, broadcasting is done without a specific recipient. An interactive dialog is not possible.

It is better to think of broadcasting as two processes that have separate objectives; one for the transmitter and a second for the receiver. First, the broadcast transmitter's objective is to make information available in a geographic area. This would be the primary objective of a VTS broadcast. Second, the user's receiver objective is to intercept the information available in a given area. From the users' perspective, it may be necessary to support simultaneous reception of several broadcasts. This is due to the fact that the user's area of interest may overlap several broadcast coverage areas. The distinctions of these two views are important when the details of the design alternatives are being considered. It is key to understanding why designing a reliable digital broadcasting system is different from designing a communications system. The following is a simple model of a broadcast system.

3.1.1 Simple Model of a Broadcast System

A random coastline is depicted on the right side of *Figure 6*. The coastal area is divided into two independent vessel traffic service areas (VTS-1 VTSA and VTS-2 VTSA). A practical example of this would be the separate US and Canadian VTS systems in the Puget Sound area. Four digital broadcast sites (A, B, C, and D) are shown along the coastline. The radio coverage of each is represented by circles drawn

around each broadcast site. Notice that the coverage area of broadcast "B" and "C" clearly cross the boundary between the two VTS areas. This begins to suggest that VTS broadcasts should be designed to provide information destined for a particular area independently of which VTS might provide the information! A vessel (V-1) is indicated on the diagram to represent a typical user of the broadcast information. Not shown in the diagram are all the shore facilities associated with the VTS systems. They are simply assumed to exist and are contributing their information to one or the other VTS database.

The left side of *Figure 6* is a detailed diagram of the "Digital Broadcasting" line that connects the "VTS Database" and "Electronic Chart System" blocks of *Figure 4*. It diagrams the flow of information from each database to the user (V-1). The information available to the user depends on where the user is located and the broadcast strategy of each broadcast scheduler (see section 3.3.1).

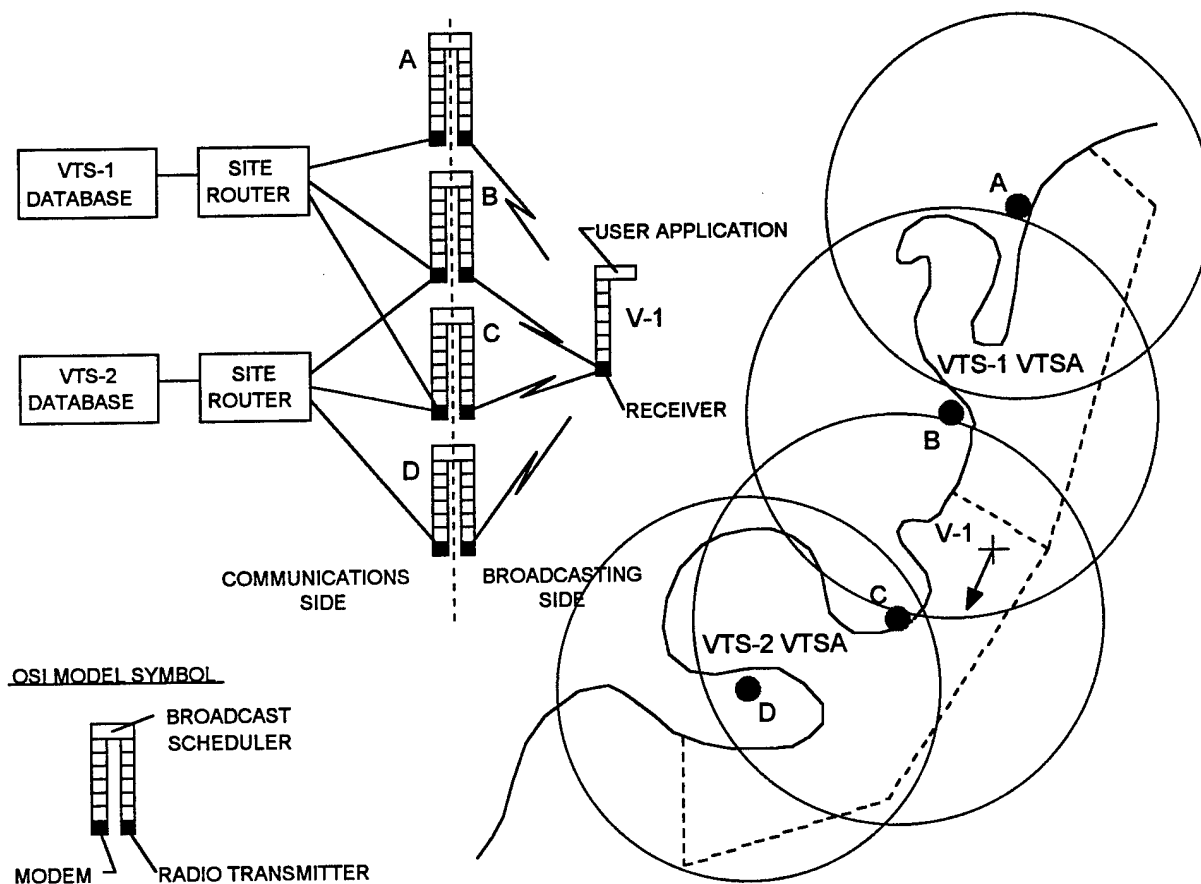


Figure 6 - Sample model of voiceless VTS Navigation Safety Broadcast system

The data to be broadcast is independently selected from each database by a "VTS database search" process. This database search process sends the selected data to the "broadcast site router" (line between the "database" box and "site router" box). This is done using standard communications methods. The broadcast site router "knows"

the coverage characteristics of each broadcast site. The router actually uses the database information to decide which broadcast sites should receive the information. Considering data characteristics, such as geographic location, the router separately sends the information to the "broadcast scheduler" process at each broadcast site responsible for transmitting the information to the different coverage areas. Again, this is done using standard communications methods. The broadcast scheduler process is the horizontal rectangle connecting the two sides of the OSI-stack. Notice that in this simple model, data from the VTS-1 database is sent to sites A, B, and C, and that data from the VTS-2 database is sent to sites B, C, and D. The broadcast scheduler process at each broadcast site independently accepts the VTS information from the router, maintains a local database, and schedules information for broadcast based on its local configuration information. In this example, it is the scheduler process that decides what and when information is broadcast. The output of the scheduler is "the broadcast" (also see section 3.3.1).

The vessel (V-1) is able to receive the signals from the "B" and "C" transmitter sites. Although both B and C were provided the same information from both VTS databases, the actual information transmitted will depend on the independent broadcast scheduler at each site. For example, the B-transmission scheduler may emphasize VTS-1 VTSA information and the C-transmission scheduler may emphasize VTS-2 VTSA information.

The purpose of this model is to expose the portion of the overall system design requiring digital broadcast standards, methods, and technology development. The communication links between the VTS database search and the broadcast site router processes; and between the broadcast site router and the broadcast scheduler processes use some form of standard OSI model communications stack. While development of these processes is needed for a VTS broadcast, the development of the communications interfaces between them is not. Standards and methods already exist. The remainder of this report will focus primarily on the OSI model stacks that connect the broadcast scheduler and the "user" application.

The full design of a broadcast system will include a number of OSI model "stacks". Most, if not all, of these stacks will describe the point-to-point communication of information and control signals between the computer systems needed to create the broadcast service. For example, in an actual system the broadcast scheduler most likely will **not** be located within the same computer that controls the signal of the broadcast transmitter. However, in order to keep the digital broadcasting issues clearly exposed, it is assumed that the broadcast scheduler and all the OSI model broadcast layers exist in the same piece of equipment. For similar reasons, the shipboard equipment assumes the radio antenna and computer display is the same equipment (although, admittedly, this is an even more remote possibility in an actual shipboard system). The following discussion of digital broadcasting, that is the link between the broadcast site and the ship, is based on the OSI model shown in *Figure 7*.

3.1.2 OSI Link between Broadcast Site and Vessels

The various processing steps needed to implement the transfer of information are distributed throughout the layers in the OSI model. The OSI model is not rigid in design. In fact, there can be "sub-layers" with greater processing responsibilities than some layers. In order to apply the OSI model to a specific design it is necessary to have a general understanding of what the design does. The significance of a layer to a particular communications problem depends on what is being attempted. *Figure 7* diagrams the processing layers that the broadcast information must flow through in order to move from the broadcast scheduler database to a shipboard application.

A continuous stream of messages containing VTS navigation information is created by the broadcast scheduler. Each of the OSI model layers then processes this message stream beginning with the application layer, "seven", down to the physical layer, "one". It is the physical layer process that actually transmits the information as a radio signal.

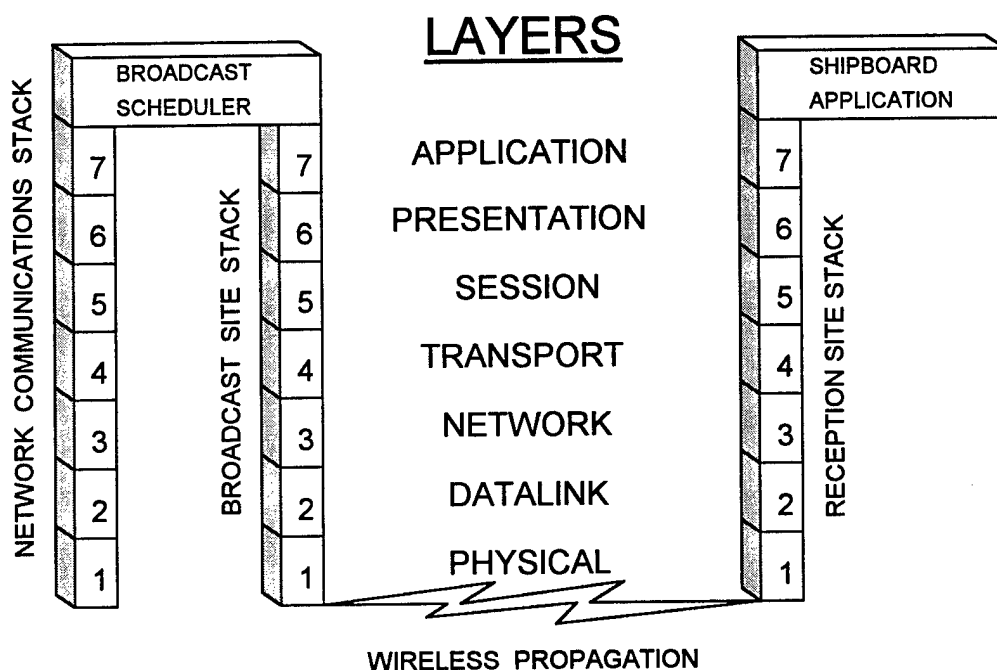


Figure 7 - OSI model for link between broadcast site and vessels

As mentioned earlier, transmitting the signal is the final objective of the VTS Navigation Safety Broadcast service. At any given time, an unknown number of users are receiving the signal. Of those messages broadcast, it is difficult (but not impossible) to

know the number of messages that are not being correctly received due to propagation, electromagnetic interference, or equipment problems.

Reception and use of the broadcast message are represented by the stack of layers on the right of *Figure 7*. Reception begins at the physical layer. Each layer from one through seven processes the received signal until the "original" message is presented to the shipboard application. There are several points to remember:

- Each layer in the reception stack complements the process of the same layer in the broadcast stack.
- While the reception layers used aboard all ships perform the same processes, the computer algorithms for those layers may not be identical in all equipment.
- The shipboard application may receive less information than a single broadcast transmits due to uncorrectable propagation errors.
- The shipboard application may receive more information than a single broadcast transmits due to the simultaneous reception of a number of broadcasts.
- The computer representation of the message data passed to the shipboard application may not match what it was when produced by the broadcast scheduler. This may be due to reception equipment design details.

The network communication's stack on the left side of *Figure 7* is simply a reminder that the broadcast site must be connected to the VTS network. The "Broadcast Scheduler" obtains navigation related information from the VTS database using point-to-point communications methods.

Based upon an analysis of the link between the broadcast scheduler and the user application using the OSI model layer definitions and implementation guidelines, a list was produced that describes the processing steps needed to implement a Navigation Safety Broadcast (NSB). Each of the processing steps is associated with a layer in the OSI model. Although it may not be necessary to incorporate some of these steps in the final design, it will be necessary to evaluate them during the research program. The following steps should be performed in the order they are presented.

Broadcast Site Information Processing Steps by OSI Layer:

Layer 7 - Organize the information to be broadcast into standard message structures.

Layer 6 - First, convert the contents of the messages into the standard symbol codes. Second, reduce the size of the coded messages using an agreed upon standard compression algorithm. Third, encrypt the messages as required to protect the information.

Layer 5 - Provide unencrypted information about the broadcast service.

Layer 4 - First, break the encrypted compressed coded messages into fixed length packets for broadcast. Second, monitor the length of the broadcast queue and provide queue length information back to the broadcast scheduling process. The queue length is an important part of the scheduler's "timely" distribution strategy. Third, maintain a separate temporary queue of recently broadcast packets for possible future retransmission. Fourth, resubmit past

packets for broadcast when directed by the "broadcast scheduler" (see section 3.1.3).

- Layer 3* - No processing responsibility. This would change substantially if the broadcast site transmitted on more than one frequency.
- Layer 2* - Place the packets into some form of synchronous or asynchronous framing structure that contains error detection and forward error correction mechanisms.
- Layer 1* - Convert the coded frames into the appropriate radio signal and transmit that signal into the coverage area.

Reception Site Information Processing Steps by OSI Layer:

- Layer 1* - Intercept the broadcast signal, demodulate the data stream and recover bit and frame synchronization. Construct the information frames and pass them to the next level for testing.
- Layer 2* - Apply the standard error detection and forward error correction mechanisms to test for and correct errors. Reconstruct packets from correct information. Throw away information that cannot be reconstructed into correct packets.
- Layer 3* - Combine data packets received from multiple broadcasts into a single stream of packets and provide them to the next layer.
- Layer 4* - Assemble the encrypted compressed coded messages from the received packets.
- Layer 5* - Recognize, capture, and provide useful broadcast service information to the layers below the session layer.
- Layer 6* - First, apply the decryption process to the messages. Second, if decryption is successful, expand the messages using the agreed upon standard decompression algorithm. Third, convert the coded message for the application being serviced.
- Layer 7* - Convert the received message into the representation needed for the application being served and provide the information to that application.

In communications systems, several strategies involving layers 2, 3, and 4 can be used to implement error recovery. These methods can be used because the receiving system can indicate to the sending system that there is a problem with the received information. This is done by using the bi-directional communications link itself. The following section suggests that there may be a system level method to recover from some reception errors in a broadcast system.

3.1.3 Extended Model of a Broadcast System

The design of an actual VTS navigation safety broadcast system would include provisions to monitor the system performance and control the system operation. While this report concentrates on identifying the broadcast-specific issues that need further development, some of the normal monitoring and control aspects of the system can be used to improve the broadcast performance. Because broadcast monitoring could be

used to improve performance, it will be introduced into the sample design and discussed.

The primary sources of errors in wireless data links are signal propagation variations and electronic interference. Some of these problems can simultaneously affect the entire area covered by a broadcast. Either problem causes the received signal to be altered or temporarily lost. Both problems are detected by the error detection and forward error correction processes in OSI model reception layer 2.

Figure 8 diagrams an example of two monitor sites (Mon. 1 and Mon. 2). The network diagram on the left indicates that the monitors could be allowed to forward information directly to the broadcast scheduler processes. In addition to this possible connection, the monitors would also provide navigation safety broadcast status to the VTS.

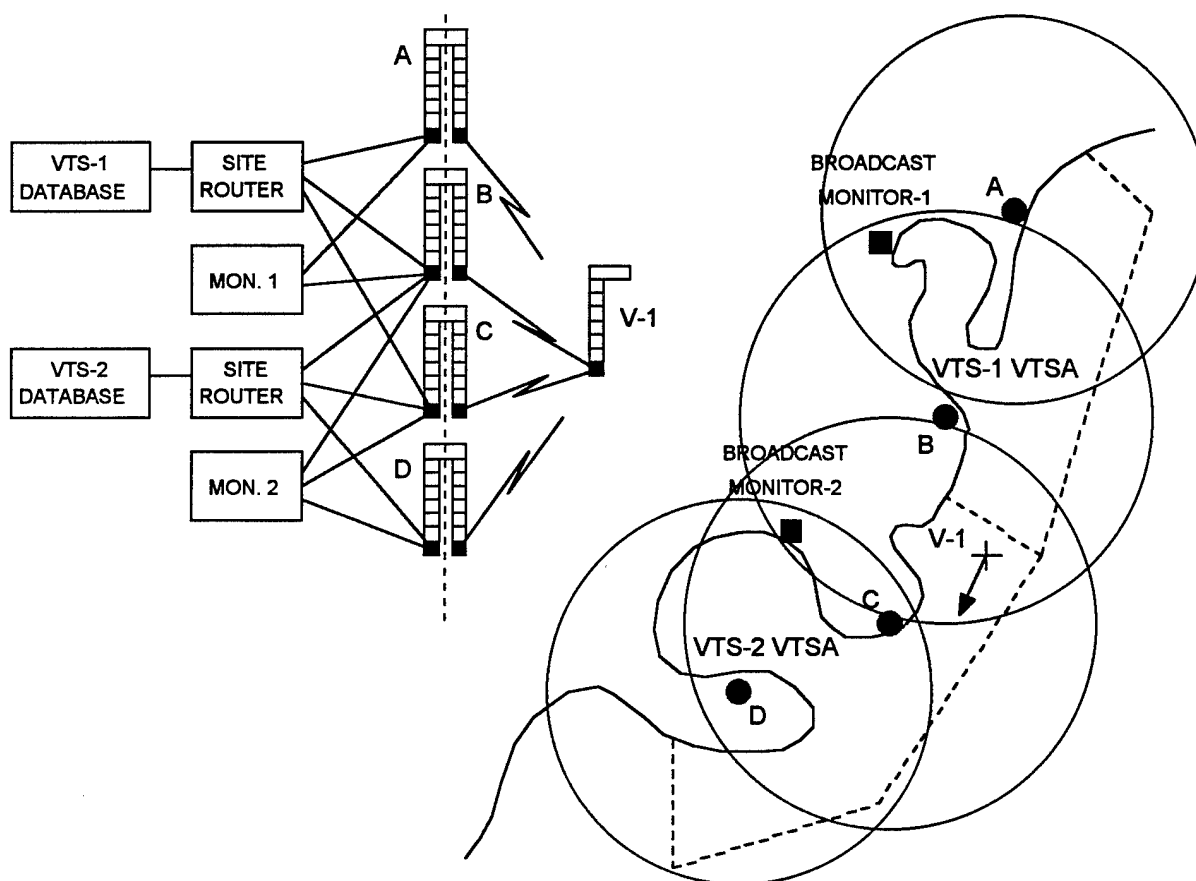


Figure 8 - Extended model of voiceless VTS Navigation Safety Broadcast system

In normal operation, the broadcast packets are identified with a sequential number. This allows the receiving transport layer (layer 4) to properly reassemble the message stream in the correct order. When a packet is damaged, the introduced error is detected at the data link layer and the packet is not passed to the transport layer. If the

monitor detects the fact that an expected sequentially numbered packet is not received, the monitor can notify the broadcast scheduler that the missing packets need to be broadcast again. If detection and re-broadcast can be done quickly, this approach could improve overall system throughput and reliability. The development and testing of this approach should be undertaken as part of future digital broadcast research.

The benefit of monitoring the navigation safety broadcast is significant for the VTS. If the broadcast is experiencing problems for whatever reason, the users will begin using the next alternative. That alternative might be VHF FM calls to the VTS.

3.2 Broadcast System Processes, Standards, and Methods

The purpose of this report is not to recommend a specific design for a navigation safety broadcast. However, processes, standards, and methods requiring further research were identified during the description of a sample design in the previous sections. A definition and background discussion of each of these processes, standards, and methods are provided in this section. The processes, standards, and methods identified in the sections described above and that require further research or identification are listed in *Figure 9*.

1. VTS Database Search process.
2. Broadcast Site Router process.
3. Broadcast Scheduler process.
4. Broadcast Monitor process.
5. Internal system message and command structure standard.
6. Broadcast message structure standard, which includes
 - a. Message compression method,
 - b. Message encryption method,
 - c. Packetizing method,
 - d. Error Detection and Forward Error Correction method,
 - e. Packet framing structure method, and
 - f. Radio transmission method and frequency plan.
7. Shipboard Information Presentation process.

Figure 9 - Processes, Standards, and Methods requiring research or identification

3.2.1 VTS Database Search Process

The sample broadcast system design (section 3.1) assumes that the information contained in the VTS broadcast originates from a valid VTS database. The VTS Database Search process is installed in the computer network containing the VTS database. Once the search rules for this process are established, this process runs independently of the broadcast system. The search scans the database or it intercepts

database updates as necessary to gather and provide the types of information it has been instructed to pass to the broadcast system. The information provided by this process is communicated to a Broadcast Site Router process using the data structure defined in the internal system message and command structure standard.

Neither this search process nor other elements of the broadcast system check the validity of information in the database. It is the responsibility of the VTS information gathering system to provide validated information. This is a critical operational assumption that may require a fresh assessment of how information is classified and entered into present VTS databases.

This process should be kept simple and access to it should be limited. A minimal computational load should be placed on a host system, such as the Joint Maritime Command Information System (JMCIS) used at existing USCG VTS. This process should be under the control of the VTS operator. The security of the VTS database and the integrity of this process must be guaranteed. This implies that the output of this process is not interactive. Rather, it is a simple flow of data in one direction, from the search process to the router process.

3.2.2 Broadcast Site Router Process

This is the intelligent bridge connecting the source of VTS information and the broadcast system. It accepts the information provided by the VTS Database Search process and routes that information to the appropriate broadcast site or sites. Considering rules designed into this process and profiles about each of the broadcast sites, this process sorts through the stream of information provided by the VTS Database Search process. When this process identifies information that satisfies all the qualifying criteria, that information is communicated to the appropriate broadcast site. If the information does not satisfy all the distribution criteria, it is simply deleted. This process does not maintain a permanent database. Once information is processed, it is deleted. The VTS information is communicated to the Broadcast Scheduler process at each broadcast site using the methods described in the internal system message and command structure standard.

The routing of VTS information to the appropriate broadcast sites is a logical, not a mechanical, process. Routing is based on the content of the information. The intelligence to make routing decisions based on the information is built into the routing process. Where information is sent may depend on the geographic location of the information and the area covered by a broadcast. It could also depend on the type of information contained in the message. Routing rules and the basis of decisions need to be developed and evaluated.

The separation of this process from the database search process allows changes to be made to the broadcast system without making any system software changes to the VTS database system (JMCIS). This is an important approach that minimizes the JMCIS costs as details of the broadcast system evolve. If the developmental work is done correctly, the JMCIS will be capable of supporting a Navigation Safety Broadcast service at the end of the research phase.

3.2.3 Broadcast Scheduler Process

The broadcast scheduler accepts, stores, schedules, and delivers VTS information to a geographic coverage area. It also maintains a permanent record of the information provided by the broadcast, and it provides status information to the VTS operator through the communications network side of the system. VTS and system control information is accepted from any number of routers and monitors. This information is used to establish and maintain a database. The broadcast scheduling process uses this database, Broadcast Monitor performance assessments, output queue status and internal rules to decide what and when information should be broadcast. The Broadcast Scheduler is the primary work horse of the broadcast system. How this process performs defines the service. The broadcasts produced by this process conform to the structure described in the Navigation Safety Broadcast standard.

The placement of the Broadcast Scheduler at the broadcast site in the sample design (section 3.1) suggests that it has the following characteristics:

- The Broadcast Scheduler operates independently of other broadcast schedulers. In particular, the content of the broadcast is the responsibility of only the site's scheduler.
- The communications input (modem shown in *Figure 6*) is a gateway capable of accepting information simultaneously from multiple site routers and monitor processes.
- The rate that information arrives at the broadcast scheduler cannot be controlled by the broadcast scheduler and will probably be greater than the rate at which it can be broadcast.
- The VTS database information may be provided by several independent VTS databases. This means that some of the information will be duplicated, but be stored under two identities! The scheduling process needs to address detection of duplicate information in the database.
- The scheduler process will have access to all the information it needs to score its own performance. This makes it possible to create an adaptable scheduling process.
- Broadcasts are continuous signals and operate on radio navigation frequencies or public broadcast frequencies protected from communications signal conflicts (unintentional jamming is not a major issue). Broadcast signals are assigned frequencies and power levels that allow continuous operation without interference to or from other radio signals.

Early establishment of performance factors should be based on an assessment of what information today's primary VTS users need (section 3.2.7). The performance factors can then be used to evaluate (score) alternative approaches to scheduling. Factors that are expected to affect scheduling performance include: the capacity of the physical transmitter link (bits per second), the size of messages, the bandwidth gain provided by the compression method, overhead of packet ED&FEC/headers, desired information range (information range is expected to be greater than the working range, see below), navigational significance of the information, number of accelerating targets, number of

moving targets, number of static targets, amount of static information, desired information accuracy, the frequency with which broadcast errors are detected by the service monitor, density of marine traffic in critical maneuvering areas, the age of the information, how often static messages need to be repeated, etc. Full anticipation of every scheduling possibility is expected to be difficult. Initial work will need to investigate adaptive processing approaches as a solution. Development and testing of alternative scheduling methods and processes should be conducted while the supporting standards, methods, and processes are under development.

The broadcast will have a working range and an information range. The range circles in *Figures 6 and 8* are the working range of the transmitter signals. The working range of the broadcast (also called coverage range) is the distance at which some percentage of the broadcast messages can be received (using FEC) on some statistical average. An acceptable percentage will need to be determined. The information range of the broadcast is addressing the content of the broadcast. Users are expected to be interested in information outside the coverage of the broadcast as they navigate away from the broadcast site. The area that a Broadcast Scheduler is expected to cover with respect to information will be larger than the working range. In general, the Broadcast Site Router will provide information based on the information range of a broadcasting site rather than the working range.

3.2.4 Broadcast Monitor Process

Broadcast monitors are installed to assess the real time effectiveness of the service. Using the content of received messages and automated methods, the Broadcast Monitor process provides real time control information to the Broadcast Scheduler process, status and warning information to the VTS operators, and maintains historic records concerning the information received in the coverage area and the performance of the broadcast system. The true benefit of the monitor's real time ability to request the retransmission of specific packets will have to be assessed after the reliability of the radio signal and FEC can be determined.

The monitor site should be located near the limit of the transmitter's working range. Each transmitted signal should be monitored by a separate monitor process. Co-located monitoring would be done using separate equipment. The overall broadcast system should be designed to continue to operate even when the monitor is unable to function as part of the system. The Broadcast Monitor process communicates with the Broadcast Scheduler using the methods described in the internal system message and command structure standard.

3.2.5 Internal Broadcast System Standard

This is a document describing the information and command signals communicated between elements of the system. Because the internal communications can be designed using existing network communications standards and services, this standard will primarily contain high level information. Communications details will be more useful as specifications for purchased services; not part of the standard. The standard is used by the process and system designers to construct and maintain the system.

3.2.6 Broadcast Message Structure

The broadcast message structure will need to be completely described in a standard. This standard will describe both the signal characteristics and the information content of the broadcast. Development of a Navigation Safety Broadcast (NSB) standard will be a significant effort. This document describes everything a potential equipment manufacturer needs to know about the transmitted "signals in space" produced by the service. It is used to build receiving equipment that intercepts the transmitted signals and software that presents the broadcast information to the user. The methods described below (sections 3.2.6.1 - 3.2.6.6) would be a portion of the information contained in this document. The document would also contain a description of all of the information provided in the broadcast with instructions on how the information should be used.

In addition to this document, it may be beneficial to plan to provide samples of software and data sets that manufacturers can use during equipment development. Previous USCG R&D experience with the development of Differential GPS equipment and software, showed that assistance of this type, shortened the commercial development process and improved the quality of the first products. Impartial testing of developmental commercial products is another means that has been successfully used to encourage commercial efforts and to guarantee quality products.

3.2.6.1 Message Compression Method

The purpose of data compression is to reduce the length of the bit string representing a message without compromising any of the information in the message. Data compression allows more information to be broadcast using a fixed number of data bits. This increases the amount of information the Broadcast Scheduler can transmit in a given time interval. The advantage of increasing the capacity of the broadcast channel is slightly offset by the increased processing burden placed on both the transmitting and receiving ends.

This form of compression (at the OSI model level) is a mechanical method that works on the bits of information in the message without knowing what the information is. The committee that develops the message structure for the NSB standard will need to address the question of how message information should be represented. It is the responsibility of the NSB standard committee to use heuristic or logical methods to represent the message information in a compact form prior to the mechanical compression process. Creating compact message structures for the NSB standard will improve the capacity of the broadcast channel.

3.2.6.2 Message Encryption Method

Message encryption limits access to information. There are several reasons why this capability should be included in the design of a broadcast system. It could be used selectively to limit the distribution of some of the information being broadcast. This might be necessary for port security reasons. It could also be used to limit information distribution to those who have paid a service fee. If included in the design, policy

decisions concerning how this capability is used can be made as circumstances warrant during the operation of the system.

Denial of access to all the information would bring into question the "navigation service" quality of this broadcast. In particular, if protected international navigation frequencies are used as the broadcast channel, the signal would be expected to be made available to the general public. However, partial denial of certain information could be viewed as a necessary feature of even a navigation service if it is necessary to protect port security. An example is the DOD selective availability on the GPS signal.

The method selected should provide for a large number of possible keys. Operating the service with a mix of encrypted and open messages should be considered normal. For example, an open message can be followed by a secure message that is followed by a message with a service charge. Use of encryption keys should not cause malfunctions in unkeyed user equipment. It should be possible to use the same broadcast channel for time multiplexed open, secure, and cost recovery messages.

3.2.6.3 Packetizing Method

Error detection and forward error correction (ED&FEC, see section 3.2.6.4) methods are easier to understand and implement if they operate on a fixed number of bits. In fact, there are optimal numbers of bits. The selected packetizing method breaks the continuous stream of coded compressed encrypted messages into chunks of bits that can be protected with a ED&FEC method. The use of message packets produces groups of bits that can be enveloped in a frame containing a header and ED&FEC information. The packet header contains sequence information that allows the received bits to be routinely arranged in proper order even if the packets are received out of order.

The use of packets allows the recovery of larger messages without retransmitting the entire message. The Broadcast Monitor will request missed information to be rebroadcast at the packet level. Selecting the optimal number of bits in a packet will need to take into consideration a number of factors; for example, the data rate of the transmitter, the nature of the electronic noise, the characteristics of the propagation medium, broadcast monitor operation, and the time it takes to signal the Broadcast Scheduler to retransmit a packet. The analysis of the packet size options and ED&FEC methods will require the use of both modeling methods and physical signal measurements at the potential broadcast frequencies.

3.2.6.4 Error Detection and Forward Error Correction Method

Error detection (ED) provides a way to recognize a corrupted packet of data when it arrives. Error detection protects the receiving system from suffering the consequences of using an incorrect packet of information.

Forward error correction (FEC) provides a way to correct corrupted information. Calculations are performed on the broadcast information before it is transmitted. The resulting correction parameters are sent along with the information by adding extra bits

to the transmitted signal. The reception process uses the correction parameters to correct errors in the received information. Forward error correction success is limited. It provides a mechanism for recovering information only when a few bits of information are in error. The Broadcast Monitor (section 3.2.4) will only be able to detect some of the coverage-area-wide data corruption problems. There will be localized problems that the Broadcast Monitor will not detect. FEC will provide a way to recover from some of these local problems. If the Broadcast Monitor process is not included in the final system design, FEC will be the only corrective option other than waiting for the next transmission of the missed message.

3.2.6.5 Packet Framing Structure Method

The packet framing structure is used to code the transmitted signal in such a way that the receiving equipment is able to identify the various bits of a continuously broadcast signal. The framing structure provides delineation of a frame's start and end and also includes the ED&FEC bits for the packet. It provides a timing point that can be identified and used to begin sorting out the received bits based upon time. This is how the identities of the received bits are established.

3.2.6.6 Radio Transmission Method and Frequency Plan

This contains the detailed electronic information needed by manufacturers building products designed to use the broadcasts. It also describes how the bits of information will be represented in the broadcast signal. The signal characteristics and frequency usage plan are important to design engineers as well as spectrum managers concerned about possible problems being created between this and existing services.

3.2.7 Broadcast Information Presentation Process

Presently, VTS information is distributed using voice communications. Therefore, pilots have become conditioned to requesting and obtaining information that can be understood using their sense of hearing. The information distributed using the Navigation Safety Broadcast proposed by this report will, more likely than not, be delivered visually. Will the pilot have to adapt his process from hearing information to seeing it, or will the computers be expected to carry-on a conversation with the pilot?

The purpose of the Broadcast Information Presentation process is to convert the "bits and bytes" of the received messages described in the Navigation Safety Broadcast standard into some form that a user can understand without having to reference the standard. The Electronic Chart System (ECS) shown as the destination of the digital broadcast in *Figure 4* is an example of such a visual presentation process. To date, the USCG view of VTS information has been conditioned by the responsibilities of the VTS operator. This does not provide much insight into how a pilot will view the same information. The pilot's responsibilities are different. What a pilot will see in the VTS information and how long it will take to see it, depends on what they expect to get out of the information. Little is understood about what a pilot will want to see and how they will want it presented, yet their understanding of the VTS information is a critical factor in the success of this entire digital broadcasting approach.

An investigation needs to be done on how pilots will transition from hearing to seeing VTS information. Does this sensory change alter their information needs? This investigation is needed to ensure that the required VTS information is being adequately broadcast and that the shift in sensory workload does not work to the detriment of the overall objective of a safer more efficient waterway. Questions that this investigation should address include:

- What is the present "VTS workload" for a marine pilot? That is; how does present VTS interaction impact a pilot (percentage of workload)?
- What impact would a visual interface containing "automated VTS information" have on his workload?
- Will the NSB simply transfer VTS operator workload to the pilots?
- What information do pilots want and how do they want the information delivered?
- What features should the pilot system have?
- What VTS information does the pilot need to understand?
- Does the NSB result in an overall workload reduction or increase for the pilot?

In addition to the human interface there are a number of technical issues that the users electronic application processes must address. For example, the application may be capable of receiving multiple broadcasts. If this is a capability, the application must be able to routinely handle duplicate information arriving from independent broadcasts.

The VTS database should be treated as a separate information layer in an ECS or IMO Electronic Chart Display Information System (ECDIS). The information should not be integrated with the chart database. The "half-life" of the information is much too short. It does not have the same temporal stability as the chart data. Functions and features of the ECS or ECDIS, that require the combination of chart and VTS information, should perform their calculations by drawing their inputs from the two separate databases at the time of the calculation. The details of how the VTS data should be presented on top of the ECS or ECDIS chart backdrop is also an area requiring more research. This question has not been addressed by either the IMO-ECDIS or RTCM-ECS committees.

Finally, the broadcast and communications links between the VTS database and the user application (such as the ECS in *Figure 4*) are intended to compliment each other. Work needs to be done to investigate the future features of an ECS (or ECDIS) that may need to access the VTS database though a communications connection.

3.3 Broadcast System Design Issues

In the process of creating and describing the sample design in *Figures 6 and 8*, some issues could not be presented under a particular process, standard, or method section. These system level issues are presented here for future consideration.

The sample design that has been presented assumed that broadcast sites transmitted on a single channel. Research into multi-frequency broadcasts may produce system wide benefits. Besides the obvious benefit of increased information capacity, broadcasts on multiple frequencies unleash the many options of OSI model layer 3, the network layer. In this report, the contribution of layer 3 was minimal due to the fact that no "network options" are available when transmissions are limited to a single frequency.

What the user sees and understands as a result of receiving the NSB is the key to realizing the desired benefits from distributing digital VTS information. The understanding is conveyed to the user through the interpretation of the shipboard display system. Some investigation into ways to guarantee the performance of the shipboard electronics and software needs to be done. The objective of the investigation would be to determine ways that guarantee that what the user sees on the display conveys the understanding that is contained in the VTS information being broadcast. What are viable options? Should the USCG develop and "give-away" software that must be used? Will equipment "type acceptance" be necessary? Could some existing commercial quality assurance program be used?

4.0 Conclusions

Implementation of the voiceless vessel traffic service concept will require the development of new or the identification and review of existing processes, standards, and methods that can be used to create the service. Because the voiceless vessel traffic service concept is based on the automatic distribution of VTS information, a fresh review of how information is entered into the vessel traffic service database will be needed to reaffirm that the information in the database undergoes sufficient validation and is suitable for automatic distribution. An assessment of the sensitivity of information in the database should also be done to determine if open and automatic distribution of that information will compromise the present levels of port security.

The voiceless vessel traffic service model suggests the use of two complementary methods for the automated distribution of information, wireless digital communications and wireless digital broadcasting. Presently, the telecommunications industry is investing heavily in the development of bi-directional wireless communications services. Significant government funding for voiceless VTS development of wireless digital communications technology is not presently required. The development of digital broadcast methods is not receiving the same level of telecommunications industry support. The processes, standards, and methods needed to deploy a VTS digital navigation safety broadcast will require government support.

There are two factors that favor the use of broadcasts for the distribution of navigation information. The first factor is the cost to the user. In general, the United States does not charge for navigation signals. The user needs to make only a "one-time" investment in equipment. On the other hand, wireless telecommunications services charge usage fees. The second factor is the ability of broadcasts to simultaneously distribute the same information to an unlimited number of users. Broadcast capacity is independent of user demand. Communications channels can become saturated and fail as demand increases. Demand for navigation information is expected to be the highest when navigating conditions are the worst. Potential failure of the voiceless VTS navigation information link during high demand is not a desired voiceless VTS characteristic.

A simple model of a NSB system was developed and used to help identify areas requiring development. The following processes were found to be necessary to create a simple design of a voiceless VTS navigation safety broadcast:

VTS Database Search - This intercepts and forwards validated VTS database information to the "Broadcast Site Router." This process should be designed to be a minimum load on an existing VTS database management process.

Broadcast Site Router - This accepts information provided by the "VTS Database Search" and reviews the content of the information. If the information is appropriate for distribution, it is forwarded to the "Broadcast Scheduler" at each appropriate broadcast site.

Broadcast Scheduler - This accepts information provided by the "Broadcast Site Routers" and enters it into its local database. Using the local database, information from the "Broadcast Monitors", and internal strategy objectives, it prepares and broadcasts VTS messages.

Broadcast Monitor - This gathers the navigation safety broadcast information off the airwaves much as a VTS NSB user equipment would. It monitors performance and detects specific problems that can be corrected by the "Broadcast Scheduler." It provides reports directly to the "Broadcast Scheduler" for each broadcast site it monitors.

Two standards describing the operation of the system are needed. The first standard would describe the internal system message and command structure of the system. This would be used to design and maintain the system. The second standard provides everything a potential equipment manufacturer would need to know about the broadcast signal in order to manufacture user equipment. A number of methods need to be developed or identified to support these standards. They include:

Message Compression method - This improves the broadcast channel efficiency thus increasing the information capacity.

Message Encryption method - This opens the operational capability to broadcast information to a limited group of users.

Packetizing method - This establishes how the broadcast bits are organized for transmission and forward error correction schemes.

Error Detection and Forward Error Correction method - This protects the user's system from being infected by erroneous information.

Packet Framing Structure method - This establishes how the transmitted information can be recovered from the intercepted signal.

Radio Transmission method and Frequency Plan - This establishes how the user's radio receiving equipment needs to be designed.

Automating the distribution of information reduces the voice radio communications between the vessel pilots and vessel traffic service operator. This is viewed as a workload reduction for the operator, but the shift of the "vessel traffic service workload" for the pilot. The significance of this shift is not well understood. The impact of automation on the pilot as a result of this switch from aural distribution to visual presentation needs investigation. The study is needed to report the change in piloting workload, impact on marine safety, and the benefits of this approach. The pilot's views on the information content and shipboard presentation are needed to develop the most appropriate shipboard presentation.

Future USCG research should include a demonstration in the form of a "voiceless VTS test bed" conducted with the cooperation of an operating USCG VTS and the marine pilots association working in their vessel traffic service area. This demonstration would provide an opportunity to develop and evaluate the needed voiceless vessel traffic services processes and standards. It would also provide an opportunity to work with the pilots to develop the true information requirements for the navigation safety broadcast's content and scheduling strategies. The demonstration would serve as a vehicle for standards and equipment development in cooperation with the industry that would support future operational deployment of voiceless vessel traffic services.

4.1 Recommendations

1. Establish a cooperative effort between the USCG VTS Upgrade (JMCIS) project and the R&D VTS project to add a new capability to JMCIS. The desired characteristics of this capability are described in section 3.2.1 (VTS Database Search Process). Installation and operation of this new JMCIS capability at an existing USCG VTS would greatly reduce the R&D costs for voiceless VTS experimentation.
2. Establish a Cooperative Research And Development Agreement (CRADA) that supports investigation of actual digital broadcast issues and the pilot's VTS information display requirements (see section 3.2.7). The goal of the CRADA is demonstration of a proof-of-concept digital navigation safety broadcast and an evaluation of its benefits for commercial pilots. This agreement would include an existing USCG VTS command and the pilots operating in their vessel traffic service area.
3. With the cooperation of the Radio Technical Commission for Maritime services (RTCM), establish a working group that would develop a standard describing the signal and content of the digital VTS Navigation Safety Broadcast. This group would contain representatives from government, industry, and academia. The work of this group would address the issues described in section 3.2.6 (Broadcast Message Structure).
4. Continue to investigate, develop, and test alternative methods and software needed to implement the internal USCG broadcast information and control structure described in sections 3.2.2 through 3.2.5.
5. Establish a new R&D effort to investigate and develop alternative VTS sensors that would automate validation of the VTS database contents (see section 2.2).
6. Establish a new R&D effort to evaluate the future information needs of voiceless VTS users and the delivery methods that minimize the impact on their workload (see section 3.2.7).

REFERENCES

- Smith, M. W., Laxar, K. V., Benoit, S., and Dowd, M. K. (1994). *Workload of the VTS Sector Operator and Implications for Task Design* (Report No. CG-D-10-95). Groton, CT: U. S. Coast Guard Research and Development Center.
- Johnson, G. W. "Communications Technologies for Automated Dependent Surveillance," *Conference Record MILCOM*, San Diego, November 1995, pp. 40-44.
- Johnson, G. W. and Pietraszewski, D. "Results of ADS Communications Testing," *Conference Record OCEANS 96*, Fort Lauderdale, September 1996, pp. 95-104.
- Maio, D., Ricci, R., Rossetti, M., Schwenk, J. and Liu, T. (1991). *Port needs study (Vessel Traffic Services benefits): Study Overview* (Report No. DOT-CG-N-01-91-1.2). Prepared by the Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, Cambridge, MA (Report No. DOT-VNTSC-CG-91-2.1). Washington, D.C.: United States Coast Guard, Office of Navigation Safety and Waterway Services. (NTIS)
- Mead, K. M., Anderson, J. H. Jr., Nakamura, E., Gazda, S. R., and Egan, C. T. (1993). *Coast Guard Selection of Ports for Establishing or Improving Vessel Traffic Service Systems* (Report: GAO/RCED-93-110). Washington, D. C.: U. S. General Accounting Office.
- Anderson, J. H. Jr., et al. (1996). *Coast Guard Should Address Alternatives as It Proceeds With VTS 2000* (Report: GAO/RCED-96-83). Washington, D. C.: U. S. General Accounting Office.