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Commission
APO Miami FL 34011

Panama Canal Fog Navigation Study

Candidate System Definition

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16. Abstract

A candidate system for solving fog navigation problems in the Panama Canal is defined. The vessel monitoring subsystem is a shore-based, all-weather, precision ranging system with ranging accuracies of 9 feet (2 standard deviations, 95 percent). A vessel's on-board Control Pilot receives all visual cues and digital data needed for safe and efficient navigation through the Gaillard Cut. Multilateration techniques employing computer-processed precision range measurements between the vessel and each of three or more shore-based interrogator stations provide vessel location, heading and velocity information. Simultaneous capacity is 25 vessels, expandable to 43. Subsystems described include: vessel monitoring, computer, display, communications, marine traffic control, weather and training.

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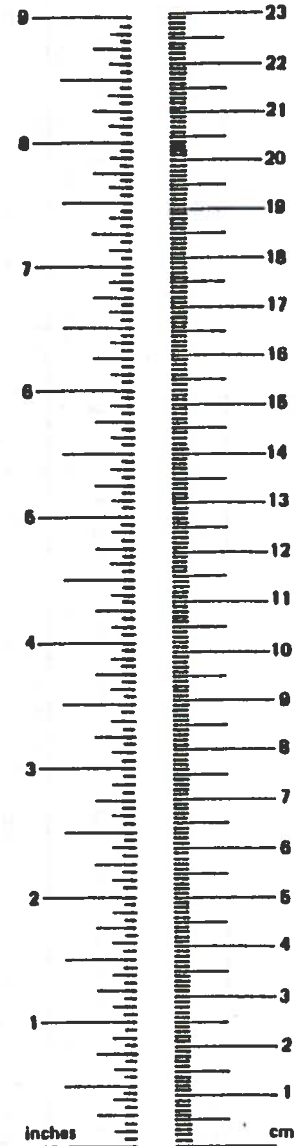
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

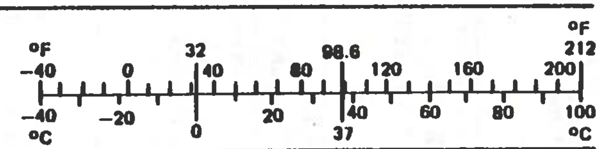
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

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



EXECUTIVE SUMMARY

The Engineering Division of the Engineering and Construction Bureau, Panama Canal Commission (PCC), is presently engaged in defining the performance requirements and the overall design characteristics of a fog navigation system which would satisfy the Commission's operational need. This effort is being coordinated with the appropriate elements of the Marine Bureau and also with the Panama Canal Pilots Branch. The Engineering Division requested the assistance of the Department of Transportation, Transportation Systems Center with the definition of performance requirements, the selection of candidate fog navigation systems and the preparation of a test and demonstration program plan.

The candidate system recommended by the Transportation Systems Center is a shore-based precision ranging system with ranging accuracies of 9 feet (2 standard deviations, 95 percent). This system measures the range to the bow and stern of transiting vessels in all weather environments. Control of the fog navigation system is exercised by a central processor which formats the vessel position information and presents it to the Control Pilot on board the vessel by means of a color graphic display. The Control Pilot receives from the display all the visual cues and digital data needed for safe and efficient navigation through the Gaillard Cut.

This system uses multilateration techniques. Precision range measurements from three or more shore-based interrogator stations to transponders located on a transiting vessel are made and, after computer processing, transmitted to the vessel as location, heading and velocity information. They appear on the Pilot's display, to scale, as a computer-generated Canal map which also shows Canal centerlines, navigation aids, and all visual cues normally seen by a Pilot in clear conditions. Similar presentations are available to the Marine Traffic Control Center for use in overall vessel traffic management.

The initial area of coverage is, at the direction of the Engineering Division, the Gaillard Cut. There, traffic is most likely to be delayed, or subject to hazardous navigation conditions, during dense fog. Presently, ships do not navigate through the Cut during fog and must anchor in Gatun Lake, or moor in Gamboa, if southbound, or if northbound, tie up at Pedro Miguel Locks. Fog, therefore, not only increases transit time for vessels, but also interrupts the orderly flow of vessels through the Canal and results in decreased utilization of the facility.

The candidate system consists of seven major subsystems.

1. Vessel monitoring system - made up of shore-based interrogators and portable, carry-on transponders placed aboard vessels in the Canal.
2. Computer subsystem - to process range data and extract vessel location, heading and velocity information.
3. Shipboard display subsystem - portable, carry-on display units placed aboard vessels to present to the Pilot, to scale, a Canal map, the location, heading and velocity of his vessel and of other vessel traffic, Canal centerline, sailing lines, and other navigational information required by the Pilot to guide his vessel safely during reduced visibility conditions.
4. Communication subsystem - made up of land lines and RF links required to transmit control commands to the interrogator array, to collect and process range data from the interrogators, and to transmit vessel navigation and guidance information to the Control Pilot display aboard transiting vessels.
5. Marine Traffic Control subsystem - consisting of operator interface stations and traffic control displays for monitoring and control.
6. Weather subsystem - to provide early warning information on fog and other adverse weather conditions.
7. Training subsystem - consisting of a computer-driven, dynamic, vessel simulator which responds to Pilot steering and speed commands, and displays resulting ship response on system Pilot Display.

The candidate system will be able to handle up to 50 transiting vessels a day, as well as dredging and drilling barges, and tugboats. The simultaneous capacity is 25 vessels and can be expanded to handle 43 vessels. It will also, with marine radar, be expandable to control entry and anchorage areas and, with a lock entry guidance system, could become the basis for a vessel management system covering the entire Canal.

Accurate cost estimates are impossible at this time, even for a system covering only the Gaillard Cut. Precise ranging can be accomplished using equipment from several manufacturers at different costs and, of course the requirement to operate in a severe environment can introduce significant cost differences. Estimates for hardware, system design and development costs range from $6,320,000 to $16,920,000.

Although the best candidate system approach - precision ranging as outlined above- has been determined by TSC, final detailed system configuration, and its costs, can only be arrived at after certain questions have been answered. For example: Which specific range measurement technique would be used? Would system elements have to be mil-spec types?

A preliminary system demonstration plan is outlined. It includes the evaluation of competing precision range measurement techniques in the Canal environment and the selection of a specific equipment for further consideration. The next phase of the program includes the assemblage of concept demonstration equipment; necessary, and minimal, integration, design and other engineering; software development; and the conduct of a system concept evaluation under operational conditions. Much of this effort would be applicable to later system implementation.

The program to evaluate ranging equipment and provide the technical data to support a selection for use in the system concept demonstration phase would cost between $800,000 and $1,000,000. This includes preparation of a formal test plan, site preparation, leasing equipment, minimal equipment purchase and engineering efforts of design, data acquisition, analysis and documentation. PCC support, in addition, would be required.

The cost of the evaluation program is very small when compared to the cost of an incorrect decision made without the benefit of the result of the evaluation.

The next phase - the concept demonstration phase - would entail additional costs ranging from $2,760,000 up to perhaps $5,510,000 (if mil-spec equipment is chosen). These estimates include plan development, equipment purchase, design, integration and test engineering, software development, field engineering support, data analysis and determination of detailed system specifications.

PREFACE

Fog has been a major and continuing obstacle to the realization of optimum and safe canal usage in all types of weather.

The Engineering Division of the Engineering and Construction Bureau of the Panama Canal Commission is engaged in defining the performance requirements and the overall design characteristics of a fog navigation system to satisfy this operational need. This effort is being coordinated with the Marine Bureau and also the Panama Canal Pilots Branch. The Engineering Division requested the assistance of the Department of Transportation, Transportation Systems Center with the definition of performance requirements for a fog navigation system, the determination of candidate systems and the preparation of a test and documentation program plan.

This report constitutes the results, in part, of that assistance.

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1. INTRODUCTION

1.1 PROBLEM DEFINITION

This report constitutes a definition of a candidate fog navigation system for the Panama Canal as a partial fulfillment of an Interagency Agreement between the Transportation Systems Center (TSC) and the Panama Canal Commission (PCC).

The PCC's Canal Improvements Steering (CIS) Committee, formed in the late 70s, was charged with developing a recommendation for a unified and harmonious package of all improvements required to insure the future viability of the Canal in line with projections of Canal traffic. One essential element in the Canal improvement package is a fog navigation system.

The occurrence of fog in the Canal did not present a real problem to the orderly flow of vessel traffic before the early 1950s. As traffic transiting the Canal has increased both in size and number, however, safety has begun to be more of an operational limitation. Thus, if unresolved, the fog problem threatens to be a serious constriction on the Canal's future capacity. The CIS Committee has determined from its investigations that one-way traffic in fog will be required when the average daily traffic level approaches 50 vessels a day (1990 to 2000 time frame).

The PCC Engineering Division (Engineering and Construction Bureau) is presently engaged in a study of fog navigation systems. The intent of the study is to establish the requirements for, and define the parameters of, a navigation and guidance system for the Panama Canal which will allow transiting vessels to safely traverse the Gaillard Cut and other Canal sections under limited or zero visibility conditions.

The first section of this report describes the quantitative impact of fog on Canal operations and the approach used to define the requirements; the second section summarizes the performance requirements; the third section describes the candidate system, the fourth illustrates the potential for further operational benefits from the candidate system, and the fifth section concludes the system definition part of the report with the cost estimates for the candidate system.

The third phase of the fog navigation study is a test and demonstration program plan. A preliminary plan is included as the sixth section of this report.

1.2 STUDY IMPLEMENTATION

Many approaches to the problems of keeping traffic safely moving have been investigated during the past ten years. Some have been based on the dispersal, prevention or prediction of fog. These in general, have been largely unsuccessful.

Another approach for keeping the traffic safely moving has been to devise a means of safely navigating through the fog. A number of proposals have been investigated over the years; some were discarded as being technically unsound and some were discarded as being unworkable in an environment like the Gaillard Cut which has narrow reaches and steep banks. Still others were not sufficiently reliable for Panama Canal requirements, or were considered prohibitive in cost or not cost effective. Specific systems and the results of PCC evaluations are available in the PCC Projects Branch (Engineering Division) files.

Since 1971, nearly all of the fog navigation work has been managed by the PCC Projects Branch, which also conducts other Canal improvement-related studies and projects. The Projects Branch's fog navigation efforts have been primarily of a management nature: project coordination, resource planning and study initiation. Two of the three PCC Bureaus, the Marine Bureau and the Engineering and Construction Bureau have teamed to conduct experimental verification trials of various systems and concepts over the past ten years. The Canal Improvements Division of the Office of Executive Planning, has provided inputs to the overall program.

The CIS Committee has stated (Canal Improvements Program, draft - April 1982) that one-way traffic in fog will be required when the average daily traffic level approaches 50 vessels a day. Recent traffic forecasts estimate that this traffic density will occur between 1990 and 2000. This additional impetus caused the Engineering Division to supplement the engineering analysis of the fog navigation system already underway with engineering support from the Transportation System Center (TSC).

Under an Interagency Agreement, TSC was asked to assist with three tasks in the fog navigation system study: prepare a statement of system requirements;* recommend a candidate system; and prepare a test and demonstration program plan. This project memorandum documents the second of the three tasks: the candidate system definition.

1.3 STUDY METHODOLOGY

At the outset of the study a visit was made to TSC by a Projects Branch engineer to brief the Navigation Center's staff on the nature of the fog navigation problem. A TSC team visited the Panama Canal in November 1982 to directly observe Canal operations. This provided an opportunity to hold discussions with Canal Pilots, the management staff, the engineering staff and traffic control personnel. In addition, this visit provided the operationally authentic knowledge required for system requirements analysis.

To prevent duplication of the Projects Branch's earlier efforts, the results of previous studies and projects related to the Panama Canal navigation problem were examined. In addition, similar work on other waterways such as the Suez Canal and the St. Lawrence Seaway was reviewed.

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*TSC internal Project Memorandum Panama Canal Fog Navigation Study Systems

A team composed of members from the Projects Branch and the TSC Navigation Center conducted the on-site studies, interviews and discussions.

1.3.1 On-site Investigations

A full length north-bound transit was made on a Panamax (maximum allowable length and beam) vessel. Multiple day and night transits were made between Pedro Miguel Locks and Gamboa (traversing the Gaillard Cut) aboard shorter vessels and aboard a radar-equipped tugboat.

Past efforts to solve the problems caused by fog in the Cut were extensively discussed with the PCC engineering staff. It was generally concluded that fog dissipation and prevention are not presently feasible, fog prediction technology is not good enough to engender a high confidence level and electronic navigation and guidance under fog conditions has good potential as a solution.

Discussions regarding the economic implications of fog navigation were held with the PCC Management Staff. Restrictions both on additional manpower and on increasing the duties of existing staff pose particular problems.

A great deal of time was spent trying to ascertain the types and sources of visual cues used by the Pilots when navigating through the Cut in the normal environment, i.e., absence of fog. A consensus was reached on what constituted the minimum required cues. These are addressed in Section 2.

Discussions with the Board of Local Inspectors (BLI) focused on the safety aspects of fog navigation. The BLI is responsible for investigating all ship groundings or collisions. The Gaillard Cut has, by nature of its narrow confines, a high accident potential. In reality, the number of accidents in the Cut per year is decreasing; traffic scheduling and Pilot performance have defused the potential safety hazard.* With more Panamax type vessels desiring to transit the Canal, pressures will be placed on the scheduling operation and on Pilots which could cause a reversal in the present decreasing accident rate in Gaillard Cut.

1.3.2 Review of PCC Fog Navigation Studies

Many approaches to the fog navigation problem have been investigated or demonstrated during the past ten years. Fog dispersal, prevention or prediction efforts in general proved unsuccessful.

Some of the approaches reviewed were:

1. Guidance by Underwater Cable. Electromagnetic guidance by buried cable was evaluated by the PCC in 1972. Propeller-caused turbulence uprooted and displaced the cable, rendering it useless for navigation purposes. Encasing the cable in a buried concrete vault - a possible remedy for the uprooting problem - was determined to be too expensive for the nine-mile Cut.

2. Radar Surveillance. The Naval Electronics Systems Command as well as several commercial companies have recommended radar surveillance from shore-based sites for the Cut. The technique is feasible, however the operational disadvantages of shore-based piloting are overwhelming and after further consideration this approach was discarded. The alternative of transmitting the shore-based, radar-derived data to shipboard displays was also discarded due to the radar's inability to resolve two targets in close proximity and to poor resolution of ship attitude.

*The BLI indicated that the cost to repair accident damage to vessels has increased faster than the decreasing rate of accidents, thereby keeping the annual accident cost about constant.

3. Portable Shipborne Radar. Radar surveillance of the Canal banks using a portable radar unit was also studied by the PCC. One specific system used reflector units installed at surveyed positions along the route. Such radar cannot provide own-ship headings; this is a major drawback. In addition, because of the complexity of the system, its heavy carry-on-board requirement, and the lack of demonstrated feasibility in a tropical environment, portable radar is not considered a feasible approach to the fog navigation problem.

4. Shipborne Radar. In an emergency, such as unanticipated fog, shipborne radar has been used to assist a Pilot in the Gaillard Cut and other Canal areas and could be used in a system. However, because quality of inspection and maintenance will vary from ship to ship, no consistent performance level can be assumed and thus this navigation method is not acceptable as the primary Canal system.

1.3.3 Review of State-of-the-Art Programs

The problem of surveillance, navigation and guidance has been addressed in many other areas: Tampa Bay, Florida; Suez Canal, Egypt; St. Lawrence Seaway, and the St. Mary's River, United States and Canada.

1. The Tampa Bay Study Group, was formed to select a system which would give warning if a vessel was on a collision path with the Sunshine Skyway Bridge while entering Tampa Bay during a fog. The sensor system selected was an enhanced LORAN-C based system: local corrections for grid warpage and seasonal variations can be used to improve the basic accuracy of the system. Tampa Bay, unlike the Panama Canal area, already has LORAN-C signal coverage.

2. Suez Canal. The Suez Canal Vessel Traffic Management System is a totally integrated system designed to expedite Canal transits and to maximize traffic flow while at the same time enhancing vessel safety. The system has three major subsystems: radar for surveillance at Port Said, Port Taufig and Great Bitter Lake; LORAN-C for position location determination of each vessel while it is in transit; and a communication subsystem to interconnect vessels, radars and the vessel traffic control center. No navigation or guidance information is given to the Pilot.

3. St. Lawrence Seaway. Over the last ten years the St. Lawrence Seaway Development Corporation has been studying methods of keeping the Seaway open (Montreal to Lake Ontario) during the winter season. The feasibility of using LORAN-C (long range), Raydist (medium range) or Trisponder (short range) ranging systems was demonstrated on a 30-mile test range. Additional studies are being conducted to determine if LORAN-C can provide the needed navigation accuracy on the Seaway.

4. Coastal Waters of Sweden. The Swedish-Finnish shipping company, Silja Line, runs jumbo ferries between Sweden and Finland, and ninety percent of the distance requires navigation through very complicated archipelago configurations and during very poor visibility conditions. The navigation system used by this company is based on the ship's radar equipment and RACONS. While the system has the potential for providing a pilot with good course-bearing and good turning point location information it does not provide accurate crosstrack information.

1.4 REQUIREMENT DEFINITION REPORT

The PANAMA CANAL FOG NAVIGATION STUDY SYSTEMS REQUIREMENTS STATEMENT, report numbered DOT-TSC-VV-365-PM-83-10, March 1983, describes the system requirements for fog navigation. The conclusions are summarized in this section. Additional technical information is given in Section 2.

1.4.1 General System Requirements

The system should be modular and sized, initially, to handle fifty ships a day. The system should not require an increase in the present PCC staffing level. It should be compatible with a tropical environment. The on-board display should give the Control Pilot all the cues during fog navigation that are available to him during daylight transits.

1.4.2 Navigation and Guidance Requirements

As indicated by discussions with the Control Pilots and verified by the Maritime Administration's Computer Aided Operations Research Facility (CAORF) studies, a graphical display must give the Pilot the following information: vessel (bow and stern) position relative to the banks and center line, velocity, all Canal markings and visual navigation aids, a heading vector and the vessel image scaled to the geographic outline of the nine reaches and eight course changes in Gaillard Cut. In addition, a digital data block will be presented on the display in support of the graphical information.

1.4.3 Safety Requirements

The two areas where the greatest demand is placed on Pilot performance are in turns and in approaches to the locks. The latter is not necessarily a "fog navigation" problem, but a system should be designed to assist the Pilot with a readout of his closing velocity - velocity over the ground in relation to the lock wall. The system should also be designed to provide the Pilot with all the cues needed for a safe turning maneuver; crosstrack and along-track vessel position with respect to the intersection point of the centerline ranges for adjacent reaches.

1.4.4 Additional Options

The modular system can be expanded later to include all the reaches in the Panama Canal if this becomes necessary for efficient traffic scheduling. In fact, the information on the Pilot's display can be also displayed in the Marine Traffic Control (MTC) Center for vessel monitoring; this would enhance the "silent transit" reputation of the Pilot force - vessel position reporting using the existing radio network would not be required.

1.5 CANDIDATE SUBSYSTEMS

The critical subsystems of any candidate system are vessel monitoring and the on-board display.

1.5.1 Vessel Monitor Candidates

The requirement to be able to locate and display the positions of both the bow and stern of a vessel is the most demanding of all the requirements. Candidate techniques include precise ranging systems and satellite-based, precise position measurements. The crosstrack accuracy requirement for both bow and stern positions is 16 to 20 feet, 2 standard deviations, 95 percent. The along-track accuracy requirement is 32 to 40 feet, 2 standard deviations, 95 percent. Existing and proposed major radionavigation systems include the following: LORAN-C/D, VOR, VOR/DME, VORTAC, OMEGA, TACAN, radiobeacons, aircraft landing systems (e.g., MLS), NAVSTAR GPS and TRANSIT. The aircraft landing systems (ranging systems) and the satellite referenced systems (NAVSTAR GPS and TRANSIT) have the potential for achieving the accuracies required in the fog navigation system. The latter systems can meet the accuracy requirements but have limitations. The NAVSTAR GPS system will be available by the late 1980s, and current policy calls for civil availability, but with a degradation in system accuracy required to protect U.S. national security interests. However, degraded GPS system accuracy will not satisfy the Canal fog navigation system requirements. The TRANSIT satellite system provides users with a postion fix rate which varies with latitude: theoretically from an average of one every 110 minutes at the equator to an average of one every 30 minutes at 80 degrees latitude. Today, due to nonuniform orbital precession, the TRANSIT satellites are no longer in evenly spaced orbits. Consequently, a user can occasionally expect periods from 6 to 11 hours between fixes. The update rate is also extremely slow. This is unacceptable for a Canal fog navigation system.

Aircraft landing systems provide range and bearing information to the aircraft pilot. The range measurement techniques are candidates for the fog navigation system. There are many commercially available ranging systems which can be considered in choosing a subsystem for fog navigation.

1.5.2 Shipboard Display Subsystem

The second most important subsystem is the shipboard display. In the restricted waterway environment of the Gaillard Cut, the Control Pilot is faced with a great many demands in addition to those of navigation. Reduced visibility, changes in navigation aids, increased potentials for collisions, channel maneuvering and stringent traffic regulations combine to place Pilots under intense pressure. In this environment, the fog navigation system must supplant the visual cues, providing immediate information not only about the present position, but about the future position, maneuver timing and vessel velocity. Simulation studies have been used to determine display requirements. The recommended graphic display depicts a map and the image of the vessel being piloted in a correct scale relationship. Other display characteristics include true motion, track-up and heading vector.

As well as graphic information, digital data would be presented in a data block on the screen. Data displayed would include rate-of-turn, distance-to turn-point, crosstrack error, velocity and other items needed by the Pilot. This combination of displayed information is sufficient to accomplish the Canal pilotage in poor visibility conditions. Adding color capability to the graphic display would make it easier for a Pilot to assimilate the displayed information. This would tend to overcome any Pilot reluctance to use a display in a poor visibility environment.

2. CANDIDATE SYSTEM REQUIREMENTS

2.1 OVERALL CANDIDATE SYSTEM REQUIREMENTS

The Gaillard Cut fog navigation system study has produced a list of general system requirements as well as specific navigation and guidance requirements.

2.1.1 General

The system should be sized to handle a maximum throughput of 50 transiting vessels per day as well as all dredging and drilling barges and tugboats*. System capacity would be 100 vessels per day overall. Simultaneous accomodation would not exceed 25 vessels: generally, one transiting vessel per reach, one tug per vessel, and seven work barges and launches. Expansion to 43 vessels, two vessels per reach plus the support vehicles, is easily accomplished.

The basic design of the system should be modular so that a restricted "pilot" installation could later be easily expanded into additional reaches if the requirement for extended coverage is warranted. As an example of modular expansion, the PCC might install a fog navigation system in the Pedro Miquel Approach. This region and the Miraflores Locks region have the largest percentage of accidents of the Canal, excluding the harbor and anchorage areas from the analysis. Based on a successful demonstration of the fog navigation system concept, the PCC can decide to expand the modular system to the other eight reaches of the Gaillard Cut.**

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*In FY 1988, there will be 19 tugboats operating in the Canal.

**The Pedro Miquel Approach and the Chagres Crossing - the entrance and exit courses for the Gaillard Cut - are included for purposes of this study in the list of reaches in the Gaillard Cut.

The Canal-bank-based elements of the fog navigation system should be serviceable by water, immune to electrical power variations, require no increase in the present PCC staffing level, be highly reliable and be compatible with the tropical environment of Panama.

The shipboard equipment should have the following characteristics: lightweight, require no increase in the number of line handlers or Pilots on a vessel, be independent of vessel power system, be easy to operate and have a display which would give the Control Pilot all the visual cues during fog navigation that are available to him during daylight transits.

2.1.2 Specific

System capacity	-	25 vessels (simultaneously)
Modular coverage unit	-	Single Canal reach
Canal-bank elements	-	Availability 99.8 percent (MTBF = 8000 hours)
	-	Reliability 99 percent minimum value
Shipboard elements		
Bow and stern units	-	Weight 25 pounds each or less
Display unit	-	Weight 25 pounds or less
	-	Reliability 99 percent minimum value

2.2 VESSEL MONITORING SUBSYSTEM

This subsystem provides the basic position location measurement of the bow and stern of the transiting vessel.

2.2.1 General

The subsystem will be capable of self-calibration; all bias errors will be removed from this subsystem. Each reach will be equipped with a minimum of four interrogators to eliminate problems of shielding as vessels meet in transit.

2.2.2 Specific

Crosstrack error	-	16 to 20 feet, 2 standard deviation, 95 percent.
Along-track error	-	32 to 40 feet 2 standard deviations, 95 percent.
Position resolution	-	0.1 foot
Range limits	-	300 feet to 10,000 feet
Spacial coverage	-	Gaillard Cut
Velocity accuracy	-	0.1 mph, 2 standard deviations, 95 percent
Velocity resolution	-	0.1 mph

2.3 PROCESSOR SUBSYSTEM

The processor subsystem performs two main functions: real time vessel tracking and updating of the shipboard displays.

2.3.1 General

The processor subsystem must be configured as a multiprocessor to permit modular expansion of the fog navigation system coverage. The heart of the system will be the main central processing unit. Application tasks will be executed in auxillary processing units. The processor subsystem power must be supplied by an uninterruptable power supply (UPS) which can sustain its operation from battery power for 0.5 hours.

The processor subsystem will be installed in two steps. It will be designed at first to collect and process data during the concept demonstration phase, followed by the addition of the auxiliary units for the fully operational system. There are nine critical factors in the design of real-time systems. The nine factors are:

1. Processing - unit core storage
2. Processing time in the computer
3. Peripheral file storage
4. Channel utilization.
5. Utilization of access mechanisms
6. Communication line utilization
7. Utilization of the various devices used in transmission
8. Display utilization
9. Capability of the display users.

These factors will be determined during the system concept demonstration phase.

2.3.2 Specific

Architecture	32-bit parallel 64-bit floating point Expandable from 1 to 9 CPUs
Central Processing Unit	Universal clock On-line diagnostic testing Power-down option
Memory System	Error correction Error logging Error scrubbing 16 Megabytes maximum 2 Megabytes minimum

2.4 SHIPBOARD DISPLAY SUBSYSTEM

The shipboard display provides the Control Pilot with the visual cues for navigating in a fog environment. A fast update time is needed in order to permit rapid assimilation of the displayed cues. Updates of once each second are needed for such activities. The need for fast refreshment of the display necessitates large buffers and considerable logic circuitry close to the display. A display microprocessor will be necessary.

2.4.1 General

The shipboard display subsystem includes a carrying case, display power supply and antenna. It must be light weight - less than 25 pounds - and compact for easy deployment on the vessel bridge and wings. The display must be readable in a high ambient light environment (sunlight) and have intensity adjustments for low ambient light levels. The equipment will be deployed and recovered by the PCC line handlers and transported to and from the vessel in PCC launches.

2.4.2 Specific

Update	- Mean value of the update time will be 1 second
	- 95 percent of the update times will take less than 6 seconds
Resolution	- 512 by 512 picture elements (pixels)
Weight	- 25 pounds
Display	- Multicolor
Indicators	- On/Off lights and receiving data lights
Microprocessor	- Generates all maps, ship wake and heading vectors

2.5 COMMUNICATIONS SUBSYSTEM

The communication subsystem must support each Pilot's display with a data stream capable of refreshing the visual image of that vessel's position once per second (mean value, 95 percent of the updates will take less than 6 seconds).

2.5.1 General

In a typical situation, a Control Pilot leaving the Pedro Miquel locks, north-bound into Gaillard Cut, would use his fog navigation system display to view the traffic picture ahead of his vessel. This scenario determines the maximum volume of messages to be sent to a single vessel display. The current estimate is 37 ship location messages per second sent to the ship display. While transiting the Cut, the Pilot would adjust his display to view the reach in which he is operating and perhaps the reach ahead to prepare for a meeting maneuver. If all vessels - one per reach - were viewing on their displays all vessels in their current reach and all the vessels ahead of them along the route, the average message volume per vessel display would be 19 ship location messages. The demand from all the displays on the communication system would be 171 ship location messages per second.

2.5.2 Specific

The types of messages sent to the Control Pilot's display includes the following:

Own-ship bow position
Own-ship stern position
Other-ship bow position (8 vessels, one per reach)
Other-ship stern position (8 vessels, one per reach)
Tug position (9 tugs, one per reach)
Other dredges, barges and launches positions (7 units)
Own-ship status
Fog navigation system status
Pilot information

2.6 OTHER SUBSYSTEMS

The performance of the fog navigation system will benefit from additional support subsystems and other options. The technology for automated weather measurement is developing rapidly. There could be an advantage to fog navigation if weather sensors were used as an alerting aid when the fog was increasing or lifting.

A communications connection with the Marine Traffic Control Center would assist the fog navigation system by making available information on ship identification and anticipated traffic.

The fog navigation system should include a training simulator to acquaint new Control Pilots with the use of the on-board display.

3. RECOMMENDED CANDIDATE FOG NAVIGATION SYSTEM DESCRIPTION

3.1 SYSTEM OVERVIEW

The recommended candidate fog navigation system uses multiple precision range measurements to calculate vessel position and velocity in real time and transmits this information to the Control Pilot aboard the vessel transiting the Gaillard Cut and to the MTC Center. The system consists of seven major subsystems: (See Figure 3-1).

3.1.1 Vessel Monitoring Subsystem

The vessel monitoring subsystem consists of a precision ranging system. An array of interrogators is installed along the Canal bank and transponders are located on all the vessels transiting the Canal. The ranges from an interrogator to transponders located at the bow and stern of each vessel is measured to an accuracy of ± 9 feet (2 standard deviations, 95 percent). Range measurements from three interrogators to the shipboard transponders are sufficient to determine the location and bearing of the ship with respect to the Canal centerline. In practice, the range measurements from more than three interrogators are used to increase the measurement accuracy and to prevent loss of signal caused by line-of-sight blockage by terrain or other vessels, and to prevent signal loss caused by multipath transmissions.

3.1.2 Computer Subsystem

The range measurements from the interrogators are transmitted to the system processor; a high-speed multiprocessor system. The data is processed to extract vessel position, velocity and heading. Since each transponder is assigned a unique code, the system can identify all transponder-equipped vessels which are within range of the shore based interrogators.

3.1.3 Shipboard Display Subsystem

The computer-derived vessel navigation and guidance data is transmitted to each ship for display to the Control Pilot. The shipboard unit depicts, to scale, the Canal banks, the position and heading of the vessel in the Canal, other vessel traffic, Canal centerline, sailing lines and other navigation information required by the Pilot to guide his ship during reduced visibility conditions. Digital data will support the graphical display.

3.1.4 Communications Subsystem

The communications subsystem consists of a processor, land lines and RF links required to transmit control commands to the interrogator array, collect and process range data from the interrogators and transmit vessel navigation and guidance data to the Control Pilot displays. The system has redundant paths to insure high reliability.

3.1.5 Marine Traffic Control Subsystem

The MTC subsystem consists of an operator interface station and traffic management displays.

The interface station is used by the MTC operators to initiate vessel tracking, assign transponder codes, terminate a tracking service, retrieve traffic data, etc.

The MTC displays provide traffic management information to MTC personnel. Each display can be used to monitor the traffic in a sector of the Gaillard Cut. In addition, an operator may request a format which duplicates on his display the information available on a specific Control Pilot's display.

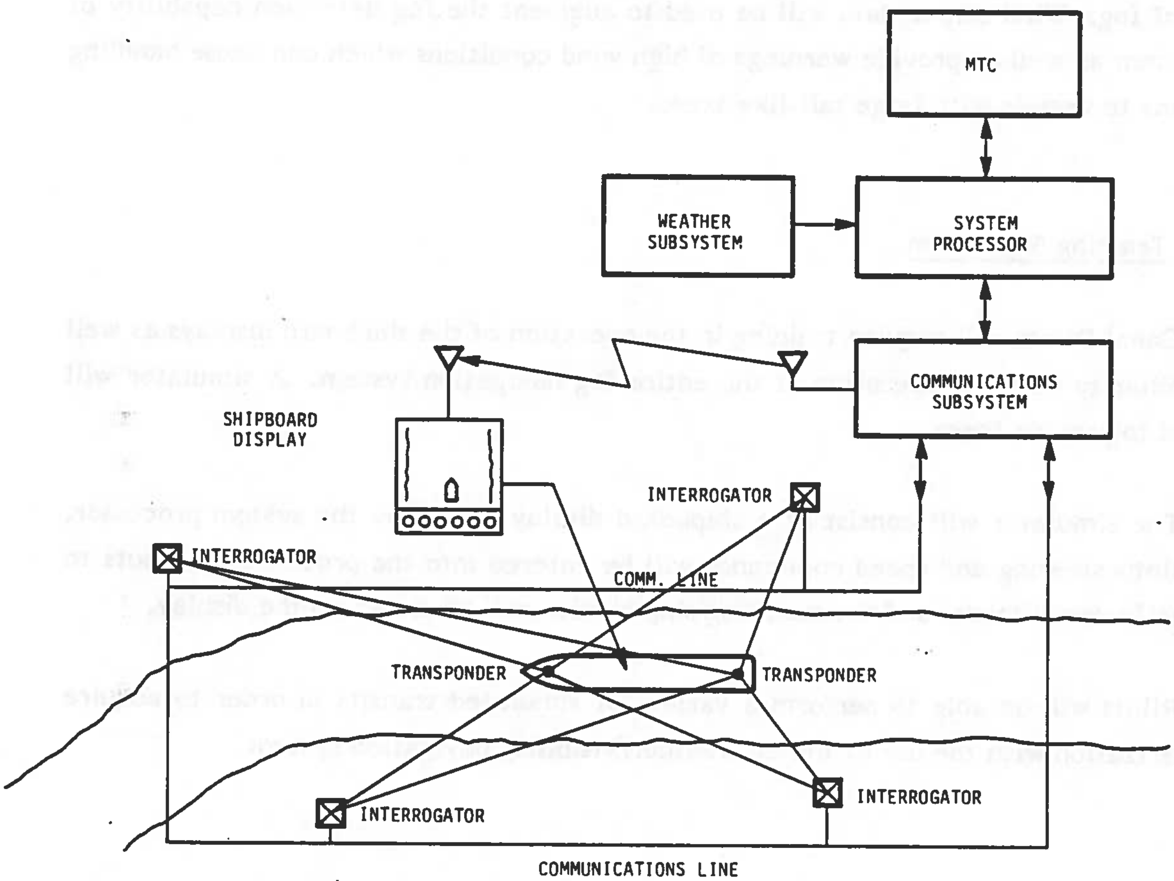

FIGURE 3-1. PANAMA CANAL FOG NAVIGATION SYSTEM

3.1.6 Weather Subsystem

The weather subsystem consists of an array of visibility and wind sensors installed along the Gaillard Cut. Forward or back scatter type visibility sensors are very sensitive to the presence of aerosols, i.e., fog, and may provide an early warning of the onset of fog. Wind sensor data will be used to augment the fog detection capability of the system as well as provide warnings of high wind conditions which can cause handling problems to vessels with large sail-like areas.

3.1.7 Training Subsystem

Canal Pilots will require training in the operation of the shipboard displays as well as familiarity with the operation of the entire fog navigation system. A simulator will be used to provide these.

The simulator will consist of a shipboard display driven by the system processor. The Pilot's steering and speed commands will be entered into the processor as inputs to a dynamic vessel model and the resulting ship motion will be shown on the display.

Pilots will be able to perform a variety of simulated transits in order to acquire familiarization with the use of the all weather/visibility navigation system

3.2 VESSEL MONITORING SYSTEM

The vessel monitoring subsystem uses precision range measurements between interrogators located at accurately surveyed reference points along the Canal banks, and transponders placed aboard the vessel, to calculate ship position. As shown in Figure 3-2, location of a transponder with respect to the reference points is determined from range measurements (trilateration). Additional range measurements (multilateration) improve the position determination accuracy while simultaneously providing the redundancy necessary to insure uninterrupted operation.

The multiple lateration measurements are transmitted to the system processor which checks the validity of the incoming data and then processes the data to extract ship position, velocity and heading.

As shown in Figure 3-2, two transponders are required on each ship to determine ship position and heading. Each transponder is assigned a unique identification code. In operation, each interrogator transmits a signal directed to a specific transponder. The addressed transponder replies to the interrogation. The time elapsed between the transmission of the interrogation and the receipt of the reply is a direct measure of the distance between the interrogator and the transponder. Since the interrogator installations on land have been carefully located (second order survey), the transponder position measurement accuracy is limited primarilyby the range measurement accuracy of the system. State-of-the-art systems are now available with demonstrated accuracies of 3 to 6 feet (two standard deviations).

The interrogators are under control of the system processor which selects the time to initiate an interrogation and also selects which transponder to interrogate. The interrogation selections are determined by the geometric relationship between the interrogator and the transponder at each instant, the vessel's location in the Cut, other traffic, etc. The nominal interrogation rate is once per second, but the interrogation rate is variable. Thus, if two vessels are meeting each other, or if the vessel is in a turn maneuver, the interrogation rate may be increased. If the vessel is in the middle of the channel without any other traffic nearby, the rate may be reduced thus adapting the interrogation rates to the existing situation.

Fixed transponders are located at a number of surveyed points along the shore to provide system self-check capability. These fixed transponders are interrogated periodically, and if the reply is within the expected time delay corresponding to a system accuracy of 3 to 6 feet a "no error" condition is indicated. Alternately, the replies from the fixed transponders can be used to "fine tune" the system by using them to compensate for small anomalies caused by changes in atmospheric transmission properties or small interrogator frequency drifts.

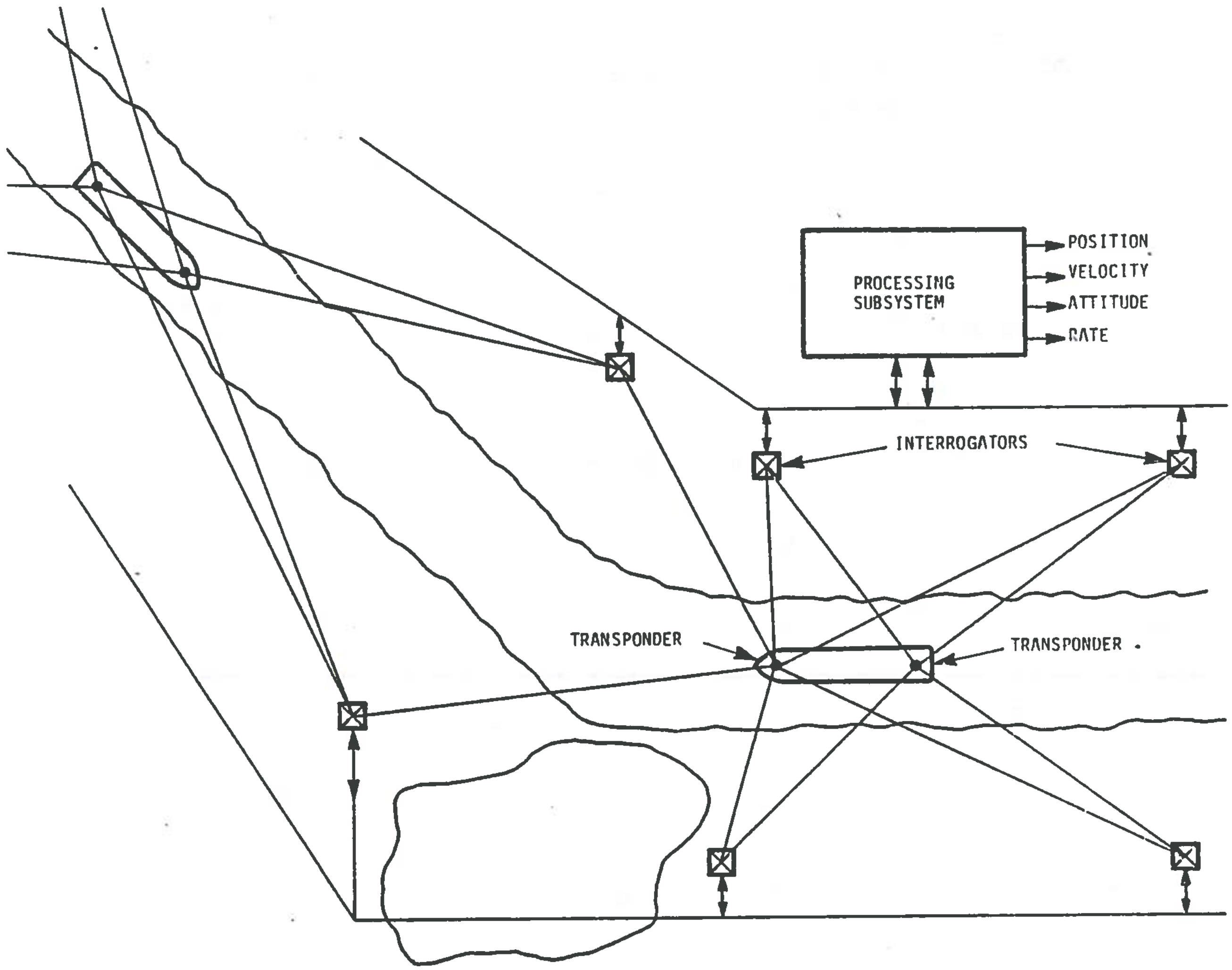

FIGURE 3-2. VESSEL POSITION MONITORING SYSTEM

The number of vessels which can be tracked by the system is limited by the number of transponder codes, processor speed, interrogation rate and communication line bandwidth. The system will be designed for an initial capacity of 50 simultaneous targets, with the capability of later expansion to a capacity of 100.

The transponders are lightweight, environmentally sealed and battery-powered. They will be loaded and off-loaded by the line handlers.

The transponders will be clamped to the ship railing or to any on-board convenient structure. The transponder antenna can be installed remote from the transponder allowing more flexibility in transponder location on various vessels.

The transponder package can withstand water immersion and is buoyant to aid in its recovery in case of an accidental drop. The transponder package can withstand impacts with hard surfaces in case of an accidental drop during loading or off-loading.

The shore-based interrogators are small, lightweight, environmentally sealed units, designed for unattended operation. Each interrogator is powered from its own uninterruptible power supply (UPS) which, in the event of a power loss, will continue operating for a specified time from the backup battery. In addition, the UPS acts as a line power regulator and transient suppressor, insuring uniform power levels to the interrogator under all conditions.

3.3 PROCESSOR SUBSYSTEM

The processing subsystem performs four main functions: real time vessel tracking, provision of navigation and guidance data to the shipboard displays, traffic data management, and output to the MTC displays.

3.3.1 Real Time Vessel Tracking

The computer directs the polling activity of the interrogators. The transponders on each vessel are interrogated by three or more interrogators which have the best geometry for solving the vessel position problem. This results in optimum position estimation.

The incoming range data from each interrogator are checked to detect any transmission errors. The replies from the land-based transponders are also checked to insure that all interrogators are operating properly.

The transponder range data corresponding to each tracked vessel are processed using an optimal estimator (Kalman filter). The calculations include a dynamic model of the vessel based on knowledge of its length, beam and gross weight. Different interrogation rates are used, the rate for a particular transponder selected based on the current control requirements of each vessel. Thus, although the nominal interrogation rate is once a second, the rate may be increased for vessels which are in a meeting maneuver or when entering a turn, and may be decreased for vessels moving in the middle of the canal without any other traffic present. The vessel parameters calculated are the vessel position, velocity, heading, distance to turn-point, rate-of-turn, course and time to start-of-turn maneuver.

3.3.2 Output to Shipboard Displays

The processor updates each shipboard display after completing the calculation of that ship's navigation and guidance parameters - once a second on the average. Since each shipboard display is separately addressable, the processor transmits the required display update parameters to each vessel individually. The transmission is made through the communications subsystems using an RF link.

3.3.3 Output to the MTC Displays

The processor drives the MTC's graphic and alphanumeric displays which provide the MTC controllers with real-time traffic information and traffic management data.

The graphic display data consists of vessel traffic subdivided into several Gaillard Cut sectors, with one display dedicated to each sector. In addition, the MTC controllers can call up a specific Control Pilot display format, which duplicates on the MTC display the information shown aboard the selected ship.

The alphanumeric display data consists of active vessel traffic lists, quick-look-up ship locations, transponder code assignments, system status, special notices, etc.

Since the MTC displays are collocated with the system processor in the MTC facility, they will be driven directly by the processor using the high speed communications link.

3.3.4 Traffic Data Management

The processor automatically performs the required data management necessary for maintenance of the orderly flow of traffic. This includes the assignment of transponder codes to specific vessels, initiation and termination of tracking service, maintenance of current vessel traffic lists, current vessel location, status of equipment, and the issuance of special traffic notices for distribution to MTC controllers.

3.3.5 Processor Description

The system processor configuration is a dual multiprocessor installation which has the necessary reliability and capacity required to meet the needs of the fog navigation system for fail-safe operations. The high speed processors use a 32-bit parallel architecture, which includes floating point arithmetic units, memory error checking and correction. The system is modular, and consequently can be initially configured with only two central processing units (CPU) and a 2 Megabyte (MB), directly addressable memory and can (as requirements increase) be expanded to 10 CPUs and a 16 MB memory. Each CPU is added to the system as a plug-in module. Critical tasks such as ship tracking and data distribution are processed simultaneously by both multiprocessing systems and the results compared for agreement. Less critical tasks can be performed by either multiprocessor alone.

The modular nature of the system allows tailoring of the system to current needs. The system has the capability to operate with 20 CPUs and 32 MB memory. This provides redundancy which allows continued system operation even though one or more CPUs may fail.

The system includes other standard features, such as a real-time clock, communications interfaces, disk drives, printers, operator terminals and a high speed tape drive. All system data may be continuously recorded on tape for later playback if desired. This feature is particularly useful in reconstructing events, such as operational difficulties, or to assist in evaluating comments from system users.

The processing subsystem power is supplied by a UPS which can sustain its operation from battery power for 0.5 hours. An auxiliary generator may be provided to supply power for longer periods if felt necessary.

3.4 SHIPBOARD DISPLAYS

The shipboard display provides the Control Pilot with the information to safely guide his vessel through the Gaillard Cut under all visibility conditions.

The shipboard displays consist of a microprocessor-driven, high resolution color display and a communications unit for receiving vessel traffic and other data transmitted to it by the system processor.

The display processor memory stores a map of the Gaillard Cut, and the location of the Canal's center line, sailing lines, range markers and buoys. A vessel's navigation and guidance data are transmitted to the vessel's display by the system processor after every new computation - on the average once a second. Other information, such as that concerning other vessels in the Cut, anchored barges and traffic advisory messages is also transmitted to the display.

The shipboard display processor overlays the received traffic information on the stored map and presents the results to the Pilot on a high resolution (512 x 512 pixel) color display.

A sample display format is shown in Figure 3-3. The display provides the following information:

1. Canal banks shown to scale, and all geographic features identified.
2. Own-ship to scale and always at the bottom of the display, with the Canal (or reach) centerline vertical (course up display); ship leader and trailer included to highlight ship motion.
3. All other traffic underway, such as vessels, tugboats, barges, displayed to scale; in addition, anchored drilling barges, rigs, or any other obstructions that the Pilot should be aware of.
4. Required guidance information including traffic lanes, turning points, range markers and buoys.
5. Identification tag identifying the vessel on all traffic.
6. Own-ship information such as speed, crosstrack error, rate-of-turn, heading, etc. in data block.

In addition, the Pilot can select the display scales, enabling him to view the traffic ahead of him in the entire Gaillard Cut, for one or two reaches or just the reach he is presently in. The Pilot may also select different horizontal scales making it possible to expand the horizontal scale which may be useful in a ship meeting maneuver.

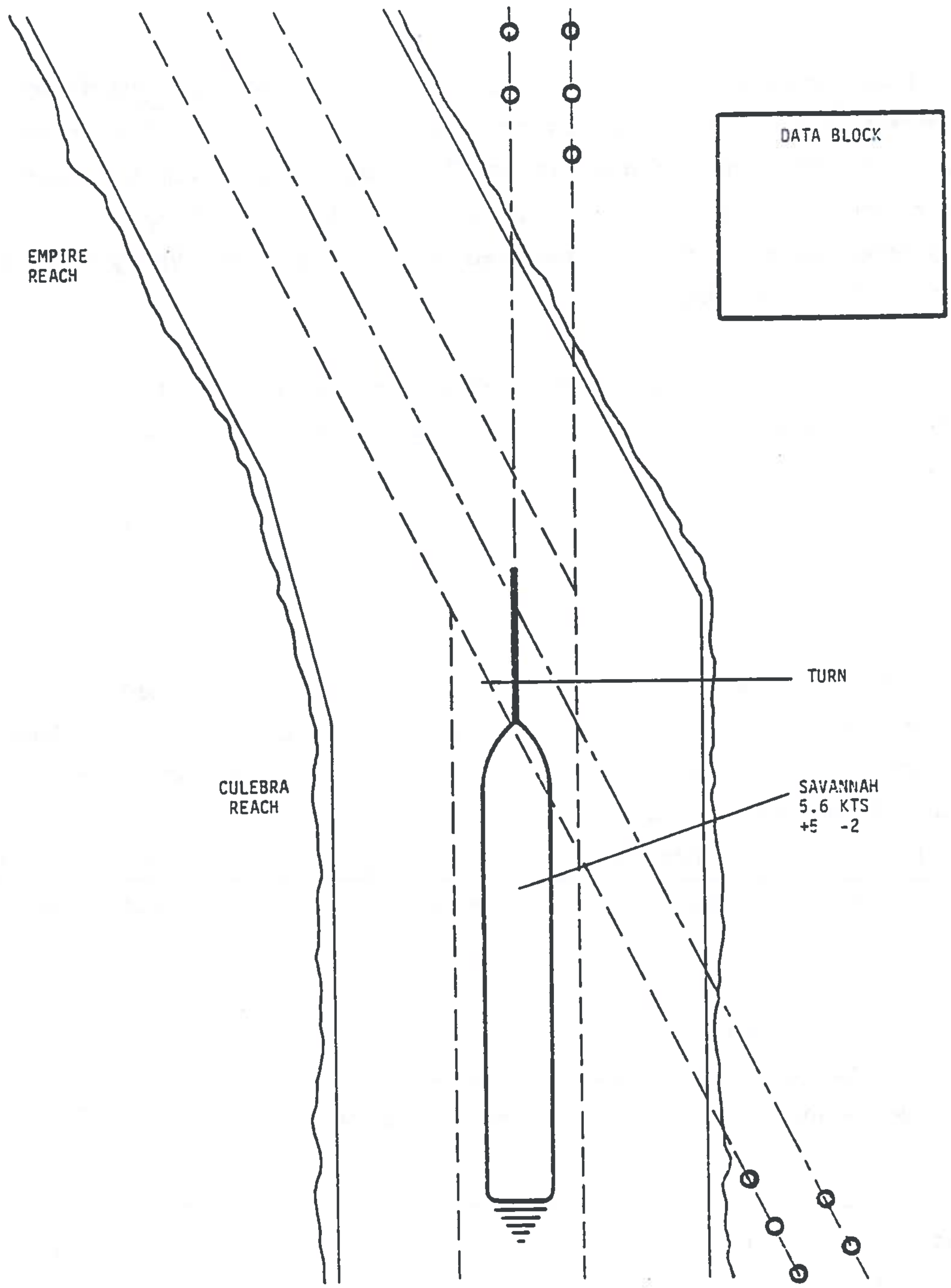

FIGURE 3-3. SAMPLE SHIPBOARD DISPLAY FORMAT

The shipboard display is lightweight (25 lb max.), battery powered, impact resistant and environmentally sealed. It can sustain water immersion and is buoyant so that it will float, to aid in recovery, if dropped overboard.

In operation, the display is placed on a small stand either brought aboard ship or supplied by the ship. A small external antenna may be required to insure good reception of the system processor transmitted data. The antenna, if required, is clamped to any pipe or other fixture near the bridge and connected to the display through a flexible coaxial line.

3.5 COMMUNICATIONS SUBSYSTEM

The communications subsystem provides the necesary communications links connecting the system computer and the vessel monitoring subsystem and the shipboard displays. Land lines as well as RF radio links are used in the communications system.

3.5.1 Vessel Monitoring Subsystem Communications

The interrogator array located along the Gaillard Cut is interconnected to the system computer via a 4800 baud land-line in a loop arrangement as shown in Figure 3-1.

The communications interface transmits and receives data from either loop end thereby providing the capability for an end-to-end loop continuity check. If a break is detected, communications with the interrogators can continue via the individual loop segments.

The interrogators are addressable by the system processor. The communications subsystem provides the means by which the system processor can command individual interrogators to acquire range information from specific transponder sets and return the acquired range information to the system processor.

3.5.2 Shipboard Display Subsystem Communications

The transmission of own-ship position information to the ship as well as all other traffic data requires the use of a low power RF link. The transmission rate is 4800 baud.

The information transmitted consists of the vessel indentification followed by navigation and guidance information i.e., vessel position, velocity, etc. Each shipboard display contains a receiver for acquisition of the transmitted data, which, after decoding, is checked for accuracy and used to update the traffic file in the display processor's memory.

In addition to vessel traffic information, the data format allows transmission of general information messages: weather, special traffic advisories, schedule changes.

The data is transmitted to the displays via low power tranmsitters located along the Canal bank.

3.6 MARINE TRAFFIC CONTROL CENTER DISPLAYS SUBSYSTEM

The MTC Center displays consist of an array of Sector Displays, the Operator Interface Station and Backup Displays.

Each display unit includes a color graphics display, an alphanumeric display, a microprocessor, an interface to the system processor, and keyboard. All displays consist of identical hardware sets; the display software provides the adaptation capability of the displays to the needs of the various stations.

The use of a common set of display hardware at all MTC stations will greatly simplify the system maintenance requirements, reduce training and the number of spare parts needed, resulting in considerable cost savings.

3.6.1 Sector Displays

During peak traffic or low visibility conditions, the system allows the surveillance of the Gaillard Cut to be partitioned into two or three sectors. The sector traffic display equipment provides the MTC traffic controller the information required for control of the vessel traffic in his sector. The color graphics display shows the location of each vessel in the Cut. Each vessel is identified by name, and its velocity, exact position and other parameters are presented in its accompanying data block. The displays are updated once a second on the average.

High resolution color displays are used for the graphics presentation. The colors are selected for ease of recognition of the tracked targets, special terrain features and navaids. Colors may be used for warnings, such as flashing red for potential collision situations.

The alphanumeric display at each sector station is used to provide the controller with required operational data. Included are lists of incoming traffic, vessel information (name, type, size, weight, draft, cargo, special handling requirements), weather conditions in the Cut, equipment status and outages, special notices of unusual conditions, alerts.

The alphanumeric display units are identical to the graphics display units; in fact the units are interchangeable. If a graphic display fails, the alphanumeric display can be converted to a graphics presentation, and a neighboring alphanumeric display shared until the problem is fixed or the failed display unit is replaced. Alternatively, the MTC controller may reconfigure his work station to one of the backup display stations.

The sectorization of the Gaillard Cut can be altered to meet traffic surveillance demands. Under reduced traffic conditions the number of displays used to sectorize the Cut can be reduced from three to two or even to one display for the entire Cut. Sectorization is entered by the MTC controllers through the keyboard to the system computer; the computer changes the traffic display to correspond to the new sector boundaries.

3.6.2 Data Management Stations

The data management station is used by MTC personnel to maintain operational data files. The data entered consists of detailed information on each vessel: the vessel entry point, the address codes of the shipboard equipment set (transponders and display) special handling requirements, equipment status and outages, weather conditions, and messges to be transmitted to various vessels.

3.6.3 Backup Display Station

The primary purpose of the backup displays is to provide assistance to Canal Pilots experiencing shipboard display problems or any other contingency. The backup display can be reconfigured to duplicate the information displayed on the shipboard display. The displayed information can be used to generate traffic advisories to the Pilot.

The backup displays are also capable of being used as sector display and data management stations to support these positions when required.

All MTC displays include a microprocessor for all local tasks: generation of the graphics, communications with the system computer, error checking and keyboard control.

The displays communicate with the system processor through dual communication busses, the redundancy insuring reliable operation even though one bus fails.

The resident software in each display includes the background map generation, operational data storage and similar tasks which, in addition to off-loading the system processor, provide an added measure of security by maintaining the display information during a temporary system failure. The information is removed after a preset time period to prevent the use of old data.

3.7 WEATHER SUBSYSTEM

The weather subsystem consists of a single visibility and wind sensor array along the banks of the Gaillard Cut. The visibility sensors can provide early warning of the onset of fog. The wind sensor data will assist in the prediction of fog motion as well as provide information on wind conditions along the Cut.

3.7.1 Visibility Sensors

Forward Scatter Meter (FSM) type visibility sensors will be used to measure the visibility along the Cut. The FSM type sensor measures the amount of light scattered out of a light beam in a 20 to 50 degree arc. The presence of aerosols, such as those caused by fog, will cause light scattering, resulting in a signal output from the sensor. The instrument has a large dynamic range. It readily detects low concentrations of aerosols and may, depending on the development of proper algorithms, provide the visibility data required to provide early fog warnings.

3.7.2 Wind Sensors

Wind speed and direction sensors will be deployed along the Cut, colocated with the visibility sensors. Since the behavior of the fog is dependent on the wind conditions, the measured wind parameters will be used in the fog warning algorithm. In addition, the sensors will detect high wind conditions along the Cut which can cause handling problems for some ships such as automobile carriers, whose high sides are subject to large wind forces.

3.7.3 Electronics

The collection of visibility and wind sensor data from each site is accomplished by a field data acquisition system. The electronics units consist of a multiplexer, analog-to-digital converter, modem, controller and clock. In addition to the visibility, wind speed and direction voltage inputs to the multiplexer, reference voltages are input to check on the conversion accuracy.

Each data acquisition system outputs the raw sensor data to the system processor at a fixed rate over the same communications system used for control of the Vessel Monitoring Subsystem interrogators.

3.7.4 Data Processing and Product Distribution

The weather sensor data is collected and manipulated by the processor subsystem. The data consists of averaged visibility, wind speed and direction values. Wind gust values are also computed. These numbers are used to predict fog conditions and to generate early warnings.

The sensor arrays may be augmented with additional sensors such as temperature, dew point, and rain sensors, in order to enhance the reliability of the weather subsystem output data.

Weather information is distributed to all users of the fog navigation system. The MTC uses the information to adjust traffic flow. Weather warnings are transmitted to all vessels in the Cut where they appear on the Pilots' displays.

3.8 TRAINING SUBSYSTEM

Introduction of the fog navigation system into the Panama Canal operations requires that all Control Pilots, both experienced and new arrivals, receive extensive training in the use of the system. The training subsystem will fullfil the majority of the initial training needs. The additional training will be received during actual Canal transits.

The training subsystem consists of a number of stations, each equipped with a shipboard-type pilot display, engine rpm and ship heading indicators. The displays are driven by a training system processor - a separate CPU in the processing subsystem.

Pilot steering commands (speed and heading) are entered using a ship control simulator, the output of which are inputs to a ship motion modelling program residing in the training processor. A number of different vessel models, ranging from Panamax vessels to small freighters and tugs are included in order to simulate ships with different handling characteristics. Also included are external effects, such as wind loading and water currents.

Control Pilots, being trained in the use of the system will be required to successfully complete a predetermined number of simulated transits through the Cut in a variety of traffic conditions and external disturbances.

4. NAVIGATION SYSTEM EXPANSION POTENTIAL

The fog navigation system can be expanded to provide additional services. The use of precision range measurements for vessel tracking is readily adapted to lock-entry guidance and toward the eventual implementation of a full Vessel Traffic Management System (VTMS) over the entire length of the Panama Canal.

4.1 PRECISION LOCK ENTRY GUIDANCE

The expansion of the system to provide precision entry guidance can be accomplished by installing additional interrogators in the vicinity of the locks, including lock dimension information in the Pilot displays, and making software changes in the system processor necessary for the coverage of the lock areas, communications and display interface changes. The training system will also require modification.

The precision lock guidance information generated by the system for the Control Pilots consists of ship velocity to nearest 0.1 mph, heading to nearest 20 minutes of arc, (turning rate to nearest degree/minute, if required) and the displacement of the bow and stern of the vessel from the lock centerline, in feet.

The Control Pilot display integrates all lock guidance information and presents it to the Pilot in graphic form with alphanumeric guidance information displayed alongside. A sample display is shown in Figure 4-1. The Pilots may want the guidance information while conning from the bridge wings so, rather than bring the entire display out on the wing, the Pilot can be given a hand-held alphanumeric display unit. The battery powered, hand-held display is driven by the Control Pilot's display using a serial data format, and requires only a thin, flexible, two-wire conductor to interconnect. The Pilots may also find the hand-held units useful during transits through the Cut.

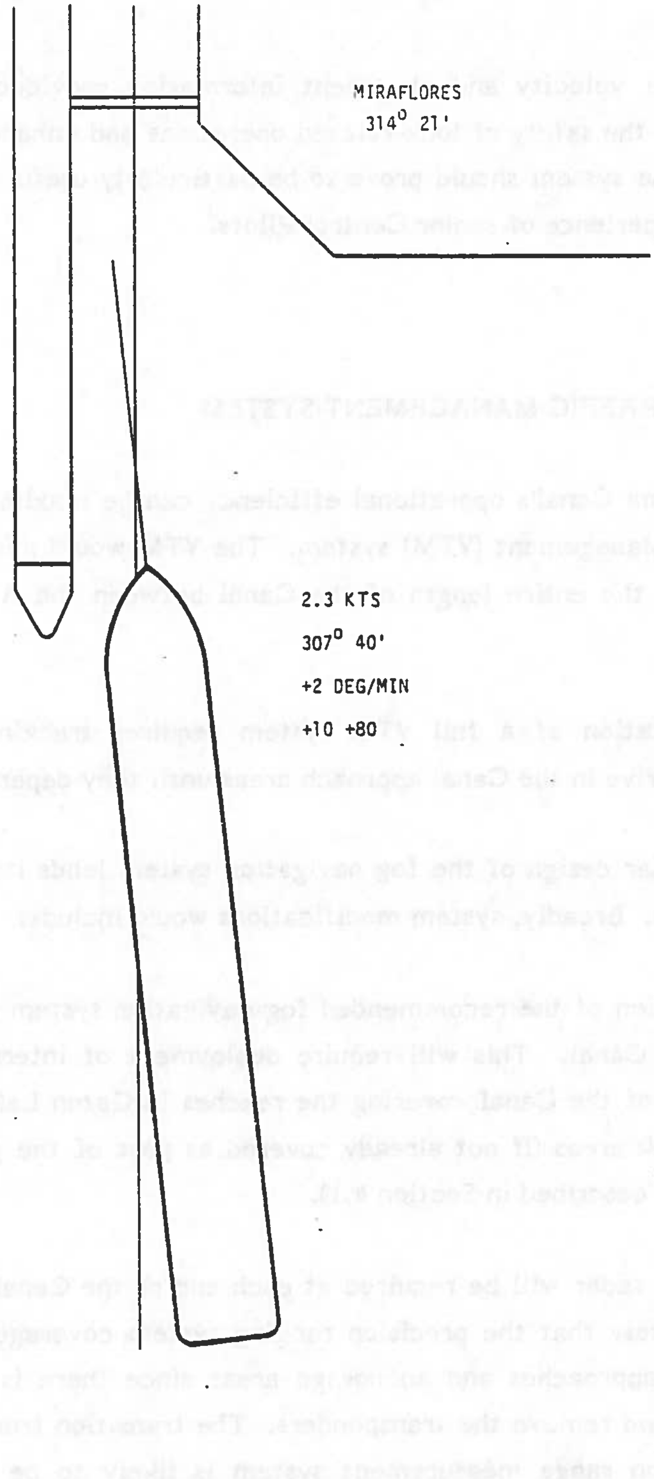

FIGURE 4-1. SAMPLE LOCK ENTRY GUIDANCE DISPLAY FORMAT

The vessel velocity and alignment information provided by the system should greatly improve the safety of lock-related operations and enhance the efficiency of the approaches. The system should prove to be particularly useful to relatively new Pilots who lack the experience of senior Control Pilots.

4.2 VESSEL TRAFFIC MANAGEMENT SYSTEM

The Panama Canal's operational efficiency can be maximized by installing a full Vessel Traffic Management (VTM) system. The VTM would monitor and control vessel movement over the entire length of the Canal between the Atlantic and the Pacific terminals.

Implementation of a full VTM system requires tracking of vessels from the moment they arrive in the Canal approach areas until they depart the Canal areas.

The modular design of the fog navigation system lends itself to expansion into a full VTM system. Broadly, system modifications would include:

1. Expansion of the recommended fog navigation system to cover the full length of the Canal. This will require deployment of interrogators along the full length of the Canal covering the reaches in Gatun Lake, Miraflores Lake and the lock areas (if not already covered as part of the precision lock guidance system described in Section 4.1).

2. Marine radar will be required at each end of the Canal to monitor vessels. It is unlikely that the precision ranging system coverage could be extended to Canal approaches and anchorage areas since there is no convenient way to place and remove the transponders. The transition from radar tracking to the precision range measurement system is likely to be in the anchorage area where the transponders can be placed aboard the vessel at the same time the Pilot boards the ship.

3. The communications system must be expanded to cover the full length of the Canal.

4. The Control Pilot display software must be modified to include a stored map of the entire Canal area.

5. Transponder battery life must be increased in order to sustain the unit during the entire transit phase (approximately 24 hours).

6. The processing system would require additional CPUs to accomodate the expanded number of tracked targets, additional communications and the increased number of VTM displays in the MTC Center.

7. The MTC displays would be expanded to cover the entire Canal area. The Canal operations would be sectorized into a number of sectors (6 to 9). The traffic in each sector would be managed by MTC personnel using a sector station consisting of graphic (G) and alphanumeric (A/N) displays and a keyboard computer interface. The vessel traffic would be displayed on the G displays. The A/N displays would contain traffic lists, notices, weather information, etc. A vessel transiting the Canal would be automatically monitored from one sector to the next, allowing positive traffic management over the entire Canal length. As an option, large-screen displays could be installed for easier viewing and monitoring.

A sample MTC layout is shown in Figure 4-2. In addition to the sector display sets, the equipment consists of a supervisor's station, data stations and backup display stations.

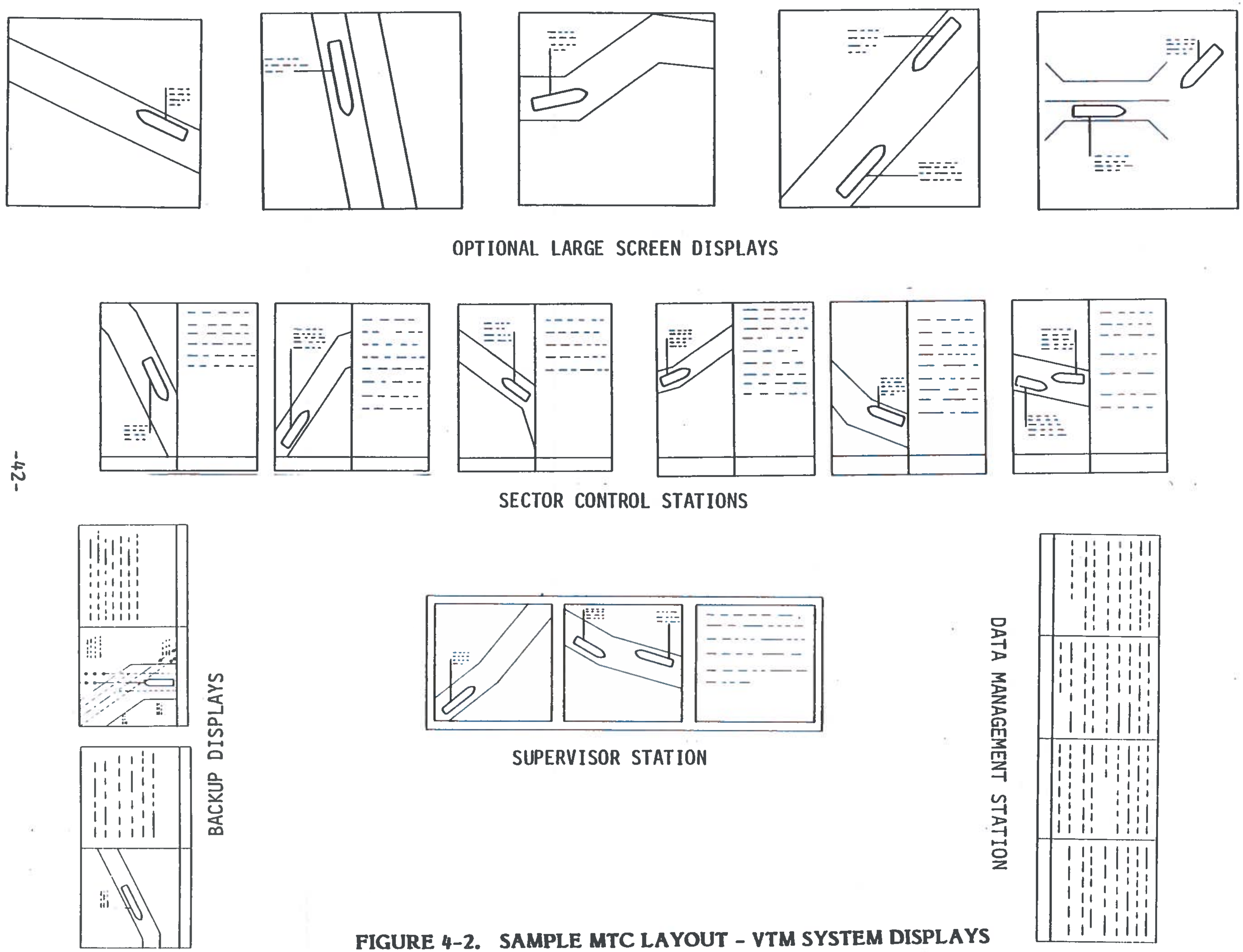

FIGURE 4-2. SAMPLE MTC LAYOUT - VTM SYSTEM DISPLAYS

The supervisor's display station is capable of performing the same functions as the sector display station, data management stations or the backup displays as well as monitoring all of these operations. This capability enables the supervisor, to provide assistance to any station where operational problems develop, verify system status, and monitor the operation.

All display station attributes defined in the fog navigation system would be retained in the full VTM system, including display commonality and fail-safe processor interfaces.

5. FOG NAVIGATION SYSTEM COST ESTIMATE

The cost of implementing any fog navigation system is heavily dependent on the selected range measurement technology, the degree of built-in system redundancy and reliability, display selection, MTC center displays, communications system, installation cost, and similar considerations. Without a more detailed system design, and within the time and funding constraints of this study, only a general cost estimate of the recommended candidate system can be made. Costs of installation of equipment have not been included in this estimate. The major hardware cost elements are as follows.

5.1 VESSEL MONITORING SUBSYSTEM

It is estimated that approximately 20 interrogators will be required to provide adequate coverage in the Gaillard Cut.

The number of shipboard transponders required depends on the number of transiting vessels, tugs, anchored work barges, etc. which may be in the Cut at any one time. If a maximum of 15 transiting vessels, 5 tugs and 5 other targets requiring transponders is assumed, the total number of active transponders would be 40 (two per vessel, one on all other craft). Allowing for turn-around time, spares and maintenance, it is estimated that 100 transponders will meet the initial systems needs.

Commercially available systems which provide precision range meansurements use one of two measurement techniques.

1. Systems which utilize pulse-time-of-arrival to measure range (example: Motoroloa Miniranger).
2. Continuous-Wave, multiple-tone modulation, phase comparison (example: Cubic CR-100, Autotape).

Depending on the measurement technique and the specifications to which the equipment is built (commercial specification vs. full military specification) there is a wide spread in equipment costs. A general price estimate for the two system types follows.

1. Pulsed System Elements (commercial)

Interrogator	$7.5K
Transponder	$7.5K
Interrogator interface to communications system, misc.	$5.0K

2. CW System Elements (commercial)

Interrogator	$60K
Transponder	$20K
Interrogator interface, etc.	$5K

3. CW System Elements (Mil-spec)

Interrogator	$200K
Transponder	$75K
Interrogator interface, etc.	$5K

Based on the above equipment costs and the previously defined equipment complement of 20 interrogators and 100 transponders, the hardware cost of the recommended candidate Vessel Monitoring Subsystem for Gaillard Cut is estimated as:

Pulsed System (commercial)	$1,000K
CW System (commercial)	$3,300K
CW System (mil-spec)	$11,600K

5.2 PROCESSING SUBSYSTEM

For cost estimation purposes, a dual multiprocessor configuration is assumed, each multiprocessor consisting of a main CPU, two auxiliary CPUs and two independent memories.

Two multiprocessors @ $250K $500K

5.3 SHIPBOARD DISPLAY SUBSYSTEM

The Pilot display is likely to use vacuum fluorescent technology or a similar approach in order to achieve the required light weight and small size. The display would incorporate a microprocessor with a large (probably bubble) memory to store the background map, and a receiver for the acquisition of the update data.

The Pilot display is the only subsystem which will require a substantial development effort, primarily in design, programming and packaging.

Based on the previously estimated traffic levels in the Cut, there is a requirement for 50 displays. The estimated costs of this subsystem are as follows:

Display development	$750K
50 displays @ $20K/display	$1000K

5.4 COMMUNICATIONS SUBSYSTEM

The communications subsystem consists of the communications processor (part of processing subsystem), interfaces to the hard-wired link connecting all land-side equipment and the RF transmitters and associated hardware. To insure reliable Pilot display updating, eight low-power transmitting sites will be required along the cut.

The estimate does not include the cost of installing the land lines. This cost depends on whether existing communication facilities along the Canal can be used for this purpose (use existing poles or require new ones), whether PCC labor can be used or contractors are required. These cost estimates are left for the PCC engineering staff whose knowledge of the local conditions allows them to make more realistic estimates.

Processor	$100K
Transmitters	$160K
Interfaces	$150K

5.5 MTC SUBSYSTEM

The assumed MTC display configuration consists of 3 sector displays, 1 data station and 2 backup display stations. The cost estimate includes the dual communications bus architecture, and the processing subsystem interfaces.

MTC Subsystem	$225K

5.6 WEATHER SUBSYSTEM

The weather subsystem is assumed to consist of 5 visibility sensors, 5 wind sensors and 5 sets of field electronics.

5 Visibility Sensors @ $10K	$50K
5 Wind Sensors @ $1K	$5K
5 Electronics Units @ $3K	$15K

5.7 TRAINING SUBSYSTEM

The training subsystem configuration consists of one processor (a separate CPU in processing subsystem) Pilots and ship instrument displays and a ship control input simulator. Undoubtedly, the design for the simulation hardware as well as the vessel simulation program exist at various locations, such as CAORF. Hence, a new design is not required, since the existing hardware and software designs can be adapted to the training system requirements.

Processor 40K	
Ship Control & Display Simulator	50K
Pilot Display	25K
Subsystem Design and Development	200K

5.8 SYSTEM DESIGN AND DEVELOPMENT

A major system design effort will be required involving a detailed system definition and the design and the development of all required software. It is estimated that this represents a 15 labor-year effort involving the services of senior system design engineers, programmers, and electronics and communications engineers. In addition, interface hardware must be designed, built and the entire system integrated. The estimated costs of these efforts are:

15LY @ $120K/YR	$ 1800K
System Integration	$ 250K

5.9 TOTAL SYSTEM COSTS ESTIMATE

1. Vessel Monitoring Subsystem (20)	
a. Pulsed	1,000K
b. CW (commercial)	3,300K
c. CW (mil-spec)	11,600K
2. Processing Subsystem (2)	500K
3. Pilot Display Subsystem (50)	1,750K
4. Communications Subsystem (1)	410K
5. MTC Subsystem (6)	225K
6. Weather Subsystem (5)	70K
7. Training Subsystem (1)	315K
8. System Design & Development	2,050K

Fog Navigation System Cost*

with Pulsed Ranging System,	$ 6,320K
with CW Ranging System (commercial)	$ 8,620K
with CW Ranging System, (mil-spec)	$16,920K

* Costs not included in the estimate:
1. Installation costs
2. Land line communication costs
3. Facility modification costs

6. PRELIMINARY SYSTEM DEMONSTRATION PLAN

A number of questions must be resolved before the configuration of the fog navigation system can be finalized. Some of the major questions are:

1. Which range measurement technique is best suited for the use in the vessel monitoring subsystem? The selection of a system will have a major impact on system costs as shown in the previous section. There are other range measurement techniques such as Sperry Corp. Baseband Radar which may provide a more cost effective solution.

2. Is the proposed Control Pilot display format and content adequate, or must additional information be provided?

3. Is the use of a Control Pilot display in the MTC Center manned by a qualified Pilot sufficient backup for the system, or must the system design encompass an alternate method? Another option is for the Pilot to have a spare display. Shall RACONS be used as part of a backup system?

4. Will expansion of the system to include precision lock entry guidance be of benefit to Control Pilots? What should the display information content be? What will be the impact on the safety operations around the locks?

These and similar issues can best be resolved by a demonstration program tailored to address them. The proposed test and demonstration programs is in two phases as follows:

1. Evaluation of competing precision range measurement techniques and selection of one for the next program phase.
2. Development of concept demonstration equipment and evaluation of the system under operational conditions.

6.1 EVALUATION OF RANGE MEASUREMENT EQUIPMENT

This test program is to evaluate the performance of available precision range measurement equipment in the operating environment of the Panama Canal. The tests will be conducted at a minimum of two Canal sites.

One series of tests will be conducted at a selected site in the Cut. Two interrogators will be installed along the banks and raw (unprocessed) time delay (range) data will be collected under a number of different conditions with transponders placed on a variety of vessels transiting the Cut. The test data will be evaluated to determine the system's susceptibility to multipath due to terrain or other vessel traffic and to shadowing problems due to terrain, equipment and structures on own-vessel, other traffic and weather effects.

The Canal lock area is the second test site where the range measurement system's performance will be evaluated. Precision lock entry guidance is a likely fog navigation system application and the ranging system's performance in the environment of multiple vessels close to the transponders, proximity of the locks, building, and walls, and the likelihood of EMI/RFI--all likely to cause multipath, shadowing or other signal interference problems--will be evaluated.

Two questions will be answered by these tests: Is the multipath interference so severe that a CW ranging system is needed? and, Does the tropical environment require a system to be designed to meet military specification?

It is proposed to formally advertise the Canal tests and invite vendors of candidate ranging systems to participate. Participation will be limited to those vendors who can supply data substantiating their equipment's ability to provide range measurements accurate to 3 to 6 feet. The equipment will be leased for a 6 month period, the expected test duration.

Since the collection at one central site of data from the distributed interrogators would require costly land line installation, which if the lines are not available is not practical for a short duration test, there will be a requirement for a data collection and recording package at each interrogator site. The recording medium can be either magnetic tape or floppy discs. A real-time clock for data synchronization is to be included in each data acquisition system.

The data acquired at each site will consist of the measured time delays (or range) and the corresponding times. The recordings will be collected periodically and brought to a central data reduction and analysis site, where the data from the interrogators will be analyzed, merged, and the systems position and velocity measurement performance evaluated.

The results of this test effort will be used to select a ranging system to be used in the follow-on system concept demonstration program.

6.2 EVALUATION OF THE FOG NAVIGATION SYSTEM CONCEPT

The evaluation of the proposed fog navigation system can be initiated after the selection of a ranging system for the system concept demonstration program. The high cost of a demonstration program dictates the need to use, whenever possible, operational equipment for the demonstration phase. While this approach will result in higher test program costs, it will result in substantial savings in the operational systems implementation costs, since much of the developed hardware and software can be applied later toward the final system implementation.

The system concept will be demonstrated at a selected test site in the Gaillard Cut. A section of the Cut consisting of two or three reaches will be instrumented for precision range measurement by placing interrogators along the shore. Any available communication links will be used to connect the interrogators to the processing subsystem. Where none are available, communication links will have to be installed. Since this could be a costly item, the selection of the test site may be dictated by the availability or proximity of existing communication lines which can be used for the test.

The processor selected for the test will be a subset of the operational multiprocessing system. The processor will consist of one host CPU and one or two auxiliary CPUs, depending on the magnitude of the demonstration program.

The selection of a physical display for use during the test represents a slight problem. While the easiest approach is to use a commercially available color display unit on which to display the vessel and map, this may result in undesirable impressions on the trial system users' evaluations. The standard commercial units are relatively large, and will not represent the compact, lightweight Pilot display to be used in the operational system. However, the cost of developing a Pilot display (750K) and the time required to develop the unit (1 year minimum) may preclude such an early development, forcing the use of a standard graphics display. In that case, the Pilots participating in the test must be carefully briefed on this part of the program, in order to prevent their getting any bad impressions.

The concept demonstration program will be scheduled over a 6 month period, during the fog season. Initial tests will involve placement of transponders at surveyed sites on shore and checking the systems accuracy. Next, the location of a transponder-equipped PCC tug will be tracked while it transits the instrumented section of the Cut. During these phases, the display will be viewed on shore in a location near the system processor. Following successful completion of these tests, the display will be transferred to the tug and its operation evaluated by Control Pilots. The final phase involves placing transponders and the display aboard vessels transiting the Canal providing a greater exposure of Pilots to the system and acquiring operational data involving Pilot impressions of the system.

The primary output from this experiment will be the Canal Pilots evaluation of the adequacy of the information supplied to him on the Pilot display, and proposed changes in content and format. Performance of the equipment in the Canal environment will also be evaluated. The results of the experiment will be summarized in a report and applied toward the detailed specification of the complete Fog Navigation System.

6.3 DEMONSTRATION PROGRAM COST ESTIMATES

6.3.1 Cost of Ranging Equipment Evaluation Program

The initial step of this test program involves the development of a detailed test plan defining the test configurations, conditions, method of data analysis and reduction, site preparation and survey requirements. This engineering effort is estimated to require the equivalent of 9 labor-months.

The costs of leasing commercially available ranging equipment is 10%-15% of purchase price per month. Based on average cost of the equipment, a 6 month lease will cost about 25K per system including engineering support for the commercial type equipment. The mil-spec equipment lease would be higher.

Two systems (each consisting of an interrogator and two transponders) will be required from each manufacturer, both to allow the evaluation of multiple interrogations and to insure that any operational problems uncovered during the tests are systematic and not caused by equipment fault in one particular unit.

It is estimated that equipment from up to six manufacturers will be available for evaluation (US and foreign).

The portable data collection and recording packages are not likely to be available as an off-the-shelf commercial product, but rather must be designed using standard modules, i.e., microprocessor, recorder, etc. requiring engineering and programming manpower estimated at 6 labor-months of engineering and 6 labor-months of programming. This equipment must be purchased, integrated and tested at an estimated cost of $75K for two units.

Analysis of the recorded data will require a computer facility, and personnel to perform the analysis. A data reduction and analysis program must be written (4 labor-months) and the data collected during the test analyzed (6 labor-months).

It is assumed that the conduct of the tests will be the responsibility of an engineering organization which will supply the required manpower. The PCC engineering staff will be responsible for the supervision of the tests, and coordination of all involved organizations. Some other support will be required from the PCC such as vehicles and labor to assist in interrogator site preparation and equipment placement.

The conduct of the tests will require the services of two individuals, a senior field test engineer and a technician for an 8 month period.

The final task in this effort is to review all result and prepare a report containing the test results, and an equipment recommendation, a 3 labor-month effort.

Test plan preparation	$105K
Test site preparation	$100K
Ranging equipment leases	$300K
Data collection and recording system design	$110K

Data collecting and recording system purchase, integration and test	$75K
Data analysis program development and data analysis	$100K
Manpower to conduct tests	$140K
Final Report	$35K

Based on the aforementioned estimates, the cost of the ranging equipment evaluation program is $800K to $1,000K depending on the number of units tested.

6.3.2 Concept Demonstration Costs

The development of a preliminary system design and a concept demonstration plan are the first and most important tasks of the demonstration program. The detailed system design is required to allow definition of the equipment, procurement of the hardware and to insure that the procured components can be used in the operational system. This initial design is a major effort as is the development of the demonstration plan, estimated to require two labor-years of senior engineering.

To adequately instrument two reaches for range measurement requires a minimum of six interrogators; eight, if three reaches are instrumented. Allowing two to four extra interrogators for use in filling coverage gaps due to terrain problems and as spares, results in total requirement of 8 to 12 interrogators. Six to eight transponders will suffice for the demonstration.

In addition, since the interrogators will operate under processor control a controller and communications system interface must be designed and included with each unit.

Interrogator costs range from $7.5K for a commercial unit to a high of $200K for a full mil-spec unit. Transponder costs range from $6.5K to $75K. The costs of this subsystem can not be estimated accurately until after determining which system performs satisfactorily during the preceding range measurement equipment tests and is selected for the follow on demonstration phase. The costs may be as low as $250K for a minimum system to a high of $3000K. The costs of special interface designs and fabrication are included in this estimate.

The processing subsystem purchased for the concept demonstration phase will consist of a host CPU and two auxiliary processors at a total cost of $250K. In addition, the system software must be developed, requiring the equivalent of 3 labor-years of senior programmers.

It is not likley that one could justify the development of the Pilot displays for the concept demonstration phase, even though it would result in a far superior demonstration program. Rather four standard, commercially-available displays will be used at a cost of approximately 30K per display. In addition, the display software must be developed, requiring a 1 labor-year programming effort.

The cost of the communications subsystem is estimated at $150K to cover the cost of a processor, transmitters and engineering. The entire system must be designed in detail, integrated and tested. This effort is estimated at 3 labor-years of engineering time.

The data acquired, processed and distributed by the fog navigation system will be recorded during the test, merged with operational data and analyzed. The data acquisition system will consist of an auxiliary processor, a digital recorder and associated software. The hardware costs are estimated at $50K. Approximately 3 labor-months of programming will be required for the software development.

During the 6 month demonstration program, the system will require both hardware and software engineering support, and field engineers and technicians at the test site. This effort is estimated to require 2.5 labor-years at a cost of $300K.

The final effort of the demonstration program involves analysis of all collected data. The data analysis will be a continuing effort during the 6-month demonstration, ending in a final summary of the test results, and specification of the operational system incorporating the knowledge gained during the systems demonstration. This effort is estimated at one labor-year of engineering and one-half labor-year of software development.

The previously described demonstration program cost estimates are summarized below.

Initial System Design and Test Plan	$280K
Site Preparation and Equipment Installation	$200K
Precision Ranging Subsystem	$250K-3,000K
Processing Subsystem	$250K
Software Development	$360K
Shipboard Displays	$120K
Display Software	$130K
Communications Subsystem	$150K
Detailed System Design, Integration and Test	$400K
Data Acquisition System	$80K
Field Engineering Support	$300K
Data Analysis and System Specification	$240K

Total: $2,760K to $5,510K

Based on these estimates, the cost of demonstrating the fog navigation system concept range from \$2,760K to \$5,5510K depending on the range measurement system selected for use in the Canal.

Figure 6-1 summarizes the preparation and evaluation programs on a time scale, giving estimates of costs for the major elements.

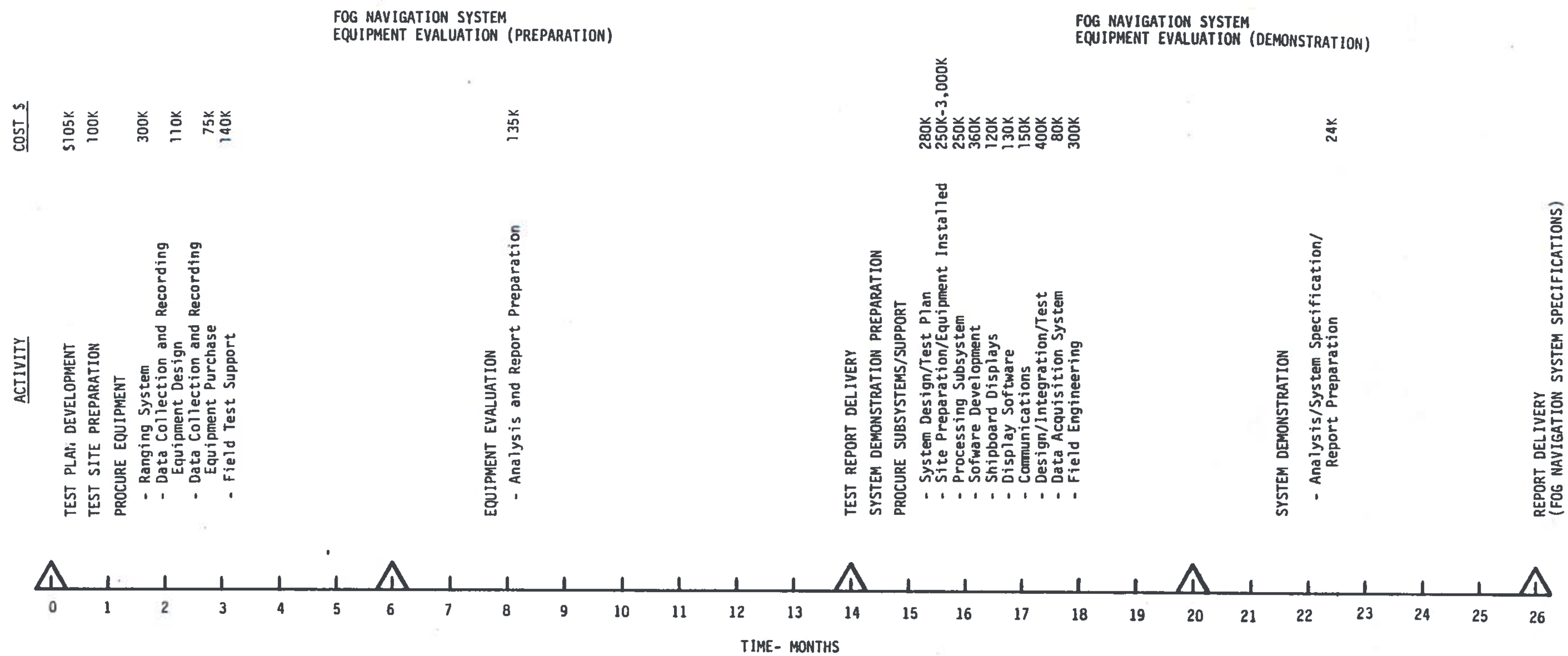

FIGURE 6-1. SUMMARY SCHEDULE AND COSTS FOR FOG NAVIGATION SYSTEM--PREPARATION AND EVALUATION PROGRAM

7. ALTERNATE IMPLEMENTATION APPROACH

It was pointed out in Section 4 that an additional application of the fog navigation system is in precision lock entry guidance. Since this application of the system may be viewed as equally if not more important to the near term Canal operations than the fog navigation system it is feasible that the system would initially be implemented as a precision lock entry guidance system and would than be expanded into the Cut in order to provide an all-weather operation capability and eventually be expanded to cover the entire canal as a full VTMS.

Implementation of the precision lock entry guidance system will include the Gatun, Pedro Miguel and Miraflores Lake, which because of its small size and location can be readily covered by the ranging systems intrrogators.

This alternate approach requires the previously defined steps toward system implementation, i.e., selection of a ranging system, demonstration of the concept and final system implementation.

7.1 EVALUATION OF RANGE MEASUREMENT SYSTEMS

The selection of the ranging equipment for lock guidance would follow the same steps outlined in 6.1 except that the activities would be confined to a lock area, preferrably the Miraflores Lock, which because of its location and proximity to Balboa would present the lesser logistic problem. A 3-month test program is envisioned.

As before, a test plan defining the test program in detail must be generated first. This effort is estimated to require a 6 labor-month.

Only one system consisting of an interrogator and two transponders will be required from each vendor, on a 3 month lease.

The remainder of the test program costs follow the itmes listed in 6.1 and 6.3.1 but at somewhat reduced levels. They are summarized as follows:

Test Plan Preparation	$70K
Ranging Equipment Leases	$75K
Acquisition of Data Collection and Recording System	$110K
Data Analysis	$60K
Labor for Test Conduct	$70K
Final Report	$25K
Total:	$450K

Based on these estimates the process of selecting a ranging system for lock guidance is estimated to cost $450K.

7.2 CONCEPT DEMONSTRATION

The demonstration of the lock guidance system concept will require instrumenting one lock (Miraflores, if it was used for ranging system evaluation), development of displays, acquisition of processing and communications hardware and software development. As indicated previously, it is cost beneficial to procure equipment for the concept demonstration phase which can be utilized in the operational system.

The test site will be instrumented with four interrogators. A fifth interrogator will be available as a spare. Four transponders will suffice to instrument two vessels.

The remaining tasks are similar to the tasks defined in 6.2, and whose costs are estimated in 6.3.2. The exception is the hand-held alpha-numeric display which if it is to be evaluated, must be developed and a minimum of two (2) units supplied for the test.

The cost of the concept demonstration is estimated to consist of the following items:

Initial System Design and Test Plan	$200K
Precision Ranging Subsystem (depending on selected system)	$70K-1,300K
Processing Subsystem	$220K
Software Development	$300K
Shipboard Displays & Software	$160K
Hand-held display development and fabrication (2 units)	$350K
Communications Subsystem	$150K
Detailed System Design, Integration and Test	$300K
Data Acquisition System	$50K
Field Engineering Support	$100K
Data Analysis & System Specification	$130K

7.3 LOCK ENTRY GUIDANCE SYSTEM COST ESTIMATE

The cost of the precision lock entry guidance system, as in the case of the fog navigation system is very heavily dependent on the ranging system selection. The other cost items are in the same categories as defined in Chapter 5. As before, the system cost estimates do not include the considerable savings which can be realized by purchasing whenever feasible, operational hardware and using it, as well as the developed software in implementing the operational system.

The vessel monitoring subsystem will require 10 interrogators (6 to cover the Miraflores Locks, Miraflores Lake and Pedro Miguel Lock area, 4 for the Gatun Lock area) and 2 spare interrogators. The transponder will be placed aboard the vessels upon entering a terminous and removed at the other end by the line crews. 100 transponders will adequately meet the requirements for intrumenting vessels, monitoring and spares.

It is assumed that a dual multiprocessor will be utilized in the system to insure high reliability each consisting of a main CPU.

The Pilots (shipboard) display will consist of the full graphics display and a hand-held alphanumeric display if as a result of the concept demonstration it is shown that both displays are necessary. The estimated costs of developing the displays were shown previoulsy. The display requirement is for 50 units of each type. The hand-held unit is estimated to cost $2.0K each.

The communications subsystem hardware consisting of a processor, transmitter and interfaces is estimated to cost $300K. This estimate <u>does not</u> include installation of land lines, towers, or pads.

Unlike the fog navigation system, the lock guidance system does not require extensive back-up since a failure by the system to provide the Control Pilot guidance information does not deprive him of the visual information. Hence extensive MTC displays are not required. One MTC display will suffice to meet any monitoring requirements. The MTC subsystem cost is estimated at 25K.

The weather and training subsystems identified in the fog navigation system description are not required by the lock guidance system. If either of these systems are desired, the cost estimates shown in 5.6 and 5.7 may be used to estimate the cost of incorporating these subsystems into the lock guidance system.

The remaining major costs are the overall systems design, development and implementation. This level of effort is estimated to require 15 labor-years, consisting of systems engineering, software, communications, interface and system integration.

Vessel Monitoring Subsystem	
1. Pulsed System (commercial)	$900K
2. CW System (commercial)	$2,780K
3. CW System (military)	$9,960K
Processing Subsystem	$450K
Shipboard Display Subsystem	
1. Graphics Display Development	$750K
2. 50 Graphics Displays @ $20K	$1000K
3. Hand-held Display development	$350K
4. 50 hand-held displays @ $2.0K	$100K
Communications Subsystem	$300K
MTC display	$25K
System Design, Development and Integrator	$1800K

Based on the above estimates, the cost of implementing a precision lock entry guidance system is:

$5,225K using a commercial pulse ranging system
$7,105K using a commercial CW ranging system
$14,285K using a military CW ranging system

The above estimates do not include the cost of developing and building hand-held pilot displays. If this display type is to be included, the cost estimates must be increased by $450K.

Figure 7-1 summarizes the preparation and evaluation programs on a time scale, giving estimates of costs for the major elements.

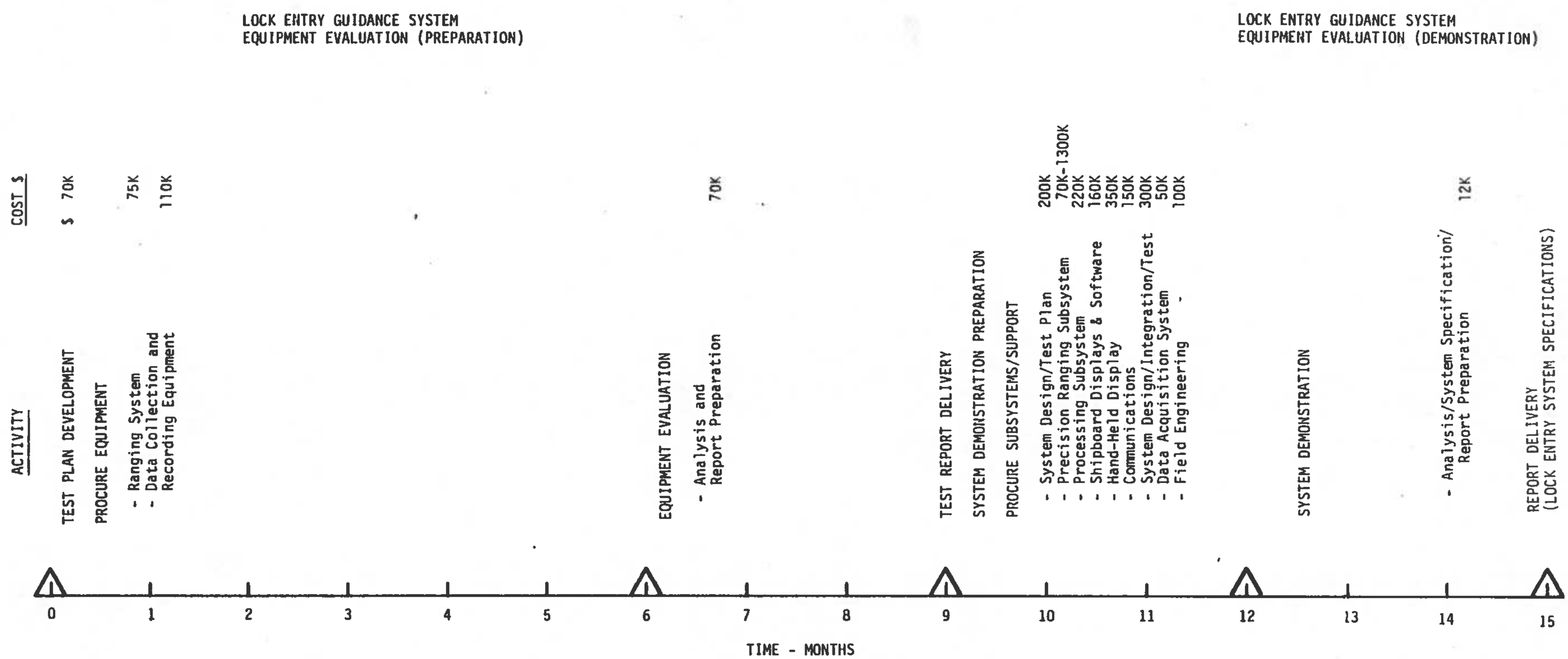

FIGURE 7-1. SUMMARY SCHEDULE AND COSTS FOR LOCK ENTRY GUIDANCE SYSTEM--PREPARATION AND EVALUATION PROGRAM

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