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SURVEILLANCE TECHNIQUES FOR THE VESSEL
TRAFFIC SERVICE
SYSTEMS OF THE U.S. COAST GUARD

by

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The U.S. Coast Guard operates several Vessel Traffic Services (VTS) in major U.S. shipping ports. These systems were designed and implemented twenty years ago. They were designed for a single mission, port safety. The surveillance and display systems are well beyond the planned service life and need to be replaced.

This thesis investigates and summarizes up-to-date methods of providing surveillance services to a VTS. The author includes a history of VTS, an analysis of the assigned missions, and a review of the C^2 factors involved. A functional model of a VTS is developed and used to evaluate the best mix of technologies for VTS systems.

The author concludes that a mixture of shore-based radar surveillance and satellite-based surveillance can provide the detection and identification information necessary to operate a multi-mission VTS. In order to take advantage of inexpensive narrow band data links, such as voice grade telephone circuits, radar information must be processed through a radar scan convertor. Use of this technology also improves automated target detection, tracking, and display capabilities of the existing radar and display systems. A second generation VTS should have a modular design, centered around a standardized Vessel Traffic Center (VTC) C^2 system. This will reduce the cost of operating a VTS by reducing the manpower needs of a VTC, improving the performance of the VTS system during multi-mission tasking, allowing the use of different sensor types, and creating a way of integrating VTS information into the main stream of Coast Guard operations.

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Surveillance Techniques for the Vessel Traffic Service Systems of the U.S. Coast Guard

by

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requirements for the degree of

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ABSTRACT

The U.S. Coast Guard operates several Vessel Traffic Services (VTS) in major U.S. shipping ports. These systems were designed and implemented twenty years ago. They were designed for a single mission, port safety. The surveillance and display systems are well beyond the planned service life and need to be replaced.

This thesis investigates and summarizes up-to-date methods of providing surveillance services to a VTS. The author includes a history of VTS, an analysis of the assigned missions, and a review of the C^2 factors involved. A functional model of a VTS is developed and used to evaluate the best mix of technologies for VTS systems.

The author concludes that a mixture of shore-based radar surveillance and satellite-based surveillance can provide the detection and identification information necessary to operate a multi-mission VTS. In order to take advantage of inexpensive narrow band data links, such as voice grade telephone circuits, radar information must be processed through a radar scan convertor. Use of this technology also improves automated target detection, tracking, and display capabilities of the existing radar and display systems. A second generation VTS should have a modular design, centered around a standardized Vessel Traffic Center (VTC) C^2 system. This will reduce the cost of operating a VTS by reducing the manpower needs of a VTC, improving the performance of the VTS system during multi-mission tasking, allowing the use of different sensor types, and creating a way of integrating VTS information into the main stream of Coast Guard operations.

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I. INTRODUCTION

A. BACKGROUND

The Ports and Waterways Safety Act (33 USC 1221) authorizes the U.S. Coast Guard to establish and operate Vessel Traffic Services (VTS) in designated areas in order to:

> ...(1) reduce the possibility of vessel or cargo loss, or damage to life, property, or the marine environment; (2) prevent damage to structures in, on, or immediately adjacent to the navigable waters of the United States or the resources within such waters;....

Surface search marine radar is the surveillance backbone within most VTS areas. Closed Circuit Television (CCTV) is used where radar surveillance is not practical. These technologies provide reliable and accurate means for general surveillance of a VTS area, vessel traffic monitoring, and for vessel traffic control. The Coast Guard is currently using microwave data links to transmit raw radar and CCTV information from remote sites to a centralized Vessel Traffic Center (VTC). These data links, as well as the entire VTS system, were designed and implemented in the early 1970's. The systems use twenty year old, "off-the-shelf" technology which had a planned life cycle of ten years. The systems are oriented toward accomplishing the single mission of harbor surveillance while the Coast Guard maintains a multi-mission policy. The cost of operating and maintaining the microwave data links has become prohibitively expensive for the Coast Guard.[Ref. 1]

In the last twenty years there have been major advancements in the computer, communication, and data networking fields. There has also been a realization within all branches of the federal government that a planned effort to improve Command, Control, and Communication (C^3) capabilities will help offset increasing costs, expanded mission requirements, and system complexity. Improving the Coast Guard's C^3 capabilities will allow the service to operate more efficiently.

B. RESEARCH OBJECTIVE

The purpose of this research is to investigate and summarize up-to-date methods of providing surveillance services to a VTC in a manner that is consistent with the Coast Guard's need to reduce overall costs, automate man-power intensive operations, and provide information that can be integrated into an effective Coast Guard-wide C^3 environment.

C. RESEARCH APPROACH

The research portion of this thesis includes a literature search, a review of Coast Guard policy, interviews with Coast Guard VTS, Research and Development, Engineering, and Program Management personnel; interviews with industry representatives, and a technology review to determine:

- The scope of the original VTS mission and required data content.
- The scope of the current VTS mission and required data content.
- Determination of desired changes for existing VTS systems and expansion of coverage to new ports.
- The status and capabilities of current VTS technology.
- Availability, applicability, and budgetary feasibility of commercially available systems or components.
- Alternative methods of harbor surveillance that can meet the overall goals of the Coast Guard.

D. IMPORTANCE TO THE COAST GUARD

This thesis will identify feasible alternatives to transmission of raw radar, video, or similar surveillance information to VTCs. Given the recent budgetary climate, it is imperative that each Coast Guard program result in the largest possible benefit within its multiple mission areas. In the case of VTS, there are synergistic effects possible through integration of surveillance information into the day-to-day C^3 of Coast Guard operations. Use of a standardized network approach can allow VTS information to provide an important input to the Coast Guard's Maritime Law Enforcement (MLE), Maritime Defense Zone (MDZ), and Search and Rescue (SAR) missions in addition to its use within the Port Security and Safety (PSS) mission of a VTS. Reductions in maintenance, operation, and personnel costs are possible through the use of modern "off-the-shelf" and commercially supportable technology. Careful planning of such an information network will allow for further cost reductions as commercial telecommunication capabilities expand, providing faster and more reliable data rates at a lower cost. Integrated Services Digital Networks (ISDN) and similar modernization programs are scheduled to come on-line during the 1990's and will impact C^3 systems like a second generation VTS.

E. THESIS OUTLINE

In order to determine feasible alternatives to the transmission of raw radar or video data by microwave link, it is necessary to appreciate the engineering, political, logistical, and operational concerns facing the Coast Guard. In the past, the Coast Guard designed systems without regard for the synergistic effects of integrated C^3 planning. System design was reactionary, often due to major accidents like the Argo Merchant, Amoco Cadiz, and Exxon Valdez oil spills. With on-going budget limitations, the Coast Guard cannot afford the overhead of major research and development costs. We must rely on commercial and defense industry interests to develop and field new technology. This new technology must be examined and then employed to complement all the missions assigned to the Coast Guard.

1. Chapter II, VTS Services in the United States

Chapter II outlines the development of VTS systems in the United States. In this chapter the author will summarize the following aspects:

- Historical events leading to development of VTS systems in the United States.
- Legal intent behind the laws that established federal VTS systems in the United States.
- Determination of which ports were to be served, and which ports are currently served, by a VTS.
- The original and expanding missions of Coast Guard VTS.
- Current VTS system requirements and the technology used to carry out these requirements.
- Data necessary to carry out the missions of a VTS.

2. Chapter III, VTS and Coast Guard C^2

Chapter III reviews some of the non-technical aspects of integrating surveillance data into a Command and Control (C^2) environment which could be used in day-to-day Coast Guard operations. A discussion of Command and Control theory is included to illustrate the importance of including C^2 considerations in the system engineering of a second generation VTS system. A description of related projects within the Coast Guard will illustrate the benefits of an integrated system architecture using standard data content and format.

3. Chapter IV, Technology Review

Chapter IV surveys and summarizes existing technology that can be used for VTS area surveillance. In this review the author will discuss various techniques that can link radar and video information to a VTC. Other technologies that are capable of acquiring and tracking VTS contacts, in a manner consistent with the applicable Coast Guard missions, will also be discussed. The chapter divides the technology into three basic sections:

- Systems capable of directly transmitting radar or video images.
- Systems using data compression and filtering of radar or video camera signals allowing use of low data rate transmissions in the order of 9600 bps or less, or analog signals with a bandwidth of 3 KHz or less.
- Hybrid systems using a mixture of technologies or based on technologies other than radar or video camera sensors.

This chapter is descriptive in nature. The summary ranges from continuing use of analog microwave links for the existing radar and video systems to the use of satellite based, non-radar, tracking and identification systems.

4. Chapter V, Evaluation of Systems

Chapter V has two basic sections. The first is development of the criteria which could be used for system selection. These criteria will be based on the Coast Guard's need to integrate systems, reduce costs, and meet mission requirements. Using the overall characteristics of the technology described in Chapter IV and the criteria developed in the first part of this chapter, the author will accomplish a rough assessment of the cost effectiveness of the different systems. Using this information the author will identify the most feasible types of technology for use in a Coast Guard VTS.

5. Chapter VI, Conclusions

Chapter VI includes the author's conclusions and recommendations regarding selection of feasible alternatives for tracking contacts in a VTS system.

II. VESSEL TRAFFIC SERVICE (VTS) IN THE UNITED STATES

A. VTS DEVELOPMENT IN THE U.S.

1. Historical Aspects of VTS Development

Vessel Traffic Services have been in operation since the late 1800's. Table 1 on page 6 lists important milestones in VTS development for the United States. Vessel traffic management became a concern following World War II as the density of traffic, particularly transportation of hazardous materials, choked the major ports of the world. By 1984 the waterborne commerce in the United States had increased by more than 200%, to slightly more than 1.8 billion tons [Ref. 2: p. 5]. The U.S. Coast Guard anticipates an annual 2% increase in traffic. This figure includes both domestic and foreign waterborne commerce flowing through U.S. ports [Ref. 3: p.358].

2. Increasing Ship Size

During the 1960's and 1970's technological spinoffs from the defense, space, and computers industries, as well as oil industry economics, allowed construction of very large commercial vessels. These immense ships are used primarily for transportation of crude oil and other hazardous materials. The average capacity of a commercial ship prior to this time was 17,000 dead weight tons (DWT). Currently the largest ship in the world, the Seawise Giant, has a capacity of 239,000 DWT of crude oil. Tankers with a capacity between 100,000 and 200,000 DWT are the rule, not the exception [Ref. 4: p. 70, 5: p. 6]. Large ship size creates economies of scale for the oil industry but greatly increases the difficulty in maneuvering these ships. According to a 1972 Senate Committee on Commerce report on the Ports and Waterways Safety Act, a 17,000 DWT T-2 tanker can "crash stop" within a half mile taking about five minutes. A 200,000 DWT supertanker takes two and one-half miles and twenty-one minutes to stop. The report also points out that these ships are out of control during a crash stop; they cannot be adequately steered in an emergency.

Year	Event
1896	VTS St. Mary's River, MI established
1948	First active surveillance VTS established in Liverpool, England
1949	First U.S. VTS organized by the Long Beach, CA Port Authority.
1962	USCG experiments with VTS in New York Harbor. Rebroadcasts radar picture using low power TV signal. Program abandoned due to technical and frequency congestion problems.
1968	Harbor Advisory Radar (HAR) experiment started for San Francisco Bay, CA. Consisted of two X-Band radar sites but no communication facilities.
1971	VTS Puget Sound opened in anticipation of increased tanker traffic due to Alaskan pipeline.
1972	HAR San Francisco added VHF-FM voice radio coverage and became the first active surveillance VTS in the U.S.
1973	USCG Vessel Traffic System Analysis of Port Needs study determines priority for VTS location and level of coverage. VTS Louisville, KY opened.
1975	VTS Houston/Galveston, TX and Berwick Bay, LA opened
1977	VTS New Orleans, LA and Prince William Sound, AK opened.
1986	VTS New York and VTS New Orleans closed due to budget constraints.
1990	Current USCG VTS locations Prince William Sound, AK; Puget Sound, WA San Francisco, CA; Houston/Galveston, TX Sault Sainte Marie, MI; Louisville, KY Berwick Bay, LA
1990	Planned VTS Locations New York Harbor, NY; New Orleans, LA

Table 1. History of VTS [Refs. 6: pp. 25-27, 3: pp. 417-420]

As ship size grew, the degree of specialization also increased. The economics of the marine transportation industry forced delivery of raw materials and containerized manufactured goods into a few large ports, visited by large, specialized, ships. Smaller ships began redistributing these raw materials and finished goods, which created a booming coastwise trade. Major ports, and the associated offshore approach areas, saw a large increases in traffic density.

Each day, a ship of over 100 DWT is lost on a worldwide basis. A large percentage of the losses are due to collision, grounding, or ramming. More often than not, the cause of these accidents can be traced back to human error rather than mechanical fault [Ref. 7: p. 1]. This illustrates the need for a "second set of eyes" when ships are in close quarters or difficult maneuvering environments like a ship channel or busy harbor.

3. The Environmental Protection Movement

During the early 1970's the environmental protection movement in the United States grew into a strong political entity. Technological advancements in television broadcasting, primarily the use of satellites, brought worldwide news coverage into the voting public's living room. In March 1967, the 118,000 DWT Torrey Canyon ran aground off the coast of Cornwall, England spilling thirty-five million gallons of oil. The spilled oil covered major expanses of both the British and French coasts. In 1969 an oil well blew out off the coast of Santa Barbara, CA. This caused a significant oil spill which threatened the entire coast of Southern California. The breakup and loss of the tanker Arrow, off Nova Scotia, in 1970, threatened the Georges Bank fishing grounds and cost the Canadian government four million dollars to clean up. These clean up costs do not include the costs to the coastal industries that lost tourism and fishing income due to the effects of the spill [Ref. 8: p. 19]. Each of these major accidents illustrated that the possibility of a major accident existed in U.S. waters. On January 18, 1971 a collision between two tankers, the SS Arizona Standard and SS Oregon Standard, spilled 800,000 gallons of heavy oil into San Francisco Bay, CA. At the time the U.S. Coast Guard was testing a Harbor Advisory Radar (HAR) system. The Coast Guard radar operators actually observed the collision which was nearly under the Golden Gate bridge. The radar operators were helpless as the facility was not equipped with radios [Ref. 9]. During 1972 there were 157 vessel collisions, rammings, and groundings that spilled 2.2 million gallons of pollutants into U.S. waters [Ref. 10: p. I-4].

B. THE PORT AND WATERWAYS SAFETY ACT OF 1972 (PWSA)

By 1972 the public outcry for an end to the destruction caused by oil spills resulted in passage of several regulations and laws. The most applicable to VTS is the Ports and Waterways Safety Act (PWSA) of 1972. The PWSA states:

> ...that increased supervision of vessel and port operations is necessary in order to- (1) reduce the possibility of vessel or cargo loss, or damage to life, or the marine environment:... [Ref. 11: sec. 1221(c)].

The intent behind this law is clear: it is to protect ships, cargo, people, and the environment from vessel accidents. It is on this basic premise that U.S. Coast Guard VTS is based. The PWSA gives the Coast Guard very wide latitude to accomplish the desired reduction in accidents and environmental harm. The PWSA states that the Coast Guard may:

...(1) in any port or place under the jurisdiction of the United States ... establish, operate, and maintain vessel traffic services, consisting of measures for controlling or supervising vessel traffic or for protecting navigation and the marine environment and may include, but need not be limited to one or more of the following: reporting and operating requirements, surveillance and communications systems, routing systems and fairways; (2) require vessels which operate in an area of a vessel traffic service to utilize or comply with that service, (3) require vessels to install and use specified navigation equipment, communications equipment, electronic relative motion analyzer equipment, or any electronic or other device necessary to comply with a vessel traffic service or which is necessary in the interests of vessel safety...(4) control vessel traffic in areas subject to the jurisdiction of the United States which the Secretary determines to be hazardous, or under conditions of reduced visibility, adverse weather, vessel congestion, or other hazardous circumstances by- (A)specifying times of entry, movement, or departure; (B) establishing vessel traffic routing schemes; (C) establishing vessel size, speed, draft limitations and vessel operating conditions; and (D) restricting operation, in any hazardous area or under hazardous conditions, to vessel which have particular operating characteristics or capabilities which he considers necessary for safe operation under the circumstances; and (5) require the receipt of prearrival messages...(b)...may order any vessel.... to operate or anchor in a manner he directs if- (1) he has reasonable cause to believe such vessel does not comply...(3)by reason of weather, visibility, sea conditions, port congestion, other hazardous circumstances, or the condition of such vessel, he is satisfied that such directive is justified in the interest of safety.... [Ref. 11: sec. 1223(a)]

C. DIFFERENCES BETWEEN U.S. AND FORIEGN VTS SYSTEMS

It is on the safety guidelines of the PWSA that the Coast Guard designs VTS systems. This is quite different from VTS design throughout the rest of the world. The primary purpose of European and Oriental VTS systems is to increase the throughput of the harbor facilities. Economic profit is the driving element. Maritime safety and environmental protection are secondary benefits. Funding is another area of difference between the U.S. and the rest of the world. In the United States, VTS systems provide a public service, protection of commerce and the environment. Funding for Coast Guard VTS systems competes within the austere budget of the Coast Guard. VTS funding is a minor, nearly transparent, player in the Coast Guard and Federal funding cycles. VTS funding is frequently based on political reaction to an accident or a politically motivated mandate. Several examples exist. VTS Prince William Sound, AK, was mandated by the Trans-Alaska Pipeline Authorization Act (P.L. 93-153) [Ref. 3: p. 421]. VTS Puget Sound was developed under Congressional budget pressure again due to the Alaskan pipeline. VTS New York is being re-established due to specific Congressional legislation tied to the Coast Guard's 1990 budget [Ref. 1].

European VTS systems provide both a private and a public good. A public good is one that benefits the population in general. Public goods are usually paid for using governmental funds. A private good is one that benefits the user or owner of the good. European VTS systems provide a public good in that they protect the environment by preventing shipping accidents. They provide a private good by increasing the flow of traffic in and out of the ports being served. These VTS systems are generally funded with both user fees and governmental support. Funding for foreign VTS systems is generally larger and more consistent than VTS funding in the United States.

D. DEFINITION OF VTS

1. Missions of VTS

To fully understand the job of a VTS it is necessary to explore the missions assigned to a VTS. As with the rest of the Coast Guard, a VTS is a multi-mission organization and must be analyzed based on assigned, and assumed, mission areas.

The official mission of a VTS is:

> ...to prevent damage to, or the destruction or loss of any vessel, bridge, or other structure on or in the navigable waters of the United States [Ref. 12: p. 4-4].

This definition does not provide a description of the functional or relational duties of a VTS. A better description of a VTS is:

> ...A vessel traffic system consists of an integrated plan, regulations, people, equipment and facilities for the collection, analysis, and dissemination of information to assist and direct as needed, the maneuvering of vessels in waters subject to congested vessel traffic [Ref. 13: p. 4-2].

Within the Coast Guard, VTS falls under the Port Safety and Security (PSS) and Waterways Management (WWM) mission areas. These missions are defined as:

> **Port Safety and Security**: Safeguarding the nation's ports, waterways, waterfront facilities and vessels, personnel and property therein, from either accidental or intentional damage, disruption, destruction or injury.
>
> **Waterways Management**: Develop and implement passive and active traffic management techniques and navigation safety procedures to assure acceptable levels of safety in U.S. ports and waterways. [Ref. 14]

The routine functions of a VTS make it useful to a wide range of Coast Guard mission areas, not just Waterways Management and Port Safety and Security. These secondary missions include Search and Rescue (SAR), Maritime Defense (MDZ), and Aids to Navigation (ATON). Table 2 on page 10 lists the contributions a VTS may make to these additional Coast Guard mission areas.

Mission	Contribution
Search and Rescue(SAR)	Communication coordination, accepting requests for assistance, active search (by radar and video camera), search area management
Maritime Defense(MDZ)	Harbor surveillance, communications coordination, vessel detection (radar, video, sonar, etc.), vessel transit scheduling, hazardous transit planning and monitoring
Aids to Navigation(ATON)	Monitoring aid position, accepting reports of aid malfunction or position error, transmission of navigation information (Notice to Mariners, Local Notice to Mariners)

Table 2. Secondary VTS Mission Areas

2. Analysis of Port Needs

In 1973 the Coast Guard contracted for a series of reports called the *Vessel Traffic Systems Issue Study*. These reports dealt with every aspect of VTS operation. Through this study of the issues, the Coast Guard developed early models for studying vessel traffic, control systems, and management plans. The numerical data was based on vessel accidents, cargo tonnage, and vessel transits through selected ports. The ports with the most transits and highest tonnage figures were further studied, primarily using the accident data. The *Analysis of Port Needs*, which is a follow up report to the Issue Studies, analyzed data for these same ports. Each port and waterway was ranked based on six factors. The factors were:

1. Estimated annual dollar damages caused by collisions, rammings, and groundings (C R G).
2. Estimated annual pollution incidents due to C R G.
3. Estimated annual deaths or injuries caused by C/R G.
4. Estimated annual dollar damage reduction due to the VTS level selected.
5. Estimated annual pollution incident reduction due to the VTS level selected.
6. Estimated annual death or injury reduction due to the VTS level selected. [Ref. 15: pp. 1-19.]

Using the information developed in the *Analysis of Port Needs*, the Coast Guard established seven levels of VTS technology that could serve the specific needs of a given port. Table 3 on page 11 details the seven levels used by the Coast Guard.

Designation	Type	Description
L0	Passive	Used to adjust early VTS information for passage of the Bridge-to-Bridge Radio Telephone Act (33 USC 1201-1208).
LR	Passive	Regulatory actions to prevent accidents. Includes speed and passing limitations and one way traffic considerations.
L1	Passive	Use of Traffic Separation Schemes to limit close passage of vessels.
L2	Advisory	Vessel Movement Reporting System (VMRS). Vessels are required to communicate their navigational information (position, ETA to next point, plans, etc.) to a VTC. The VTC coordinates this information and advises ships of traffic in their vicinity. Minimum reporting requirements are specified.
L3	Advisory and Active	Basic area surveillance including radar or CCTV. Improves VTC knowledge of vessel presence and movement. Considered necessary where blind corners, bends, or intersections exist.
L4	Active and Advisory	Advanced surveillance including more accurate and complex surveillance equipment. May include limited computer interface.
L5	Active	Advanced surveillance with full computer interface providing the highest reliability and accuracy in traffic management. Designed for control of high density, complex areas.

Table 3. VTS Levels [Ref. 15: App. 1, p. vi]

The *Analysis of Port Needs* also identified and rank ordered twenty-two ports and waterways that would benefit from the construction of a VTS. Table 4 on page 12 summarizes this report by listing the selected ports and detailing the number of VTS sectors to be used and which level of technology (from Table 3) should be used.

A comparison of the ports currently served by Coast Guard VTS systems (Table 1 on page 6) and the list from the Port Needs study (Table 4 on page 12) illustrates that VTS development in the United States has not proceeded as expected. This is due to the sensitivity of the VTS program to political and popular support. During the middle 1970's, several highly ranked ports were passed over while low priority ones received major VTS systems. This was due ability of local politicians to control the VTS program. During severe Coast Guard budget cuts in 1986, the two most needed VTS systems, New York and New Orleans, were closed. The reason these two ports were selected for closure is that they were voluntary systems and suffered from a lack of participation and local support. They were simply not effective [Ref. 1].

The Coast Guard recently contracted for an up-to-date Port Needs Study. The new study is scheduled to be completed by the summer of 1991. The purpose of this study is to provide an updated list of major ports that may benefit from a VTS. The new study will concentrate on analysis of risk (the potential for an accident) rather than analysis of historical accident data [Ref. 16].

Port or Waterway	VTS Sectors and Levels Needed		
New York	1.0	2 of 1.2	2 of 1.3
New Orleans	2 of 1.2	1.3	
Houston Galveston	1.2	1.3	
Sabine-Neches (ICW 265-290)	1.0	2 of 1.2	
Chesapeake Bay	1.0	1.2	1.3
Morgan City (ICW 80-99)	1.R	1.2	
Cote Blanche (ICW 107-129)	1.4		
Baton Rouge	1.2		
San Francisco	1.2	1.5	
Houma (ICW 50-69)	1.2		
Chicago	1.R		
Delaware River and Bay	1.0		
Tampa	1.0		
Puget Sound	1.2		
Mobile	1.0		
Detroit River	1.0		
Vermillion River (ICW 155-179)	1.0		
St. Louis	1.0		
Long Island Sound	1.0		
Los Angeles Long Beach	1.0		
Corpus Christi	1.0		
Boston	1.0		

Table 4. Ports and Waterways Ranking [Ref. 15: p. vi]

3. Functional Description of a Vessel Traffic Center (VTC)

The nerve center of a VTS is the Vessel Traffic Center (VTC). Typically the VTC is manned by a Watch Officer, a Watch Supervisor, and one or more Watchstanders. A description of the duties of these people will complete a picture of what a VTS is responsible for.

a. Watch Officer

The Watch Officer is a commissioned U.S. Coast Guard officer (O-2/O-3) generally following completion of a tour as Commanding Officer of a small Coast Guard Cutter. He or she is responsible for the overall performance of the VTS. The Watch Officer's duties include: supervision of VTS operation, regulation of anchorage use, reporting regulation violations, physical security of the VTS system facility, and training of new watchstanders. When necessary, the Watch Officer has the authority to exercise vessel traffic control. In this case he or she may direct the movement of vessels in the VTS. Normally a VTS will simply monitor vessel traffic and provide traffic and navigation information when it is necessary.

b. Watch Supervisor

The Watch Supervisor is a Coast Guard civilian employee (GS-11) or Chief Petty Officer (E-7/8). The Watch Supervisor assists the Watch Officer. He or she supervises the watch in the absence of the Watch Officer. The Watch Supervisor is also responsible the training of new watchstanders.

c. Watchstanders

The Watchstanders are either enlisted Coast Guard personnel (E-5/6) or civilian employees (GS-9). The watchstander monitors and advises traffic in the VTS area and anticipates the movement of traffic within his or her VTS sector. The watchstander is seated so that he or she can monitor one or more radar and video displays. The watchstander also monitors the associated VHF-FM voice communications equipment. The watchstander maintains radar and voice contact with each vessel in his or her sector. He maintains an information base that includes:

- Vessel name.
- Pilot identifier.
- Vessel type.
- Position.
- Draft.
- Designation of vessel in VTS system.
- Route.
- Any other relevant information.

In most cases this information is kept on a paper card similar to Figure 1 on page 15. The watchstander attaches this card to a magnetic board that provides a graphic display of the VTS sectors. As vessels in non-surveillance sectors update their positions, these cards are annotated with the time and location, then advanced on the board. Examples of non-surveillance sectors areas include rivers and offshore approach lanes. In some areas video cameras are used to monitor the accuracy of the vessel position reports. These voice reporting systems are called Vessel Movement Reporting Systems (VMRS) for river areas or Offshore Vessel Movement Reporting Systems (OVMRS) for deep sea approach areas, respectively.

If a vessel is in an active surveillance area (normally radar coverage), the watchstander will acquire and designate the target so an Automatic Radar Plotting Aid (ARPA) can track it, if the VTS is so equipped. If the VTS is not ARPA equipped, manual radar plotting techniques are used (grease pencil marks on a plan position indicator (PPI)). When a vessel requests it, or in anticipation of a traffic conflict, the watchstander will issue advisories to the appropriate vessels. During periods of low traffic density, one watchstander may be responsible for monitoring multiple radars and VTS sectors, including the OVMRS and the VMRS [Refs. 9, 17: pp. 12-14].

E. VTS PROGRAM MANAGEMENT

The Coast Guard program manager for VTS is the Office of Navigation Safety Programs (Commandant G-NSP). This headquarters office is charged with management of Coast Guard VTS programs involving active traffic management. As a program office, G-NSP has suffered from decreasing budgets, personnel cuts, and a lack of project priority. Following the Exxon Valdez oil spill, the program office was boosted in personnel strength and status. This was a reaction to a Congressional mandate to install a VTS in New York harbor and interest in reactivation of VTS New Orleans.

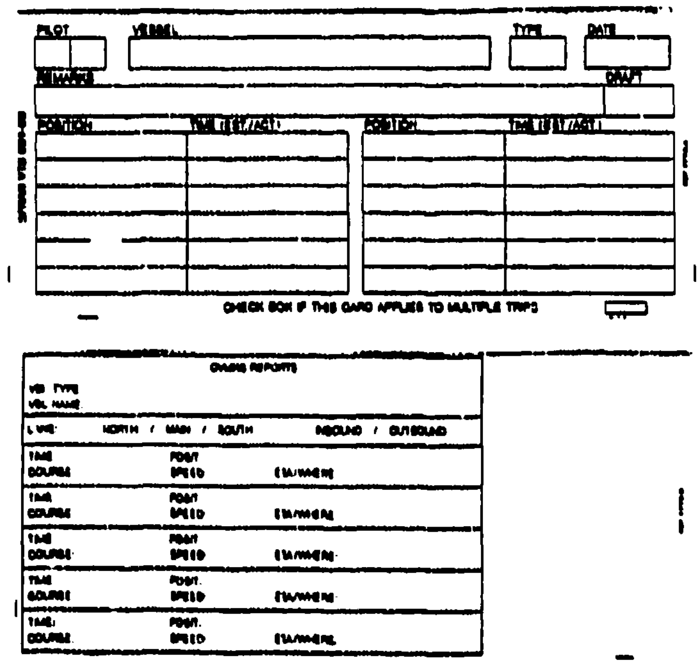

Figure 1. VTS Vessel Tracking Card

The complement to active traffic management is, of course, passive traffic management. Passive techniques include the rules and regulations developed by the Coast Guard. These techniques are used where responsibility for compliance may safely be placed on the user. Examples of passive traffic management techniques include:

- Administration of Federal Anchorages.
- Designation of Safety Zones.
- Regulated Navigation Areas.
- Navigation Safety Regulations.
- Navigation Rules (International and Inland).
- Bridge-to-Bridge Radiotelephone Regulations.

The Coast Guard does not have a specific program office for passive traffic management.

F. COAST GUARD VTS CONFIGURATIONS

1. Ports and Equipment

The Coast Guard currently operates seven VTS systems. The location and equipment suites are listed in Table 5 on page 16.

Location	# of Sectors	VTS Levels	Mandatory?	Radar System	# of B/W LLLTV Sites	# of VHF-FM Sites
San Francisco, CA	4	1.2 1.3	No	2 AN FPS-121 X&S Band	1	3
Houston-Galveston, TX	3	1.3 1.4	No	1 AN FPS-121 X-Band	8	3
Puget Sound, WA	5	1.2 1.3	Yes	10 AN FPS-109 X-Band	0	11
Prince William Sound, AK	2	1.2 1.3	Yes	2 AN FPS-121 X-Band	0	7 + 2 HF sites
Berwick Bay, LA	1	1.3	Yes	1 AN SPS-64V X-Band	1	1
Louisville, KY	1	1.2	Yes	none	none	1
Sault Sainte Marie, MI	1	1.2	No	none	1	2
New York Harbor (proposed)	4	1.4	Yes	7-8 X-Band	7	unknown

Table 5. Summary of VTS Capabilities

2. Equipment Description

a. Radar Equipment

The Coast Guard operates two radar systems as the primary surveillance tool for VTS. These radar systems are based on commercially available, maritime surface search radars. Remote radar sites normally consist of redundant transmitter receiver systems, wide band radar data link systems, and a radar control signal system using either wide band or narrow band (voice grade) data links.

(1) Radar Frequency Bands. The Coast Guard primarily uses X-Band radars. These radars provide a higher degree of target resolution. As seen in Table 6 on page 17 the X-Band radars can suffer significantly due to rain, snow, or similar meteorological phenomena. To counter the effects of this type of system degradation,

a few VTS radar sites are equipped with both X-Band and S-Band radar transmitter receivers.

Table 6 lists the general characteristics of the radar bands used by Coast Guard VTS radar systems.

Radar Band	Frequency	Range	Characteristics
S	2-4 GHz	0.5 to 100 Km	Low attenuation due to weather Medium target resolution
X	8-12 GHz	0.5 to 100 Km	High target resolution High attenuation due to weather (30 times greater than S-Band)

Table 6. Radar Band Characteristics [Ref. 18: pp. 5-1 to 5-13]

(2) AN-FPS-109. The AN-FPS-109 radar is used in the Puget Sound VTS and will be the initial radar at Governor's Island in the resurrected New York VTS. This radar is a twenty year old, analog radar. It does not include enhancements beyond being equipped with a PPI for manual, grease pencil, contact plotting. The remote transmitter receivers are linked to the VTC indicators using 10MHz microwave circuits. These twenty year old analog microwave circuits carry broadband radar signals which include the following components:

- Radar Video (broadband target information).
- Radar Synchronization (system timing).
- Azimuth Information (antenna direction).

Control signals from the operator position (range selection, gain, filter control, etc.) are returned to the remote site by either voice grade telephone circuits or on the microwave circuit.

The AN/FPS-109 has reached the end of its economical life. Repair parts are becoming expensive and scarce. They are X-Band radars and enjoy relatively good target resolution. The indicators must be used in a darkened room.

(3) AN-FPS-121. The AN-FPS-121 radar is a slightly modified version of the commercially available Raytheon Pathfinder radar. This radar is also very similar to the standard surface search radar installed in Coast Guard Cutters. The AN-FPS-121 is a step up from the FPS-109 system. The FPS-121 uses digital processing to enhance the radar display and to provide the functions of an Automatic Radar

Plotting Aid (ARPA). This radar may use either the X or S radar frequency bands. The remote radar transmitter receiver systems also use 10MHz microwave circuits to link broadband radar signals to the VTC. Control signals are sent to the remote sites by telephone or microwave systems. The advantage of the FPS-121 system is use of digital signal processing and incorporation of ARPA functions.

The processing techniques used in this system are becoming standard in all commercial marine radars and will be briefly discussed. The system converts the analog radar information, received at the indicator, into digital information. These digitized signals are saved in a digital memory on a sweep-to-sweep basis. Each sweep is compared with the following sweep. Only target information that is present in both sweeps is displayed. Radar clutter (sea and rain return) is greatly reduced using this technology. Target range and bearing is then extracted and displayed on the indicator. This target information may also be accessed by add on systems like an ARPA.

The ARPA system for the FPS-121 system is basically a stripped down version of Raytheon's RAYCAS V ARPA. The RAYCAS V collision avoidance system (CAS) is standard on Coast Guard Cutters and is also commercially available. The ARPA system provides several features designed to assist a radar operator. Using symbolization and digital displays, an ARPA provides the following functions and information:

- Manual and automatic target acquisition
- Automatic ta[illegible]et tracking (of acquired targets)
- Display of tracking history (speed and direction)
- Display of current heading and speed
- Alarms for close passage of tracked targets
- Display of the location of potential collision between contacts
- Display of basic navigation information (fairway and channel boundaries, buoy position, etc.)

The A/N-FPS-121 also provides an RS-232 port for automatic collection of tracked target information. The indicators used by the Coast Guard must be used in a darkened room.

b. Closed Circuit Television (CCTV)/Low Level Light Television (LLLTV) Equipment

Closed Circuit Television with Low Level Light Television camera technology is used by several VTS systems. These systems are used to monitor VTS areas composed of narrow channels, sharp bends, or similar "bottle-neck" areas where radar is not effective. The CCTV systems provide the VTC with visual information allowing the operators to identify vessels and directly monitor traffic conditions. Use of LLLTV camera technology allows monitoring at night. The broadband video data from remote camera sites is linked to the VTC using 10MHz microwave circuits. Camera operators are able to remotely control the azimuth (direction), tilt, zoom, and focus of the cameras. Control information for the cameras is sent from the VTC using either voice grade telephone lines or broadband microwave circuits.

c. VHF-FM Voice Communications Equipment

The primary means for a VTS to communicate traffic information to participating vessels is over VHF-FM radio telephone circuits. The Coast Guard operates many of these systems. VHF-FM provides high quality, line-of-sight, voice communications. Due to the line-of-sight restriction, several VHF-FM sites may be required to obtain full VTS coverage. The technology used to control the VHF-FM remote transmitter receiver equipment is normally audio tones sent over voice grade telephone lines. The audio information travels to the remote site on the same voice grade channel. VTS Prince Williams Sound has the capability of communicating using either VHF-FM or high frequency (HF) radio equipment. Use of HF communication equipment provides longer ranges as the signal is not limited to line-of-sight propagation.

d. Computer Equipment

The Coast Guard operates a very basic computer system for vessel tracking in VTS Houston Galveston. The computer system, and hardware, was designed in the early 1970's. There is currently a Coast Guard project to update both the software and hardware to provide a more integrated approach to vessel management.

e. Data Link Equipment (microwave)

The Coast Guard relies heavily on microwave systems for transmitting broadband radar and video signals from remote sites back to the VTC. These systems were installed in the early 1970's. They are analog, 10 MHz, solid state systems. The maintenance costs of keeping them on-line with better than 99% reliability have become prohibitive [Ref. 1].

G. VTS DATA CONTENT

As an information source, the current VTS systems capture static, dynamic, and processed dynamic data. Static data includes information that does not change during the period the vessel transits the VTS area. The name of the vessel is one of the static data elements. Dynamic data changes as a function of time while the vessel is in the VTS system. The position of the vessel is the most obvious example of this type of data. Processed dynamic data is information calculated from the dynamic data in the VTS. One example of processed dynamic data is vessel speed. Vessel speed is calculated from successive positions over a period of time. The data captured and recorded by Coast Guard VTS systems is listed below.

- Vessel Identification Tag (static).
- Vessel Type (static).
- Vessel Draft (static).
- Vessel Position (dynamic).
- Vessel ETA to Next Reporting Point (dynamic).
- Date (dynamic).
- Weather Conditions (dynamic).
- Vessel Course (processed dynamic).
- Vessel Speed (processed dynamic).

Each VTS is required to collect historical data such as the total number of transits through the VTS. This data is normally calculated manually as part of the overall administrative requirements of the VTS. An example of historical data collection is calculation of the total number of vessel transits by manually counting the number of OVMRS and VMRS cards used in a month.

In the course of normal operations, VTS personnel create an informal database consisting of general knowledge regarding participating ships, and their actions while in the VTS. This information is static in nature and includes the following elements:

- Regulatory violations.
- Owner information.
- Master information.
- Navigation accuracy.
- Radio communication skills including problems with a language barrier.
- General work history including ports visited and routes used.

Although informal in nature, this information is used by VTS controllers in deciding what actions are most appropriate for the situations present within the VTS.

III. VTS AND COAST GUARD COMMAND AND CONTROL (C^2)

A. C^2 PLANNING FOR A MULTI-MISSION ENVIRONMENT

As the Coast Guard enters the 1990's, the diversity of missions, operational platforms, and geographic necessities will continue to strain the command and control (C^2) systems of the Coast Guard. This includes the VTS systems. With decreasing budget levels, the need for maximum efficiency and effectiveness will continue to grow. These factors have caused the Coast Guard to look toward the use of computer enhanced C^2 to better manage the already stretched resources.

Due to the complexities of the Coast Guard's various mission areas, it has been necessary to maintain several specialized Operations Centers (OPCENs) in a single area. Even though specialized, these OPCENs share a common need for basic information and Coast Guard resources (personnel, ships, boats, and aircraft). In a simple sense, these shared needs may be summed up by three questions. They are:

- What are the missions?
- What Coast Guard resources are assigned?
- Where are all the players?

In order to effectively manage missions and resources, Coast Guard OPCENs need an accurate tactical picture, tailored to their specific interests. Coast Guard OPCENs are hierarchical in nature over a geographic area. The upper level OPCENs provide mission tasking and guidance. The lower echelon OPCENs act as the communications link between the Coast Guard resources and the upper echelon OPCENs. At the present time, the primary means of sharing information between Coast Guard OPCENs and operational resources are voice circuits (telephone and radio) and message exchange (E-Mail and record traffic on dedicated circuits) [Ref. 19 : pp. 2-22 to 2-28]. These circuits are subject to data and human error, circuits outages, and are inherently inefficient.

Coast Guard VTS commands possess a part of the tactical picture needed by these OPCENs. The VTS can provide a geographically oriented picture of harbor and coastal areas, including the location of Coast Guard resources and other mission essential information. This information is, however, stuck within the VTS. In planning the second generation of VTS systems, the Coast Guard can greatly increase the effectiveness of this surveillance information by making it available to other Coast Guard C^2 systems. This is possible through careful system planning that recognizes the need for improved and integrated C³ capabilities [Ref. 19: p. 4-14].

B. C³ THEORY AS APPLIED TO VTS SYSTEMS

1. Definition of a C³ System

A C³ system is essentially an information handling system. It provides the information necessary for accurate and timely decision making. A C³ system must interface with a variety of external information sources. These sources provide data in ways that reduce the probability of making an incorrect decision. Interoperability between information sources is a key factor in the design of an efficient and effective C³ system [Ref. 20: p. 282].

As a management tool, a C³ system has three basic characteristics. The first is that the C³ system is used to implement management functions which include control, supervision, warning, situation assessment, decision making, and decision execution [Ref. 21: p. 4]. The second characteristic is that, in most situations, the system must work in "real-time". A real-time operation may be defined as:

> ...one that presents an answer to a continuing problem for a particular set of values, while those values are still available [Ref. 21: p. 4].

This element of time is measured relative to the needs of the system and decision maker. For a VTS, "real-time" may be quantified as the latency between data acquisition and data display. The Coast Guard has stated that a latency of between ten and fifteen seconds is acceptable [Ref. 22, 23: p. 11]. For a ship steaming at fifteen knots, this represents a distance of about 250 feet. This is approximately half of the width of a small major shipping channel in the United States. Many heavily travelled channels are much wider. The third C³ management characteristic that such a system should provide is an efficient means for planning, managing, and controlling operations [Ref. 21: p. 5]. This includes both graphical and analytical tools for planning future operations, display of the current (real-time) information, and analysis of historical data.

A Command and Control system is actually made up of three sub-systems working together to support a decision maker. These sub-systems are defined as:

> ...a *command subsystem* consists of those processes and staff that directly support any decision maker, military or civilian. A *control subsystem* consists of the functions and entities through which both a decision is executed and information is received to facilitate future decision making and to monitor progress. *Communications subsystems* interconnect the elements of the command and control subsystems. [Ref. 20: p. 282]

For a VTS these sub-systems could be delineated as:

- Command Subsystem - VTC Watchstanders and vessel location displays (radar and VMRS boards).
- Control Subsystem - Surveillance equipment (radar, video, and radio position reports) and the regulations supporting VTS.
- Communication Subsystem - VHF-FM voice radio, wide band microwave radar and video links, and telephone circuits for system control links.

2. Conceptual Models of C^3 Systems

a. Boyd's OODA Loop Structure

One of the best models of a C^3 system is Boyd's OODA Model, illustrated in Figure 2 on page 24. Boyd's model illustrates the C^3 process functions that support a decision maker. Table 7 shows how Coast Guard VTS fits into this model.

Model Block	VTS Function
Observe	The task of observing the ENVIRONMENT. This includes both active and passive sensing techniques. The goal is to provide continuous coverage of the environment, under all conditions. The key parameters of this function are coverage and information timeliness.
Orient	The task of this function is to detect significant situations and to forecast changes in the current situation. Forecasts guide the OBSERVE function by indicating where to look, and what to look for. This function also provides background information such as draft, destination, and past history. The ORIENT function provides the tactical picture. Key parameters are completeness, accuracy, and responsiveness.
Decide	This function is extremely complex and is carried out by the decision maker, using the C^3 system. Decisions are based on the tactical picture and other relevant information provided by the ORIENT function.
Act	ACT is the interface between the decision maker and the ENVIRONMENT. It is the means for the decision maker to influence the ENVIRONMENT. This part of a VTS C^3 system includes the laws, regulations, and communication systems supporting the VTS.
Environment	For a VTS, the ENVIRONMENT includes the surveillance area, vessel traffic, weather, political climate, and similar factors. These items influence, or may be influenced by, the decision maker.

Table 7. Boyd's OODA Model and VTS [Ref. 24: pp. 26-36]

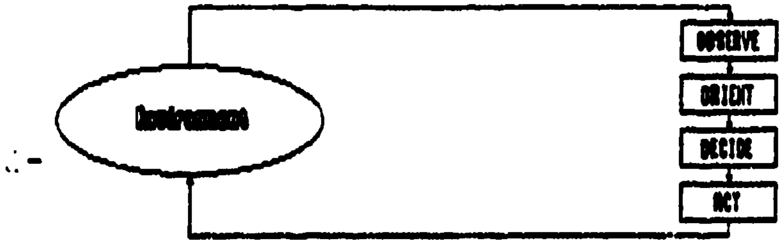

Figure 2. Boyd's OODA Model [Ref. 24: p. 26]

In designing a C^3 system it is necessary to understand the nature of the environment to be controlled. The environment is generally categorized into one of four classes based on the predictability of probable outcomes [Ref. 24: pp. 51-52]. The four classes are:

- Deterministic - for a given initial condition there is only one possible outcome.
- Moderately Stochastic - only a limited number of similar results are possible with a given initial condition.
- Severely Stochastic - a larger number of outcomes are possible with a given initial condition.
- Indeterminate - for a given initial condition, the outcome cannot be predicted.

When viewed as a probabilistic process, a VTS seems to be best described as moderately stochastic. The number of possible outcomes are highly constrained. The possible outcomes are limited by federal regulations such as the Inland and International Collision Regulations [Ref. 25] and by the physical nature of ships moving in restricted channels. VTS control techniques will affect the environment in a predictable way. Based on this ability to predict the outcome of a set of conditions, timely facts and data become very important to the decision maker, in a moderately stochastic process. The control process structure is also important as it guides the construction of predictive models, allowing better control of the environment [Ref. 24: pp. 51-53]. Based on a moderately stochastic OODA model of a VTS, the decision maker will need a mixture of timely data (vessel position, identity, and movement), facts (vessel draft, weather, and maneuverability), and control process structure (voluntary or mandatory participation, vessel control or position monitoring, etc.) in order to make the best decision and then monitor the outcome of that decision.

b. The Command Supervisory Post (CSP)

The most important part of a C^3 system is the Command Supervisory Post (CSP). This is the conceptual point where decisions are made. In a VTS, the CSP is the VTC. Figure 3 on page 26 illustrates Morris's CSP model. This model details the types of information used to make a decision in a CSP. Decisions are made by both the human decision makers as well as automatically by the C^3 system software. The decisions made solely by the C^3 system software are generally constrained to a specific response to particular set of data conditions. An example of an automated C^3 decision is software sounding an alarm when a radar contact moves out of an established transit zone.

c. An Expanded C^3 Model

Boyd's OODA Model and Morris's CSP Model are useful as conceptual aids in seeing the need to segment C^3 into distinct functions. In order to apply this type of conceptualization to fitting a VTS into a Coast Guard wide C^3 system, it is necessary to expand the model. Morris's expanded model (Figure 4 on page 27) details the C^3 process into eleven functions. The following list annotates these steps with comments relative to the inclusion of VTS information as one of several information sources for an upper echelon CSP [Ref. 21: p. 6].

1. Data Acquisition - VTS data is currently acquired from three sources. They are video, radar, and voice communication. When this information enters a C^3 system it should be in a standard form. This will allow for design modularity and flexibility. Each source of information will require a subsystem to put the data into a standard format.

2. Data Assembly, Validation, and Correlation - Raw data is assembled into a usable form for a database and checked for validity. Raw data is correlated with data stored in a database. For VTS information this may be seen as linking the incoming data to a particular data set (ship name) that includes a wide range of information including present position, historical position, and descriptive information.

3. Data Processing - Data is processed in order to provide further information such as course, speed, and other relevant information.

4. Data Updating - Processed data is written on to a database record. This is similar to the VTC operator annotating the Vessel Tracking Card (Figure 1 on page 15).

5. Data Storage - The updated database record is placed into storage for use in a tactical display, vessel traffic analysis, and communication to external C^3 systems.

6. Information Display - Real-time information is combined with user selected information and displayed. In a VTS this could be real-time radar contacts being overlayed on a digital chart with the composite being displayed on a computer monitor. Each contact could have its identity, vessel type, and similar information

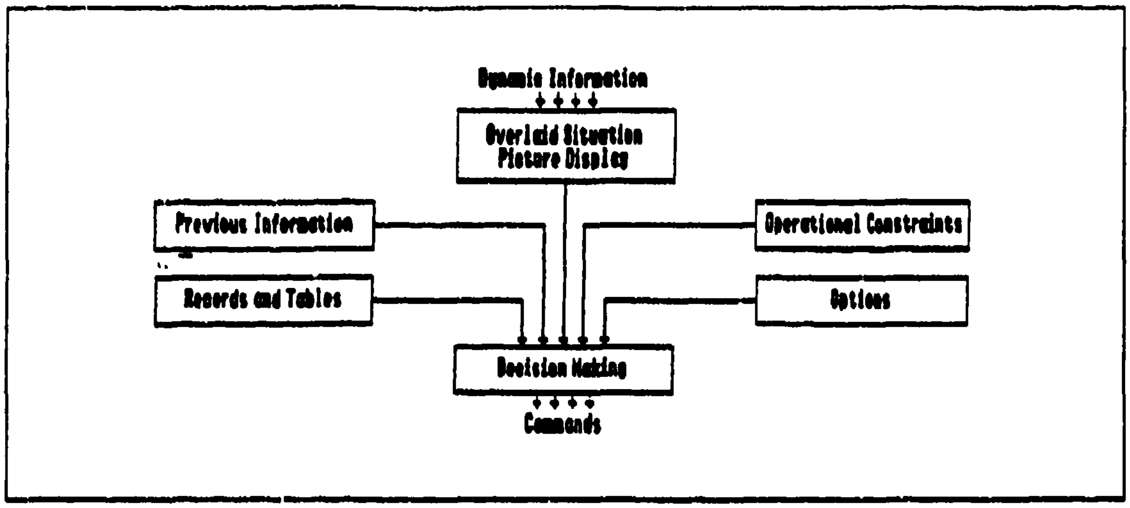

Figure 3. Morris's Command Supervisory Post (CSP) [Ref. 21: p. 12]

displayed. Potentially dangerous situations could be highlighted for operator action.

7. Data Retrieval - Information is selected for display, or further analysis based on the desires of the user.

8. Decision Making - This is where the human element and the information processing element of a C^3 system meet. Some decisions are made automatically, based on rules established within the C^3 system. The user may modify these rules and select other information to better suit his or her current needs.

9. Command Dispatching - This function provides the decision maker with a means to control the C^3 environment. In the current VTS systems, this function is carried out over VHF-FM voice radio circuits.

10. Command Implementation - This function contains the interface between the decision maker and the C^3 environment. It is easily characterized as the VTC Watchstander ordering a ship to anchor. The regulations supporting VTS require the vessel to comply, so the vessel acknowledges the order and carries it out.

11. Controlee Actions - Within the overall environment the C^3 system is designed to detect particular events. Controlee actions, such as maneuvering to anchor, are events the C^3 could detect and monitor. [Ref. 21: p. 6]

In a macro sense, a VTS is one of several information sources that could be available to Coast Guard decision makers. A large scale C^3 system would use some of the information stored in a VTS C^3 system, based on the needs of the decision makers running the upper echelon C^3 system. In this context it is important to note that the communication systems supporting such a system are as important as the lower level C^3 systems. A C^3 system linking geographically separated information sources will de-

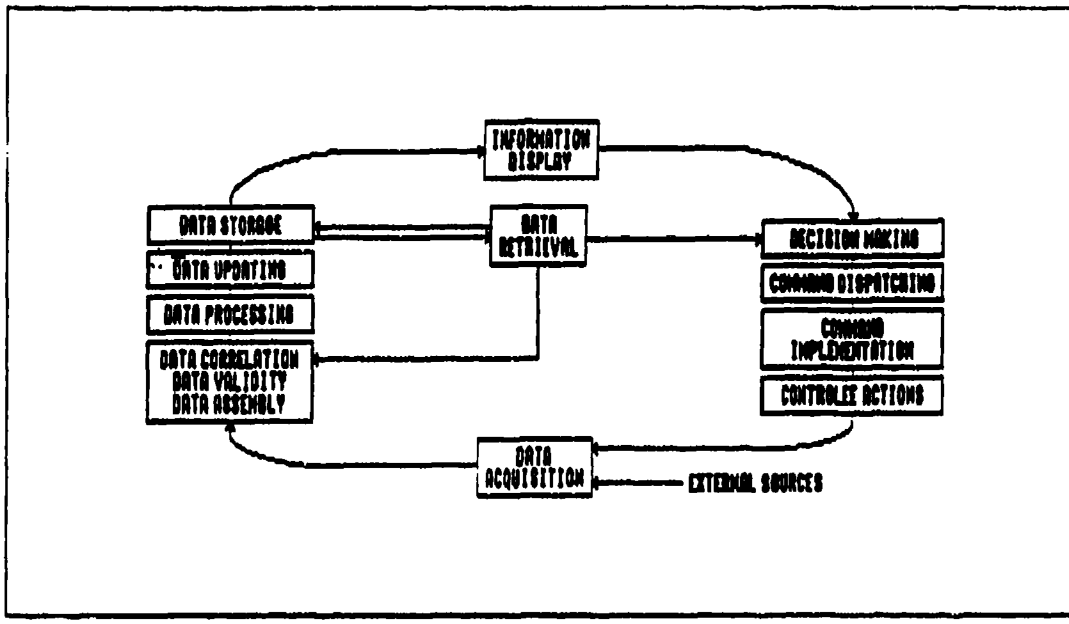

Figure 4. Morris's Expanded C^3 Model [Ref. 21: p. 6.]

pend heavily on rapid and reliable information transfer. This dependence must be considered part of the sophisticated system.

3. C^3 System Examples

a. *World-Wide Military Command and Control System (WWMCCS)*

WWMCCS was developed in the late 1960s and is used to facilitate the planning and execution of military operations. It is composed of over eighty mainframe computers being linked by a dedicated data network using the Department of Defense AUTODIN system. Many mini-computers and terminals are also linked into the system. This equipment is centered in about thirty locations worldwide. WWMCCS contains database information on the operational status of military units. The database includes information regarding geographic position, mission readiness, training status, supply status, personnel status, and equipment problems. Operational units input information using strictly formatted message traffic. Authorized users are able to select the information they need, and display it, in a wide variety of ways. WWMCCS also includes tools used to assist with planning military operations.

As a C^3 system, VTS differs from WWMCCS in that VTS requires real-time information oriented to a particular geographic location. WWMCCS may be used as an analogy for an upper echelon Coast Guard C^3 system that supports multi-mission decision making and that requires standardized information from several sources.

b. Air Traffic Control (ATC)

The Federal Aviation Administration (FAA) maintains an extensive Air Traffic Control (ATC) system throughout the United States. This system is often viewed as a parallel to Coast Guard VTS systems. The ATC system is composed of several layers of control being linked by various data communication networks. These layers [Ref. 26] include:

- Airport Traffic Area. This is the area within five miles of an airport with an operating control tower. All aircraft are required to comply with the instructions of the federally manned control tower. Airport Surveillance Radar (ASR) is used to detect and control airborne traffic.
- Airport Radar Service Area (ARSA). This is the area within twenty miles of busy airports. All aircraft are under radar surveillance and are required to comply with ATC directions. ARSAs contain one or more Airport Traffic Areas and the associated ASR systems.
- Air Route Traffic Control Center (ARTCC). This is the heart of the ATC C^3 system. The U.S. is broken into several geographic sectors, each being serviced by an ARTCC. Tracking information from ASR and ARSA radars selectively flows into and out of the ARTCC based on the path of an aircraft. ATC sector controllers "handoff" this information as an aircraft moves from one area to another. The handoff is in the form of contact identification and tracking information only. The handoff information is digital data which may be passed over high speed, narrow band communication links. The new controller hooks the radar contact to begin the automatic tracking process. The ARTCC is also the link between a pilot's flight plan and the ATC. Through this system ATC manages route congestion and airport arrivals and departures. This is done through a combination of route selection, holding an aircraft at a particular airborne area, and authorized departure times.

The major difference between ATC and VTS is the degree of control over participants. Unlike Coast Guard VTS, ATC assumes direct control of all commercial air traffic. This includes takeoff, routing, speed, altitude, and landing instructions. The ATC system is designed to facilitate both safety and traffic volume. Due to the speed of jet aircraft and the complexity of U.S. airspace, the ATC C^3 system requires direct human control, extensive redundancy, and in-depth training for both the user (pilots) and C^3 system controllers. In the busy U.S. airspace, ATC requires real-time radar information with a data latency of less than one second.

The Airport Traffic Area and its ASR system provide a good analogy for a Coast Guard VTS C^3 system. The ASR covers a limited geographic area and passes surveillance information to the upper echelon sectors (ARSA and ARTCC). It does not, however, provide the depth of service or planning flexibility needed for multi-mission operational support. Incorporation of the real-time ATC data into the planning functions and information structure of the WWMCCS system illustrates, conceptually, the direction that systematic planning can take Coast Guard VTS systems.

c. *Automated Mutual-Assistance Vessel Rescue System (AMVER)*

The Automated Mutual-Assistance Vessel Rescue System (AMVER) is an international, computer based position reporting service run by the Coast Guard. The purpose of the system is to provide a database of commercial vessel positions that can be used for SAR response in areas not covered by a SAR resource. Vessels file voyage plans using several communication sources including commercial and government radio stations and services. These messages are manually entered in the database. Vessel positions are kept current using subsequent position reports and dead reckoning techniques. When requested by one of the Coast Guard OPCENs, the AMVER database is queried with a position and radius. The identity and position of participating merchant vessels is returned. Nearly 2500 vessels are active in the database daily. This represents approximately one third of the world's merchant fleet.

AMVER participation is voluntary for foreign flag vessels. U.S. flag vessels are required to participate under the U.S. Maritime Administration's U.S. Merchant Vessel Reporting System (USMER). The USMER system is designed to provide the position of U.S. merchant vessels for SAR and national defense purposes. USMER information is forwarded to the Coast Guard AMVER system, the U.S. Navy, and to the U.S. Maritii Administration.

C. COAST GUARD PROJECTS AND COMMAND AND CONTROL

1. Adoption of C^3 in the Coast Guard

The Coast Guard has started to integrate C^3 into the daily routine of the operational Coast Guard. In the following pages the author will outline some of the important policy movements within the Coast Guard and briefly describe projects related to both C^3 and VTS.

a. *C^3 Policy and Operating Precepts*

In an effort to establish an integrated C^3 policy within the Coast Guard, the Commandant commissioned a study to determine and document the strategic direction of information system technology [Ref. 27: p. 2]. While the focus of this study, titled the U.S. Coast Guard Information Technology Architecture, was on Coast Guard administrative information systems, the policy that the report established directly impacts the design of Coast Guard C^3 systems. Of the major strategies identified, the following most directly impact the design of a VTS C^3 system.

(1) Federal Information Processing Standards (FIPS). The Coast Guard will comply with the emerging Federal Information Processing Standards (FIPS). These include:

- POSIX (FIPS 151). Portable Operating System Interface for Computer Environment. This standard provides a tool that is designed to provide a vendor independent interface between application programs and machine specific operating systems. This will allow programs to be written in a manner such that they can run on many machines, without expensive and difficult conversion. The standard is applicable for all computer systems from micro computers (PCs) to main frames. POSIX defines a C language source code level interface to an operating system environment and will mature to include other languages including Ada, Fortran, Pascal, and Cobol.

- GOSIP (FIPS 146): Government Open System Interconnection Profile. This set of standards requires all federal agencies to use the seven layer ISO Open System Interconnection (OSI) protocols for new and updated information systems and networks.

- SQL (FIPS 127). Database Language SQL (Structured Query Language). This standard is designed to promote portability of database definitions and application programs between computer systems. It specifies two languages that make up a relational database management system. While SQL is not specifically designed for distributed systems, it does include enough flexibility and power to allow for this type of programming.

(2) FTS-2000 and Commercial Telecommunication Systems. The Information Technology Architecture report also established that data, message, record, and voice transmission is to be accomplished using the most cost effective means available while meeting user requirements for response, security, interoperability, and survivability. This is to be accomplished primarily through FTS-2000 and commercial telecommunication systems for shore-to-shore needs and through a combination of radio, satellite communication, and cellular phone systems (close to shore) for Coast Guard ship-air-shore communication links.

(3) National Security Regulations. The Coast Guard's information technology architecture will also follow National Security Regulations. One of the most important aspects of this policy is the requirement that computer systems using secure information must be wholly separated from non-secure systems. This regulation specifically prohibits telecommunication links between non-secure and secure information systems. This requires use of an "air gap" data transfer system.

b. Information Technology Architecture Precepts

In 1988 the Coast Guard completed a study on the design of an Integrated Command Center (ICC). The purpose of this study was to:

> ...provide a top-level structure for promoting teamwork and efficiency among all participating functional areas of the command center complex [Ref. 19: p. 4-1].

In doing this, the ICC study recommended adoption of four precepts. These precepts further indicate the Coast Guard's shift toward integrated C^3 planning. The precepts are:

- Focus on the needs of the principal decision makers.
- Command Centers (or OPCENs) should function as a "single entity", a unified team with closely cooperating members. Command centers should be functionally integrated, even though they are physically separated.
- The ICC must be prepared for all modes of operations. This requires the ICC to be organized and equipped to handle all possible missions or mission combinations as well as being prepared for extended high tempo operations during civil or military crisis.
- The ICC must be prepared for all possible security requirements, from non-secure SAR cases to highly secure military operations.

c. Automated Geolocational Plotting Capability

During the course of the ICC study, the strengths and weaknesses of Coast Guard OPCENs were highlighted. The report noted:

> The general lack of an effective and fully integrated automated geolocational plotting capability emerged as one of the most severe deficiencies of the command center survey. An automated geolocational plotting capability refers to the capability of an ADP system to provide tools for displaying high-resolution, video-based charts of significant geographic areas. Such a capability necessarily includes varying chart scale and incorporates economic, military, and cultural cartographic features, as desired, as well as the capability to overlay trackplots of high interest vessel traffic. Such a capability has been demonstrated to be of great value in SAR operations where rapid location of SRUs (*Search Resource Units*) is required, and in LE operations where multi-vessel interdiction operations requires near-continuous knowledge of all vessel positions. A key element of this capability is the automated processing (i.e., plotting) of vessel track data extracted from formatted message traffic. This capability would be particularly useful in high intensity crisis and MDZ scenarios. [Ref. 19: p. 2-16]

2. Coast Guard C^3 Projects

A "fully integrated automated geolocational plotting capability" is an example of the type of computer enhanced C^3 that the Coast Guard needs. The Coast Guard has a number of projects underway that are designed to meet the C^3 needs of the service. In the following paragraphs the author will briefly describe some of these projects. The technologies being used by these projects are state-of-the-art and must be considered in the design of a second generation VTS.

a. Tactical Computer Systems

The Coast Guard is designing two tactical computer systems. They are the Shipboard Tactical Computer (STC) and the Geographical Tactical Computer (GTC). The purpose of these systems is to improve the tactical information management and decision support within the Combat Information Centers (CICs) of Coast Guard Cutters and Group and mission specific (third echelon level) OPCENs. These systems will integrate sensors, displays, communication, and advanced computing technology to provide a geographically oriented tactical display. The information summarized in the video display will be tailored to the needs of the decision makers commanding an operation. While the GTC project is in the "concept definition" stage, the prototype STC was installed in USCGC Hamilton during March of 1990 [Refs. 28, 29]. The initial STC system capabilities are briefly listed below.

- Accept digital heading and speed input from ship's gyro and doppler speed log.
- Accept digital radar target data (air and surface) from a SPA-25G or RAYCAS V radar indicator.
- Accept digital ship's position information from LORAN, GPS, and other electronic sources.
- Accept Over-the-Horizon (OTH) and Aerostat target and data information. This type of information is received via radio transmission and demodulated into digital information. This capability includes use of U.S. Navy NTDS information.
- Accept intelligence and operational information from a Coast Guard standard workstation. This information includes suspect vessel descriptions, locations, vessel sightings, and similar intelligence information.
- Display and manage navigation quality digitized charts including a zoom function. Patrol, SAR, transit, and similar operational and intelligence information can be overlayed the navigational charts.
- Overlay real-time and intelligence target information as well as own ship's position.
- Assist with operational planning (SAR, MLE, Warfare) through selective plotting of tactical information.

This system provides a very flexible tactical C^3 system through its display and planning features. Information is put into the system through specially designed interfaces that feed a database. When STC is fully mature, it will use a LAN to link shipboard information system resources. The LAN will be the dual token ring fiber-optic network known as the U.S. Navy Shipboard Adaptable Flexible Embedded Local Area Network (SAFENET). With the incorporation of SAFENET, STC will accept and display many additional information sources including SONAR and Electronic Counter-Measure (ECM) information. [Ref. 30]

b. Coast Guard Data Communication

The Coast Guard is looking into several digital data communication concepts. The purpose of these types of systems is to increase the information flow between operational resources and the operational commanders. One of the concepts being explored include High Frequency Datalink (HFDL). This program uses high speed synchronous modems to transfer digital data over high frequency (3-30 MHz) radio circuits. Eventually this program may lead to the development of a Coast Guard packet radio network.

The Coast Guard is also establishing its own data network. This data network is call the *Coast Guard Hybrid Data Network*. This network will consist of both dedicated and dial-up telephone lines used to route E-Mail protocol messages. It will establish an X.25 Wide Area Network (WAN) providing Coast Guard-wide connectivity. This system will be the backbone of administrative management as the Coast Guard moves toward a paperless environment. It is also possible that operational information will flow over this system in conjuctions with projects similar to the HFDL described above [Ref. 29].

c. Automated Dependent Surveillance System

These systems use a radio circuit to automatically transmit position information from an operational platform of interest to a Coast Guard OPCEN. An example of this type of system is Geostar Corporation's Radio Determination Satellite Service (RDSS). Such systems use satellite navigation and satellite communication technologies to link position information to a shore based OPCEN. The Coast Guard is considering the use of this type of system to automate position and status reports for operational units such as boats and aircraft.

d. VTS System Updates and Reestablishment

As mentioned in Chapter II, Congress is requiring the Coast Guard to reestablish VTS New York. The initial phase of this project will be completed in August, 1990 with a final completion date of 30 September, 1992. The requirements of this project include use of integrated target and digital chart display [Ref. 23: p. 65]. This capability is similar to the capabilities of the Coast Guard's STC project. Other VTS projects that are being investigated include:

- Re-opening VTS New Orleans.
- Expanding the surveillance capabilities of VTS Prince William Sound. Due to the remoteness of the area, the Coast Guard has determined that expansion of the existing radar system is not an acceptable option. Automated Dependent Surveillance is being considered for this project [Ref. 22].
- Up-date of VTS Houston Galveston's computerized vessel tracking system. This project is designed to bring the computer system (hardware and software) up-to-date. The end result will provide a more flexible, capable, and user friendly system [Ref. 31].
- Expansion and Modernization of VTS Puget Sound. This project will expand the VTS area farther south, into Tacoma. In addition the Coast Guard is looking into modernizing the overall VTS system [Ref. 32].

e. Shipboard Radar Update

The Coast Guard is planning to start the process of replacing the surface search radar system used aboard the service's cutters. The current radar system, the AN-SPS-64 series, was introduced in the middle 1970's. Most of the current VTS systems also use a variation of this radar system in an effort to maximize the obvious economies of scale. Determination of the replacement system and fleet installation will be carried out over the next three to five years [Ref. 28]. The author expects the Coast Guard to continue the practice of equipping VTS systems with the "standard" Coast Guard radar system.

f. Coast Guard ADP Updates

The Coast Guard is in the process of modernizing its ADP resources. This program involves replacing out-of-date computer systems, rewriting major application programs, and establishing a major data network. The application programs are being rewritten in conjunction with the computer system replacement as most of the programs are machine specific. Some other programs are receiving a major overhaul in order to accommodate necessary changes. This will allow the Coast Guard to move toward compliance with the GOSIP and POSIX standards. Listed below are some of the programs being rewritten or overhauled.

- PMIS JUMPS - Personnel and pay administration.
- AMVER - Automated merchant vessel position system for SAR.
- CASP - Computer assisted SAR planning.
- SARMIS - SAR management information system for general data.
- MSIS II - Maritime safety information database.
- AMMIS - Automated requisition management system.

D. SUMMARY OF REQUIREMENTS FOR A VTS C^3 SYSTEM

Coast Guard VTS systems will become one of several sources for a larger C^3 system used to support the operational needs of the Coast Guard. Based on Coast Guard progress in establishing computer enhanced support systems, the author expects this integration to occur over the next three to five years. In order to support a larger system, the second generation VTS will have to be developed using a common base of standards for information systems architecture, particularly with regard to data format. This effort will require an integrated plan that includes the following modules.

1. Distributed Database Architecture

As one of several information sources for a larger system, the new VTS systems will have to create a database of information. This database will contain real-time, dynamic, and static data in a standard format. Information from the data base will be selectively drawn by VTS personnel to create a tactical display. The database information will also be queried by upper echelon C^3 systems needing tactical information. This will be accomplished through the use of open system interfaces as established in the GOSIP requirements. This can be conceptualized through the use of STC within a VTC while allowing superior C^3 systems to receive the database information via HDN.

2. Communications Support

Development of an distributed C^3 system requires development of a highly capable communication system linking the nodes of the C^3 system. In his book, Morris states:

> ... The full exploitation of the potential power of C^3 systems can only be achieved by merging both the processing equipment and the communication network in a single operational configuration, that is, blending them into a single sophisticated system [Ref. 21: p. 21].

Although separate from the data acquisition, processing, storage, retrieval, and display subsystems, the communication subsystem is an integral and equal part of any effective C^3 system. This is the basis for the more common terminology, Command, Control, and Communication (C^3).

3. Information Security

Integrating several information sources in a hierarchical C^3 system will require the use of both secure and non-secure data. This type of data fusion must be conducted through the use of a one-way communications link that segregates secure data from non-secure data acquisition. Technology will have to be implemented that provides the same degree of protection as the current "air gap" requirement.

4. Management Support

A VTS C[3] system must support the management functions of planning, real-time operations management, and analysis of historical data. This system should allow use of the database information and graphical display tools in an planning (not real-time) environment, while the VTS (real-time) operation continues. Due to the regulatory nature of VTS, the track information becomes an important element of an accident investigation and must be securely maintained as a legal document. In addition, the information is valuable in the analysis of the overall port operation and, in particular, analysis of the effectiveness of the VTS system.

IV. SELECTED TECHNOLOGY FOR COAST GUARD VTS SURVEILLANCE

A. ASSUMPTIONS FOR TECHNOLOGY SELECTION

During the author's interviews and research, several themes ran through the opinions, documentation, and data. These themes are discussed in the following paragraphs and create a group of assumptions. These assumptions are necessary in order to assure that technologies surveyed for VTS surveillance are feasible within the fiscal, operational, and public service constraints of the Coast Guard.

1. Low System Cost

The recent fiscal austerity within the Coast Guard has kept the VTS program from maturing with improved technology. In spite of three highly publicized oil spills (Prince William Sound, AK; Huntington Beach, CA; and New York Harbor), there has not been a public call to expand or improve the Coast Guard's VTS system. Improvements to VTS will be funded on a competitive basis within the Coast Guard. VTS must compete against the day-to-day operational, maintenance, and administrative needs of the Coast Guard. As a small agency within the Department of Transportation, the Coast Guard does not have the financial resources for original design and development of new systems or technologies. These fiscal constraints will force new VTS systems to be composed of existing, commercially available, and relatively inexpensive modules. This sort of acquisition strategy can allow the Coast Guard to field a new and flexible system at a minimal cost, in a reasonable amount of time.

2. Economies of Scale

Development of a second generation VTS will not enjoy the cost reductions related to the economics of large scale production. The actual number of ports served by a Coast Guard VTS is not expected to significantly change. Each port served by a Coast Guard VTS system has different geographical, climate, and traffic density characteristics. This requires a specifically tailored mix of VTS technologies to meet the port needs. Use of a modular approach to the design of a VTS system will provide the flexibility and may provide some cost savings and is consistent with the design needs of a computer enhanced C^3 system. One example of the Coast Guard's efforts to spread the cost of VTS system development over several programs is the possible use of the Shipboard Tactical

Computer (STC) as the VTS backbone architecture. Although developed for shipboard use, STC hardware and software can provide most of the functions needed in a VTC.

Another area of possible savings is use of sensor and communications equipment (radar, VHF-FM, computers) that is standard throughout the Coast Guard. This will provide a wider equipment acquisition, operation and maintenance cost base.

3. Use of Current Capital Assets

Wherever possible, the Coast Guard will use capital assets (equipment and land) that are already owned or controlled. Acquisition costs and administrative delays in the federal procurement system require this. The existing radar systems, AIL and Raytheon, will continue to provide surveillance information for many years. VTS New York will use radar and radio sites that the Coast Guard currently controls, even though the sensor coverage will be less than optimum [Ref. 33]. The design of a new VTS system should be modular in order to allow use of the best sensor types based on the overall needs of the VTS system. The cost of the sensor suite should be balanced against the fiscal constraints of the Coast Guard.

4. Action in the Public Sector

Many of the constraints placed on the design of a second generation VTS are political in nature and stem from the Coast Guard's service in the public sector. In many cases this role has created a requirement for immediate action, rather than an engineered solution to a studied problem. As a player in the public sector, the Coast Guard reacts to the demands of the people, normally voiced through Congress. In the case of VTS New York, this mechanism is requiring the Coast Guard to "throw together" a system to meet a Congressional mandate to have the VTS on-line within a year. System engineering, in this case, is limited to design with what is either on-hand or quickly and easily procured. Long range planning is not possible in a reactionary environment.

Coast Guard VTS systems provide a public good where the benefits are shared by both the VTS participants and local area population and environment. The burden of paying for this service will continue to come from the public sector, not from the users. The idea of "user fees", for any federal service, continues to run into political walls in Congress. The Coast Guard, through the Ports and Waterways Safety Act (PWSA), can require certain classes of vessels to carry particular equipment. The cost of that equipment is the responsibility of the vessel owners. In the past the merchant marine industry and boating public have been cooperative in complying with Coast Guard efforts to enhance maritime safety and environmental protection. This is because their out-of-pocket costs have been relatively small compared to the benefits of carrying the Coast Guard required equipment.

5. System Integration

The Coast Guard will continue to move toward an integrated environment where information from many independent sources and operational resources can be managed through computer enhanced C^3 systems. VTS will be a subsystem for larger C^3 systems serving the overall mission needs of the service. VTS C^3 systems will rely on computerized interfaces, data exchange, and flexible graphics capabilities for day-to-day operation and planning. The GOSIP requirements will force the Coast Guard to implement standard protocols. This will enhance data exchange, network development, and the interoperability of resources through data sharing.

6. Nature of Information Returned to VTS Participants

The Coast Guard will continue to provide real-time information to VTS participants in the form of voice traffic reports. In general, the Masters and Pilots of the ships participating in Coast Guard VTS systems are happy with the information provided over the voice circuit [Ref. 34]. Advance warning of other traffic, by voice, allows them to prepare for and monitor the actions of the other ships. Merchant ships are required to carry and use radar. Most are also equipped with a wide array of communications and navigation equipment that allows them to receive weather reports and charts, navigation warnings, and similar information prior to entering the VTS. VHF-FM provides a clear voice channel in nearly all weather situations, allows for use of different VHF-FM channels in different VTS sectors, and the equipment is reliable and inexpensive. Modular design of a VTS system will allow for the automation of the traffic data exchange when public acceptance and manpower workload require it.

B. FUNCTIONAL MODEL OF A VTS

Based on the information in Chapters II and III of this thesis, a functional model for a VTS (Figure 5 on page 40) was developed. The basic functions of a VTS system are briefly discussed below.

1. Information Collection

A VTS relies on three basic types of information input. They are:

- Target Detection and Identification.
- Target Tracking.
- Miscellaneous Target Information including vessel name, draft, length, destination, and cargo.

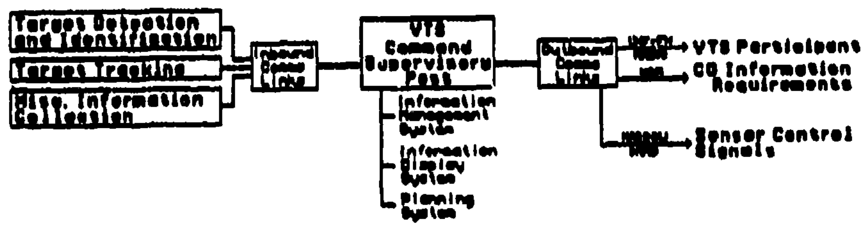

Figure 5. Functional Model of a VTS

Vessels entering a VTS must be detected and identified in order for the VTS to be able to track vessel movement. The ability to detect an unwilling or unusual vessel is essential to the operation of the VTS. The MDZ, SAR, and ATON missions require a VTS to detect or search for vessels or objects that will not or cannot participate in the VTS system.

A VTS relies on tracking information to determine the position of each vessel in the VTS. VTS operators normally do not track small (typically pleasure or fishing vessels) contacts, but monitor their activity in a general manner. The operators watch for dangerous situations involving actual VTS participants. One example is a heavy concentration of sailing vessels in or near a commercial shipping lane due to a scheduled sailing regatta. The VTS would monitor the traffic and provide VTS participants with advance warnings of the unusual traffic. This sort of surveillance requires a VTS to have a detection capability.

As mentioned in Chapter II, a VTS collects an assortment of information regarding each vessel participating in the VTS. This information includes draft, cargo, and destination. This miscellaneous information provides important data that rounds out the overall view of the VTS. VTS participants also report navigation aid discrepancies, unexpected weather, and similar information which is recorded in the VTC.

2. Inbound Communication Links

This is the physical means used to transfer information into the VTS system. Currently the inbound communication links include VHF-FM voice radio and wideband microwave. One of the major needs of the VTS program is to reduce the expense of these communication links. In general, link expense is proportional to the bandwidth of the channel. Wideband links are much more expensive than narrow band links. The wideband microwave links are currently owned by the Coast Guard whereas narrow band links are commonly available for lease, inexpensively, in the commercial market.

3. VTS Command Supervisory Post (CSP)

The functions of a VTS CSP, or VTC, are complex and include the ability to assist the VTC decision maker to assimilate information from several sources into a concise picture of the current status of the VTS. This is primarily done using the vessel tracking and miscellaneous data available in the VTC. Detection and identification information provide the basis for the VTS tracking process. VTS decisions are based on the wide variety of information available in the VTC. When necessary, orders may be passed to VTS participants using the outbound communication links.

4. Outbound Communication Links

The outbound communication links provide the connectivity necessary for the effective operation of a VTS. Traffic and navigation safety information is provided to VTS participants using the VHF-FM voice network within the VTS. Prior to entering the VTS ships may receive similar information using other communication networks such as Coast Guard high frequency teletype broadcasts. Surveillance sensors are controlled using narrow band communication links. Future VTS systems should provide information to superior C^3 systems. This may be done using high data rate packet switching services with a DS1 or greater data rate.

C. TECHNOLOGY REVIEW

In the following paragraphs the author will review some of the technologies capable of providing some or all of the functions necessary to operate a VTS. These technologies will be reviewed using Figure 5 on page 40 to organize how each could be used in a VTS system. Following this, the author will review some of the technologies that the Coast Guard has rejected for use in a VTS system.

The technologies that are most applicable to VTS fall into three categories. The three categories are:

- Direct transmission of surveillance information using wideband systems. For the purposes of this thesis, wideband is defined as greater than 1.544 Mbps (DS1 or T-1) for digital signals or 100 KHz for analog signals. In simple terms a wideband signal cannot be carried over a voice grade communication circuit.
- Remote processing of surveillance information allowing use of narrow band transmission systems. Narrow band is defined as a data rate of 9600 bps or less for digital signals or analog signals having a bandwidth of 3000 KHz or less. Signals of this type are able to be transmitted over voice grade communication circuits.
- Systems based on technology other than radar or video surveillance and using a hybrid mix of telecommunication technologies.

The first two categories deal with transmission of radar and video camera signals from a remote site to the VTC. The third category deals with technologies that would allow the Coast Guard to move away from radar and video camera surveillance sources altogether. In general, these non-radar and non-video camera systems rely on a group of technologies that require the cooperation of the target to provide surveillance information to the VTC. These technologies are termed "dependent" because the system relies on data transmissions that originate from target vessels.

1. Direct Transmission of Wideband Surveillance Information

The technologies included in this category are capable of transmitting wideband radar and video camera signals. These technologies make up the major portions of the current inbound communication link illustrated in Figure 5 on page 40. The data links must be capable of supporting an analog signal with a bandwidth of 10 MHz. This is the bandwidth of the radar (video and synchronization signals) and LLLTV video signals used by the Coast Guard. In general, the signals required for control of the remote radar and video camera equipment can either be incorporated within the 10 MHz link or carried by separate voice grade links having a bandwidth of 3 KHz or less.

a. Microwave Systems

Microwave communication systems provide a line-of-sight wideband communication link. This link is based on the use of highly directive antennas with a transmission frequency in the range of 1.71 GHz to 40 GHz. Microwave transmissions suffer a substantial signal strength loss due to atmospheric effects. This free space loss limits the overall range for a single hop microwave system to approximately 50 Km. Weather conditions, particularly rain, snow, or sand can further degrade a microwave link. In general, microwave systems using the lower authorized frequencies provide longer ranges and are less susceptible to weather related signal loss. Disciplined system engineering can provide a microwave system with a reliability of greater than 99.95% [Ref. 18: pp. 3-15 to 3-17].

(1) Analog Microwave Systems. Analog microwave systems are common in the communications industry. They provided the backbone of the telephone industry through the 1970's. The technology is mature, system engineering refined, and a wide variety of products exist in the commercial market. Both AM and FM modulation techniques are commonly used. AM microwave systems enjoy better spectral efficiency and have become more popular recently [Ref. 35: pp. 4.17-4.18]. A low to medium capacity analog microwave system is capable of providing up to 20 MHz of bandwidth. This is sufficient for the needs of a VTS.

(2) Digital Microwave Systems. Digital microwave systems are replacing analog systems as the communication industry moves toward use of purely digital signalling. The telephone industry's backbone networks use only digital signalling. A low to medium capacity digital microwave system has a capacity of up to 25 Mbps. The use of a digital microwave system for the existing Coast Guard VTS equipment would require conversion of an analog video signal (radar or video camera) to a digital representation of that signal (A-D Conversion). Use of modern conversion techniques, like Adaptive Differential Pulse Code Modulation (ADPCM), would create a digital signal at a rate of more than 100 Mbps. Advanced digital modulation techniques, like 16QAM, allow transmission of more than one information bit per Hertz. These digital modulation techniques could be used to transmit digitized radar and video camera video signals over a low to medium capacity (25Mbps) microwave circuit. If the Coast Guard continues to use the existing VTS radar and camera display equipment, it would also be necessary to reconvert the signals from digital to analog format (D-A Conversion) for use by the VTC display equipment.

b. Satellite Microwave Systems

Satellite communication systems operate in the same manner as terrestrial microwave systems. This is due to the fact that satellite systems operate on comparable frequencies and use similar equipment as terrestrial microwave systems. There are two major differences between terrestrial and satellite microwave systems. One difference is that having a repeater in space provides an extremely wide coverage area for a satellite system. The other difference is that the satellite signal must travel 75,000 Km between the terrestrial source and terrestrial receiver. This causes a delay of about 500 msec between reception of a signal and acknowledgement of the received signal. This delay must be accounted for in computerized data transfer systems. A typical commercial satellite channel (C-band) has a bandwidth of 36 MHz. These circuits are capable of providing data capacities up to 50 Mbps. A satellite system channel is capable of carrying surveillance signals from either radar or video camera sources. Analog service is possible over these systems but digital signalling is, by far, the predominate technology. Use of a satellite system would require A-D and D-A conversion if the existing VTS surveillance and display equipment is used. [Refs. 20: pp. 49-84., 36: pp. 305-323]

c. *Guided Media Systems*

Guided media includes all cable transmission systems. The signals are guided within the cable, and not radiated through the atmosphere. The use of guided media removes the probabilistic effects of atmospheric propagation loss, leaving a highly predictable loss function that is based on the physical media being used. The two types of guided media capable of wideband transmission are fiber optic systems and coaxial cable systems. These media are characterized by their point-to-point nature (verses broadcast technologies), the need for periodically spaced amplifiers (analog systems) or repeaters (digital systems), the need for cable right of way, and terminal equipment costs being 25% or less of the overall cost of a system.

(1) *Optical Fiber Systems.* Optical fiber transmission systems are composed of the following components.

- *Semiconductor Light Sources.* Light Emitting Diodes (LED) and Injection Laser Diodes (ILD) are used as fiber optic system light sources. LEDs are highly reliable and inexpensive but have a low output power. ILDs are slightly less reliable, temperature sensitive, more expensive, and have a much higher light output power. A 850 nm LED source (which is standard) is limited to a maximum data rate of 100 Mbps and 2-3 Km in distance (without a repeater). Higher data rates and longer, repeaterless, distances are possible with ILD light sources [Ref. 36: pp. 53-56].

- *Optical Fiber Cable.* Optical fiber cable is made of a thin filament of glass surrounded by a glass cladding layer. This is in turn surrounded by a protective polymer covering. Several small cables may bundled together along with stiffening and strengthening material to form an optical fiber cable. The core filament varies in thickness from 8-50 μm depending of the type of optical fiber cable used. Optical fiber cables are approximately ten times lighter in weight than a coaxial or twisted copper pair cable capable of carrying the same data rate.

- *Semiconductor Photo Detectors.* Two detectors are available, the PIN photodiode and the avalanche photodiode (APD). These devices convert light energy to electrical energy. PIN detectors are less expensive and less sensitive than the APD detector.

The use of optical fiber transmission systems has grown enormously over the past ten years. Optical fiber is used extensively for the long haul trunking systems of the major telecommunication companies. Optical fiber use is also spreading into metropolitan areas for use in the local loop feeders which connect the subscriber loops to the telephone company central office. Optical fiber is also being used for undersea cables, Local Area Networks (LAN), and is planned for use in Metropolitan Area Networks (MAN) [Ref. 20: pp. 26-45]. Optical fiber systems enjoy the following characteristics:

- Extremely wide bandwidth. 2 Gbps typically. Tests have shown that serial bit rates of 8 Gbps are possible [Ref. 20: p. 44].
- Immunity to electrical interference.
- Analog and digital signalling capability. Analog signalling is normally limited to short haul links not requiring amplification.
- Repeater spacing of 40-50 km at a data rate of 500 Mbps (digital signalling) or 2-3 km for analog signalling at 4 MHz. Bell Labs has demonstrated a 68 Km repeaterless digital link at 8 Gbps [Ref. 36: pp. 54].
- Splicing of fibers is difficult [Refs. 20: pp. 23-24, 35: pp. 17.30-17.31].

Optical fiber systems have the bandwidth necessary to directly transmit the video signals from VTS radar and video camera sites to the VTC. In fact, there is sufficient bandwidth for multiple video signals to be carried. Realistically, the surveillance signals would be digitized and possibly multiplexed for transmission over this type of guided media.

(2) Coaxial Cable Systems. Coaxial cable transmission systems include the ubiquitous cable TV (CATV) networks that are common throughout the United States. Coaxial system are characterized by the physical dimension, and therefore the impedance, of the coaxial cable. Coaxial cables range in thickness from about .3 to 1 inch. These systems typically have a bandwidth of 350 MHz or more with a data rate of 500 Mbps. Coaxial cable is used for both analog and digital signalling. Repeaters or amplifiers are necessary at intervals of 10 km or less, with the distance decreasing as the data rate or frequency of the transmission increases. Coaxial cable is simpler to work with than optical fiber as cable connections are easily made without loss of significant signal strength. Recent trends in the telecommunication industry have been away from the use of coaxial cable due to the decreased cost and increased signal efficiency of optical fiber systems. [Ref. 36: pp. 50-53]

d. Commercial Wideband Telecommunication Services

(1) T-3 Service. Commercial telecommunication companies are able to provide digital service up to the DS3 (44.736 Mbps) rate. This service is provided as a

leased line service and is available in major metropolitan areas. T-3 service is generally implemented over optical fiber networks, however microwave circuits are also used. As T-3 service requires a digital format, A-D and D-A conversion would be necessary if the existing VTS equipment was to be used.

(2) Integrated Service Digital Network (ISDN). ISDN service is being provided in isolated major metropolitan areas. The bandwidth available over current ISDN circuits is limited to 1.544 Mbps using the Primary Rate Interface (PRI). As ISDN evolves into a robust network architecture, the maximum available bandwidths will increase. The H-Channel family will provide expanded bandwidth with the maximum being 1.920 Mbps on an H12 channel. Broadband ISDN (B-ISDN) is also under development and will further increase the available bandwidths. It is expected that both the H-Channel and B-ISDN will be based around fiber optic technology. Neither service has been commercially deployed.

2. Remote Processing of Surveillance Information

In this section the author will review an emerging technology that allows transfer of surveillance data over low bandwidth communication links. This capability is possible due to high speed digital processing of radar information, at the remote radar site. This technology is modular in that it can process nearly any radar signal, use any two-way low bandwidth communication link, and can be combined with other digital data (digital charts and geographic overlays) to create an integrate display in a control center.

a. Radar Scan Conversion

The heart of a remotely processed radar information system is a radar scan converter. These units accomplish the following processes:

- Accept and condition raw radar video, azimuth, and trigger signals.
- Digitize the incoming radar information.
- Convert the radar data from polar (rho-theta) to rectangular (X-Y) form.
- Detection of moving targets, target extraction, and target tracking.

The output of a typical radar scan converter provides target tracking information in a format that can easily be transmitted over voice grade communication links. This target tracking information creates a "Target Table" which simply lists the identity tag, position, course, and speed of targets detected by the radar and processing system. Target extraction is based on the contact being present for three to five consecutive antenna sweeps. Contacts that do not meet this, or other user-adjustable criteria, do not receive further processing. This scan-to-scan comparison is the same basic technology employed in the AN/SPS-121 VTS radar system to reduce the instance of false targets, sea and rain clutter, and similar interference.

b. VTS Systems with Radar Scan Conversion

Radar scan conversion alone could allow the Coast Guard to move toward use of inexpensive data links (9600 bps voice grade telephone, VHF-FM radio, etc.). Effective use of scan conversion would require the Coast Guard to move toward fully synthesized video, raster scan display technology. One example of this technology is Radar Digital System's VTMS-87/90 VTS system. This technology uses remote radar scan conversion, local (VTC) graphics processing, and high speed data processing to provide the following capabilities:

- Improved radar clutter control.
- Color displays using high resolution daylight viewing computer monitors.
- Display of user selected digital chart information including coastline, aids to navigation, port facility, and similar information.
- Overlaid vessel information based on the radar derived target table database entries. The vessel tracking capabilities include all the functions of the ARPA systems which are part of the AN/SPS-121 VTS radar system.
- Target alarms based on proximity to other targets, channel boundaries, navigational dangers, or operator selected criteria.
- Control of remote radar sensors is accomplished using low data rate communication links. Control parameters include radar gain, interference rejection settings, range selection, etc.. [Ref. 37]

This type of integrated system closely matches the functional requirements of a VTS (see Figure 5 on page 40) and has the possibility of reducing the operating costs of a VTS. This is possible due to the decreased costs for the inbound communication links and a possible reduction in VTC manpower levels due to greater system automation. The planning needs of a C^3 system are not directly addressed in vendor literature. Given the rapidly improving computer capabilities, planning tools (search planning, facility positioning, etc.) could be added through software additions to a standard VTS package.

c. Video Signal Compression

Compression of video pictures can reduce the bandwidth necessary for transmission of the information. While this technology is being developed primarily for use with video conferencing, VTS surveillance systems could benefit from the reduced bandwidth. The compression techniques require the video to be shifted to a digital format. The most common A-D conversion technique is PCM. This digital information is stored as a frame which is similar to a photograph; it is static. This original, or base, frame is also transmitted to the remote site. When the next frame is digitized, it is compared to the original. The only information returned from this process are the differences between the two frames. This change information is then transmitted and processed at the remote site. There are many complex techniques that are capable of compressing a video signal. Every system will degrade as motion, or changes, between the frames increases. The most optimistic systems claim to be able to reduce a video signal from about 90 Mbps (using PCM A-D conversion) to 19.2 Kbps. This degree of compression will degrade severely with motion. A more practical compressed data rate is in the range of 3.1 Mbps to 384 Kbps. A system working in this range should be capable of reproducing the motion typical in a VTS video signal. [Refs. 18: pp. 4-10 to 4-13, 38]

3. Alternatives to Radar and Video Camera Surveillance

a. Dependent Surveillance

Dependent surveillance is a technology that is applicable for some VTS mission needs. The term "dependent surveillance" means that the target of interest is an *active* participant in the surveillance system. The remote target is active in that it transmits a short digital message containing an identification tag and position data. This data is used by a surveillance and tracking system at a central location. In general a dependent surveillance system is made up of the following components:

- Electronic position determination system. Typically the systems currently available use LORAN C to determine the geographic position. Other possible systems include Omega, Decca, Global Positioning System (GPS), and inertial navigation systems.
- Communication link equipment. As the targets of a dependent system are mobil in nature, a radio communication link is necessary. The bandwidth requirements are determined by the overall system needs. Voice grade radio links are generally capable of carrying the position information. The radio system propagation characteristics determine the geographic boundaries of a dependent surveillance system.
- Target display system. Information from targets is typically used to build a database of target positions. This information can be displayed by laying it over a digital map. Computer systems capable of medium to high resolution graphics can be used to run the database engine and as well as act as the display medium for a dependent surveillance system. This component provides most of the functions of a C^3 system.

(1) Radar Beacons. An example of a dependent surveillance system based on radar beacons is the FAA's 4096 Transponder system. Nearly all aircraft are

equipped with microwave transponders that reply to an interrogation signal. This interrogation signal is transmitted by equipment that is coupled to FAA airsearch radar. The airborne transponders transmit a four digit code that FAA controllers instruct a pilot to enter. The transponder transmits this identifying code and the aircraft altitude when the airsearch radar "paints" the aircraft. The FAA has also established particular codes that indicate communication equipment failure, aircraft highjacking, or general emergency. When FAA ground systems receive one of these special codes, an alarm is sounded and the aircraft is highlighted on the radar display system.

An important element of this FAA system is the use of a robust C^3 system that displays operator selected information, including the radar beacon data. This system automatically tracks selected beacons and displays relevant data including position, altitude, and converging targets. Using visual symbols and audio alarms this system greatly reduces operator workload, helps manage the airspace system, and enhances the safety of the system participants. A system similar to this could be implemented in a VTS area. Commercial vessels that are required to participate in the VTS are also required to use radar and carry other electronic equipment. Transponders could be added to the list of required equipment. The interrogation equipment would be added to the existing Coast Guard radar systems. The VTC display system would have to be modified to accept and efficiently display this added information. [Ref. 26 : AIM para. 31, 170, 451, 461, 463, 471]

(2) Direction Finding (DF) Systems. One of the simplest, and best understood, dependent surveillance systems is a direction finding system. These systems use two or more land based stations equipped with highly directions antennas to derive bearings from the DF station to the active transmitter on the target. These bearings are used to "triangulate" a geographic position for the target. Use of line-of-sight radio propagation technology (VHF, UHF, Radar) increases the accuracy of the bearings and allows for sectored operations within a VTS area. Use of a coded transmission, like the FAA 4096 transponder system, would allow determination of target identification as well as target location. Use of a system of this sort would also require addition of a C^3 display system in the VTC. [Ref. 18: pp. 5-19 to 5-21, 7-23 to 7-30]

(3) Geostar Corporation RDSS. One of the most robust of the commercially available dependent surveillance systems is Geostar Corporation's Radio Determination Satellite Service (RDSS). As the product's title implies, RDSS uses microwave satellite communication links. These links are based on short burst, spread spectrum communication techniques. Use of satellite links allows this system to cover

a very wide geographic area. Their most advanced system, System 2C, uses two satellite links and covers all of North America and the Caribbean Sea. One link is used to send short query and alphanumeric messages, to the target system. The other link carries the target's position information back to Geostar's control center near Washington, D.C. From the control center Geostar uses commercial electronic mail systems to forward the position information to their customers. This system includes one-way message handling (to the remote target only). The RDSS process takes about three minutes to complete and includes the following steps:

1. Geostar Control queries the target. The query is either a periodic report, with the period determined by the customer, or a special request from the customer. A short alphanumeric message may be included in the query.
2. The target receives the request, displays the alphanumeric message (if included), processes the navigation information, and transmits the reply.
3. Geostar control receives the reply, acknowledges it back to the target, processes the information, and forwards the position to the customer's display system.

System 2C uses LORAN C to electronically determine the target's position. LORAN C has been shown to have an accuracy of between one-half and five miles, depending on the location of the target relative to the LORAN transmitting stations. System 2C is currently used by several major trucking firms and the federal government (for tracking nuclear materials shipments). Use of LORAN C as the position determining subsystem precludes System 2C from use in a VTS due to the poor resolution of the reported positions. The Coast Guard has determined that the data latency is too long for use in a VTS system.

During the spring of 1992 Geostar intends to field their new system, Geostar System 3. This system will use the Global Positioning System (GPS) for position determination. This will provide position accuracy of the precision necessary for remote surveillance in a VTS. Geostar's System 3 should have an accuracy of between five and ten meters and a data latency in the order of a few seconds. GPS accuracy can be changed by the U.S. government by activating the Selective Availability (S A) mode within the constellation satellites. This would downgrade the accuracy to approximately 100 meters for non-military GPS users. This precision should still be acceptable for VTS operation.

Differential GPS (DGPS) is a technique that can be used to increase the accuracy of position information to between 75cm and 5 meters. In a DGPS system a master DGPS unit is positioned at a fixed and precise location. Knowing its own actual position, the master unit calculates the difference between the actual position and the position developed using the GPS. This difference may be broadcast over a narrow band radio link. Mobile DGPS units receive and use the differential information in their position calculations. Differential GPS systems are capable of providing this highly accurate position information even when the GPS satellite S/A mode is activated. [Ref. 39]

b. *Passive Sonar Sensors*

A passive sonar sensor networks can collect VTS surveillance information. Such a system would consist of sonobuoys being moored across a harbor entrance. These sensors would be linked to a central processing station in the VTC. The link could be narrow band. Such a system would provide detection and tracking capabilities. Identification of the targets would be nearly impossible. Effective detection and tracking requires a highly trained and experienced operator as the automatic processing equipment is less capable than a good operator. Due to the technology and methods involved, such a system would most likely be classified. Operation of the system would be expensive due to the requirement to periodically service the sonobuoys and to maintain a pool of trained and experienced operators. The cost of sonar equipment is directly related to the equipment capabilities as measured in detection range and tracking accuracy. [Refs. 18: pp. 11-1 to 11-6, 40: pp. 5-18]

4. Rejected Technologies

The Coast Guard has conducted wide ranging research on the best means of providing the functions necessary for an effective VTS. This research has concentrated on target detection, identification, and tracking. Some research has also been done on the communication links necessary for VTS operation. Table 8 on page 52 outlines the results of research projects that have shown a technology to be inappropriate for use in a VTS. Table 8 on page 52 also indicates, briefly, the reason for such a decision.

Some of the technologies reviewed are not feasible for use in a Coast Guard VTS system. This is primarily due to the expense of designing, developing, and fielding a technology that is used only by the Coast Guard. The chance of an independently developed Coast Guard system being truly efficient and effective is small. It would lack efficiency due to economies of scale in production, user acceptance would be low, and maintenance costs would be high due to the need for specialized parts, tools, and technician training. Listed below are the systems that fit this category of possible, but not feasible, VTS technologies.

- Maritime radar transponders. Would require development of custom interrogation systems and ship mounted transponders, user training, and development of an acceptable display system.

- Direction Finding Systems. Would require development and use of an extensive receiver network in each port. User equipment would have to be developed to transmit a "packet" with a unique ID code for each ship. Equipment costs would be high. Design of a Coast Guard display system would be necessary.

- Coast Guard Dependent Surveillance System. Design of a Coast Guard owned and operated dependent surveillance system would be very expensive due to the design and development costs. There is a wide range of technologies that could be used to link the position reports to the VTC. With the exception of satellite based systems, the propagation characteristics of the transmission systems would require construction of individual receiving stations, information processors, and displays systems.

Date	Technology	Reason for Rejection
1980	Infrared Thermal Imaging - Pyroelectric Videcon Model 84	Capable of detecting 20-40 foot vessels at a range of 400 yards or less. Typical harbor traffic did not provide enough relative motion for camera detection. For effective operation the camera continuously panned. System required human interpolation of imagery. Determined to be impractical due to limited effectiveness [Ref. 40: pp. 4, 18, B-1].
1980	AN SSQ-41 Sonobuoy Network	Limited range of detection (1500 yds). System expensive due to the cost of buoys, signal processing equipment, and the requirement for servicing the sonobuoys. Detection and tracking required constant operator attention. Automatic processing less capable than a well trained and experienced operator. Operator skill critical to system effectiveness. The system has no realistic potential for vessel identification. The system subject to high rate of errors from background noise (surf, storms, wind, etc.) and interaction of multiple contacts. Sonobuoy networks could be relevant to the MDZ mission but are too complex and expensive for peacetime VTS operation [Ref. 40: pp. 5-18].
1980	AN TAS-6 Night Vision Device	Tests determined Night Vision Device could be effective. Required trained observers situated at a well chosen vantage point. Vessel detection range 2-3 miles. Equipment cost exceeded $45,000 per unit. System determined to be impractical due to expense, requirement for operator interaction, and limited detection range [Ref. 40: pp. 5, 18].
1981	Digital Data Communication Systems	A dependent digital data communication system based on VHF-FM radio system was designed. The system captured position (LORAN C), course, and speed data. Vessel operator could add information like destination and ETA. Mobile system was to be polled by VTS and to build a database of information. Project dropped due to lack of funding [Refs. 41, 1].
1981	Narrow Band Communications	Investigation of various techniques and equipment which could reduce the bandwidth requirements for radar and video transmissions to a VTC. Project dropped due to lack of funding [Ref. 1].
1982	Meteor Burst Communication	Investigated meteor burst communication for radar and video links. System feasible with data rates to 4000 bps but with message wait times of 30 seconds to 15 minutes. Costs for system installation moderately high. System seen as too complex for VTS served by commercial data or simple micro wave links [Ref. 18: pp. 3-24 to 3-34].
1987	Video Compression	A CCTV analog signal requires about 6MHz. If digitized it requires about 90 Mbps. Current CODEC equipment can reduce the data rate to 384 Kbps. These systems can handle only small changes in the picture from frame to frame. As technology advances, Codecs may be used to allow use of narrow band circuits for video sensors links [Ref. 18: pp.4-7 to 4-13.].
1987	Laser Ranging	Use of low power laser range measuring technology could be coupled to video imaging technology. LLLTV equipment could provide a picture and bearing. Laser system would provide range. This could establish target's position. System determined to be impractical due to the need for cooling of laser equipment and concern over eye damage from the laser ranging [Ref. 18: pp. 9-1 to 9-4].

Table 8. Rejected VTS Technologies

V. EVALUATION OF SYSTEMS

A. EVALUATION CRITERIA

1. Criteria Introduction

The criteria developed to evaluate VTS surveillance system technology stem from the issues discussed in the earlier chapters of the thesis. These criteria focus on how VTS may best fulfill its missions and fit into the larger operation of the Coast Guard. Fiscal realities require the Coast Guard to optimize the cost of a system within the context of the wide range of Coast Guard responsibilities. If a second generation VTS can work in an integrated manner with other operational resources, the Coast Guard, and VTS, will become more efficient and effective through the symbiotic relationships between missions and resources.

2. Criteria Categories

The evaluation criteria form seven basic evaluation categories. Each category contains several major areas of emphasis. The following paragraphs highlight the categories and areas of emphasis. The evaluation criteria categories are:

- Ability to safely and efficiently control vessel traffic.
- Ability to adapt to changing mission needs.
- Ability to enhance Coast Guard C^3 capabilities.
- Ability to reduce VTS operating costs.
- Ability to adapt to technology changes.
- A reasonable implementation time frame.
- A reasonable expectation of system acceptance.

a. Ability to Safely and Efficiently Control Vessel Traffic

The primary function of a VTS surveillance system is to provide the VTC with traffic data that can be used to monitor and control vessel traffic. The degree of control varies with the dynamic situation present within the VTS area. Typically the Coast Guard monitors traffic flow rather than actually controlling it. The capability to control traffic flow is, however, an important element of the VTS structure. This capability will become more important as traffic density increases. During periods of military port operations, such as a mobilization or natural disaster, a VTS may be tasked with the direct control of traffic flow. Any new VTS system must be capable of providing at least the same level of control as the current systems provide.

The ability of a system to safely and efficiently control vessel traffic has three major elements. These elements are discussed below.

(1) *Data Latency.* Data latency refers to the period of time that it takes for a system to sense, process, and display surveillance data. Data latency is a critical factor in the Coast Guard's ability to safely and efficiently control traffic in a VTS area. A vessel under VTC "control" receives general directions and information. The Coast Guard needs the ability to check vessel movements for compliance with VTC orders, traffic regulations, and navigation requirements.

In a general sense, the Coast Guard needs to make sure vessels stay on their side of a shipping lane or channel. Assuming this is the case, an acceptable data latency can be calculated based on vessel speed and the transverse distance the vessel would have to move to physically leave the channel. Data latency would therefore be a function of the channel width and would decrease to a shorter period of time as a vessel moved into increasingly constricted navigation areas. A surveillance system must be able to provide surveillance information with an acceptable data latency based on either the most constricted VTS area or based on vessel location. Using vessel location as the tool for judging data latency would allow the "acceptable" latency to change based on vessel location within the VTS.

(2) *Data Accuracy.* Accurate data is essential to efficient and effective control of vessel traffic. The ability of the proposed data links to accurately support data flow is well established by the communication industry and will not be further evaluated. Sensor accuracy must be considered. The necessary degree of accuracy may be viewed as a function of channel width in a similar way as data latency. Based on this assumption, a surveillance system should be capable of providing position data with enough accuracy to allow the Coast Guard to "see" that the vessel is safely in the channel. The most constricted channel may establish the highest degree of accuracy necessary. A graduated accuracy scheme based on vessel location and channel width should also be acceptable.

(3) *Data Interpretation and Use.* A VTS system is a form of C^3 system. The data must be displayed in a fashion that allows the watchstanders and supervisors to interpret the current situation in the VTS area. Display technology is important to the effective use of information. The techniques used to display surveillance data should follow well established guidelines for data display. In general these guidelines include the

amount of data displayed; use of symbols, flashing symbols, and color; as well as use of "user friendly" techniques for data and sensor manipulation.

b. Ability to Adapt to Mission Needs

The mission of a VTC is constant with respect to monitoring traffic safety. However, this is the minimum mission level. A VTC may also be tasked with additional and concurrent mission areas including SAR, MDZ, MLE, and ATON. Effective execution of these additional missions affect the overall requirements for a fully capable VTS system. The following paragraphs highlight some of areas that must be considered to evaluate a fully capable VTS surveillance system.

(1) VTS Surveillance Capability. Addition of missions or a change in mission priority may require different surveillance capabilities. Under the PSS mission, the VTS may only need to track willing (dependent) targets. During periods when the MDZ mission receives a high priority, the VTS may be required to detect and track unwilling contacts, sub-surface contacts, or very small contacts (like periscopes). A VTS system should therefore be capable of supporting a sensor suite capable of performing the surveillance necessary for the missions at hand. This added capability should be available without a major system change. The ability to integrate different sensor types is important to the overall flexibility of the VTS system.

(2) Display Flexibility. As the VTS mission changes it will be necessary for the operators to tailor their displays to emphasize the information they need to perform the mission or missions assigned. A common scenario involves VTS participants steaming through active SAR search areas. If the VTC watchstander display included a representation of the search areas, the participant could be advised to assist in the search while moving through the area. In some cases it could be useful to dedicate a surveillance display to a particular mission by filtering out routine VTS information. These examples illustrate the degree of flexibility need for an effective C^3 system.

(3) Support of U.S. Navy and Other C^3 Systems. The MDZ mission requires Coast Guard VTS to conduct surveillance in an attempt to protect vital naval and national resources. This requires a detection capability and, possibly, the ability to interface with U.S. Navy C^3 systems. The most efficient method for this interface is through a computer network interface where selected VTS data is transferred via a gateway. This sort of system could also be used to interface vessel traffic data with "foreign" users such as the Canadian VTS system adjacent to Puget Sound and the maritime industry in general.

(4) VTS System Expansion. Expansion of mission requirements often creates a demand for expansion of VTS surveillance areas. Expansion of the surveillance area normally requires the addition of sensors, inbound communication links, and changes to the display hardware. The current VTS systems are not easily expanded. One of the needs for a second generation VTS is to be flexible enough to allow for system expansion without the absolute requirement for additional display equipment and manpower. This capability will also allow for the design of a standard VTS system that may be tailored to the specific needs of the many ports served by Coast Guard VTS.

c. Ability to Enhance Coast Guard C^3 Capabilities

During a study of the Coast Guard's management of major automated systems the U.S. General Accounting Office (GAO) stated:

> ...the Coast Guard's ability to accomplish its missions depends on its ability to implement information systems that serve the needs of the organization overall [Ref. 42].

As the Coast Guard brings its information resource system up to a modern capability, VTS should be capable of taking advantage of the increased communication capabilities. A VTS system should be capable of importing and exporting information for the use of the decision makers needing information. This will require the VTS C^3 system to be capable of using both LAN and WAN technologies to send or receive traffic surveillance and other operational data.

(1) Support of Queries from Remote C^3 Systems. With an increase of information sharing, it will be necessary for the end users to determine exactly what VTS information they need. Use of a standard query language, such as SQL, can maximize the connectivity and flexibility between the system and a local or remote end user.

(2) Support of C^3 Decision Making. A VTC C^3 system must support the decision making processes within a VTC regardless of the mission priorities. During emergent SAR there will still be a need for routine traffic monitoring. The VTS system should provide the C^3 planning and presentation tools necessary to allow for flexible use of the system. The display should be capable of presenting information relevant to all operational missions. It must also be capable of filtering this information to allow for a display tailored to the needs of the user.

d. Ability to Reduce VTS Operating Costs

One of the factors driving the author to review Coast Guard VTS systems is the cost of keeping aging VTS systems operational. Given the fiscal pressure to reduce costs, new systems must be less expensive to operate while increasing the efficiency and effectiveness of the VTS. Operation costs are split into four categories. Some of the technologies evaluated will fit into one cost category while others may bridge all four categories. The four operation cost categories are:

- Sensor operation.
- Inbound data link operation.
- Display system operation.
- Personnel.

The largest cost of operating a VTS is the cost of the personnel. The evaluation will include the ability of a technology to reduce the man-power needed to safely and efficiently run a VTS. Listed below are some of the technical capabilities that can allow a VTS to meet this goal.

- Automated target acquisition.
- Automated target tracking.
- Automated target alarms based on traffic conflicts, navigation warnings, loss of a target by the sensors, and ATON tracking.

e. Ability to Adapt to Technology Changes

Given the rapid advancement of computers, and electronic equipment in general, it is important that the Coast Guard be able to take advantage of emerging technology. Modular design, based on VTS functions, will allow future VTS systems to mature with technology changes. This will allow the Coast Guard to take advantage of more advanced processing and surveillance capabilities without the need to scrap modules that remain efficient and effective.

f. Implementation Time Frame

The Coast Guard VTS systems are twenty years old and need to be replaced. In the best case, the time between selection of a system and its operational fielding would be three years. The evaluation of the technologies will consider the time necessary to get a system on-line. This is particularly important when evaluating an emerging technology.

g. System Acceptance

In order for a VTS system to be effective, it is necessary that the users (the maritime community) accept and trust the system. One of the major factors affecting user acceptance can be quantified by the size, cost, and ease of operation of equipment required for VTS participation. It is equally important that the Coast Guard accept the system. Coast Guard acceptance may be quantified by the cost, complexity, flexibility, and overall usefulness of a system.

B. SYSTEM EVALUATION

1. The Nature of VTS Systems

No single technology can fully address the system needs of Coast Guard VTS. An optimally configured VTS system must balance the usefulness of the selected sensors, the operating costs and data latency of the inbound communications link, and the advantages of the selected display system against the overall purchase price and system operation costs over a ten to twenty year life span. In the following paragraphs the author will evaluate the effectiveness and costs of technologies within each functional group. This will be followed by an evaluation of a proposed system based on technologies selected from each functional area.

2. Evaluation of VTS Sensors

Table 9 on page 59 summarizes the evaluation of the most feasible VTS sensors. The author's comments regarding each sensor type are outlined below. None of the sensors surveyed c . address the full range of needs for a VTS. For the sensors to be useful they must be linked to a VTC and the data must be processed and displayed in an efficient and effective manner.

a. Radar

The Coast Guard is using radar equipment that is optimized for use as a shipboard, surface search radar. The reason for this is based on the theory of economies of scale in maintaining one radar type throughout the Coast Guard. It is important to note that the accuracy of data from a radar is function of target range, the characteristics of the radar transmission and radar antenna equipment (including pulse repetition frequency, emission polarization, and beam width), and the weather in the area. In normal practice radar range is set for a twelve nautical mile observation radius. Based on the characteristics of the AN-FPS-121 radar system, this creates a maximum range error of 240 yards and a maximum azimuth error of 1250 yards. These error ranges decrease linearly as a function of the target range. The common Coast Guard opinion is that the accuracy possible with the current VTS radar is sufficient for routine VTS purposes. Thus, radar sets a standard for sensor accuracy and probability of target detection.

Criteria	Radar	Video Camera	Sonar	RDSS	Voice Reporting
Control of Traffic					
Data Latency	Real Time	Real Time	Real Time	15 sec	indeterminate
Data Accuracy (position)	3 degrees of arc, 1% of range	No position information	.5% of range, function of system expense	100 meters or better	indeterminate
Interpretation	1 operator sector	1 operator sector	1 operator sector	1 image of VTS area	Operator intensive
Adapt to Mission Needs					
Surveillance capability	Detection and tracking of small surface vessels	Detection and identification of medium surface vessels	Detection and tracking of subsurface target	Dependent; identification and tracking	Dependent; unreliable
Display Flexibility	Little flexibility	Little flexibility	Little flexibility	Good flexibility	Little flexibility
Support of External C^2 Systems	No direct support	No direct support	No direct support	Support possible via Gateway	No direct support
Ease of Surveillance Expansion	Hard due to bandwidth	Hard due to bandwidth	Expensive	Easy and relatively inexpensive	Easy and relatively inexpensive
Ability to Enhance Coast Guard C^2					
Support of Data Exchange	None directly	None directly	None directly	Possible via Gateway	Limited application
Support of Decision Making	Good but provides segmented information	Fair; provides limited data	Fair; provides limited data	Excellent; flexible display, covers user defined areas	Poor; requires high amount of user action to correlate data
Ability to Reduce Costs					
	Equipment costs steady, no manpower reduction	Equipment costs steady, no manpower reduction	High equipment costs, increases manpower needs	Low equipment cost, may decrease manpower needs	Low equipment cost, no manpower reductions
Reasonable Implementation Period					
	Yes	Yes	Possible	Yes	Yes
Acceptance of the System					
	High	Moderate	Low	High	Moderate

Table 9. Evaluation of VTS Sensors

b. Video Cameras

Video cameras are used only in very confined areas that are not suited for radar coverage due to sharp bends in a channel, physical obstructions, or a requirement for one-way traffic in a confined area. A single video camera cannot provide position information on a target. The probability of detecting a target is a function of the distance to the target and the clarity of the atmosphere in the area. On a typically clear day, Coast Guard experience has shown that a ship can be detected up to ten miles away, and identified up to three miles away. LLLTV systems can provide detection and identification of contacts during the dark hours of the day, but at shorter ranges. The detection range for LLLTV is a function of ambient light as well as the factors common to a normal video camera. During periods of low visibility due to inclement weather or smog, video cameras are ineffective for target detection or identification. Effective use of video cameras requires a large output of manpower. Given the lack of positioning information, video technology is not cost effective for most VTS applications.

c. Sonar

Sonar provides a means of detecting and tracking subsurface contacts. As discussed in Chapter IV, this technology requires highly experienced personnel, expensive supporting equipment, and has limited capability for use in the typical VTS environment. One possible use for sonar is the establishment of a sonar barrier at the seaward reaches of important ports during periods when the MDZ mission is a high priority. VTS personnel could, with training and experience, monitor the barrier for "unfriendly" sub-surface activity. Given the equipment costs, sonobuoy network maintenance costs, and the requirement for a high degree of manpower use of sonar technology is not cost effective for the typical, peace-time, operation of a VTS.

d. RDSS

RDSS provides a means of accurately tracking cooperative targets. It does not have the capability of detecting targets that are either unwilling or unable to provide a tracking signal. This lack of a detection capability is the major drawback to RDSS. RDSS cannot support any missions assigned to Coast Guard VTS systems that require ability to detect vessels. The capability of sharing the cost of an RDSS system reduces the Coast Guard's investment. The display system supplied by a vendor would up-grade the overall capabilities of a VTC, but only for dependent vessel tracking.

e. Voice Reporting Systems

Voice reporting systems are a type of dependent surveillance. In this case, the target must verbally provide position information to the VTC. It is a well established fact that this information is often in error due to untimely or neglected reports. A voice reporting system alone is not capable of allowing the Coast Guard to effectively monitor vessel position.

3. Evaluation of Inbound Communication Link Systems

The inbound communication link, and specifically any remote terminal equipment, can provide the degree of flexibility needed to allow design of a "standard" VTS system capable of using the optimum sensors for the assigned missions. The specifics regarding use of a particular communication link used should be transparent to a VTS user. Table 10 on page 62 summarizes the author's link technology evaluation. The author's comments regarding each technology type are outlined in the following paragraphs.

a. Microwave Systems

Microwave data link systems provide an expensive but highly effective and flexible conduit for surveillance data. These systems are well suited for use in very remote areas where public utility services are not available. This flexibility is offset by the purchase, operation, and maintenance expenses of operating a dedicated microwave system. Microwave data channels may also be used in metropolitan areas. Unfortunately, these areas often suffer from frequency allocation limitations due to microwave congestion. In these metropolitan areas, short and successive microwave hops may be necessary due to physical obstruction or severe interference in an optimal transmission path.

b. Satellite Link Systems

Satellite link systems (particularly wideband systems) are an expensive, but highly reliable, conduit for surveillance data. The cost of these systems can normally be justified when the terrestrial path distance is more than 1000 miles or extremely rugged geography makes multiple hop terrestrial microwave systems impractical. The most efficient way to establish a wideband satellite link is to lease a data link through a commercial service. For most Coast Guard applications use of terrestrial microwave circuits will be much for cost efficient than a wideband satellite circuit.

c. Coaxial Cable Systems

It is not practical for the Coast Guard to own and operate a private coaxial cable system. This is due to the costs of right-of-way, cable, and terminal equipment. Where available, a coaxial cable system may be leased from teleconmmunication companies as a dedicated line. Leasing, in this sense of the word, involves leasing a data rate or bandwidth capacity and leaving the specific path details to the contractor. If leased, routine maintenance and technological upgrade of the cable system would not be a direct expense to the Coast Guard. The biggest drawback to the use of coaxial cable systems is the fact that it is not economical for use in remote areas where the Coast Guard would have to construct, operate and maintain a dedicated system.

Criteria	Microwave and Satellite Systems	Cable Systems (Coaxial and Optical Fiber)	Radar Scan Conversion & Video Compression	RDSS	Voice Reporting
Control of Vessel Traffic					
Data Latency due to Link	Real time	Real time	10-30 seconds	15 seconds	Indeterminate
Data Accuracy (Link transmission)	Excellent	Excellent	Excellent	Excellent	Good
Data Interpretation due to Link	Indeterminate	Indeterminate	Indeterminate	Indeterminate	Indeterminate
Adapt to Mission Needs					
Link Effect on Surveillance capability	Adaptable	Adaptable	Radar or Video only	RDSS only	Moderately adaptable
Display Flexibility due to Link	Does not affect display	Does not affect display	Good flexibility for radar, little flexibility for video	Good flexibility	Does not affect display
Support of External C^2 Systems via Link	No direct support	No direct support	No direct support via inbound link	No direct support via inbound link	No direct support
Link Effect on Expansion of Surveillance Area	Hard due to site and equipment expense	Depends on local telecomm industry capabilities	Moderate due to low bandwidth requirements	Easy due to system flexibility	Moderate due to site and equipment costs
Link Ability to Enhance Coast Guard C^2					
Support of Data Exchange by Link	No direct support	No direct support	Support available in system	Support available in system	No direct support
Support of Decision Making by Link	No direct support	No direct support	Support via system software	Support via system software	Limited support
Ability to Reduce Link Costs					
	No change in costs	Moderate reduction in costs, where available	Large reduction in costs	Large reduction in costs	No change in costs
Implementation Period for Link					
	6 Months for Equipment, Site indeterminate	2 Months where available	2 Weeks for link, 6 months for terminal equipment	2 Months for system including links	6 Months for equipment and sites
Acceptance of Link					
	Transparent to users	Transparent to users	Transparent to users; Good for VTS	Good for users, moderate for VTS (no detection)	Fair for users and VTS

Table 10. Evaluation of VTS Inbound Link Technologies

d. Optical Fiber Systems

Optical fiber cable systems are becoming available in most large cities. Just as with coaxial cable, the Coast Guard would be best served by leasing a data rate capacity and leaving the path details to the contractor. Use of fiber optic cable in metropolitan areas should be feasible in three years, but only for VTS systems that will coexist with commercial enterprises that are also demanding high data rate services from the telecommunications industry. Use of an optical fiber network is not economical in remote areas. As with coaxial cable, economies of scale would not occur for a private optical fiber system developed, operated, and maintained by the Coast Guard.

e. Bandwidth Reduction Systems

Bandwidth reduction can provide the Coast Guard the flexibility to choose one of several inexpensive methods of transmitting surveillance data to a VTC. Reduction of the bandwidth can also allow the Coast Guard to put more information through an established wideband data link that it currently owns and operates. This provides one avenue for VTS surveillance system expansion where the data link is a limiting factor. Reduction in the signal bandwidth can allow the Coast Guard to use the most economical and simple data link available. Some of the possible systems include VHF-FM radio, UHF radio, HF radio, cellular telephone circuits, and terrestrial or satellite voice grade telephone circuits.

(1) Radar Scan Conversion. Radar scan conversion can allow use of inexpensive voice grade telephone or broadcast technologies for the inbound data link. The fact that the signal is converted to a digital format allows rapid processing of the raw information. The advantages of this digital processing spill over into the capabilities of the associated C^2 display system. The disadvantages to radar scan conversion are the data latency (10 -15 seconds) and the fact that it is an emerging technology. There is a small amount of risk involved in designing a system that relies on radar scan conversion. The equipment cost would be offset by a large decrease in operation and maintenance costs of the data link. This is due to the use of inexpensive, narrow band, voice grade circuits for the data link. Radar scan conversion is also applicable to other Coast Guard missions, particularly MLE. Using radar scan conversion, it would be a fairly simple matter to set up remote radar surveillance of a "suspect" harbor and send the target data to a central operations center via telephone or other voice grade circuits.

(2) Video Compression. Use of a Codec (Coder-Decoder) to compress video signals may become an efficient means of reducing the cost of linking video information back to a VTC. At present, commercially available Codecs are not capable of reducing video signals enough to allow use of narrow band circuits. The use of "freeze-frame" technology and compression can allow transmission of the picture if a data latency of one to two minutes is acceptable. This technology is rapidly improving and should be reviewed if video surveillance is used as a primary surveillance sensor for VTS.

f. RDSS

A commercial RDSS dependent surveillance system includes its own inbound communication link. In this case the link would actually be provided through a land based telephone network from the contractor's RDSS receiver processing site. One advantage of this type of system is that the Coast Guard would be relieved of the direct expense of operating and maintaining a dedicated communication service. The cost of the RDSS reports could be the responsibility of the maritime users while the cost of the link for the contractor's receiver site to the VTC would be the Coast Guard's responsibility. There is a possibility that RDSS will also be used as a position reporting system for operational Coast Guard units. In this program, the intent is to replace Coast Guard safety and position voice reports with accurate and timely RDSS reports for Coast Guard small boats, helicopters, and aircraft. These reports, as well as VTS surveillance reports, would be "piped" from the commercial receiver processing center to a central Coast Guard location, then retransmitted to the necessary Coast Guard organizations which would include applicable VTC C^3 systems. This would further defray the expense of operating an RDSS based VTS.

g. Voice Reporting Systems (VHF-FM Voice Radio)

Use of VHF-FM voice radio is sufficient for transferring the information required for a voice reporting system. VHF-FM is required for all merchant vessels in U.S. waters and provides a clear channel that is not greatly effected by weather. The effectiveness of a VTS based only on voice reporting is marginal when compared to the capabilities of more complex systems.

4. Display and C^3 Systems

The display system is the heart of a VTS system. As a C^3 system, the display system must be capable of supporting the decision makers, regardless of the assigned missions and mission priorities. The ability of a VTS to become a working part of a larger C^3 system is directly affected by the technology used to support the VTC. Table 11 on page 66 summarizes the author's evaluation of selected VTS display or C^3 systems.

a. Manual Systems

The Coast Guard currently uses radar and video systems that require the operator to manipulate and interpret target data. Effective use of these radar systems require trained and experienced operators. Accurate interpretation of the data requires supervisors to watch multiple radar and camera displays. This increases the probability of an incorrect decision. Most of the manual radar displays are well past their expected equipment life cycle and should be replaced. The video equipment should be updated when significantly more capable equipment becomes economically available. These manual systems are inefficient due to the need for a large number of trained and experienced system operators and the latency involved in calculating a large amount of traffic information during periods when the VTS area is busy.

b. Automatic Systems

Automation of VTC functions can provide the Coast Guard with accurate data, a reduction in the required manpower, and a more flexible system. Some automation was introduced into Coast Guard VTS in the middle 1970's when the A/N-SPS-121 radar and display became a "standard" for VTS. The addition of this equipment, however, did not keep the VTS Command and Control System up to pace with the requirements of multi-mission tasking or with advancements in the computer and electronics industries.

(1) ARPA Radar. The Coast Guard uses an ARPA system that is integrated into the A/N-SPS-121 radar display. This ARPA automatically track targets that have been manually acquired and can display target information for one manually selected target. While this system provides a fair amount of work relief for the radar operators, there is still the requirement for one operator to operate the equipment for a particular sector. Watch supervisors must observe several displays and interpret all the data available in the VTC. There is no data fusion in these systems. The A/N-SPS-121 has the capability to output tracking data (through an RS-232 port) but the Coast Guard does not use this capability. Advancements in target detection and tracking algorithms, sweep-to-sweep correlation, and the digital enhancement of radar information have shown that it is technically feasible to operate an advanced, computer driven radar network with fewer, less skilled, operators.

(2) Target Tracking Sensor Indicators (SPA-25-G). In an effort to bridge the gap between the existing ARPA radar displays and a truly integrated VTS system, the Coast Guard is looking to use of the SPA-25-G display system. This system requires the operator to "hook" a target at least twice before tracking information is computed. Once computed this tracking information can be integrated into a computerized

C^2 system, like the Coast Guard's STC project. One advantage to this indicator is its ability to interface to different radar and sensor systems. The disadvantage is the requirement for the operator to be intimately involved in target tracking within one specific sector. For the expense of this display system the Coast Guard actually increases the workload on the VTS watchstanders as compared to the AN-SPS-121 ARPA system. This is due to the requirement to manually update the tracking plot for each contact on the SPA-25-G indicator.

Criteria	Manual Radar Video	ARPA Radar	Radar Scan Conversion	RDBS
Control of Vessel Traffic				
Data Latency due to Display (after receipt of data)	Real time data display but information extracted by operator; up to 3 minutes	Tracking indication immediately, full information in 30 seconds or less	Tracking information immediate, one complete sweep in 15-30 seconds	Tracking information immediate
Data Accuracy Due to Display	Limited by sensor	Limited by sensor	Limited by sensor	Limited by positioning technology on target
Ability to Interpret Data	Relatively hard, manual data extraction, segmented view	Moderately hard, segmented view	Good, overall view or detailed view with graphic overlays of supporting information	Good, overall view or detailed view with graphic overlays of supporting information
Adapt to Mission Needs				
Display Effect on Surveillance capability	Limited by radar equipment	Limited by radar equipment	Radar site can be networked to create one display	Display limited by software; can handle hundreds of contacts
Display Flexibility	Little flexibility	Little flexibility	High degree of flexibility	High degree of flexibility
Support of External C^2 Systems via Display	No direct support	No direct support, ARPA can provide target information	Can support external C^2 systems via gateway	Can support external C^2 systems via gateway
Display Effect on Expansion of Surveillance Area	Area expansion requires additional display and operator	Area expansion requires additional display and operator	Display can support additional sensors in new areas	Display can be expanded to show wider area, no additional sensors required
Ability of Display to Enhance Coast Guard C^2				
Support of Data Exchange by Display	Not directly supported	Not directly supported, not capability exists	System can interface with external C^2 systems	System can interface with external C^2 systems
Support of Decision Making by Display	Poor; presents data only	Fair; presents target information and traffic conflicts with a sector	Good; presents traffic information and other selected graphical data	Good; presents traffic information and other selected graphical data
Ability of Display to Reduce Costs				
	None	None	Can reduce the number of operators	Can reduce the number of operators
Implementation Period Display				
	Good, 6 months	Good, 6 months	Good, 6 months	Good, 6 months
Acceptance of Display				
	Poor; manual plotting	Fair; automatic plotting	Good; automatic, integrated information	Good; automatic, integrated information

Table 11. Evaluation of VTS Display Technologies

(3) Displays Based on Radar Scan Conversion. The digitally processed data available from radar scan converters can provide the Coast Guard with an effective and efficient VTS C^3 system. This is due to the system programming that allows sensor and software modularity as well as user tailored display screens. These systems have the capability of providing a summary picture of the entire VTS area or showing a highly detailed view of some specific part of a VTS area. These display systems are capable of interfacing to external C^3 systems as well as controlling the sensors themselves. The computer systems used with radar scan conversion use up-to-date digital processing for clutter suppression, gain control, target detection, and target tracking. Using faster, more capable processors, a radar scan convertor system can improve the capabilities of the Coast Guard's existing radar systems. Use of this sort of system should allow for a decrease in manpower due to the integrated and improved approach to target detection, tracking, and data display. Radar scan conversion also provides a way to implement a radar network. This system would also be capable of integrating data from other sensor types as well as from data sources external to the VTS.

(4) RDSS Displays. The display systems available with commercial RDSS systems are graphics based and provide C^3 advantages similar to those available through a system based on radar scan conversion. As these systems are generally microcomputer based, the software can be adopted to most any requirement. This can allow the RDSS information to be shared with external C^3 systems. The software for the display system is generally provided and maintained by the RDSS contractor (like Geestar, Inc.). This removes the expense to the Coast Guard for software development and maintenance. The possibility of linking the tracking information to external C^3 systems would hinge on the data rights incorporated in such a system and the classification of the external C^3 systems.

5. System Cost Analysis

Table 12 on page 68 summarizes the equipment cost for a single sensor and display system. This table does not include the cost of a data link due to the practical requirement for a VTS to use the most effective and efficient data link available in a particular area. In the case of VTS Prince William Sound, Alaska, a Coast Guard owned and operated microwave system may be the only pratical data link while VTS San Francisco may have the option of choosing from several different technologies. For all the systems surveyed, the annual maintenance costs for sensor equipment ranges between ten and twenty percent of the equipment costs. [Ref. 43: pp. 6-16]

Sensor and Costs	Data Link Terminal Type and Costs	Display Type and Costs
Radar - $60,000	Microwave - $70,000	ARPA or Tracking Indicator - $52,000
	Optical Fiber or Coax - $40,000	
	Satellite - $40,000	
	Radar Scan Convertor - $70,000	Raster Scan C^2 System - $30,000
Video Camera - $25,000	Wideband termination included in video equipment costs	Raster Scan Monitor - $1,000
RDSS - $13,000 (vessel equip.)	Included in basic system	VTC C^2 System - $425,000
	Codec - $70,000	
Sonar System - More than $200,000	Included in basic cost	Included in basic cost
VHF-FM Voice Radio - $10,000	Included in basic cost	Included in basic cost

Table 12. Sensor and Display System Acquisition Costs

Table 13 summarizes the non-maintenance, recurring costs for each data link technology surveyed. Annual maintenance costs are generally ten to twenty percent of the terminal equipment costs. Installation costs are not listed, as they vary widely. [Ref. 43: pp. 6-16]

Technology	Costs
Microwave	maintenance only - $15,000 or 15% of acquisition costs
Satellite-wideband	Annual lease costs greater than $100,000.
Satellite-narrow band	Annual lease costs for 2-way voice grade circuit - $9,000
RDSS	Service Charges - $1,400 to vessel and $600,000 to Coast Guard
Optical Fiber and Coaxial Cable	Lease cost will vary depending in data rate needed and service availability.
Voice Grade Telephone (9600 bps)	Service charge (lease) - $3,000
Voice Radio Circuit for narrow band surveillance data (VHF-FM, UHF, HF)	Terminal Cost - $20,000; Annual maintenance costs $3,000 or 15% of terminal equipment costs

Table 13. Annual Data Link Costs

A determination of the "best" system for the Coast Guard requires clearly defined mission requirements, surveillance levels, and integration standards. Since these do not exist for the Coast Guard VTS program, system flexibility and reduced life cycle costs become predominant factors in determining a best system. A reduction in required manpower, rental costs (for leased systems), or maintenance costs (for USCG owned systems) are therefore key elements in the selection of a system or technology base due to the long range savings possible over the life cycle of a system.

6. Evaluation of a Proposed System

The following paragraphs describe a proposed, second generation Coast Guard VTS. Geographically a VTS may be divided into three areas. They are the offshore approach area, the active surveillance (harbor) area, and any areas inland of the harbor. These areas would be similar to the offshore approaches to San Francisco Bay, San Francisco Bay (from about ten miles at sea to some demarcation line inland), and the "river" areas currently managed by the VMRS. For the second generation VTS, these areas would be managed using an up-to-date C^3 display system capable of overlaying navigation, topographic, and operational information on the contact data. Surveillance of these three areas would be done using the technologies listed below.

- Approach Area - RDSS and VHF-FM voice communication circuits.
- Harbor Area - Active radar surveillance using radar scan conversion and narrow band data links. Communication would be conducted over VHF-FM voice circuits.
- River Areas - RDSS and VHF-FM voice communication circuits.

Figure 6 on page 70 illustrates this proposed system, the surveillance equipment, and data link technologies to be used.

The advantages of such a VTS system are listed below.

- Use of any radar system. This would allow continued use of the existing radar systems in anticipation of a standard replacement system in three years.
- Use of low cost terrestrial narrow band data links (9600 bps). This significantly decreases operation costs and increases the flexibility of sensor placement or future system expansion.
- Manpower reduction due to sensor integration. The number of people actively monitoring the VTS may decrease as the integrated C^3 system automatically manages contact tracking and display.
- Manpower expansion possible to meet immediate mission requirements. Use of a database approach can allow for expansion of the VTC when necessary. One example of this is the separation of operator positions by mission area for SAR or MDZ while routine VTS functions continue. It would be a relatively simple matter to increase the number of "smart" displays to allow for such functionality.
- Sensor expansion possible to meet mission requirements. The number and type of sensors could be changed if the assigned missions or mission priorities warranted it. Any sensor capable of providing position information in an acceptable data format could be displayed by the C^3 system.
- Support of other Coast Guard C^3 systems. The VTS could export contact information to other operational C^3 systems. Examples include providing data to an

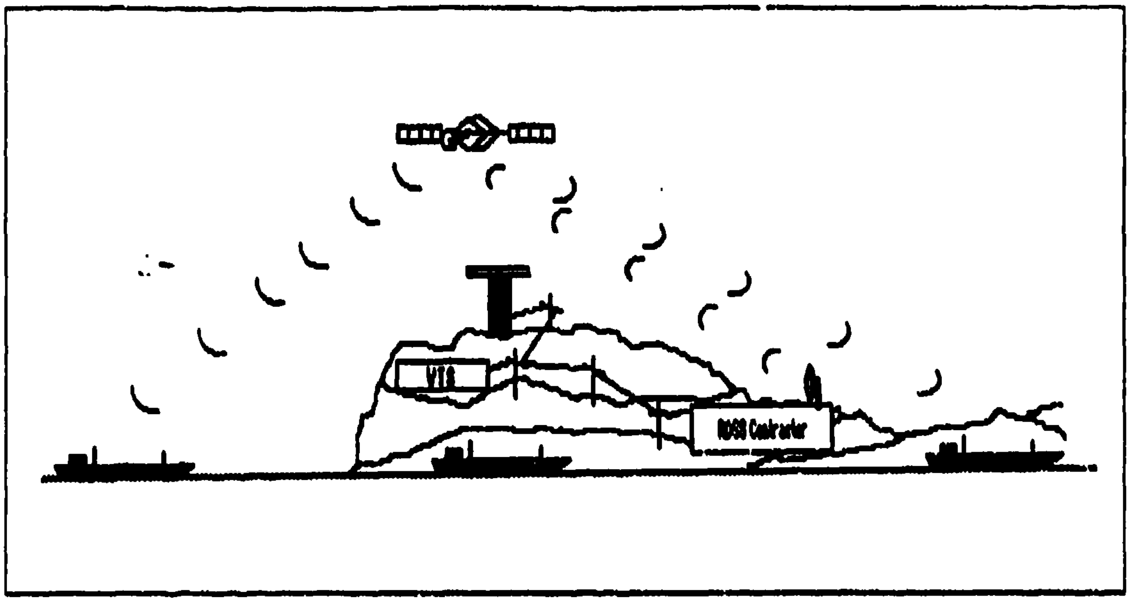

Figure 6. A Proposed Second Generation VTS

adjacent, but foreign, VTS (as in the Puget Sound area) and allowing the U.S. Navy to use VTS information for military tracking purposes.

- This system allows for implementation of a VTS system based on a standard C^3 "engine" system, inexpensive data links, and flexible sensor technology.

The disadvantages of such a systems include:

- Use of an emerging technology (radar scan convertors) and the attendant risk factor in fielding a system based on proven, but new technology.
- Requirement to customize a C^3 system to meet the flexibility and display requirements desired. The Coast Guard's STC program could be modified for use in a VTC. This would require an undetermined amount of money and time.
- Acceptance problems due to the general lack of a "real" picture of the surveillance area. The ability to display the "real radar picture" is a requirement the Coast Guard insists on having. Radar scan conversion technology can transmit a frozen frame of "real" radar, but with a data latency greater than desired by the Coast Guard.

Table 14 on page 71 lists the equipment and maintenance costs for a single sector VTS, excluding manpower. Sensor and sector integration will benefit multi-sector VTS systems by decreasing the manpower requirements. This reduction is a function of the specific VTS requirements and is not applicable to this example.

Equipment	Purchase Cost (single time expense)	Recurring Cost (on an annual basis)
Radar sensor system	$60,000	$6,000
Radar scan convertor	$70,000	$7,000
Telephone line data link (9600 bps)	Unknown installation fee (less than $300)	$3,000 (Conditioned telephone leased line)
Display System	$15,000 (equipment only. Cost of converting STC software to VTS application is unknown)	$1,500
RDSS for non-harbor areas	$425,000	$600 per vessel in RDSS system

Table 14. Costs, Excluding Manpower, for a Proposed Second Generation VTS

VI. SUMMARY AND CONCLUSIONS

One of the Coast Guard's missions is protection of the marine environment in and near the United States. The recent rash of pollution incidents in U.S. waters has highlighted the limitations of the twenty year old Coast Guard Vessel Traffic Service (VTS) systems. In general, Coast Guard VTS systems use radar surveillance of harbor sectors to allow a Vessel Traffic Center (VTC) to monitor harbor traffic. Each radar requires an operator, a wideband data link, a display, and enough redundant equipment to keep the system functioning with a very high level of reliability. A supervisor coordinates the Coast Guard's response to the immediate situation by observing the several radar displays and assimilating information from several other sources.

Coast Guard VTS systems are not standardized. Due to the age of the equipment and a lack of data integration, they are expensive to operate and maintain. This is particularly true with regard to the microwave data links being used. Coast Guard VTS's work as isolated systems. They function independently from the mainstream of Coast Guard operations.

Advancements in the electronics industry, and particularly the computer industry, can significantly change the system architecture of Coast Guard VTS systems. The use of modern, high speed computer technology can provide the Coast Guard with a highly automated, accurate, and reliable VTS capability. This can, in turn, decrease the cost of VTS maintenance and operation, reduce the personnel levels required for routine operations, and provide the degree of flexibility necessary to allow VTS to operate within the multi-mission environment of normal Coast Guard operations.

A. SYSTEM ENGINEERING FOR A SECOND GENERATION VTS

Design of a surveillance system for VTS is dependent on the management aspects of the program. Mission requirements lead to system and equipment capability requirements. The following paragraphs highlight the author's conclusions regarding design of a second generation VTS.

1. System Flexibility

The Coast Guard traditionally operates in an unstable, multi-mission environment. A "good" VTS system must therefore be a flexible system, capable of meeting ever changing mission demands. This flexibility can be accommodated through the use of a modular system made up of sensors, data links, and a VTC C^3 system for display of the sensor information and overall control of the system. This system should be able to export target information to other C^3 systems throughout the Coast Guard.

2. **Sensor Selection**

VTS sensors should be viewed as an information source with an associated accuracy and latency. Fiscal constraints and mission requirements should determine the specific sensor or sensor types used. These sensors should feed a database and be controlled by operator signals via the C^3 system. Different missions dictate use of different sensors. In a similar manner, different ports have different surveillance needs. VTS Valdez, AK may be most efficiently served through the use of an RDSS system as there is very little traffic other than the oil tankers in the area. VTS San Francisco may need a more extensive VTS due to the traffic density and a need for an active detection capability for SAR, MLE, and MDZ missions.

3. **VTC C^3 and Display System**

The VTS C^3 system would link the operator's information needs to a computer database and originate the signals needed to control each sensor. This would help to optimize the effectiveness and efficiency of the entire system by providing a high degree of system flexibility. The VTC C^3 system would display operator-selected target data and overlay graphically based information including buoy schemes, channel limits, anchorage areas, and similar typographical information. Integration of VTS target data into a backbone Coast Guard network would also be handled by the C^3 system.

4. **Narrow Band Data Links**

The technology exists to allow the use of narrow band data links, regardless of the sensor used. The cost of operating or leasing a narrow band data link is significantly less than that of operating a wide band link. The cost of terminal equipment for a narrow band link is essentially the same as the terminal equipment costs for terrestrial wideband circuits. This equipment expense is small compared to the costs of building and operating wide band circuits. The data latency associated with the use of narrow band terminal equipment is approximately ten seconds. Given that a ship travelling twelve knots would only move forward sixty-seven yards in this period, this latency is not significant for VTS purposes.

B. MANAGEMENT OF THE COAST GUARD'S VTS PROGRAM

In conducting research on VTS technologies, the author determined that one of the limiting factors was management of VTS as a program. VTS, in the Coast Guard, has existed for more than twenty years. The commitment of the Coast Guard, in personnel and funding, has been very cyclical and generally dependent on Congressional awareness following marine pollution accidents. This "on-again, off-again" program support has caused the Coast Guard's VTS system to age rather than evolve.

In order for a second generation VTS system to be properly designed, there are several areas that must be specifically addressed. The following paragraphs outline the author's conclusions regarding these areas.

1. Scope of the VTS mission.

The Coast Guard needs to specifically identify the missions that a VTS is to carry out. The technological requirements for a true traffic management system (including vessel routing, control of entry times, and vessel speed) are different from those for a system that simply monitors the progress of independent vessels in a harbor environment. The latter requirements form the original, twenty year old, concept of Coast Guard VTS. The sensor requirements for a system capable of monitoring port security in a warfare or threat environment are very different than those for simply monitoring shipping traffic in peacetime.

Planning for a second generation VTS should include assignment of specific mission areas to VTS. This specific assignment would serve to detail what is routinely expected from a VTS as well as any exceptional requirements stemming from assigned, but infrequently executed, missions. The MDZ mission would fall into this category.

2. Stable Program Support

Coast Guard VTS is a program that the public learns about following a maritime accident. In the absence of public or political interest, the Coast Guard has repeatedly absorbed the Headquarters level support (personnel and funding) to shore up higher priority needs. The resurgence of Congressional interest in the VTS program following the Exxon Valdez grounding in Price William Sound, AK has once again peeked Coast Guard and Congressional support for VTS. This increased support has resulted in the development of a VTS Office in Coast Guard Headquarters (G-NSP), expansion of VTS Puget Sound, and reopening of a modernized VTS New York. Unfortunately, Congress also mandated quick action which is resulting in ad-hoc system engineering.

The VTS program should have a stable base of support at the Headquarters level. The purpose of this support would be allow VTS to evolve with technological advancements and changes in assigned mission areas and mission priorities.

3. Coast Guard Information Resource Management (IRM)

A second generation VTS should have strong ties to the information resources of the Coast Guard. It should be able to export, and possibly import data from other C^3 systems. The Coast Guard has started the process of updating many computer-related programs to take advantage of standard protocols and modern equipment. Data integration is one of the goals of this Coast Guard wide modernization. The Coast Guard is developing its own data network (HDN) in order to link these new resources together. In order for a new VTS system to be integrated into this IRM architecture, the VTS system must be designed to use the standard protocols. VTS should be a full partner in the Coast Guard's IRM program.

APPENDIX A. GLOSSARY

The acronyms and abbreviations used throughout the thesis are defined in the following list.

Acronym	*Definition*
μm	Micrometer
A-D Conversion	Analog to Digital Signal Conversion
ADPCM	Adaptive Differential Pulse Code Modulation
AM	Amplitude Modulation
AMVER	Automated Mutual-Assistance Vessel Rescue System
ARSA	Airport Radar Service Area
ARPA	Automatic Radar Plotting Aid
ARTCC	Air Route Traffic Control Center
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATON	Aids to Navigation
AUTODIN	Automatic Digital Information Network
bps	Bits per second
C^2	Command and Control
C^3	Command, Control, and Communication
C-band	C-band (6/4 MHz) Satellite System
CAS	Collision Avoidance System
CATV	Community Antenna Television
CCTV	Closed Circuit Television
CIC	Combat Information Center
CODEC	Coder-Decoder for compression of video camera signals
CSP	Command Supervisory Post
CVS	Commercial Vessel Safety
D-A Conversion	Digital to Analog Conversion
DF	Direction Finding
DGPS	Differential GPS

DoD	Department of Defense
DS1	Digital Signalling Rate 1 (1.544 Mbps)
DWT	Deadweight Ton (roughly equal to cargo capacity)
ETA	Estimated time of arrival
FAA	Federal Aviation Administration
FM	Frequency Modulation
FTS-2000	GSA sponsored telecommunication system
G-NSP	Office of Navigation Safety Programs in Coast Guard Headquarters
GHz	Giga-Hertz (one billion Hertz)
GOSIP	Government Open System Interconnection Profile (FIPS 146)
GPS	Global Positioning Satellite System
GTC	Geographical Tactical Computer
HAR	Harbor Advisory Radar
HF	High Frequency (3-30 KHz frequency band)
ICC	Integrated Command Center
ILD	Injection Laser Diode
IRM	Information Resource Management
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
KHz	Kilo-Hertz
Km	Kilometers
LAN	Local Area Network
LE	Law Enforcement
LED	Light Emitting Diode
LLLTV	Low Level Light Television
LORAN	Long Range Navigation System
MDZ	Maritime Defense Zone
MLE	Maritime Law Enforcement
MSD	Maritime Sanitation Device
NTDS	Navy Tactical Data System
OPCEN	Operation Center
OSI	Open System Interconnection protocols

OTH	Over-the-Horizon
OVMRS	Offshore Vessel Movement Reporting System
POSIX	Portable Operating System Interface for Computer Environment (FIPS 151)
PPI	Plan Position Indicator
PSS	Port Security and Safety
PWSA	Ports and Waterways Safety Act of 1972
QAM	Quadrature Amplitude Modulation; (16QAM, 64QAM)
RDSS	Radio Determination Satellite Service (Geostar Corp. dependent surveillance system)
S/A	Selective Availability. A mode of GPS that degrades position accuracy to about 100 meters
SAFENET	Shipboard Adaptable Flexible Embedded Local Area Network
SAR	Search and Rescue
SQL	Structured Query Language (FIPS 127)
SRU	SAR Resource Unit
STC	Shipboard Tactical Computer
VHF-FM	Very High Frequency (30-300 KHz) -FM Voice
VMRS	Vessel Movement Reporting System
VTC	Vessel Traffic Center
VTS	Vessel Traffic Service
WWMCCS	World-Wide Military Command and Control System

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