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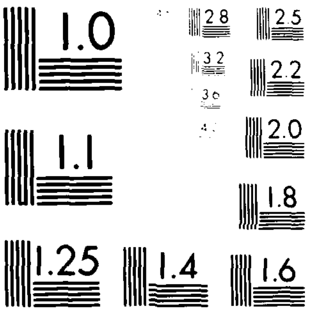

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16. Abstract

This study assesses the benefits and costs to the marine community of various LORAN-C alternatives for possible expansion into the Eastern Caribbean. Also considered, but at a lesser level of detail, is the application of Differential Omega as an additional alternative. Included are projections through the year 2000 for user and government costs and benefits, user populations, and traffic flows are trade patterns. User populations are defined in terms of large and small commercial vessels, fishing and commercial sport fishing vessels, and pleasure craft. Trade and traffic flows are characterized by principal commodity, vessel type, origin and destination and vessel routing.

Measures of comparative system value include benefit/cost ratios, benefits and costs generated per vessel, and benefits and costs per square mile of signal coverage. Also included are case studies of marine groundings in the Caribbean, studies of current and future directions of the Puerto Rico-Virgin Islands fishing industry and future trends for recreational boating in the region.

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LORAN-C, Cost-Benefits, Caribbean, Marine operations, Marine traffic, Vessel groundings, U.S. Coast Guard, Fishing industry, Puerto Rico, Virgin Islands, Radionavigation systems

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PREFACE

This study of the benefits and costs of the Eastern Caribbean LORAN-C expansion was performed by the Transportation Systems Center for the United States Coast Guard, Office of Navigation under PPA CG-121. The Coast Guard Project Manager was CDR B.C. Mills of the LORAN Branch. Special thanks are due to CDR R.C. McFarland and LCDR W.K. May for their comments and help during the course of the study.

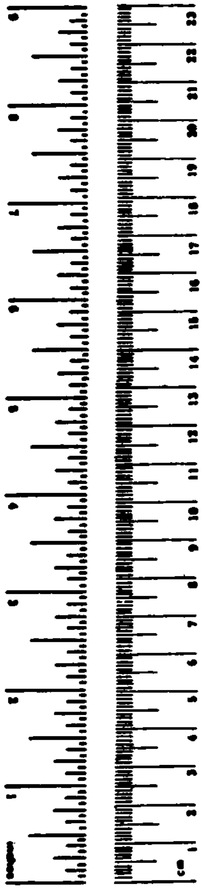
Much of the data base development was performed by the support services contractor, Input-Output Computer Services Inc. (IOCS) of Waltham, MA. In particular, a substantial contribution to this study was due to the efforts of Andreas Tzioumis of IOCS who was responsible for Appendixes C, D and E and parts of sections 3 and 5. Also contributing to this study was Daniel Mesnick of IOCS.

The consultation provided by George J. Skaliotis of TSC's Operations and Management Systems Branch during the determination of the benefits and costs is greatly appreciated.

METRIC CONVERSION FACTORS

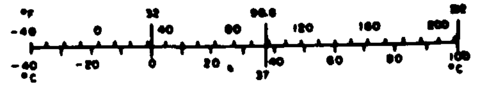
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



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Executive Summary

The issue concerning the expansion of LORAN-C coverage into the Eastern Caribbean is addressed in this study. In this sense, it is not only a conventional benefit/cost analysis but also a study which probes many of the underlying elements regarding the expansion decision. In addition to an evaluation of the relative quantitative and qualitative attributes of the LORAN-C expansion, Differential Omega is assessed as an alternate to LORAN-C.

The drive for the expansion of LORAN-C into the Eastern Caribbean is motivated in part by requests from various local government, economic and maritime organizations in the Puerto Rico-Virgin Islands area who perceive this expansion as a means of improving the marine safety and economic viability of the region. Further, the designation of LORAN-C as the government-provided navigation system for the Coastal Confluence Zone raised the question as to whether such coverage should include the Caribbean Coastal Confluence Zone; that is, the contiguous waters surrounding Puerto Rico and the Virgin Islands. This study projects the impact of both LORAN-C and Differential Omega upon vessel safety and the maritime economy in not only the Puerto Rico-Virgin Islands region, but also in the entire Eastern Caribbean.

Three LORAN-C system expansion alternatives are considered: a regional (Midi) chain covering the local waters surrounding Puerto Rico and the Virgin Islands and two wide area chains covering the entire Eastern Caribbean. Two cost options are addressed for the wide area chains: the United States assumes the full cost burden or; the costs are shared with a host nation. The investment costs for these options range from $30 to $41 million for the wide area chains to $15 million for the Midi Chain (FY82 dollars). Cost sharing will lower the investment costs by approximately 50 percent. The Differential Omega investment costs are assumed to be $400 thousand.

The results of this study are based upon detailed assessments of the current status and projected trends for the large and small commercial marine operators, probable future directions for the Puerto Rico-Virgin Islands fishing industry and the growth and distribution of the recreational boater.

The following conclusions were drawn with respect to the costs and benefits of the LORAN-C expansion or, alternatively, the introduction of Differential Omega.

o In the aggregate, the benefit/cost ratios for any of the LORAN-C system alternatives or options do not reach a level commonly deemed necessary to justify a favorable investment decision. In the most optimistic configuration, the life cycle benefits barely exceed the life cycle costs. On the other hand, an investment decision regarding Differential Omega appears promising from a benefit/cost criterion. A benefit/cost time stream for both LORAN-C and Differential Omega is shown in Figure 1.

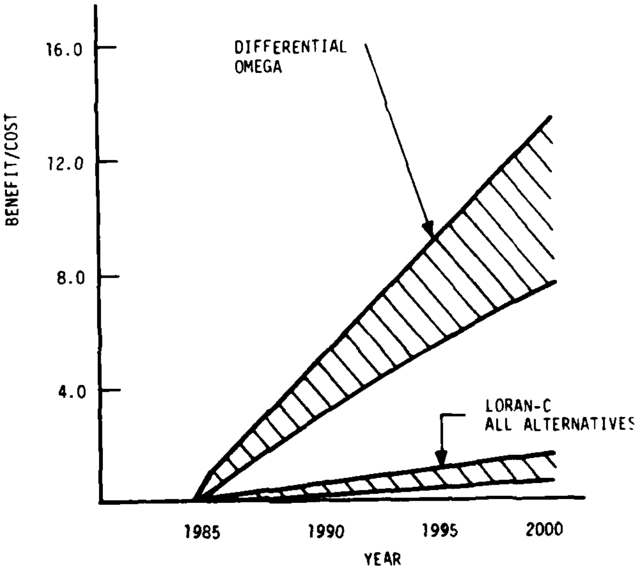

FIGURE 1: LORAN C AND DIFFERENTIAL OMEGA BENEFIT/COST TIME STREAM

- Benefits were derived from improved vessel productivity and enhanced vessel safety; government benefits (principally Coast Guard) were obtained from service and operational savings. No single benefit was sufficiently large so as to constitute a major, overriding element in the final results.
- Productivity benefits were based on fuel savings through improved accuracy in navigation and from the ability to determine port arrival and schedule times with greater precision. Safety benefits stemmed from reduced vessel groundings and savings in insurance premiums.
- As well as benefit/cost ratios, other measures of system value were used. These were the benefits and costs generated as a function of vessel traffic density and the benefits and costs per square mile of system coverage. These measures were used to evaluate relative system merits among the LORAN-C alternatives. The Midi chain was the most promising in the basis of benefits generated per vessel, however it is also least promising on the basis of costs per vessel. The Midi chain is similarly rated based on the costs and benefits per square mile of coverage.
- The technical and operational feasibility of Differential Omega in the Eastern Caribbean has yet to be established and because of the availability characteristics of Omega, it may not meet the navigation requirements of the Coastal Phase of navigation in this region.
- In the Differential Omega Alternative, the benefits generated per vessel are similar to the two wide area chains; on the basis of vessel-generated costs, it is lower by nearly an order of magnitude than the most favorable LORAN-C system (High Power Chain). On the basis

of benefits generated per square mile of coverage, it is the most favorable of all alternatives while on the basis of costs per square mile, it is equivalent to both of the wide area chains. However, because of the small number of Differential Omega users, the absolute dollar value of benefits is the lowest of all alternatives.

- The benefits attributable to NAVSTAR GPS were not specifically determined although this system may prove to be a valid substitute for all radionavigation systems, either current or contemplated, in the Eastern Caribbean. The advent of this system could significantly affect the number of ships that equip with LORAN-C or Differential Omega. This, in turn, would lower all projected benefit-cost ratios thereby making all system alternatives investigated even less promising. Some large marine operators have already indicated their intent to defer the acquisition of any additional radionavigation systems until the availability of NAVSTAR GPS.
- Coast Guard benefits were attributable to savings in the search and rescue effort for a given level of capability and to cost avoidance and improvement in capability in the Marine Environment Protection mission.
- As a secondary benefit, both Differential Omega and LORAN-C would provide a navigational capability which would permit the introduction of Vessel Traffic Separation Lanes in congested seaways and passages.

- The impact on the LORAN-C benefit/cost ratio of a major navigation-related casualty was assessed. While increasing the benefit/cost ratio substantially, such impact would not raise this ratio to the level of a favorable investment decision.
- Political benefits, while treated only peripherally in this study, may by implication from external events, override the quantitative benefits.

1. INTRODUCTION

1.1 BACKGROUND

Radionavigation coverage in the offshore regions of the United States is currently provided by LORAN-A and LORAN-C. Included in LORAN-A capability is ground wave fix coverage of the northwest corner of the Caribbean. On December 31, 1980, LORAN-A coverage is scheduled for termination. With the termination of LORAN-A, radionavigation capability in this region is provided in part by LORAN-C. While LORAN-C and LORAN-A both provide similar coverage of the Caribbean, LORAN-A coverage in the Bahama Islands is greater. On the other hand, LORAN-C provides improved coverage of the Florida Straits. Neither system has groundwave fix coverage of the waters surrounding Puerto Rico and the Virgin Islands (Caribbean Coastal Confluence Zone).

The Coastal Confluence Zone in its strictest definition includes not only the contiguous waters of the United States, but also the offshore waters surrounding Puerto Rico and the Virgin Islands. LORAN-C has been designated by the Secretary of Transportation as the government-provided navigation system for the U.S. Coastal Confluence Zone. By June 1, 1982 all Commercial vessels of 1600 GT or more calling at ports in the continental U.S. are required to be equipped with LORAN-C or satellite-based hybrid receivers. The designation of the Coastal Confluence Zone has been interpreted by some parties to include LORAN-C coverage in the Caribbean region, particularly Puerto Rico and the Virgin Islands--regions which heretofore did not have fix coverage. In addition, there has been the mistaken belief that the termination of LORAN-A coverage will leave certain Caribbean areas without LORAN coverage, when in fact, such coverage has never existed.

Motivation for the expansion of LORAN-C into this region is based in part on safety and in part on economic reasons. The Governors of Puerto Rico and the Virgin Islands have requested additional LORAN-C coverage as a possible means of extending navigational capability in this area and enhancing the economic viability and maritime safety of these islands. Ship owners and agents have requested coverage of this area as a means of improving vessel operations and increasing the utility of the LORAN-C receivers already installed. However, most of the pressure for LORAN-C expansion in the private sector has come from the recreation and boating community who are urging LORAN-C coverage of the principal Caribbean cruising waters (mainly the Bahamas, Virgin Islands, and Leeward Islands).

Within the framework of possible LORAN-C expansion is the possible availability of NAVSTAR GPS. This latter satellite-based system although not currently available could provide not only equal or greater accuracy and availability but also world-wide coverage including all of the Caribbean. If and when available NAVSTAR GPS should be considered as a viable alternative to expanded LORAN-C coverage.

In addition, as a low cost alternative to LORAN-C, the application of Differential Omega must also be considered. Such a system would provide comparable confluence zone coverage and accuracy, can be installed and maintained by the government relatively inexpensively and will complement a similar system already planned for the French West Indies by the French Government. The role for Differential Omega is addressed in this study as an alternate to Eastern Caribbean LORAN-C coverage.

The question must be asked: Are the benefits to be gained sufficient to justify an expansion of LORAN-C or other comparable systems into an area where some navigation coverage already exists and where continuous world-wide coverage is expected to be provided by satellite systems within the next 5 to 7 years? This report attempts to put in perspective the economic and safety needs of the various marine entities for improved navigation vis-a-vis the costs and benefits which may accrue.

1.2 SCOPE AND OBJECTIVES

This report is an appraisal of the costs and benefits of an expansion of LORAN-C coverage into the Eastern Caribbean; other alternate systems (NAVSTAR GPS, Differential Omega) are addressed where appropriate but in less detail. Inasmuch as LORAN-C or other contending systems would not be available in the Caribbean until the mid 1980's, the data presented are based on projections and trends. Where uncertainty exists, ranges of values are shown.

The objective is to provide an early indication of the requirements, if any, for enhanced coverage of LORAN-C in the Caribbean together with the government costs for such augmentation. Implicit in this objective is a consideration of the cost impacts upon the user as well as an evaluation of the benefits which may accrue both to the user and to the government. These benefits and costs are considered not only within a structure of current and conceptual system alternatives but also within a framework of marine operations in the Caribbean. This latter area includes the economic environment, trade and traffic patterns, hazards to navigation and vessel casualties.

1.3 ASSUMPTIONS

In this study, the eastern Caribbean is defined as that region generally east of 70°W and extending to 60°W, and from 10°N to 20°N. The Bahamas are defined as that region east of 80°W to 70°W and from 20°N to 28°N. Included in this study are the principal islands of the Caribbean, and the north coast of Venezuela. While this study focuses on the islands of Puerto Rico and the Virgin Islands, the other islands are also considered, but at a lesser level of detail and analysis. Where relevant, the Bahamas have been included in this study since this region interacts with the Eastern Caribbean principally because of the U.S. recreational boating traffic which moves through the region enroute to the Virgin Islands and Lesser Antilles. Not included are the Panama Canal Zone and Central America.

Civil marine users are deemed to be the principal beneficiaries although Coast Guard air and marine users are also considered. Of the civil marine users, only these vessels (both U.S. and foreign flag) engaged in U.S. trade or calling at Continental U.S., Puerto Rico or Virgin Islands ports were considered. Foreign vessels engaged in foreign trade or transiting through the Caribbean were outside of the scope of this study although it is probable that these vessels would derive benefits from LORAN-C system expansion.

Civil aviation users are assumed to be outside the area of interest inasmuch as the FAA has certified OMEGA to replace LORAN-A and hence there is no aviation requirement for LORAN-C in the Eastern Caribbean (Reference 1, 56). However, FAA certification of the aviation use of Omega is obtained only upon request from the individual airlines. Further, such certification is limited to the Oceanic phase of navigation and is restricted to the region between 70°N and 45°S. At present, only Pan American Airways has received certification for Omega. Military users were not considered because the stated DOD position assumes that LORAN-C will be phased out in favor of NAVSTAR GPS when the latter system becomes operational (Reference 1).

Only the coverage provided by LORAN-C ground wave is considered. At this time the quality of coverage for LORAN-C sky waves is unknown and a definition of their utility for navigation will require a program of monitoring and surveying beyond the scope of this study.

NAVSTAR GPS is assumed to be fully operational by 1987 (Reference 1). Current estimates indicate that this date may slip to the latter part of the decade. Differential Omega is assumed to be available within the time frame of the LORAN-C expansion alternatives (in place and operational by 1984) and that it is technically and operationally feasible.

Additional specific assumptions are addressed in the individual sections where they appear.

2. DISCUSSION OF THE PROBLEM

This section addresses the need for government provided navigation services in terms of the legal and political issues which have been used as arguments for the development and implementaion of previous electronic systems. In the past, most of the electronic navigation systems have had their development motivated by wartime expediency. For example, the development of LORAN-C was initially under the aegis of the Department of Defense and it was justified under the argument that it is a requirement for national defense.

LORAN-C has now become principally a civil system, operated by the Coast Guard. Similarly, other DOD systems are expected to become civil systems in the near future. Omega is operated by the Coast Guard with funding provided by DOD. Current plans are for Omega to become fully funded by the Coast Guard in FY81. Both of these systems were initially introduced and expanded to meet DOD requirements.

The issue is the justification of the expansion of LORAN-C into the Eastern Caribbean as a purely civil system. Implicit in this issue is the extent to which the government has a responsibility to provide civil navigation service not only in U.S. waters but in foreign waters as well. As a civil issue, the requirement for radionavigation service can be addressed on the grounds of safety; that is, will the availability of a radionavigation system reduce accidents, save lives, lower property damage and reduce pollution?

There are international conferences and agreements which have addressed the issue of safety at sea. The Intergovernmental Maritime Consultative Organization (IMCO) is an agency of the United Nations which served to promote international cooperation in maritime shipping, and in particular safety of life at sea. The International Convention for Safety of Life at Sea in 1960 (SOLAS 60) has established international regulations with respect to improving vessel safety. Neither of the organizations or conferences have countenanced the installation of any radionavigation receiver equipment except the radio direction finder. SOLAS 60 has required that all ships above 1600 GT be equipped with a radio direction finder receiver; however this requirement may be exempted by any nation for ships less than 5000 GT. IMCO has no current requirement for the installation of common shipboard radionavigation equipment. However, IMCO appears headed toward the acceptance of several systems including LORAN-C which a nation may make mandatory for a foreign vessel calling at its ports.

On the national level, the United States has adopted a regulation requiring that all vessels entering the Coastal Confluence Zone be equipped with an electronic position fixing device meeting the standards established for LORAN-C (Reference 2). One of the motivating factors for this proposed regulation is the availiability of a LORAN-C signal in the Coastal Confluence Zone of the U.S. The principal rationale for the regulation is the promotion of marine safety and the reduction of the probability of pollution.

In the Eastern Caribbean the proposed configurations for the extension of LORAN-C range from limited coverage surrounding the Coastal Confluence Zone of Puerto Rico and the Virgin Islands to major chains covering the entire Eastern Caribbean. While the legal requirement for the former chain might be justified under the designation of LORAN-C as the government provided system for the Coastal Confluence Zone, the justification for the latter chains are not so clear. Title 14 permits the construction of electronic aids to navigation anywhere in the world to serve the needs of the maritime commerce of the United States. Puerto Rico and Virgin Island coverage could be justified under Title 14; however it is debatable whether larger area coverage is equally justifiable. Such wide area chains would cover foreign and international waters and provide signal availability to all users and all interests, particularly foreign shipping. Because of the international aspects of these latter wide area chains, the rationale for their construction and operation should be amenable to cost sharing or partnership agreements similar to those negotiated for Omega and other jointly operated radionavigation systems.

Under the requirements of national defense coverage of all global areas was justified. Subsequent to their implementation, systems covering these areas have been made available to the international user either through joint operation of the system (Omega) or through unrestricted signal availability (Transit). In addition, a third defense-based system (NAVSTAR GPS) is being considered for implementation in this decade with partial or complete signal availability to the civil sector.

Will LORAN-C extended into the Caribbean merely provide redundant coverage or is there a viable role for this system in the near and mid- range era such that it is economically, operationally and politically justifiable both to the user and system operator? The foundation of this study is an examination of the underlying technical, safety and economic issues justifying this expansion.

3. CHARACTERIZATION OF THE CARIBBEAN REGION

3.1 ECONOMIC ELEMENTS THAT AFFECT MARINE TRAFFIC

3.1.1 General

In general, the Caribbean region is characterized by underdeveloped economies. Many islands have not managed to create the conditions which are conducive to economic development and as a result, many of the economies are based primarily on agriculture, fishing, tourism and secondarily on handicraft and small scale manufacturing. The major exception to this is Puerto Rico which through "Operation Bootstrap" in the 1960's created an economic environment which was conducive to the establishment of manufacturing and production facilities by major U.S. mainland corporations. This economic growth has increased marine traffic not only between Puerto Rico and the U.S., but Europe and South America as well.

3.1.2 Agriculture and Fishing

Although the climate in the Caribbean region is conducive to agriculture, cultivation methods, lack of trained personnel and modern specialized machinery limits the agriculture to small yields. The primary agricultural products exported by Caribbean islands are sugar, citrus, rice, bananas, avocados, green coffee, and papaya.

However, despite the fact that the Caribbean islands are principally agriculturally oriented, they are net importers of agricultural products. The main U.S. ports which handle the trade related to agricultural products are Miami, Jacksonville, New Orleans, Corpus Christi, and New York. Part of the trade is handled by small local marine operators, and the balance by American companies which mainly operate containerships and bulk cargo ships (Sealand, Puerto Rico Merchant Marine).

The fishing grounds in the Caribbean Sea are not poor; nevertheless, lack of sophisticated fishing boats and methods results in poor catches. Fishing in many islands is accomplished by small boats, usually 10 - 16 ft. long, and the catches barely suffice to feed the local population. However, Puerto Rico has adopted various incentives to promote fishing such as the establishment of a Fisheries Management Council and the Fisheries Development Program. In addition, there are shrimp and tuna processing facilities. A detailed discussion of the Puerto Rican fishing industry is given in Appendix D.

3.1.3 Tourism and Manufacturing

Tourism for some islands is an important source of domestic income. In 1972 and in 1976, the U.S. Department of Commerce estimated that 1.2 million tourists visited the U.S. Virgin Islands. Those tourists who travel by cruise ships use foreign flag vessels. This is also true of tourists visiting other Caribbean Islands. The U.S. operates very few cruise ships and none visit Caribbean ports. Table 3-1 shows cruise ship (foreign flag) arrivals in various Caribbean ports. The usual U.S. ports of departure are Miami, Fort Lauderdale, San Francisco, and New York.

By world standards the manufacturing sector in the Caribbean region is underdeveloped. The only exceptions are Puerto Rico, the U.S. Virgin Islands, Haiti and Trinidad-Tobago. Puerto Rico has developed a diversified economy. There are approximately 380 food processing, pharmaceutical, drug, and chemical plants. Table 3-2 shows trade patterns between the U.S. and Puerto Rico as well as the U.S. and other Caribbean Islands. In the U.S. Virgin Islands there is some manufacturing activity as well. There are several watch and textile plants, and one aluminum plant. In recent years U.S. firms have been exporting unassembled components to Haiti for hand assembly and subsequently "re-export" to the U.S. as finished goods.

TABLE 3-1
CRUISE SHIP ARRIVALS IN THE BAHAMAS, SAN JUAN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

	1976	1977	1978	1979	1980
San Juan	658	679	653	640	650
U.S. Virgin Islands	N.A.	N.A.	N.A.	680	690
Bahamas	N.A.	N.A.	N.A.	523	606

N.A. - Not Available
Source: Reference 3

TABLE 3-2
IMPORTS-EXPORTS BETWEEN U.S. AND SELECTED CARIBBEAN ISLANDS

	EXPORTS TO U.S.	IMPORTS FROM U.S.
Bahamas (1975)	$148,594,000	$1,194,000,000
Trinidad-Tobago (1975)	371,904,901	1,402,182,600
Grenada (1975) (Windward Islands)	2,978,000	427,000
St. Lucia (1975)	1,165,212	12,044,242
Haiti (1976)	69,400,000	84,500,000
U.S. Virgin Islands (1976)	1,936,000,000	3,669,506,041

Source: Reference 4

Radios, T.V. sets and automobiles are produced in small quantities in Trinidad-Tobago. Approximately 11,000 automobiles were produced in 1975. Radios and T.V. sets are sold to the Caribbean region market.

3.1.4 Raw Materials - Extracting and Processing

Bauxite is the main mineral that is produced in the Caribbean, and Jamaica is one of the largest producers. Kaiser Corporation operates a few bauxite mines as does the Reynolds Corporation. Kaiser Corporation, in 1979, shipped 5,588,000 short tons of bauxite from Jamaica to its two plants in Baton Rouge and Gramercie, Louisiana. These shipments represented approximately 124 vessel movements. However, due to the high rates charged by American shipping companies, no American ships were utilized for any of the 124 shipments. Reynolds primarily utilizes ships registered under foreign flags (80-90 percent). This bauxite is shipped from Jamaica to its alumina plant in New Orleans, Louisiana. Reynolds also operates bauxite mines in Haiti. This operation produces approximately 750,000 short tons shipped to the New Orleans alumina plant.

3.1.5 Petroleum Exploration and Refining

In the Caribbean region, the oil refining plants are located in the Dutch West Indies, Virgin Islands, Puerto Rico and Trinidad-Tobago. Petroleum exploration is mainly centered in the Venezuela-Trinidad Tobago region, while offshore petroleum activity is principally located in the Gulf of Paria off the Western Coast of Trinidad.

The refineries at Trinidad have a processing capacity of 461,000 barrels per day. However, this capacity exceeds that of the locally produced oil, and additional oil must be imported from Venezuela, Columbia, Saudi Arabia and Nigeria. Further, while the offshore drilling platforms can produce 210,000 barrels of crude oil per day, this oil must be shipped outside of Trinidad-Tobago because local plants on these islands are designed to refine other types of crude oil.

The Commonwealth Oil Refinery at Guayanilla Bay in Puerto Rico produces petroleum, gasoline, middle distillates, residuals, rubber-oils, slack wax and lubricant base oil. This feedstock is supplied from Venezuela, the North Slope of Alaska, Trinidad-Tobago and Africa. During the fiscal year 1976, Puerto Rico exported to the U.S. petroleum products which amounted to $864 million.

In St. Croix, U.S. Virgin Islands, there is another oil refinery owned and operated by the Amerada Hess Oil Co. This refinery processes crude oil from Persian Gulf, (60 percent) and Venezuela, Angola and Libya (40 percent). Most of the refined oil is shipped to New Jersey where it is distributed to retail outlets in the East Coast of the U.S. The shipments from St. Croix to New Jersey account for approximately 1000 vessel movements.

3.2 OCEAN BASIN ENVIRONMENT

3.2.1 Weather Conditions

The Caribbean Region is characterized by a tropical climate which is generally favorable to the mariner. Skies are rarely overcast for long, continuous periods and fog is rare. Adverse weather conditions which do occur can be violent but are relatively infrequent or short-lived. The following is an account of the weather conditions and their effect upon navigation (Reference 5).

o Tropical Cyclones - One out of every three cyclones escalates into a full-fledged hurricane. These storms are a threat to the entire Caribbean area, especially in the Bahama Islands. Cyclones are most prevalent during the late summer and fall; however, they may strike during any time of the year. Late summer and winter cyclones tend to develop in the Western Caribbean and move in a northeasterly and northwesterly direction. In July, storms develop around the Windward Islands. During August and September, cyclone activity shifts to the West Indies and around Puerto Rico. Later in the season, cyclones of hurricane intensity prevail in the Western Caribbean. These hurricanes cause gale force winds and sometimes produce ocean waves of 35-40 feet above normal. In an average year nine or ten tropical cyclones occur and about six of them reach hurricane intensity.

o Winds - The trade winds that prevail over this region originate in the clockwise circulation around the Subtropical High. In the summer when the High is strongest and most extensive, the trades are most persistent. They are mainly northeast through east and frequently reach 10 to 15 knots. These trade winds also prevail along most coasts and are reinforced on the windward coasts by the sea breeze.

o Rain, Clouds, and Fog - The rainy season occurs during late August through September, and another period of less intensity occurs in December. Each island has a slightly different rainy season. For instance, the heaviest rains in the northern Bahamas fall from May through October; while in the southeastern Bahamas, heavy rains fall from September through November. In Puerto Rico, precipitation is greatest in October through November, and May. While cloudiness is abundant in the area, usually completely clear skies persist for an entire day. Average amounts range from 4 to 6/10 coverage and cloudiest periods usually coincide with rainy seasons. Visibility is usually good except in heavy rain showers. Along the coastal areas, fog is usually associated with the early morning hours.

3.2.2 Ocean Currents

Two major ocean currents flow past the Caribbean Islands. These are the Antilles Current and the Caribbean Current.

The Antilles Current originates around the Leeward Islands and flows through the Mona and Windward Passages. It then follows a route to the northwest past the Bahamas. The average speed of the surface current is 0.6 knot and may reach a maximum speed of 2.0 knots. During the winter, the current moves southward and its speed and direction varies.

The Caribbean Current is strongest in the southern part of the Caribbean Sea. It moves to the west and has an average speed of 0.9 knot and a maximum of 3.5 knots. It is characterized by a one-way flow through the channels and countercurrents of up to 2.0 knots may be created along the shores of the Caribbean.

3.3 MARINE NAVIGATION IN THE CARIBBEAN

Marine navigation in the Caribbean is a function of the generally favorable weather conditions that prevail throughout the area and of the availabilities of the radionavigation system in the region. In addition, the Eastern Caribbean is characterized by deep water and the relative absence of shoals except extremely close inshore. Because of the benign weather and hydrographic conditions and the configuration and proximities of the island chains, visual navigation, supplemented by radar and fathometer, is most frequently practiced by all vessels sailing in inter-island traffic. In fact, many of the inter-island and fishing vessels carry navigation equipment no more sophisticated than a compass.

For open water and trans-Caribbean navigation by large and high value vessels, long range electronic navigation systems (Omega and Transit) are generally used. Omega signals are available although this region is one of the poorer areas for this system due to the crossing angles of the available signals and the adverse nighttime propagation of the Liberian Station. Transit is frequently used by large ocean-going vessels and sea going tugs. A complete discussion of radionavigation systems and user requirements is given in Appendix A.

Celestial navigation is still frequently used by many of the vessels which do not have Omega or Transit aboard. These vessels include both the large and small commercial operators and government vessels, particularly Coast Guard. In addition, many of the purist deep water recreational sailors eschew the modern electronic navigational methods and opt for the more traditional means, particularly celestial.

A single LORAN-A line of position is available north of Puerto Rico and Hispaniola but will be terminated on December 31, 1980. LORAN-C groundwave signals from the Southeast Chain are available up to the mid-point of Cuba but frequently can be used as far East as the Windward Passage (Between Cuba and Hispanola). With a skilled operator and a sophisticated receiver, LORAN-C skywave signals have been successfully used to the North of Puerto Rico and the Virgin Islands. South of these islands including Hispaniola there is no coverage of LORAN-A or LORAN-C.

Radiobeacons are available throughout the Caribbean, however their reliability is a direct function of the state of development and level of political stability of the country overseeing their operation and maintenance.

No other radionavigation aids (e.g. Consol, Decca) are available in the Caribbean. However, the French Government is now in the process of installing a Differential Omega station in Guadeloupe in the French West Indies (See Section 6.0).

4. MARINE OPERATIONS IN THE EASTERN CARIBBEAN

4.1 INTRODUCTION

This section characterizes the maritime environment in the Caribbean in terms of navigation in the territorial waters and Coastal Confluence Zone, the principal trade routes and passages through the Caribbean, vessel traffic patterns and traffic volumes, navigational hazards, ports and harbors and other marine elements which influence the safe and efficient flow of vessels through the area. This section also defines the principal marine users of navigation in the area in terms of vessel characteristics and operating patterns.

4.2 REGIONS OF INTEREST

4.2.1 Coastal Confluence Zone (CCZ)

The Coastal Confluence Zone is characterized as a region of moderate maritime traffic and reasonable proximity to the coastline and as such is an area which requires more precise and more reliable navigation aids than on the high seas. The Coastal Confluence Zone of the United States is that region extending from the harbor entrance to 50 nm offshore or to the edge of the continental shelf (100 fathom curve), whichever is greater. The designation of a Coastal Confluence Zone in its strictest interpretation is applicable both to major land masses (continental United States) but also to island groups (Hawaii and Puerto Rico/Virgin Islands). In the Puerto Rico/Virgin Islands area, the Coastal Confluence Zone extends from 16°50'W to 19°21'N and from 63°40'W to 68°50'W (Figure 4-1). This area is roughly oval shaped and encompasses Puerto Rico and the U.S. Virgin Islands, as well as the British Virgin Islands. To the west, a portion of the Dominican Republic on the eastern end of the Island of Hispaniola is also included. The Coastal Confluence Zone as defined by the Continental Shelf of the U.S. also

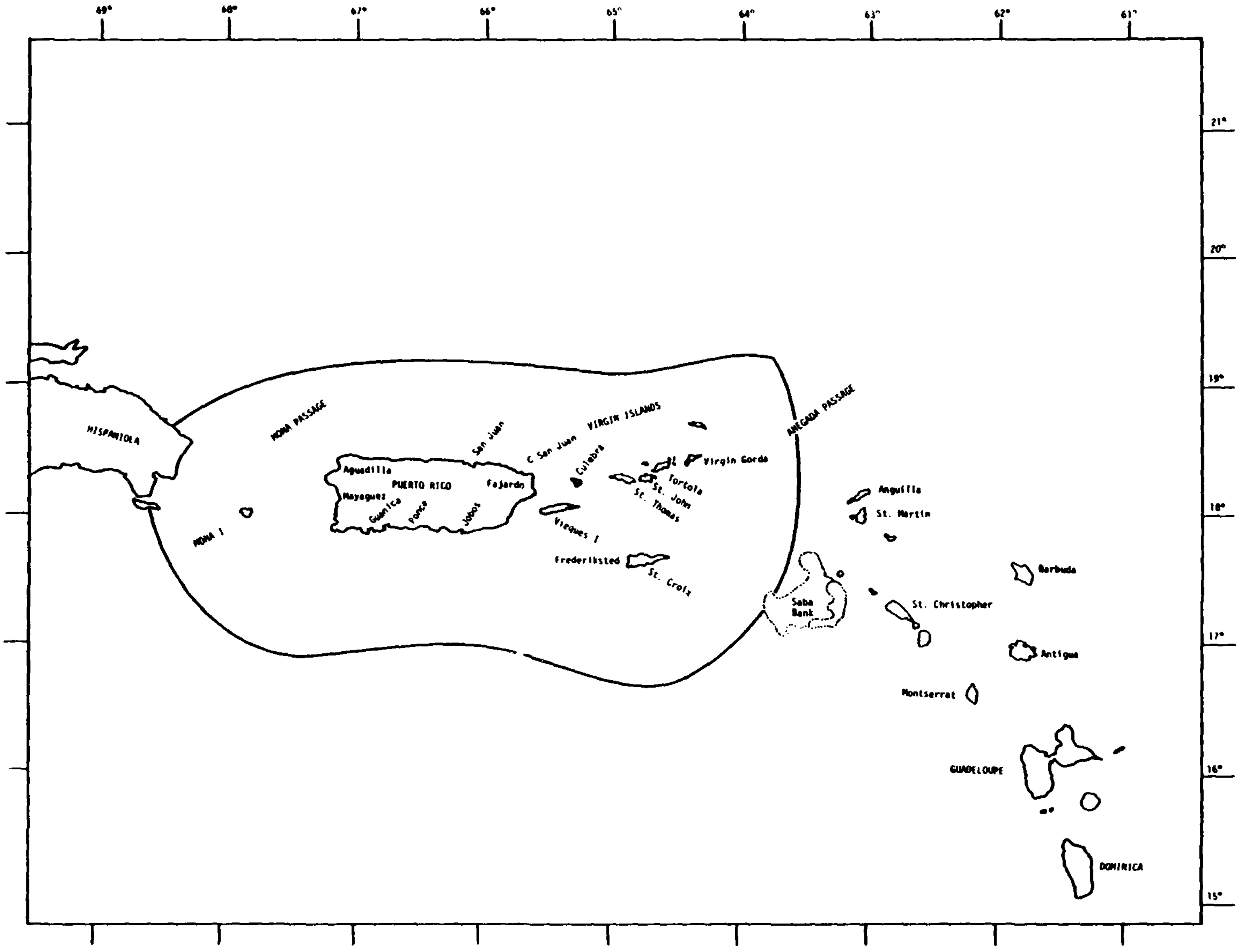

FIGURE 4-1 CARIBBEAN COASTAL CONFLUENCE ZONE

impinges on certain areas of interest to this study, particularly that area off the southeastern coast of Florida. In this region, the Coastal Confluence Zone includes westernmost Bahama Islands including Bimini and Grand Bahama Islands.

4.2.2 Fishery Conservation Zone (FCZ)

The Fishery Conservation Zone (FCZ) was established by the Fishery Conservation and Management Act of 1978 and as such delineates a region wherein the United States exercises fishery management jurisdiction. Generally, this region is defined as a zone 200 nm seaward from the baseline from which the territorial sea is measured (Reference 6). With respect to Puerto Rico and the Virgin Islands, the FCZ is defined in a somewhat different manner. To the north of these islands the zone extends 200 nm from the territorial sea; however, to the south, east, and west, the zone is defined as indicated in Figure 4-2. In the southern direction, the zone is a maximum distance of 160 nm from the southern limits of the territorial sea, to the west it encompasses most of the Mona Passage, while to the east it demarcates the U.S. Virgin Islands from the British Virgin Islands. The Caribbean Fishery Conservation Zone is of interest to this study since it defines an area over which the Coast Guard exercises jurisdictional control in its mission of enforcement of laws and treaties. However, at present, such fishery as does occur within this zone is limited to regions close in shore, mainly in Vieques Sound between the islands of Puerto Rico, Vieques, and Culebra. For a detailed discussion of the Puerto Rico-Virgin Islands fishing industry, see Appendix D.

4.2.3 Other Eastern Caribbean Regions

As well as the Caribbean Coastal Confluence Zone and the Fishery Conservation Zone, there are three other principal regions in the Caribbean which are used in this report to define traffic patterns and other maritime activity.

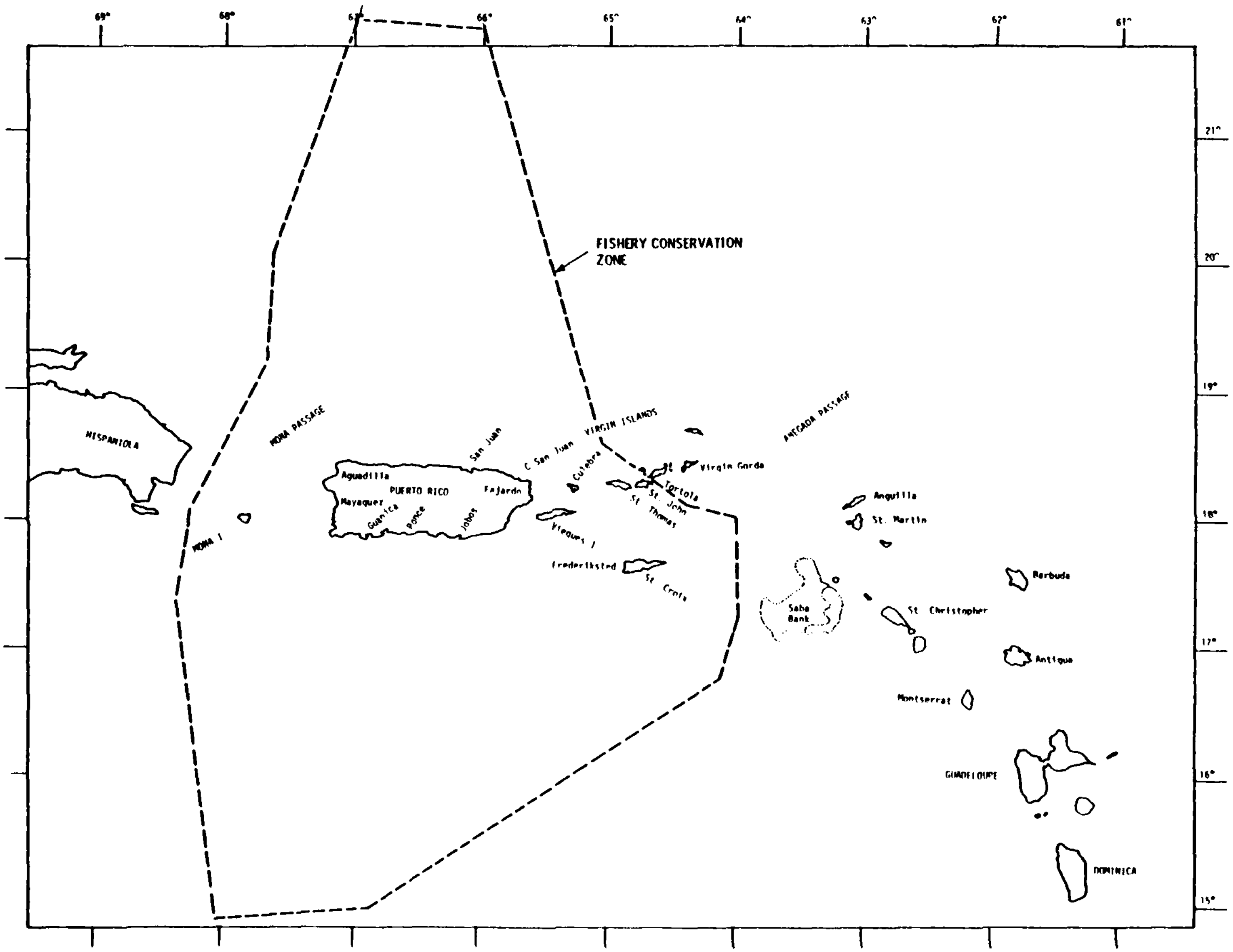

FIGURE 4-2 FISHERY CONSERVATION ZONE

These regions are:

The Lesser Antilles which includes the Leeward and Windward Islands but excludes the U.S. and British Virgin Islands. This chain of islands runs northwest-southeast and lies between 60.8°W to 63°W and 10°N to 18.2°N

The Greater Antilles and the Bahamas which includes the Islands of Cuba, Hispaniola and Jamaica but excludes Puerto Rico

North Coast of South America extending from Trinidad to the La Guajira Peninsula of Venezuela including the offshore islands of the Netherlands Antilles.

4.3 PRINCIPAL TRADE ROUTES AND PASSAGES

There are many trade routes utilized by vessels transiting the Caribbean. While the routes taken are governed by the origin and destination of the vessel and by cargo and characteristics of the vessel, there are options and variations in the routes which depend upon the desires of the master. There are eight principal routes which are utilized. These are shown in Figure 4-3 and were derived from data in Reference 7. These trade routes are categorized in terms of the principal regions of the Caribbean and are constrained by the major passages through which the vessels must pass as they transit the area. In addition, there are minor, but hazardous passages through the Bahamas, these are discussed in Section 4.3.3.

Traffic Separation Schemes are devised to reduce the risk of collision in congested and/or converging areas by separating vessel traffic. While such schemes are in effect in many areas including the East Coasts of the U.S. and

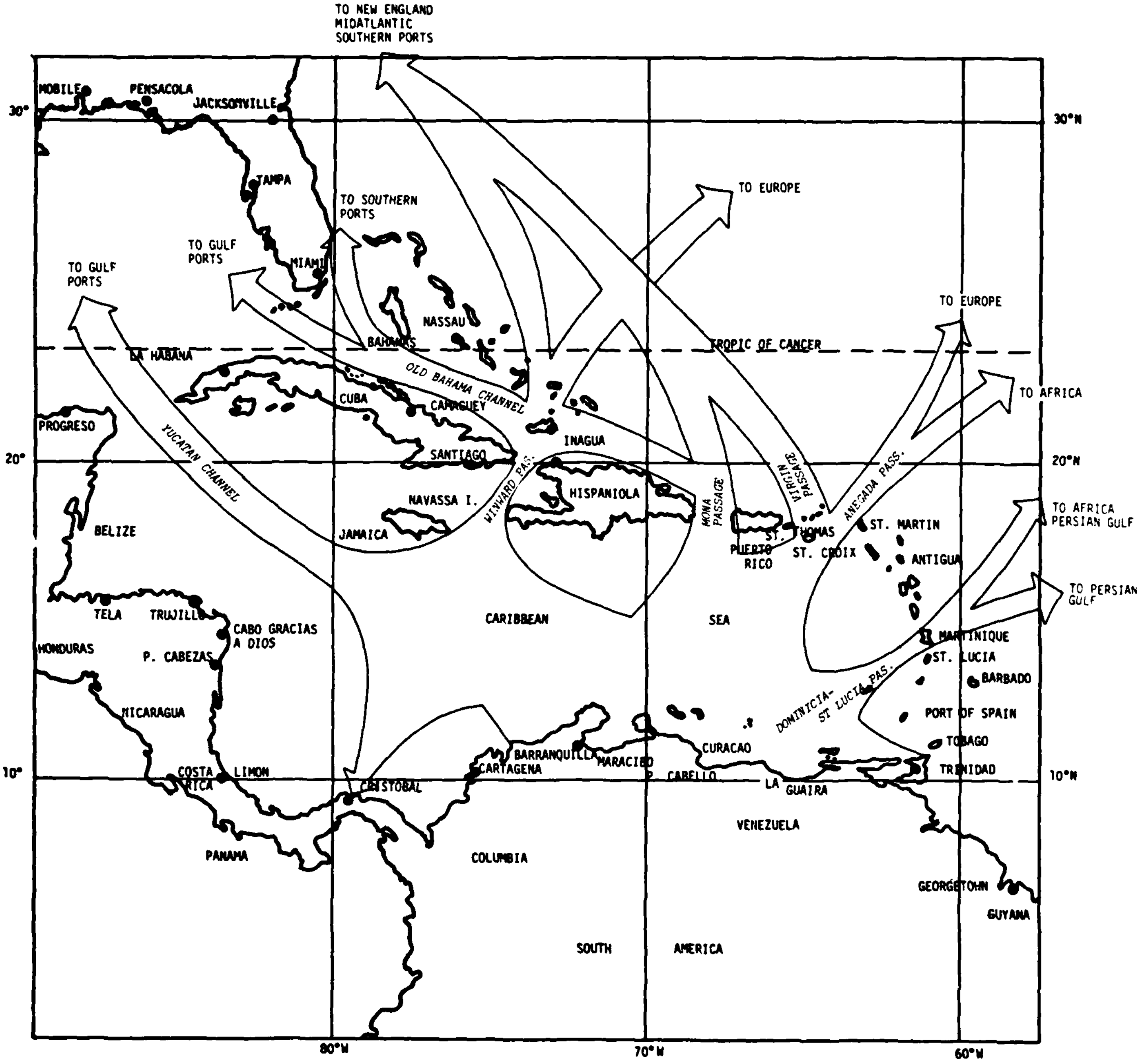

FIGURE 4-3 PRINCIPAL TRADE ROUTES AND PASSAGES

Canada, they are not being used in the major passages of the Caribbean. Traffic separation implies the ability of the vessel to fix its position within 0.25 nm in day and night under all weather conditions (Reference 8). Such an ability is not present in most regions of the Caribbean either through vessel capability or aids to navigation. However, the expansion of LORAN-C into the Caribbean, NAVSTAR or Differential Omega would permit the application of traffic separation lanes in restricted passages. This concept is discussed further in section 8. "System Benefits".

4.3.1 Caribbean Coastal Confluence Zone Trade Routes

The trade routes through the Caribbean Coastal Confluence Zone are constrained by three principal passages: Mona Passage between Hispaniola and Puerto Rico, Virgin Passage between Puerto Rico and the U.S. Virgin Islands, and the Anegada Passage between the British Virgin Islands and the Island of Anguilla. These passages, their locations, traffic patterns and navigational hazards are summarized in Table 4-1 and were derived from data in References 9 and 10.

The Mona Passage between the islands of Hispaniola and Puerto Rico is the principal passage for traffic from Panama to Western European ports. For traffic from the northeast coasts of the United States and Canada, bound for ports in the Dominican Republic or west of Curacao, Mona Island Passage is used with traffic passing to the west of Mona Island. For ports in Puerto Rico or east of Curacao vessels pass to the east of the island. Recent estimates indicate that this volume of traffic is approximately 1,300 vessels per year (Reference 11). Navigation in Mona Passage is somewhat hazardous inasmuch as there is only one navigational aid, Mona Island Light which is partially obscured at distances greater than 8 miles and to vessels which approach from the northeast. In addition, there is a radiobeacon at Cape Caucedo on the Dominican Republic which provides somewhat limited coverage of the southern approaches to Mona Passage.

TABLE 4-1 PRINCIPAL PASSAGES IN THE CARIBBEAN COASTAL CONFLUENCE ZONE

Name	Location	Traffic	Hazards to Navigation
Mona Passage	Between west end of Puerto Rico and east end of Hispaniola	Principal route between Panama Canal and South European ports. Principal tanker route between Venezuela and Curaco and U.S. East Coast and Southern European ports	Isla De Mona Isla Monita Isla Desecheo
Virgin Passage	Between St. Thomas and Culebra Islands (18°19'N, 65°09'W)	Principal tanker route between Trinidad, St. Croix and U.S. East Coast ports	Bajos Grampus Sail Rock
Anegada Passage	Between Anegada Island in British Virgin Islands and Anguilla Island (18°30'N, 63°46'W)	Principal route from Europe to Caribbean for bloc countries	None

The Virgin Passage lies between Puerto Rico and the Virgin Islands and is the principal passage for tank vessel traffic from Trinidad and the east coast of Venezuela as well as the Amerada Hess Refinery at St. Croix. It also is the principal passage for general cargo and passenger vessels from the east coast of the United States to ports in the Lesser Antilles and Venezuela. In addition, vessels en route from Panama to Europe will utilize the Virgin Passage or the Anegada Passage depending upon final destination. Generally, traffic passes to the west of St. Croix and St. John before diverting to the destinations. The passage is reasonably clear and well marked with lights; there is some radio beacon coverage from the beacons on Puerto Rico. It is estimated that approximately 1,600 vessels utilize the Virgin Passage annually.

The Anegada Passage is between the Island of Anegada in the British Virgin Islands and Anguilla in the Leeward Islands. It is wide and deep and has few hazards to navigation. It is the principal route from Europe and Africa to the Caribbean; approximately 5,000 vessels use this passage each year, the majority of which are en route to the Panama Canal. The passage is marked by a light on Sombrero as well as some radiobeacon coverage from Saint Martin.

4.3.2 Lesser Antilles Trade Routes

While there are many passages and channels separating the islands in the Lesser Antilles, the principal passages are the St. Lucia Channel and the Dominicia Channel. The former lies between the islands of St. Lucia and Martinique, while the latter is between Dominicia and Martinique. These are relatively free of hazards to navigation. Entrance to these passages are marked by a light on Pointe des Salmis on Martinique. In addition, there is daylight radiobeacon coverage of the western approaches from St. Lucia. These passages are major points of entrance to the Caribbean Sea for tank vessel traffic from Africa, Cape of Good Hope and the Persian Gulf. The volume of this traffic is estimated at 500 tankers annually.

4.3.3 Greater Antilles Trade Routes

In this study the Greater Antilles is defined to include the Bahamas as well as the islands of Hispaniola, Jamaica and Cuba. In this region there are four principal passages: the Windward Passage between Hispaniola and Cuba; the Crooked Island Passage in the southern Bahamas; the Caicos and Turks Island Passage, also in the southern Bahamas; and the old Bahama Channel between the North Coast of Cuba and the Bahama Islands. The principal characteristics of these other passages are summarized in Table 4-2 and are shown in Figure 4-4.

The Windward Passage lies athwart the major trade routes from U.S. East Coast and United Kingdom ports to the Panama Canal Zone. This passage is bounded on the west by Cape Maisi on the extreme eastern tip of Cuba and on the east by Cap a Foux on the western tip of Hispaniola. The Passage is wide (51 nm) and deep and can be navigated with comparative safety. Aids to navigation consist of the Cape Maisi Light and the Point Caleta beacon at Guatanamo Bay which provides coverage for the southern approaches. In addition, some LORAN-C groundwave fix coverage is available from the Southeast U.S. Chain for the northern approaches, but is unreliable in the southern approaches.

Navigation within and around the Bahama Islands must be done with caution. The area abounds in shoal water and while hazardous to deep draft vessels, represents one of the finest cruising regions for pleasure craft. Many of the charts of the region are based on old and occasionally unreliable information. In some cases, position errors may be as great as five miles. Deep water passages through the Bahamas number more than a half dozen and present no difficulty to full powered vessels. The principal passages through the Bahamas are Crooked Island Passage, Caicos Passage, Turks Island Passage and Old Bahama Channel.

TABLE 4-2 PRINCIPAL PASSAGES IN THE GREATER ANTILLES AND BAHAMAS

Name	Location	Traffic	Hazards to Navigation
Windward Passage	Between east coast of Cuba and west coast off Hispaniola (20°03'N, 73°46'W)	Principal route between Panama Canal, U.S. East Coast ports and North European ports	None
Crooked Island Passage	*Southern Bahamas between* Long Island and Crooked Island (22°55'N, 74°34'W)	Principal route between Panama Canal and U.S. East Coast ports	Diana Bank (7 FMS) Mira Por Vos Cays Stranded vessel on Hogsty Reef
Caicos and Turks Island Passage	Caicos Passage is between Mayaguana and Caicos Island, past Little Inagua Island in Southern Bahamas (22°00'N, 72°30'W) - - - - - - - - - - - - - - - - Turks Passage lies between Caicos and Turks Island in Southern Bahamas (21°25'N, 71°19'W)	Used principally by vessels in transit from the Caribbean to Europe via Windward Passage. Vessels bound for the Mediterranean transit Turks Island while those for N. Europe transit Caicos Passage. Turks Passage principally used by south-bound vessels.	Caicos Passage Shoal water 9 miles east of Little Inagua Island. Avoid at night and use Crooked Island or Turks Island Passage - - - - - - - - - - - - - - Turks Island Passage Swimmer and Endymion rocks in southern entrance.
Old Bahama Channel	Between Great Bahama Bank and northeast coast of Cuba (22°32'N, 78°00'W)	Convenient passage for vessels from Floridian Gulf coast ports to Puerto Rico	Narrow passage with potential for athwart channel set

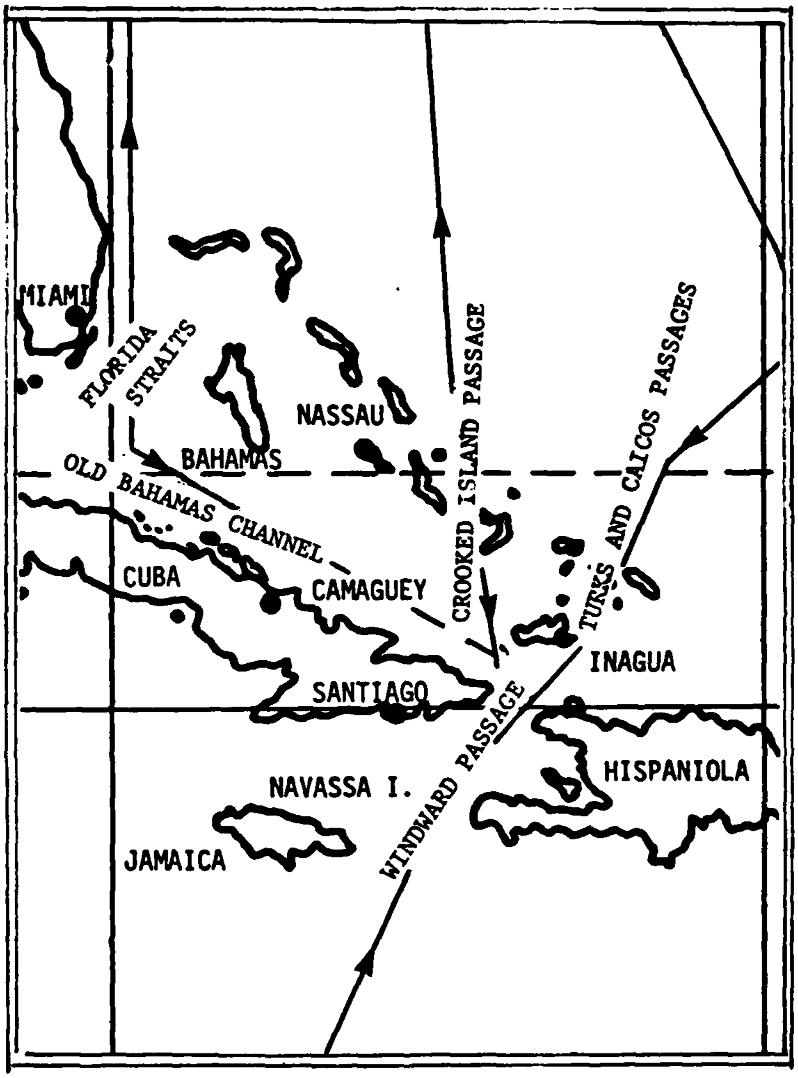

FIGURE 4-4 GREATER ANTILLES BAHAMAS TRADE ROUTES

Vessels that transit Windward Passage for East Coast U.S. ports commonly use the Crooked Island Passage for transit of the southern Bahamas. This route is shown in Figure 4-5. This passage is distinctive in that the vast expanses of shoal water which characterize the Bahama banks to the northwest are largely absent (Reference 5). Nevertheless, transit through this passage can be hazardous because of the presence of Diana Bank, Brown Bank and Mira Por Vos Cays. In addition, there is a vessel stranded on Hogsty Reef in a bolt upright position which presents a source of dangerous confusion to the mariner. This reef is lighted as is Castle Island, Long Cay and Long Island. In addition, there is radiobeacon coverage from Great Inagua Island.

For vessels in transit from the Caribbean to Europe the Turks and Caicos Passages are used. The Caicos Passage is between Mayaguana and Caicos Islands and is used principally by vessels bound for Northern Europe. This passage can be navigated safely at daylight; however because of the presence of shoal water east of Little Inagua Island passage at night is not recommended. Instead vessels are advised to use Crooked Island or Turks Island Passages. Turks Island Passage lies between Caicos and Turks Island and is the principal passage for vessels bound for the Mediterranean from the Caribbean via the Windward Passage. In addition, it is frequently used by southbound vessels. Aids to navigation in the area include lights on East Caicos and Grand Turk Islands as well as a light on Sand Cay. In addition, there is a radiobeacon on Grand Turk Island.

For vessels bound from U.S. Southeast and Gulf Coast Ports to Puerto Rico, the Florida Straits and the old Bahama Channel is used. The latter is a deep, considerably narrow seaway which leads between Great Bahama Bank and Cuba. It is recommended that vessels steer a mid-channel course and proceed with caution through this passage (Reference 5). Aids to navigation are available but they are principally on the Cuban coast and are frequently extinguished or unreliable. In

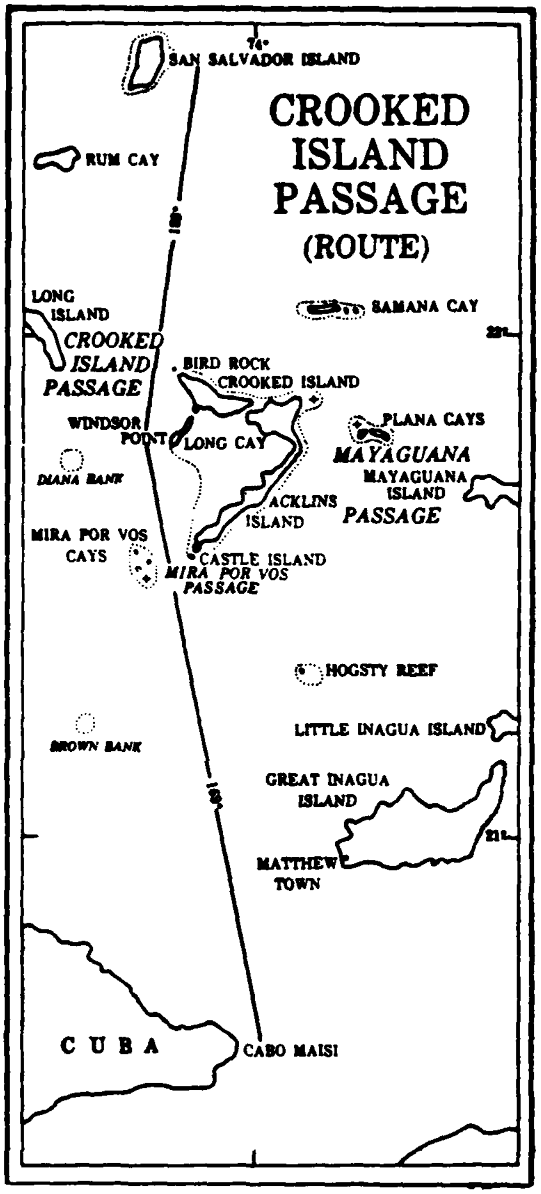

FIGURE 4-5 CROOKED ISLAND PASSAGE

addition, there is some groundwave LORAN-C coverage from the Southeast U.S. Chain.

4.3.4 North Coast of South America Trade Routes

The major passage in this region is the Dragon's Mouth which separates the Island of Trinidad from the mainland of Venezuela. Vessels depart Port of Spain, Trinidad, transit the Gulf of Paria, proceed through the Dragon's Mouth and enter into the Caribbean Sea. The Gulf of Paria must be navigated with care because of the oil well platforms and drilling rigs which are located in the middle and southern parts of the Gulf. The Dragon's Mouth is about 10.5 miles wide and, although marked by three islands, can be easily navigated. Lighted navigation aids are available on Chacachacare Island and there is an aeronautical radiobeacon at Piarco.

The outlying islands off the north coast of Venezuela which include both the Venezuelan territories and the Netherland Antilles are located far offshore and are well separated such that navigation between and through them can be accomplished with reasonable safety. This region generates a significant level of petroleum traffic and worldwide tank vessel traffic originates and departs from here. These islands are well lighted with aids to navigation and with ample radiobeacon coverage as well.

4.3.5 Traffic Patterns and LORAN-C Coverage

The trade and traffic patterns and the assured LORAN-C coverage provided by the Southeast U.S. Chain were synthesized to produce a matrix of

LORAN-C availabilities for the principal passages of the Caribbean. This matrix is shown in Figure 4-6. The assured LORAN-C coverage was based on the data given in Appendix A together with discussions with Coast Guard officers, mariners and fishermen accustomed to operating in the Caribbean (Appendix F). From these discusssions, it appears that a usable LORAN-C groundwave signal of decreasing accuracy is available from the Old Bahama Channel to the North Coast of Puerto Rico. However, the usability of this signal is a direct function of the skill of the mariner in the operation of the LORAN-C receiver and the degree of sophistication of the receiver. For purposes of this comparison, the Windward Passage was assumed to have partial coverage, and the Mona Passage none.

In this matrix, the origins and destinations of the various U.S., foreign, and Caribbean trade route combinations are shown as a function of the principal passages and channels. Within each trade route, the various passages through which the vessel may transit are identified. In some cases, more than one alternative passage is available for the route; however, no attempt was made to subdivide these alternatives. For each trade route, the availability of LORAN-C was determined for each passage. In some instances, only partial coverage was available either because there were multiple passages in the route and not all had coverage, or because there was only partial coverage of the passage (e.g., Windward Passage).

Of the 57 origin-destination route combinations, 37 require transit through one or more of the Caribbean passages or channels. Ten of these route passage combinations have full LORAN-C coverage, in particular, those that transit the Old Bahama Channel. Thirteen of these combinations have partial coverage, principally those that involve the Windward Passage while the remaining fourteen have no LORAN-C coverage. These latter routes all lie east of 70° W and

ORIGIN-DESTINATION	NEW ENGLAND	MID ATLANTIC	SOUTHERN	GULF	PUERTO RICO	VIRGIN ISLS	GREATER ANTILLES	LESSER ANTILLES	NORTH COAST SOUTH AMERICA
PUERTO RICO	-	-	▨ OB	▨ OB					
VIRGIN ISLS.	–	–	▨ OB	▨ OB	V				
GREATER ANTILLES	W	W	OB W	OB Y W	M	M V			
LESSER ANTILLES	M V	M	OB M V	OB M V	-	-	-		
NORTH COAST SOUTH AMERICA	M V	M V	OB W M V	OB W Y	-	-	-	-	
BAHAMAS	-	-	-	▨ OB	▨ OB	▨ OB	OB W	M V	OB M W
EUROPE				▨ OB	-	A	A W	-	D STL
AFRICA				▨ OB	-	A	A W	-	DOM STL
PERSIAN GULF				▨ OB	-	A	A W	-	DOM STL

PRINCIPAL ROUTE PASSAGES

V - VIRGIN
M - MONA
W - WINDWARD
OB - OLD BAHAMA (WEST OF 80° W)
A - ANEGADA
D - DOMINICA
STL- ST LUCIA
Y - YUCATAN

EASTERN CARIBBEAN PASSAGES WITH LORAN-C COVERAGE

▨ FULL
☐ PARTIAL
☐ NONE

FIGURE 4-6 EASTERN CARIBBEAN TRADE ROUTES AND PASSAGES WITH LORAN-C COVERAGE comprise the region for the proposed increased coverage in radionavigation aids, principally LORAN-C and Differential Omega.

4.4 PRINCIPAL PORTS AND HARBORS

4.4.1 Caribbean Coastal Confluence Zone

There are six major ports in Puerto Rico in terms of physical size, vessel calls and tonnage handled (Figure 4-7). The principal port is San Juan on the north coast. This port handles over 60 percent of the traffic in terms of arriving vessels and tonnage. The second largest port is Guayanilla on the south coast of Puerto Rico which handles 16 percent of the vessels, and 22 percent of the tonnage. The remaining major ports are Mayaguez, Guanica, Los Mareas and Yabucoa. Detailed data on Puerto Rico traffic is given in Appendix C.

Most of the traffic in terms of vessel arrivals and departures for ports in Puerto Rico is inter-island which includes trade to all islands in the Caribbean, the North Coast of South America and other ports in Puerto Rico and the Virgin Islands. The principal tank vessel activity is in Ponce which includes the Ports of Guayanilla and Tallaboa. This activity is primarily attributable to the giant Commonwealth Oil refinery complex at Guayanilla. Cargo vessels generally call at four ports: San Juan, Ponce, Mayaguez and Yabucoa with San Juan handling the majority of the traffic. San Juan is the principal port for passenger vessels which consists of cruise ships from North America as well as inter-island traffic.

Vessel traffic in the Virgin Islands consists principally of tank vessel traffic to Limetree Bay at St. Croix (site of the Amerada Hess Oil Refinery), cargo and passenger traffic to Charlotte Amalie on St. Thomas and small inter-island cargo recreational traffic to Cruz Bay at St. John (Figure 4-7). Detailed traffic data are given in Appendix C. Most of the Limetree Bay traffic originates in Europe, Africa, and Mid East and is characterized by large tank vessels carrying

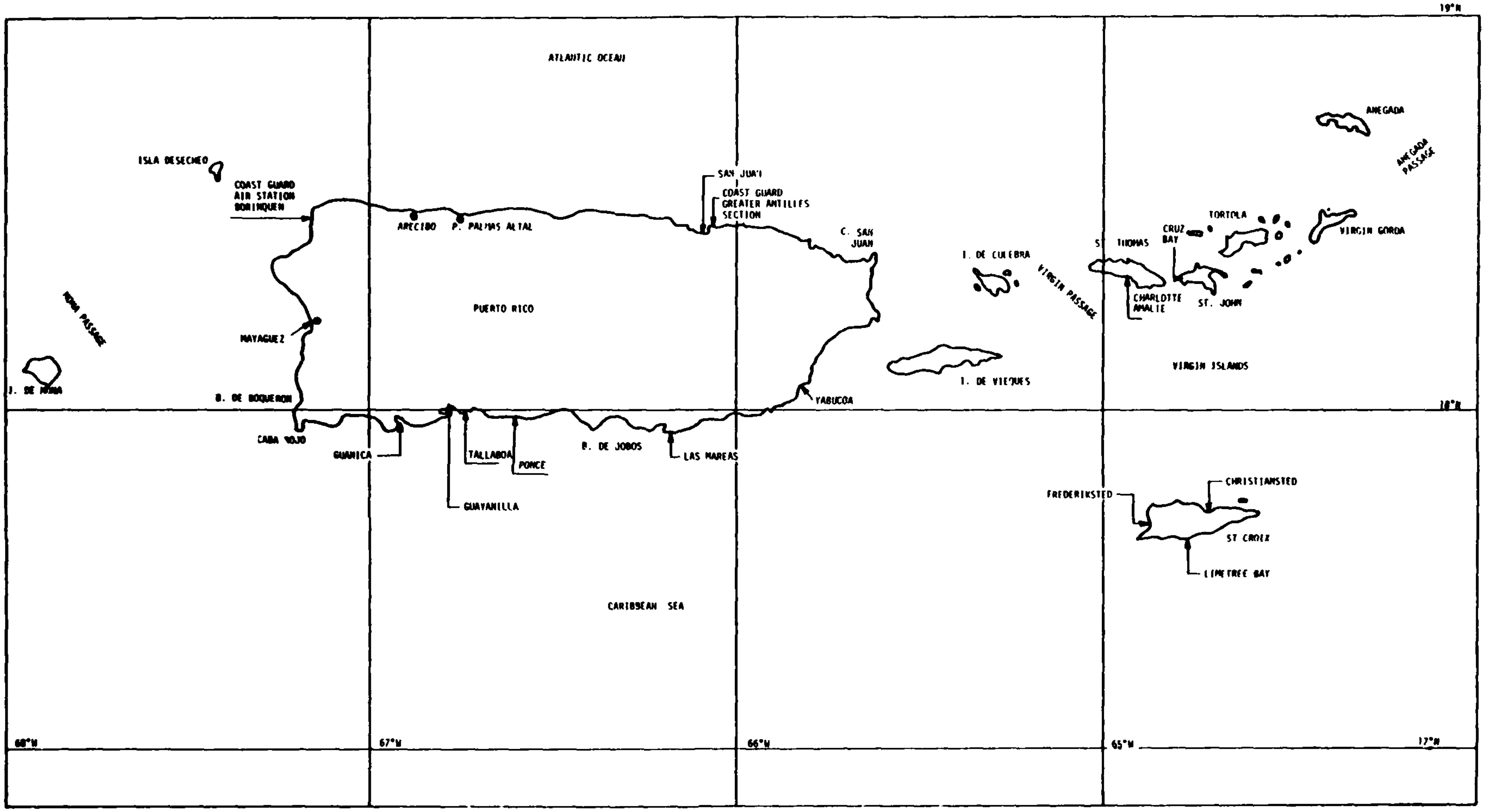

FIGURE 4-7 PRINCIPAL PORTS IN PUERTO RICO AND VIRGIN ISLANDS

crude; the refined product is carried in smaller vessels to North American East Coast ports. This ratio of small vessels to large vessels is approximately 3 to 1 and has remained at this level for the last three years. Virtually all of the cargo and passenger vessel traffic is inter-island, although all cruise ship traffic which originally calls at other Caribbean ports is classified as inter-island despite the fact that such vessels may originate at North American East Coast ports.

4.4.2 Lesser Antilles

The ports of the Leeward Islands of the Lesser Antilles are generally small and large ships must anchor in the small roadsteads or on the narrow banks off the island towns. For the most part, such port facilities as do exist, are extremely limited. In the Windward Islands, there are four ports which have berthing accommodations for large vessels. These ports are Fort de France, *Martinique; Port Castries*, St. Lucia; St. Georges Harbor, Grenada and Bridgetown, Barbados. The other harbors are small, the port facilities limited and large vessels must anchor in roadsteads to work cargo. Overall, in the entire Lesser Antilles there are ten principal ports. Detailed traffic characteristics are given in Appendix C.

4.4.3 Greater Antilles Including the Bahamas

In the Greater Antilles and the Bahamas there are 33 ports of various sizes, complexities and levels of accommodations. Among these, the principal ports are: Kingston and Montego Bay on Jamaica; Santo Domingo and Port au Prince on Hispaniola and Freeport and Nassau in the Bahamas. Traffic from these ports constitutes approximately 14 percent of the total U.S.-Eastern Caribbean trade. Detailed data on these vessel movements is provided in Appendix C.

4.4.4 North Coast of South America

This region includes the islands of Trinidad and Tobago, the mainland of Venezuela and the outlying islands of Netherland Antilles. As such, this region is marked by considerable petroleum related activity, both in exploration and refining. In addition, bauxite, manganese and iron are also shipped from ports in Trinidad and Venezuela. There are over thirty ports in this region of which over half can be classified as major ports principally due to the large volume of petroleum traffic generated. In the Netherlands Antilles and Venezuela there are seven major oil ports in each country, assuming that the Maricaibo Lake Ports are considered a single port. In Trinidad there are three major ports. The traffic generated from this region accounted for approximately 25 percent of the U.S.-Eastern Caribbean volume, of which over two-thirds was oil tanker traffic (See Appendix C).

4.5 MARINE USERS OF NAVIGATION

4.5.1 Large Commercial Operators

In this study the large commercial operators are those vessels greater than 1600 GT whose activities are customarily in the Eastern Caribbean. The majority of these vessels are tankers carrying crude and refined product between the oil producing countries, the refineries and the North American consumer; general cargo vessels particularly container and break-bulk carriers; and, cruise ships operating in the U.S.-Caribbean tourist trade. These vessels are further identified as U.S. Flag and Foreign Flag vessels. Because of the limitations of the data base, no attempt was made to identify those U.S. owned-Foreign Flag vessels (flags of convenience). Further, the data were limited to those vessels engaged in U.S. trade (including Puerto Rico and the U.S. Virgin Islands). Also included in this category are government owned vessels, and vessels engaged in resource exploration, oceanography, hydrography and other special operations where accurate radiolocation determination is important and cost relatively minor in importance.

4.5.2 Small Commercial Operators

This category consists of the smaller marine vessels (less than 1600 GT) whose operations are generally constrained to offshore and inter-island trade. Included in this category are seagoing tugs and barges, coastal cargo and passenger vessels and offshore service vessels. Only U.S. Flag vessels or Foreign Flag vessels engaged in the support of U.S. trade are considered. This category comprises most of the inter-island traffic as well as traffic to the mainland U.S. Southern and Gulf Coast Ports.

4.5.3 Commercial Fishing and Commercial Sport Fishing

Commercial Fishing Vessels are those vessels habitually engaged in fishing operations from which the captain and crew derive their principal source of income from the landing of fish. Commercial sport fishing vessels are vessels available for charter or hire by private parties and any income derived from the landing of fish is incidental to the basic mode of operations. Only U.S. (Puerto Rico and Virgin Islands) fishing vessels are considered. A detailed analysis of the Puerto Rico-Virgin Islands fishing industry is given in Appendix D.

4.5.4 Recreational Boats

This category of vessels includes cabin cruisers, sailboats, and yachts whose principal operations are in pursuit of leisure time activities. Also included are those recreational boats in the Eastern Caribbean which are available for charter, either bareboat or with crew. This category consists principally of those vessels registered in Puerto Rico or the U.S. Virgin Islands. In addition, those recreational boats which are registered in the U.S. mainland but which habitually cruise to this region are also included. No foreign registered vessels are considered.

5. VESSEL TRAFFIC AND POPULATIONS

5.1 INTRODUCTION

This section provides an estimate of the traffic between the U.S. and the Eastern Caribbean, a determination of the number of vessels generating the traffic, and an identification of the users of LORAN-C should this system be expanded into the Eastern Caribbean. This section also projects traffic, vessel populations, and LORAN-C users through the year 2000. Only summaries are presented. Appendices C, D and E show the data sources, methods used to derive the traffic and population estimates as well as detailed tables presenting this information.

Two concepts, vessel traffic and vessel population, are very often used in this analysis and they require some further clarification. Traffic refers to the vessel movements from port to port. Traffic is a dynamic concept because it changes over time and reflects time-dependent trade among nations. Vessel population, on the other hand, refers to the number of vessels generating the traffic. Vessels whose movements are such that they have no destination, but rather habitually return to the same port (e.g., fishing vessels), or are random in nature (e.g., tramp vessels) are difficult to estimate. Because of these latter limitations only vessels with definite origins and destinations were deemed to generate traffic.

5.2 VESSEL TRAFFIC

Traffic estimates were developed for the following vessel categories:

- Large Commercial Vessels, principally ocean-going cargo, passenger and tank vessels

- Small Vessels, principally those engaged in inter-island activities.

5.2.1 Large Commercial Vessels

Three traffic patterns were developed to estimate the traffic between U.S. and Eastern Caribbean for large ocean-going vessels. The nature of the data base required that the data be segregated in this manner. These patterns are as follows:

- U.S. to Eastern Caribbean excluding Puerto Rico and the U.S. Virgin Islands
- U.S. to Puerto Rico
- U.S. to U.S. Virgin Islands

General cargo and oil tanker traffic estimates were developed for each of the above patterns. Passenger vessels were included with the general cargo vessels. The traffic generated by U.S. flag vessels versus foreign flag vessels was also estimated. The scope of this study did not include large vessel traffic passing through the Caribbean. Similarly, the traffic generated by large vessels which sailed from a foreign port in the Caribbean (non-U.S. territory) to another foreign port either in the Caribbean or elsewhere was not included.

The traffic for all three patterns is presented in Table 5-1. The annual traffic between U.S. and the Eastern Caribbean consisted of 18,524 moves*. The heaviest traffic occurred between the Gulf ports and the North Coast of South America, accounting for almost 21.4 percent of the total traffic, or 3,974 moves.

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* A vessel move is defined as the movement of a vessel transiting a given region or sector of the Eastern Caribbean. Vessel moves are estimates, however, and calculations were not rounded for consistency purposes.

TABLE 5-1 ANNUAL U.S. - EASTERN CARIBBEAN VESSEL TRAFFIC (1979)

PORTS	COMMERCIAL VESSELS															TOTALS		
	GREATER ANTILLES			LESSER ANTILLES			NORTH COAST OF SOUTH AMERICA			PUERTO RICO			U.S. VIRGIN ISLANDS					
	GENERAL CARGO	TANKER	TOTAL	GENERAL CARGO	TANKER	TOTAL	GENERAL CARGO	TANKER	TOTAL	GENERAL CARGO	TANKER	TOTAL	GENERAL CARGO	TANKER	TOTAL	GENERAL CARGO	TANKER	TOTAL
NEW ENGLAND	60	0	60	0	0	0	0	892	892	256	0	256	0	216	216	316	1108	1424
MID-ATLANTIC	276	0	276	252	12	264	408	2004	2412	1026	0	1026	0	420	420	1962	2436	4398
SOUTH	1236	12	1248	468	0	468	1500	684	2184	1796	0	1796	204	360	564	5204	1056	6260
GULF	900	84	984	108	0	108	936	3038	3974	1028	108	1136	0	240	240	2972	3470	6442
INTRA-CARIBBEAN	--		--	--	--	--	--	--	--	5004	396	5400	15432	372	15804	20436	768	21204
NORTH COAST OF SOUTH AMERICA	--	--	--	--	--	--	--	--	--	1452	456	1908	264	108	372	1716	564	2280
BAHAMAS	--	--	--	--	--	--	--	--	--	60	48	108	60	12	72	120	60	180
AFRICA	--	--	--	--	--	--	--	--	--	48	24	72	0	132	132	48	156	204
EUROPE	--	--	--	--	--	--	--	--	--	204	48	252	0	96	96	204	144	348
PERSIAN GULF	--	--	--	--	--	--	--	--	--	0	0	0	0	132	132	0	132	132
OTHER	--	--	--	--	--	--	--	--	--	684	132	816	72	336	276	756	468	1224
TOTALS	2472	96	2568	828	12	840	2844	6618	9462	11558	1212	12770	16032	2424	18324	33734	10362	44096

The majority were generated by oil tankers which accounted for 3,038 moves or 76.4 percent of this traffic. Most of the oil tankers transported crude oil from Venezuela to the Gulf Coast refineries. The traffic between mid-Atlantic ports and the North Coast of South America accounted for 2,412 moves, the majority of which, 2,004, were due to oil tanker traffic. This tanker traffic was mainly refined product from the refineries located in Aruba.

Similarly, the traffic between New England ports and the North Coast of South America was generated excusively by oil tankers transporting refined product from Aruba to Portland, Maine and Boston, Massachusetts. The traffic between southern ports and this region consisted of 2,184 moves which accounted for approximately 23 percent of the total traffic between U.S. and the North Coast of South America. Approximately 69 percent, or 1,500 moves, of this traffic were generated by general cargo vessels.

The traffic between the Greater Antilles and the U.S. consisted of 2,568 moves or 13.8 percent of the total traffic generated between U.S. - Eastern Caribbean traffic. Southern ports accounted for the majority of this traffic, 1,248 moves of which nearly all were due to general cargo vessels. Likewise, most of the Gulf port traffic (984 moves) was generated by general cargo vessels. New England and Mid-Atlantic ports handled 60 and 276 moves, respectively. All of this latter activity was due to general cargo vessels.

The least amount of Eastern Caribbean traffic was between the Lesser Antilles and the U.S. which accounted for only 840 moves or 4 percent of the total. Southern ports handled the majority of this movement (57 percent). In all, general cargo vessels generated 828 moves and oil tankers 12 moves.

The traffic between the U.S. and Puerto Rico consisted of 4,214 moves, accounting for 22.4 percent of the total traffic generated between the U.S. and

Eastern Caribbean Ports. Southern ports handled most of this traffic (43 percent) which was generated exclusively by general cargo vessels. Gulf ports handled 1,136 moves, of which 1,028 were general cargo and the remaining, oil tankers (108). New England and Mid-Atlantic ports handled 256 and 1,026 moves, respectively. These moves were all general cargo vessels.

The traffic between the U.S. and the U.S. Virgin Islands consisted of 1,440 moves accounting for 7.7 percent of the total traffic between the U.S. and the Eastern Caribbean. The majority of this traffic, 1,200 moves, was due to oil tanker movements from St. Croix. Southern ports handled the majority of the traffic, 564 moves of which 204 were general cargo and 360 oil tankers. Southern ports handled all the general cargo traffic generated between the U.S. and the U.S. Virgin Islands. New England, Mid-Atlantic and Gulf ports handled 216, 420, and 240 oil tanker moves, respectively.

A detailed discussion of the traffic generated between Puerto Rico and other Caribbean and non-Caribbean ports as well as between U.S. Virgin Islands and other Caribbean and non-Caribbean ports is presented in Appendix C.

The split of traffic handled by U.S. flag vessels and foreign flag vessels is shown in Table 5-2. Of a total of 7,950 tanker moves, foreign flag vessels handled 7,400 shipments. The balance (550 moves) was handled by U.S. flag tankers. U.S. general cargo vessels accounted for 3,764 moves, or 36 percent out of a total of 16,435 moves.

Large commercial vessels generated approximately 66 percent of the total traffic and small commercial vessels generated 34 percent.

5.2.2 Small Commercial Vessels

Small commercial vessels accounted for approximately 6298 moves or 34 percent of the total U.S. to Eastern Caribbean traffic. The majority of these

TABLE 5-2 ANNUAL U.S. AND FOREIGN FLAG EASTERN CARIBBEAN TRAFFIC (1979)

U.S. REGION	GREATER ANTILLES				LESSER ANTILLES				NORTH COAST OF SOUTH AMERICA				PUERTO RICO				U.S. VIRGIN ISLANDS			
	U.S.		FOREIGN		U.S.		FOREIGN		U.S.		FOREIGN		U.S.		FOREIGN		U.S.		FOREIGN	
	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER
NEW ENGLAND	0	0	60	0	0	0	0	0	0	36	0	756	-	-	-	-	-	-	-	-
MID-ATLANTIC	0	0	276	0	60	0	192	12	60	36	348	1968	-	-	-	-	-	-	-	-
SOUTH	0	0	1236	12	36	0	432	0	12	60	1488	624	-	-	-	-	-	-	-	-
GULF	132	60	768	24	12	0	96	0	36	146	900	2892	-	-	-	-	-	-	-	-
TOTAL	132	60	2340	36	108	0	720	12	108	278	2736	6240	3350	0	755	108	120	212	120	1024

moves, 2737 or 43.5 percent were in the U.S.-Puerto Rico trade. In this activity, U.S flag small vessels (less than 1000 gross tons) generated approximately 2234 transits while small foreign flag vessels accounted for 503 transits. This traffic was prinicpally to the U.S. mainland, Gulf Coast and southern ports. Of the remaining traffic, 3561 moves were handled by foreign flag small vessels operating primarily in the U.S. to Greater and Lesser Antilles trade routes.

However, most of the small vessel activity in the Caribbean was from Puerto Rico and the Virgin Islands to other Caribbean ports. The inter-island traffic from Puerto Rico consisted principally of tugs and barges and small cargo and tank vessels and amounted to 5400 moves. Of this figure, 5004 moves were handled by small cargo vessels, the balance by barges and small oil tankers. In addition, there were 1908 moves between Puerto Rico and the North Coast of South America of which 1452 moves were handled by cargo vessels and the balance by oil tankers. No data were available as to the distribution between small and large vessels.

Inter-island traffic originating or terminating in Virgin Island ports amounted to 15,804 moves or 94 percent of the total traffic generated by the Virgin Islands to foreign ports. This traffic was attributable primarily to small passenger and cargo vessels and recreational boats having an identifiable traffic pattern (e.g., charter boats).

5.2.3 Traffic Densities

Using the data discussed previously in this section together with the detailed data base given in Appendix C, traffic densities for the large and small vessels were determined as a function of the principal trade routes through the Caribbean. The trade routes used were those discussed in Section 4.3 and were further subdivided to reflect the four mainland U.S. regions used in the vessel traffic analysis (New England, Mid Atlantic, South and Gulf Coast). These routes provided the basis for the analysis of traffic density flows.

Traffic was assumed to flow via the most direct route. When two equal routes were available such that it was indifferent as to which one to use, the traffic was assumed to be equally divided. Where origins and destinations incorporated large regions, e.g., North Coast of South America and U.S. Gulf ports, the traffic was divided based on cargo and vessel function. For example, crude oil traffic moved from Venezuela to the western Gulf refineries at Galveston and Port Arthur via the Yucatan Channel, while refined product and general cargo moved to the Eastern Gulf ports via the Windward Passage and Old Bahama Channel. This analysis yielded commodity-specific traffic flows.

Traffic was separated into segments as it diverted to the various regions. The number of vessels was then determined for each route segment as it merged or diverted into the various traffic patterns. The results of this traffic density analysis are depicted in Figure 5-1. This figure shows not only the various route structures, but also the amount of vessel activity associated with each structure.

This traffic was divided into four categories of activity: low (less than 3000 transits per year), low to moderate (3000 - 6000 transits), moderate to high (6000 - 9000 transits), and high (greater than 9000 transits). The two regions of greatest activity are the North Coast of Venezuela and the Lesser - Greater Antilles trade routes. This latter region consists principally of inter-island traffic, while the former is predominantly oil tanker traffic. As this latter traffic proceeds northward it separates and divides into that bound for the western Gulf ports and that bound for ports on the Eastern Gulf Coast, Southern and Eastern Seaboards and Europe. The traffic bound for the southern and eastern Gulf ports merges with traffic from Puerto Rico and the Virgin Islands bound for the same

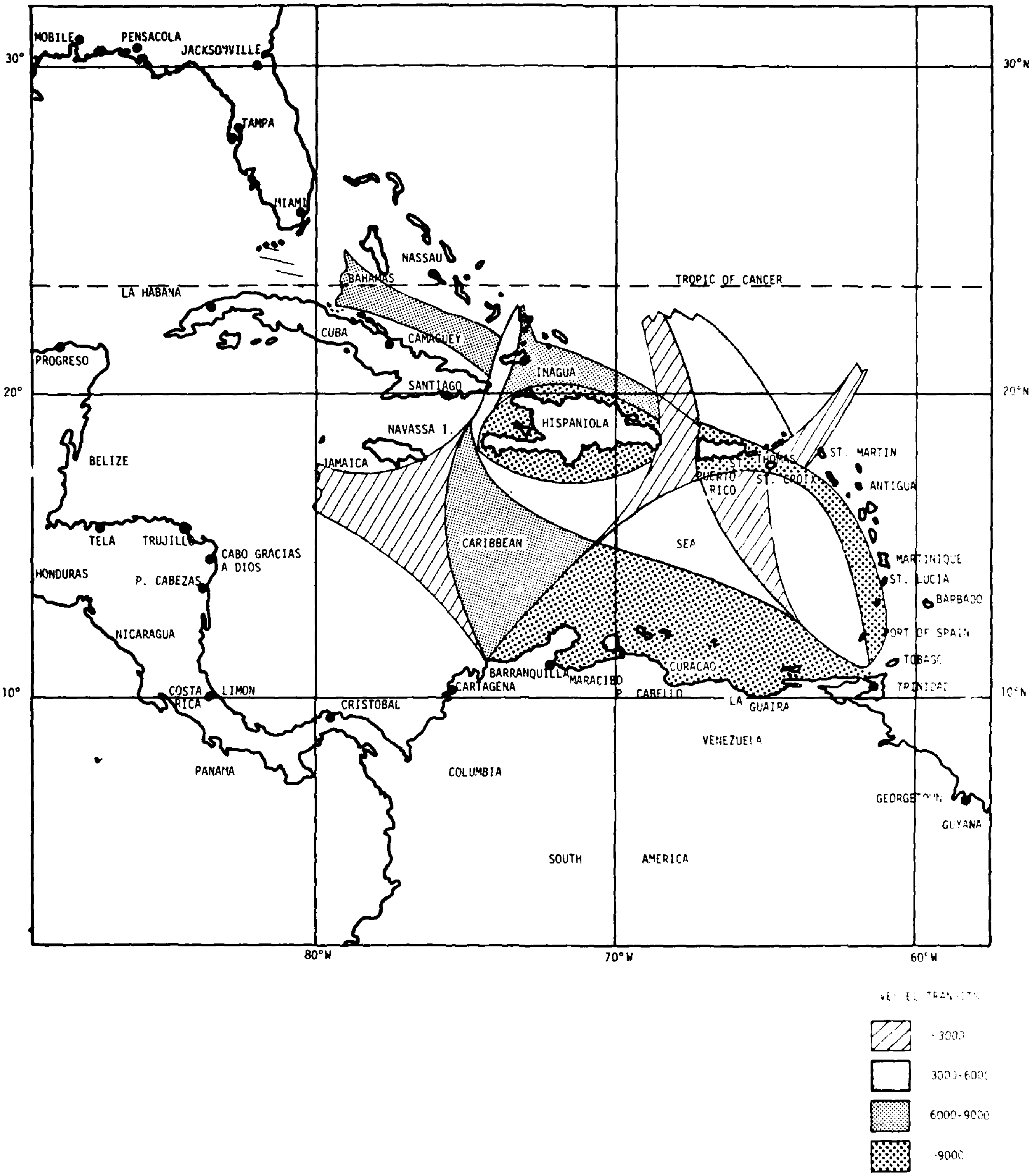


FIGURE 5-1 EASTERN CARIBBEAN TRAFFIC DENSITY

destinations to form regions of moderate to high traffic density. On the other hand, the remaining traffic which flows northward has separated into several distinct patterns of moderate density. Some of this traffic terminates at Puerto Rico and the Virgin Islands while other segments have separated into traffic bound for the Southern, Mid Atlantic and New England ports as well as Europe. All of these latter elements are in the low to moderate traffic density range.

With respect to the traffic density in the various passages in the Eastern Caribbean, the areas surrounding the Virgin Islands are regions of greatest density, in particular the Virgin and the Anegada Passages. On the other hand, the traffic through the Windward and Mona Passages are of low to moderate density; however, this does not reflect European traffic enroute to the Panama Canal. The Old Bahama Channel and the Bahama Passages are of moderate to high density and reflect the inter-island and coast-wise traffic bound for southern and Gulf coast ports. Regions of little to no activity lie in the central and eastern sectors of the Caribbean away from the principal traffic patterns.

5.3 VESSEL POPULATIONS

5.3.1 Commercial Vessels

The number of large commercial vessels customarily operating in support of U.S. trade in the Caribbean was estimated at 350 vessels of which 175 are tankers, the balance are general cargo vessels. Of the tankers, 120 to 150 are foreign flag oil tankers transporting refined product to U.S. from Puerto Rico, U.S. Virgin Islands, Aruba and Venezuela. They also transport crude product from the Persian Gulf, Africa and the North Coast of South America to Puerto Rico and U.S. Virgin Islands. Approximately 25 U.S. flag oil tankers transport refined oil from U.S. Virgin Islands to the continental U.S. and crude product from the north coast of South America to the U.S.

Approximately 80 to 100 foreign flag, general cargo vessels operate habitually in the Caribbean area. Most of the vessels handle the trade between the U.S. and the North Coast of South America and the U.S. and the Greater Antilles. The number of U.S. flag, general cargo vessels operating in the Caribbean is 75 vessels. These vessels predominantly operate between U.S. and Puerto Rico. The major U.S. maritime companies operating in the Eastern Caribbean region are as follows:

	No. of Vessels
Puerto Rican Merchant Marine (Navieras de Puerto Rico)	12
Sealand	8
Delta S.S. Lines	18
United States Lines	9

The number of small commercial vessels (tug/tow, small cargo, barges and others) handling the trade between the U.S. and Eastern Caribbean, as well as the trade among the Caribbean Islands was estimated as approximately 220 units. The number of U.S. flag vessels was estimated to be approximately 70 vessels, the remainder are foreign flag.

5.3.2 Fishing and Commercial Sport Fishing

The fishing vessels which operate in Puerto Rico and the U.S. Virgin Islands were classified into two categories: commercial fishing vessels and commercial sport fishing vessels. The former category refers to those vessels whose operator and crew members derive their primary income from the fish they land. The latter category includes vessels whose operators charter them to private parties for a fee.

The population of the fishing vessels registered in Puerto Rico and the U.S. Virgin Islands is shown in Table 5-3. The combined populations of both Puerto Rico and U.S. Virgin Islands fishing vessels consist of 1524 to 1604 vessels. Information on the sizes and distribution of the commercial fishing vessels registered in the U.S. Virgin Islands is not currently available and the best estimates available indicate that the vessel population ranges between 420-500 vessels (Reference 12, 13). On the other hand, the estimates of the Puerto Rican fishing vessels are considered to be reasonably accurate due to the detailed analysis of the current status and future directions of the Puerto Rican fishing industry (Appendix D). The majority of the fishing vessels are small boats, 10 to 30 feet in length and tend to operate 1 to 50 miles from the shore. Very few vessels, approximately 45 units, are greater than 30 feet in length and these sail to Saba Bank and St. Martin (30 units) and to the North Coast of South America.

5.3.3 Recreational Boats

Included in this group were all pleasure boats which are registered and documented in Puerto Rico and the U.S. Virgin Islands such as sailboats, cabin cruisers, and yachts (greater than 50 feet). Table 5-4 shows the pleasure craft populations of Puerto Rico and the U.S. Virgin Islands in 1978. The number of boats registered in Puerto Rico consists of 17,468 units. Approximately 15,501 or 89 percent, were up to 26 feet, 1972 boats or 11 percent were over 26 feet and only 192 boats were greater than 40 feet. The number of boats registered in the U.S. Virgin Islands consists of 2,567 units. Approximately 264 boats are greater than 40 feet. The total number of boats registered in Puerto Rico and the U.S. Virgin Islands in 1978 were 20,035.

TABLE 5-3 CURRENT AND PROJECTED POPULATIONS OF COMMERCIAL AND COMMERCIAL SPORT FISHING VESSELS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

PERIOD	PUERTO RICO						U. S. VIRGIN ISLANDS		
	COMMERCIAL LENGTH IN FEET				COMMERCIAL SPORT	TOTALS	COMMERCIAL	COMMERCIAL SPORT	TOTALS
	10-20	21-30	30-36	36 AND OVER					
1980	924	71	27	18	21	1061	420-500	43	463-543
1985	924	86	42	23	25	1100	430-520	48	478-568
1990	924	96	52	63	30	1165	440-540	55	495-595
1995	897	99	54	103	35	1188	450-550	60	510-610
2000	871	103	57	143	40	1214	460-550	65	525-615

TABLE 5-4 PLEASURE CRAFT POPULATION
PUERTO RICO AND VIRGIN ISLANDS
INCLUDING MAINLAND TRANSIENTS (1978)

LENGTH	PUERTO RICO	U.S. VIRGIN ISLANDS	CONTINENTAL US
Under 26 ft.	15,496	1631	-
26 to 40 ft.	1,780	672	-
40 to 65 ft.	192	251	-
Over 65 ft.	-	13	870
TOTALS	17,468	2567	870

In order to derive the total number of recreational craft operating in the Eastern Caribbean which are registered under U.S. flag, the number of recreational boats cruising from the continental U.S. through the Bahamas to the Eastern Caribbean should be added. There are approximately 870 boats in this category which cruise to the Caribbean each year. Thus, the total number of U.S. flag recreational boats is approximately 20,905.

5.4 PROJECTED TRAFFIC AND POPULATIONS

The U.S. to Eastern Caribbean traffic will increase modestly over the next twenty year period. These assumptions are based on MARAD projections and discussions with the Puerto Rican Economic Development Commission (References 14, 15). Table 5-5 indicates that the traffic between U.S. and Eastern Caribbean will increase by 7,300 moves or 40 percent. Approximately 5,171 moves, or 71 percent of the increased traffic volume will be generated in the U.S. to the North Coast of South America trade. This substantial traffic growth is due to 17.5 percent increase anticipated in oil tanker traffic. Traffic between the U.S. and Puerto Rico will increase by 1387 moves, or 24 percent and reflects the continued economic growth of this region. This increase will be generated principally by general cargo vessels and cruise ships. The traffic between the U.S. and the U.S. Virgin Islands will not change substantially. General cargo traffic will change only by approximately 180 moves because the additional tonnage will be shipped on larger vessels. At present the Amerada Hess oil refinery in St. Croix, operates close to full capacity (Reference 16) and, therefore, unless the current facilities are expanded, the oil traffic will not change substantially from the Virgin Islands. The traffic between the U.S. and the Greater and Lesser Antilles was projected to change by approximately 550 vessel moves. The additional traffic will be generated by general cargo vessels.

TABLE 5-5 PROJECTED U.S. TO EASTERN CARIBBEAN TRAFFIC (1985 to 2000)

	GREATER ANTILLES				LESSER ANTILLES				NORTH COAST OF SOUTH AMERICA				PUERTO RICO				U.S. VIRGIN ISLANDS			
U.S.	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
New England	63	65	67	69	0	0	0	0	1,060	1,229	1,376	1,513	--	--	--	--	224	233	240	245
Mid Atlantic	290	300	310	318	290	304	319	335	2,783	3,181	3,531	3,858	--	--	--	--	437	454	468	477
South	1,310	1,356	1,404	1,440	491	508	526	539	2,379	2,586	2,780	2,930	--	--	--	--	586	597	616	629
Gulf	1,032	1,068	1,106	1,135	113	117	121	124	4,553	5,173	5,722	6,234	--	--	--	--	250	260	268	273
TOTAL	2,695	2,789	2,887	2,962	894	929	966	998	10,775	12,169	13,409	14,535	4,628	4,970	5,337	5,601	1,496	1,544	1,592	1,624

The population of large commercial vessels will not be affected by the projected additional trade. However, the character and mix of these vessels will change because of the improvements in the operating efficiency of vessels and the utilization of larger vessels to carry the anticipated additional tonnage.

The projected traffic between Puerto Rico and non-U.S. ports is shown in Table 5-6. The traffic between Puerto Rico and other Caribbean Islands was projected from 1980 to 2000 to increase by 2301 moves. The traffic between Puerto Rico and the North Coast of South America was estimated to increase by 301 moves for the same period. The substantial traffic increase between Puerto Rico and other Caribbean Islands is due to the fact that this traffic is generated mostly by small vessels. In general, operators of these ships are not likely to respond immediately to shipbuilding or efficiency improvement trends of the industry.

The projected traffic between the U.S. Virgin Islands and non-U.S. ports is also shown in Table 5-6. In 2000, it is projected to increase by 6,452 vessel moves, or a net increase of 38 percent. Most of this increase was projected to account for the intra-Caribbean traffic. For the reasons discussed above, the oil tanker traffic was projected to increase by only 30 to 40 moves.

Projections of the population of Puerto Rico and the U.S. Virgin Islands commercial fishing fleets were based on discussions with relevant organizations in the U.S., Puerto Rico, and the U.S. Virgin Islands (References 13, 17, 18 and Appendix F). These organizations have recognized that the Puerto Rican commercial fleet is outdated, inadequately equipped and consists of small boats. At the present time, there are plans to increase the fishing fleet, upgrade its quality and diversify the species sought. These plans are discussed in detail in Appendix D.

TABLE 5-6 PROJECTED PUERTO RICO AND U.S. VIRGIN ISLANDS TRAFFIC EXCLUSIVE OF THE U.S. (1985 to 2000)

	PUERTO RICO				U.S. VIRGIN ISLANDS			
REGION	1985	1990	1995	2000	1985	1990	1995	2000
Intra-Caribbean	5,938	6,526	7,113	7,701	17,384	18,964	20,414	22,124
North Coast of South America	2,003	2,098	2,192	2,290	391	410	429	448
Bahamas	113	116	119	122	77	82	87	89
Africa	75	78	81	84	134	136	138	138
Europe	262	270	276	283	98	100	102	102
Persian Gulf	-	-	-	-	134	136	138	138
Others	849	883	926	959	282	289	295	297
TOTALS	9,240	9,971	10,707	11,439	18,500	20,017	21,733	23,336

In general, there are no specific plans to increase the number of commercial fishing boats, or more importantly improve the composition of the U.S. Virgin Islands commercial fishing fleet. Estimates for the number of commercial sport fishing boats were based on the projections that the number of tourists (the major group utilizing these boats in Puerto Rico and the U.S. Virgin Islands) that will visit Puerto Rico and the U.S. Virgin Islands will double by 2000.

Table 5-3 shows the current and projected populations of Puerto Rican and the U.S. Virgin Islands commercial and commercial sport fishing vessels, respectively. This table indicates that by 2000, the Puerto Rican and the U.S. Virgin Islands fishing fleets will consist of 1214 and 525 to 615 units, respectively. Further, by 2000 the number of commercial sport fishing vessels registered in Puerto Rico and the U.S. Virgin Islands will consist of 40 and 65 vessels, respectively.

Table 5-7 indicates the populations of pleasure craft in Puerto Rico and the U.S. Virgin Islands from 1980 to 1985. In 2000, the population of recreational boats in Puerto Rico will consist of 31,202 units. Of those, only 322 will be large boats, 40 to 85 feet in length. The majority, 26,382 craft will be from under 16 to 26 feet in length. The population of craft registered in the U.S. Virgin Islands by 2000 will consist of 4,275 units. Of these, 365 will be greater than 40 feet in length (See Appendix E).

5.5 LORAN-C USERS - CURRENT AND PROJECTED

These projections for LORAN-C users are based on the assumption that some LORAN-C coverage will be available in the Eastern Caribbean by 1984. The availability of this coverage will have the greatest impact upon the fishing and recreational boating community by inducing these operators to acquire LORAN-C receivers. The large commercial operators engaged in shipping operations with the

TABLE 5-7 CURRENT AND PROJECTED POPULATION OF PLEASURE CRAFT IN PUERTO RICO AND VIRGIN ISLANDS (1980 to 2000)

	PUERTO RICO					U.S. VIRGIN ISLANDS				
LENGTH	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
Under 26 feet	17,232	21,572	25,912	26,297	26,682	1,740	2,000	2,310	2,640	2,970
26 to 40 feet	2,168	3,138	4,108	4,153	4,198	700	750	790	850	940
40 to 65 feet	212	262	312	317	322	265	280	300	320	340
Over 65 feet	-	-	-	-	-	14	17	20	23	25
TOTALS	19,632	24,972	30,532	30,767	31,202	2,719	3,047	3,420	3,833	4,275

U.S. mainland will have already acquired LORAN-C receivers in order to enter U.S. navigable waters. The small commercial operator will be driven by the nature of the specific operation, e.g., oceangoing tugs engaged in mainland towing operations already have and will continue to utilize LORAN-C. The inter-island cargo vessels who are slow to respond to innovation will eventually acquire LORAN-C, but in smaller quantities and late in the time frame of this study. The projected users are shown in Table 5-8. Discussed below are the specific acquisition strategies of the various users in the Caribbean.

Seven companies which own or operate 62 large commercial vessels were contacted to obtain information on the type of navigation equipment carried aboard their vessels and the principal means by which they navigate. Of the 62 vessels surveyed, 35 or 56 percent, carry LORAN-C receivers. Omega equipment is carried by 24 vessels, or 39 percent. All U.S. flag vessels which are over 1600 gross tons are required to carry LORAN-C or its equivalent. Similarly, all foreign flag vessels over 1,600 gross tons which call at U.S. ports are required to carry LORAN-C or its equivalent. It is assumed that all large commercial vessels will carry LORAN-C and either Omega or Transit.

Four companies, which operate 21 small commercial vessels were contacted to obtain information on navigation equipment. Of the 21 small vessels surveyed, 12 carry LORAN-C and 11 LORAN-A. Projections for the small commercial vessels were based on the type of equipment the vessels currently carry, and attitudes expressed by the vessel operators contacted. Based on their findings it was estimated that approximately 60 percent of all U.S. small commercial vessels are or will be equipped with LORAN-C.

Fishing organizations contacted in the U.S., Puerto Rico and the U.S. Virgin Islands indicated that none of the commercial fishing boats registered in Puerto Rico and the U.S. Virgin Islands are currently equipped with LORAN-C receivers.

TABLE 5-8 PROJECTED LORAN-C AND DIFFERENTIAL OMEGA USERS

VESSEL TYPE	CURRENT LORAN-C USERS	PROJECTED LORAN-C USERS				PROJECTED DIFFERENTIAL OMEGA USERS			
		1985	1990	1995	2000	1985	1990	1995	2000
LARGE COMMERCIAL	62	100	100	100	100	25	75	95	95
SMALL COMMERCIAL	42	50	55	60	65	10	20	40	40
FISHING[1]	200	240	360	465	577	0	0	0	0
RECRE-ATIONAL[2]	270	323	433	638	737	100	180	250	300
TOTAL	574	713	948	1263	1479	135	275	385	435

[1] Included in these estimates over 200 tuna vessels regeistered in the continental U.S. but bringing their catch in Puerto Rico

[2] Included in these estimates are recreational vessels registered in the continental U.S. but sail to the Caribbean

Similarly, discussions with dockmasters and marina managers in Puerto Rico and the U.S. Virgin Islands revealed that none of the commercial sport fishing vessels operating in these two islands are equipped with LORAN-C sets. Projections for there two categories were based on discussions with knowledgeable individuals in the U.S., Puerto Rico and the U.S. Virgin Islands. It was estimated that by 2000, approximately 217 Puerto Rican large commercial fishing vessels will be equipped with LORAN-C. By 2000 approximately 60 U.S. Virgin Islands commercial fishing vessels will be equipped with LORAN-C. It was estimated that approximately 100 commercial sport fishing boats will be equipped with LORAN-C by 2000. Availability of LORAN-C will induce their operators to equip their boats with LORAN-C because in its repeatable mode it provides for the rapid and accurate relocation of prolific fishing areas.

From discussions with dockmasters and marina managers, as well as surveys taken in Puerto Rico and the U.S. Virgin Islands it was determined that no local recreational boats are equipped with LORAN-C sets. Projections for this group were based on an analysis of LORAN-C users among recreational boats operating in the Miami and Fort Lauderdale area. From this experience, it was projected that approximately 467 recreational boats registered in Puerto Rico and the U.S. Virgin Islands will use LORAN-C by 2000. These boats are large craft over 35 feet in length. In addition to the local population it was estimated that out of the 870 continental U.S. boats sailing to Eastern Caribbean, 270 utilize LORAN-C. By 2000 the total number of recreational boats utilizing LORAN-C will consist of 737 vessels.

5.6 DIFFERENTIAL OMEGA USERS

In this analysis, it is assumed that Differential Omega will exist in the Puerto Rico-Virgin Islands area by 1984 and that the coverage provided by this system will be compatible with the French system in Guadeloupe. Further, it is assumed that both the French and U.S. systems can be used by a common receiver without the requirement for additional equipment. It is also assumed that there will be no federal regulation requiring the installation of Differential Omega by the large marine operator for operations in the Caribbean Coastal Confluence Zone. Purchasing strategies will be based upon the benefits perceived by the user. GPS is assumed to be unavailable.

Some of these users may install Differential Omega as well as LORAN-C because nature of their operations includes trips to regions where either or both of these systems are in use. However, the acquisition of these LORAN-C sets were determined by perceived benefits external to the Eastern Caribbean and hence these latter costs did not enter into the Benefit/Cost calculations. Only Differential Omega costs were considered. The summary of the Differential Omega users is given in Table 5-8.

The large marine operators whose operations are dedicated to the Puerto Rico-Virgin Islands trade will install Differential Omega as part of their suite of electronic navigation equipment. The principal users would be the Puerto Rico Merchant Marine (Navieras de Puerto Rico), tankers operating into Guayanilla and Limetree Bays and container and general cargo traffic from Puerto Rico. It is assumed that 75 percent of the above vessels will acquire Differential Omega between 1985 and 1990 and will reach 95 percent by 1995 and remain at that level.

Few of the small commercial operators will adopt Differential Omega with the oceangoing tugs the most likely potential users to acquire the system. It is assumed that 20 users will initially install Differential Omega and that this number will double by 1995. The small inter-island cargo vessels will probably not use Differential Omega at all since these users are reluctant to accept change and the relatively high cost of the receivers will further deter acceptance of the system.

No commercial fishing vessels will use Differential Omega since the projected coverage patterns of this system will not include the principal offshore fishing grounds. However, those regions which would have coverage are close inshore (Vieques Sound) such that visual means will suffice.

The large recreational power boat owner in the Puerto Rico-Virgin Islands area will probably readily accept Differential Omega since these users are generally price inelastic and are willing to acquire and install new electronic equipment for their vessels regardless of cost. It is assumed that all of the vessels greater than 65 feet will have Differential Omega by 1990 and that 30 percent of the users greater than 40 feet will adopt this system.

6. SYSTEM ALTERNATIVES

6.1 INTRODUCTION

The current and planned mix of navigation systems in the Caribbean consists of those systems identified in Appendix A. While this mix includes LORAN-C coverage in the northwest region, assured coverage by this system throughout the balance of the region is lacking. The purpose of this report is to assess the economic and cost-beneficial validity of this mix of systems vis-a-vis various concepts for the expansion of LORAN-C into additional regions of the Caribbean. Further, this report also considers an additional system, Differential Omega, as a low cost alternative to LORAN-C expansion.

The current mix of systems represents a baseline or "business as usual" approach. This baseline configuration reflects not only what is available now in the Eastern Caribbean but also what is planned to be available in the mid- range future. Against this baseline of systems, certain system concepts have been proposed by the Coast Guard which will expand coverage and availability. These proposed expansions are in addition to systems already in place or expected to become available in the future. These alternative system concepts are not meant to replace, but rather augment and enhance current coverage.

Four system alternatives are considered:

- Caribbean Coastal Confluence Zone LORAN-C Chain which consists of the so-called "midi" chain and includes only Puerto Rico and the Virgin Islands

- Caribbean High-Powered LORAN-C Chain which covers the Coastal Confluence Zone, the Lesser Antilles and the North Coast of South America

- Caribbean Maxi LORAN-C Chain which covers the Eastern Caribbean and has the potential for expansion to include the Bahamas and the Panama Canal Zone

- Differential Omega System providing coverage of the Caribbean Coastal Confluence Zone, principally Puerto Rico and the Virgin Islands.

These system alternatives are discussed in the following sections. All costs given are in FY82 dollars.

6.2 IMPLEMENTATION TIMES

6.2.1 LORAN-C Expansion

The time required to implement the LORAN-C expansion is assumed to be identical for all configurations. This lead time includes OMB and Congressional approvals (1 year); site acquisition (1 year); and, design construction and check out (1.5 years). In fact, some configurations may require longer. The time required for land taking is varied and often unpredictable; further, some of the above concepts require the installation of stations on foreign soil which may delay the implementation times even further. However, for comparison purposes it is assumed that given a go-ahead it would require a minimum of 3.5 years for any of the above LORAN-C system alternatives to become operational.

The impact of the time required to implement a LORAN-C expansion is shown in Figure 6-1 which time-phases this expansion in the context of current system availabilities. From this figure, enhanced LORAN-C coverage in the Eastern Caribbean will not become available until late 1984. Against this data

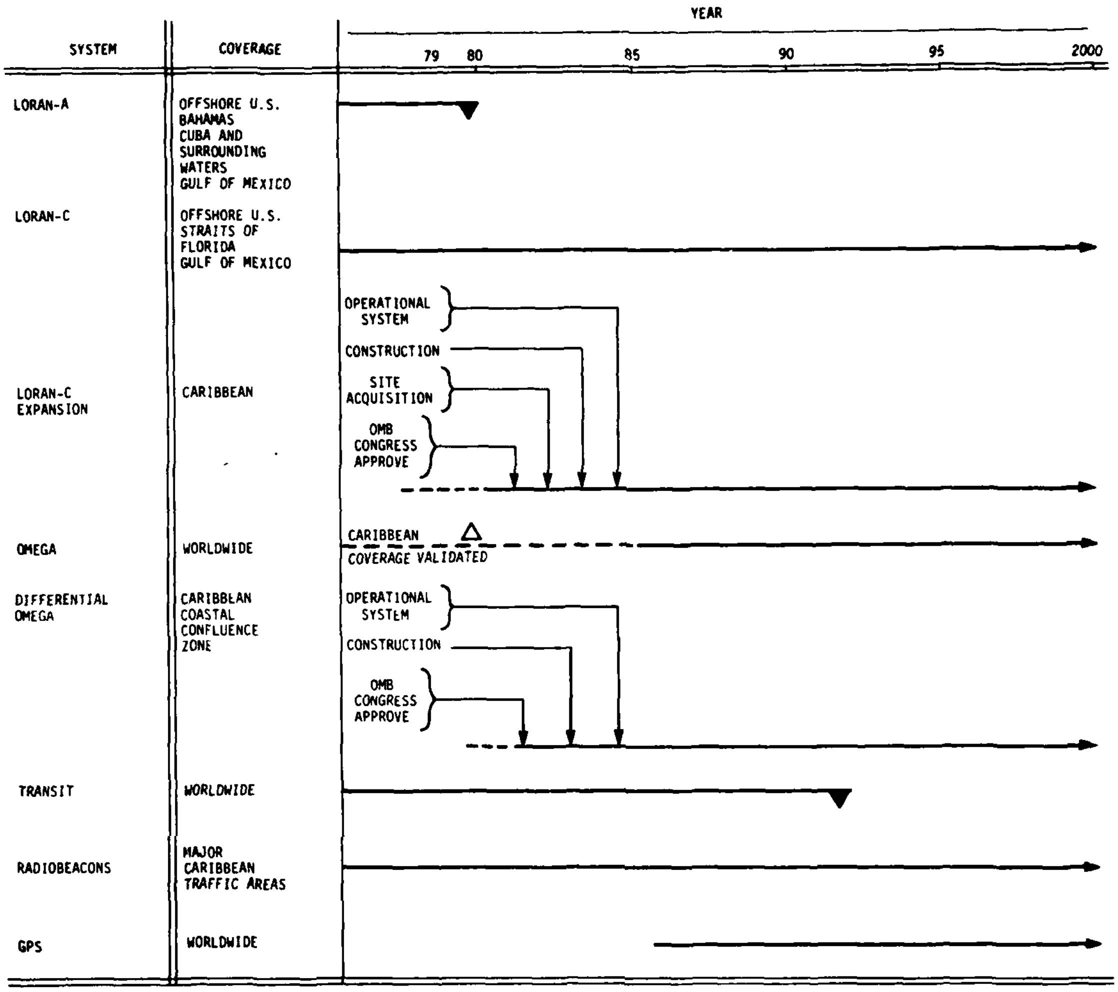


FIGURE 6-1 TIME PHASED ALTERNATIVE SYSTEMS AVAILABILITIES

must be weighed the implementation of NAVSTAR GPS which is scheduled for marine (2-dimensional) operational availability in 1985-87. Thus there would be at most three years between expanded LORAN-C coverage and NAVSTAR GPS availability. Slippages in the NAVSTAR GPS program and an accelerated LORAN-C program may increase this differential, however. This time phasing of planned vs. conceptual systems indicates that one of the critical issues in this study are the costs and benefits of improved LORAN-C coverage vs. the availability (and also improved coverage) of NAVSTAR GPS.

6.2.2 Differential Omega

The implementation times for Differential Omega are in the same time frame as those for the LORAN-C expansion alternatives. The concept of Differential Omega postulated for the Eastern Caribbean relies upon the use of marine or aeronautical radiobeacons to provide the carrier signal for the transmission of Omega error corrections. In this study, it is assumed that the existing radiobeacon stations in Puerto Rico will be adequate for Differential Omega coverage of this region and therefore implementation of this system by 1984 is conservative. However, if subsequent studies should indicate the need for additional sites in Puerto Rico and the Virgin Islands, then the problems of land acquisition and additional radiobeacon/Differential Omega station construction may increase this implementation time period. Further, the problems caused by lack of experience in installation and checkout of this system may further militate against an early operational date. Thus, for analytical purposes, a system operational date of 1984 is assumed. This time phasing is also shown in Figure 6-1.

6.3 LORAN-C MIDI CHAIN

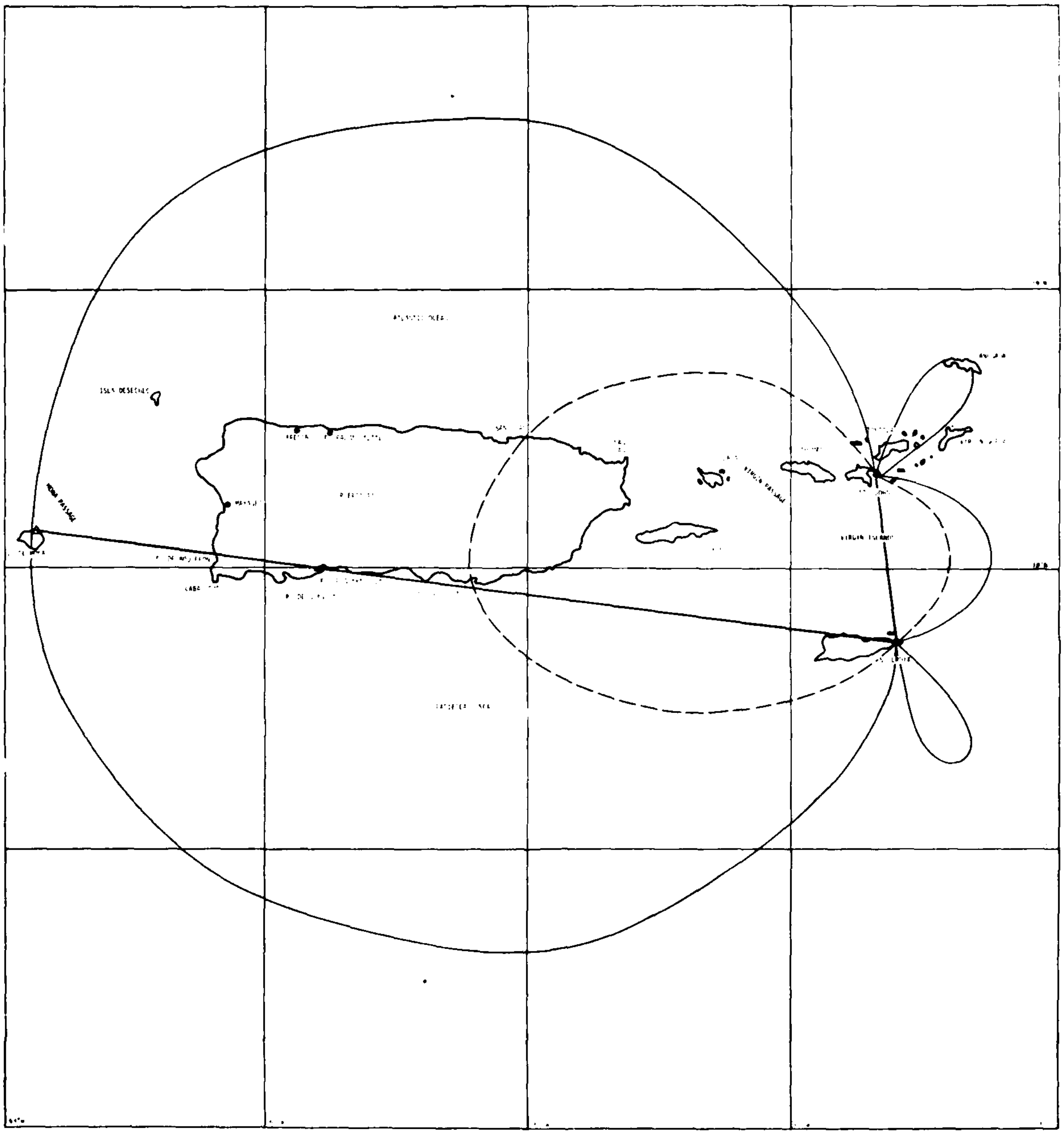
This station configuration provides coverage of most of the Caribbean Coastal Confluence Zone (approximately 34,000 square miles). It is based upon the installation of three low power (10-25 KW) transmitter stations on Mona Island, St. Croix and St. John. A monitor and control station would be located at the Coast Guard base at San Juan under the assumption that reliable communications would be available.

This configuration is shown in Figure 6-2 with fix contours of 0.25 nm and 300 ft. (2 drms at Sigma = 0.1 Microseconds). This configuration provides complete coverage of the coastal waters in the immediate vicinity of the U.S. Virgin Islands and Puerto Rico. Coverage of the Mona Passage is provided only to the east of Mona Island. Principal fix capability of both in terms of accuracy and coverage is to the north and south of the eastern region of Puerto Rico thus providing optimum coverage of the Virgin Passage. There is little coverage of the Anegada Passage and marginal coverage of the waters to the southeast of St. Croix. This latter route is used frequently by vessels approaching St. Croix with crude from the Persian Gulf countries. The entire configuration is sensitive to the location of the stations, there is some doubt as to whether the appropriate land would be available and considerable site preparation may be required.

This configuration costs about $15M to construct including manned facilities at the remote station on Mona Island. Including personnel cost, operating costs are estimated at $1.2M per year.

6.4 LORAN-C HIGH POWER CHAIN

The high power chain provides coverage of the entire Eastern Caribbean including the Caribbean Coastal Confluence Zone, all of the Lesser Antilles, the North Coast of South America and part of the Island of Hispaniola (Figure 6-3).

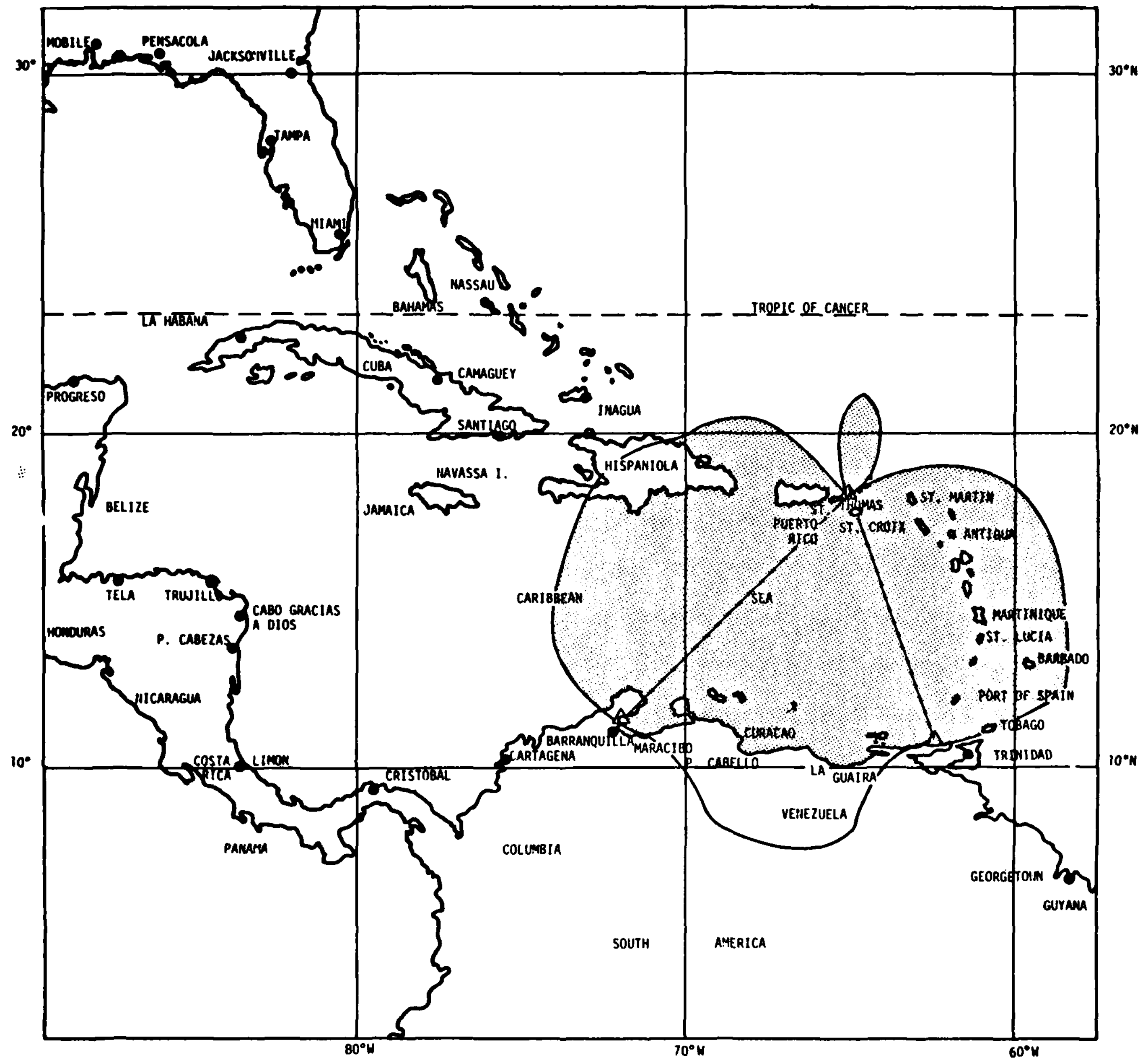


—— 1/4NM or Better

--- 300 Ft.

2 drms at Sigma=0.1 microseconds

FIGURE 6-2 LORAN-C MIDI CHAIN



1/4 NM or better fix accuracy
2 drms with Sigma = 0.1 microseconds
1:3 Signal to Noise Ratio
95% Signal availability
62 dB Noise Limit

FIGURE 6-3 CARIBBEAN HIGH POWER LORAN-C CHAIN

This configuration is based upon the utilization of high power transmitters (1 MW) and could be a joint effort by the United States and Venezuela. It assumes a master station funded, installed and manned by the Coast Guard in the U.S. Virgin Islands (St. Thomas/St. John). It further assumes two secondary stations on the north coast of Venezuela at Maracaibo and Carupano. It is hypothetical that these latter stations would be built, manned and monitored by Venezuela.

This alternative provides over 540,000 square miles of LORAN-C fix coverage including most of the principal passages of the Eastern Caribbean. However, optimum coverage is provided where it is least required (i.e., the open waters of the Caribbean Sea). In other, more critical areas, in particular the North Atlantic approaches to the North Coast of Venezuela and Netherlands Antilles, coverage is less than optimal particularly in the summertime when high noise levels affect signal availability.

Costs to construct these stations are predicated on the willingness of the Venezuelan Government to provide station sites. Assuming no land acquisition costs or abnormal site preparation or access problems, construction costs are estimated at $30M. Annual O & M costs are estimated at $2M. If Venezuela were to assist in the construction and operation of these stations, then U.S. costs are estimated at $17M and $1M respectively.

6.5 LORAN-C MAXI CHAIN

This is a wide area LORAN-C chain designed to provide optimal coverage of the Eastern Caribbean and the oil trade routes serving the East Coast of North America (Figure 6-4). This chain consists of a master station and monitor in Puerto Rico and secondary stations in Venezuela, the Leeward Islands and South Caicos Island. All stations are assumed to be 400 kW. The Leeward Island station would be located as far to the east as possible, possibly on the edge of the Bahamas

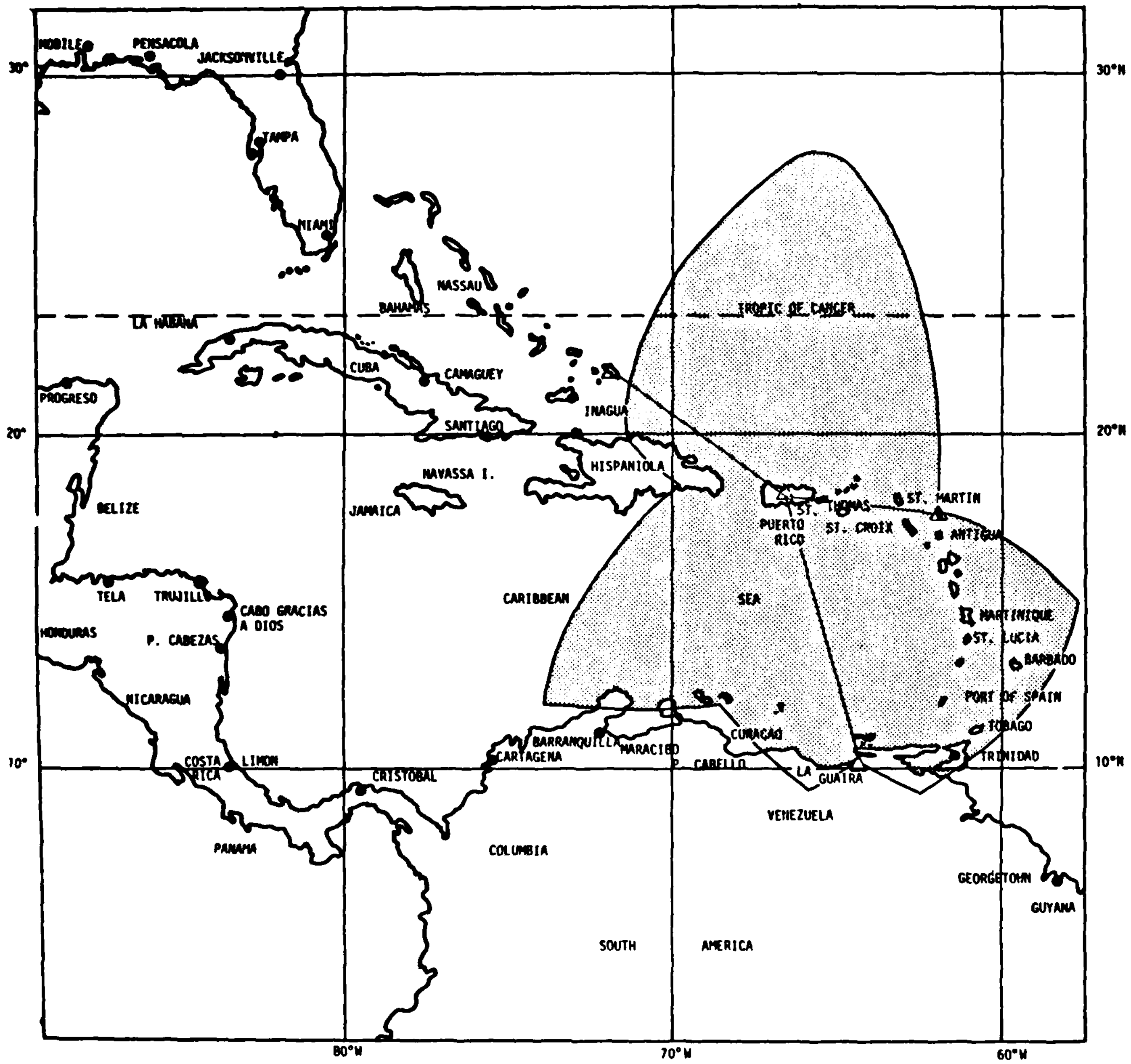


FIGURE 6-4 CARIBBEAN LORAN-C MAXI CHAIN

1/4 NM or **Better** Fix Accuracy

2 drms with Sigma = 0.1 micro-seconds

1:3 Signal to Noise Ratio

95% Signal Availability

67.5 dB Noise Limit

and would provide the basis for furure expansion into this region. South Caicos Island is the site of one of the LORAN-A stations comprising the Bahamas chain and hence this facility could be used as the basis for a LORAN-C station. While the Venezuelan site would help to provide optimal coverage of the Eastern Caribbean, coverage of Venezuelan waters to the west and north would be limited.

The principal feature of the design of this chain is its potential for future expansion to the Western Caribbean. This capability could be used to provide coverage of the approaches to the Panama Canal and Gulf of Mexico as well as the Bahama Islands. A principal disadvantage of this concept is the requirement for station locations on foreign soil thereby engendering additional elements of difficulty on site acquisitions and construction.

Because of the multinational station locations in this configuration and because of the precise role and contribution of those nations is as yet undefined, total costs must be regarded as extremely tentative and may vary as much as 50 to 100 percent. Assuming that the U.S. would build, operate and maintain these stations, construction costs were estimated at $42M. This figure does not include land acquisition costs nor abnormal access or site preparation costs. These latter costs may be substantial in the remote sites postulated for this chain. Annual operating costs could be at least $3M. If host nations were to participate in the operation of this chain, these annual costs may be reduced by $1-$2M.

6.6 DIFFERENTIAL OMEGA

The Differential Omega alternative is designed to provide radionavigation aid coverage of the Caribbean Coastal Confluence Zone including the waters surrounding Puerto Rico and the Virgin Islands, Mona Passage and the Virgin Passage. Such a system would be comparable in accuracy to that postulated for LORAN-C and would cover a region similar to the Midi Chain expansion alternative. In the proposed configuration, 14,000 square miles would be covered with 0.25 nm accuracy.

The concept of Differential Omega is based upon the installation of an Omega monitoring station at a precisely known location colocated with a marine or aeronautical radiobeacon. The monitor receives the standard Omega signals, measures the propagation errors and transmits in real time the propagation correction values using the radiobeacon signal as the subcarrier. In the Differential Omega receiver the correction is automatically added to the standard Omega signal to yield a corrected line of position. Accuracy tends to degrade as a function of distance from the radiobeacon, and it is assumed that 0.25 nm accuracy can be obtained at distances up to 50 nm. At distances between 50 nm and 100 nm, accuracy is reduced to 0.5 nm (Reference 55). The application of Differential Omega to the Caribbean Coastal Confluence Zone is based upon the utilization of existing radiobeacon coverage in the area from stations in Puerto Rico. This projected Differential Omega coverage is shown in Figure 6-5 using 50 nm, 0.25 nm accuracy contours. Coverage may be increased through the installation of additional stations on the South and West Coasts of Puerto Rico, St. Thomas and St. Croix. Further study is necessary to determine optimum station location and whether additional stations would be necessary. Also shown in Figure 6-5 is the location and coverage contour of a Differential Omega station under development at Pointe a Pitre in Guadaloupe by the French Government. As can be seen this coverage would complement the Caribbean Coastal Confluence Zone alternative.

Costs for this configuration are approximately $100K per station, or $400K for a four station system, exclusive of radiobeacon costs. Annual operating and maintenance costs are estimated at $40K. No isolated personnel billets are anticipated.

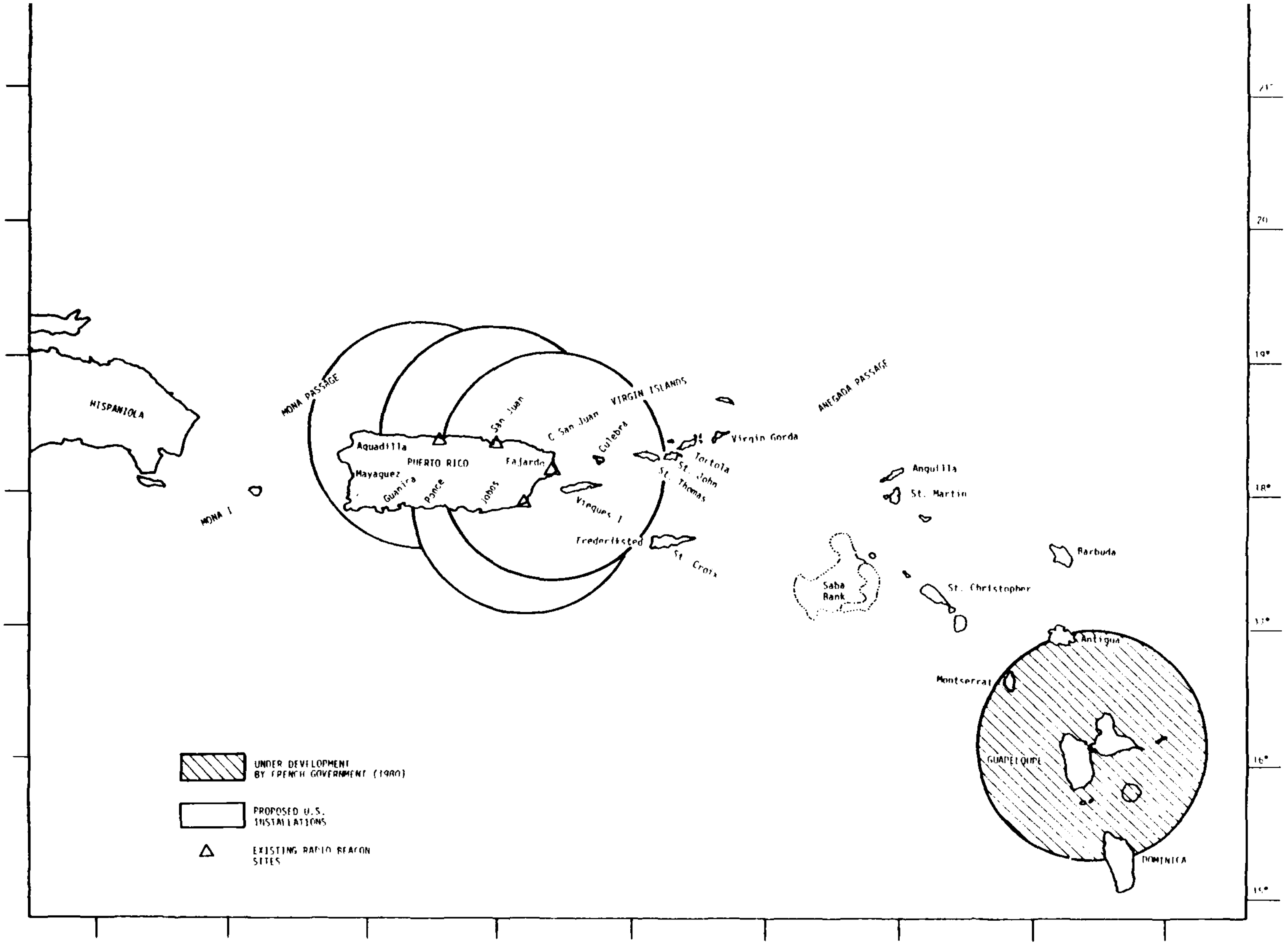


FIGURE 6-5 DIFFERENTIAL OMEGA CONFIGURATIONS
50 NM 1/4 NM ACCURACY

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BENEFITS AND COSTS OF LORAN-C EXPANSION INTO THE EASTERN CARIBB--ETC(U)
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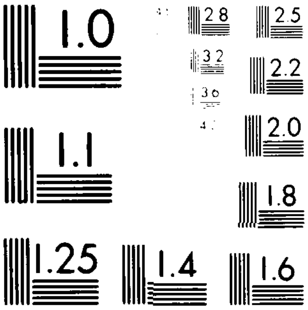

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

In addition, the French Government is currently considering the implementation of Differential Omega at Martinique in the French West Indies. A decision on this system extension is expected by 1983. When implemented, this station would provide coverage of the St. Lucia - Dominicia Channel and augment the Guadeloupe station.

6.7 TRAFFIC AND COVERAGES

Using the traffic patterns and traffic densities discussed in Section 5.6, the relative coverages of the four system alternatives were determined. In this determination, both traffic coverage and area coverage were used as measures of comparative system capability. The traffic figures used were those that were expected to be generated in the year 2000. For consistency purposes, the entire Caribbean region was used for comparison. It was assumed that this region extended from 60°W to 80°W and from 11°N to 23°N. Considered in this region were only those vessels engaged in United States commerce.

The results of this determination are shown in Figure 6-6. As can be seen, area coverage and traffic coverage are not identical, but vary as a function of traffic density. The Differential Omega alternative while providing the least area coverage, covers nearly as much traffic as the Midi Chain. The Maxi Chain provides 16 percent more area coverage than the High Power Chain yet captures essentially the same amount of traffic thus indicating that the former chain provides coverage of open and low density areas. From these observations, it would appear that the Differential Omega system and the High Power Chain are preferable from the prospect of greater potential utilization of the signal by the projected users. On the other hand, if greater relative coverage is the criterion, than the Maxi and Midi Chains appear preferable.

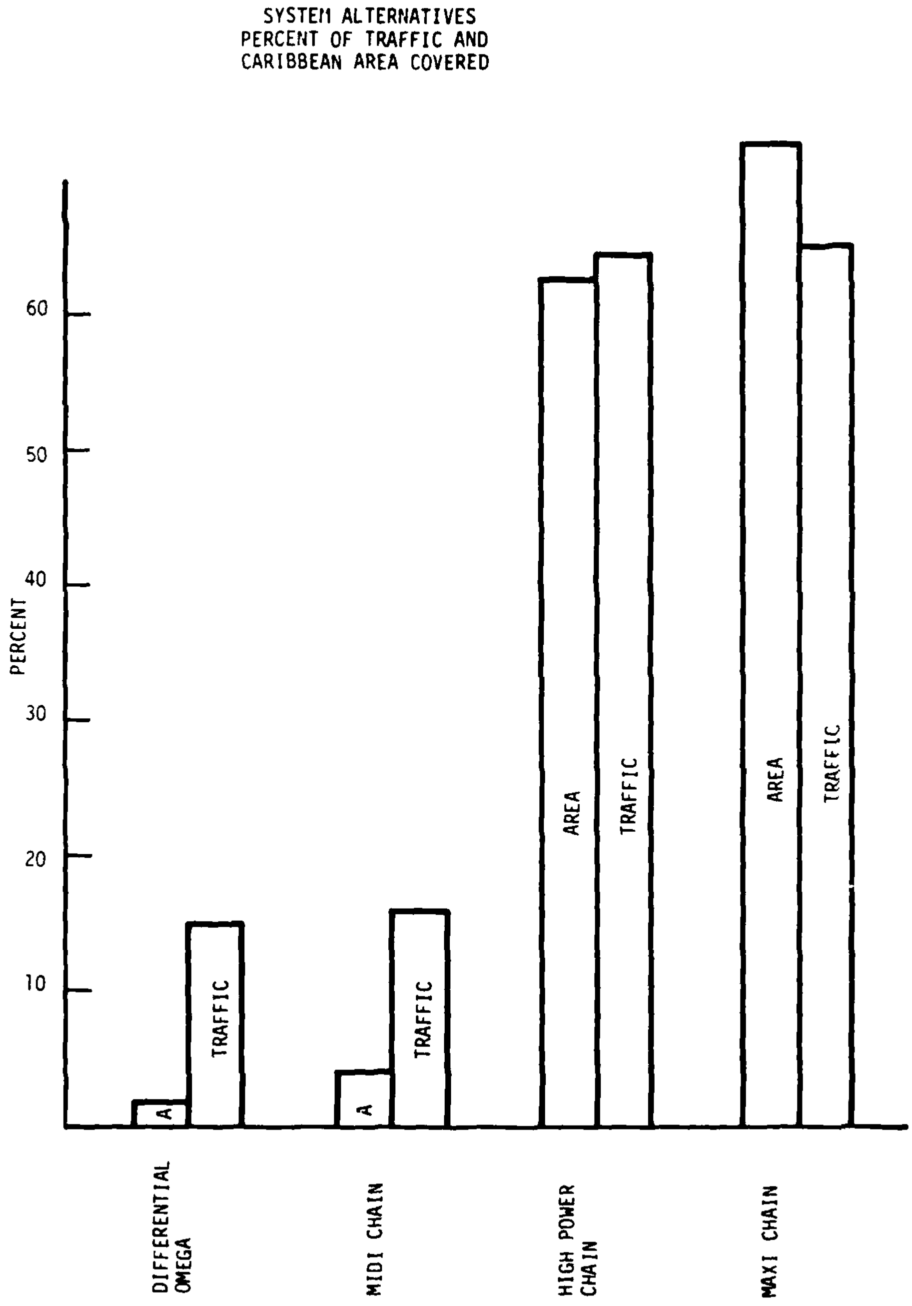
SYSTEM ALTERNATIVES
PERCENT OF TRAFFIC AND
CARIBBEAN AREA COVERED

FIGURE 6-6 PERCENT OF TRAFFIC AND AREA COVERED

7. SYSTEM COSTS AND IMPACTS

7.1 APPROACH AND ASSUMPTIONS

Using Coast Guard supplied estimates, station costs for the various LORAN-C and Differential Omega system configurations were determined. These station costs were assumed to consist of investment costs and annual operations and maintenance (O & M) costs. The investment costs included the electronics equipment; antennas, buildings and power; communications and test equipment; and costs associated with the installation and check out of the stations. Not included are the costs associated with the site, such as land acquisition, or abnormal site access and preparation. These costs may be considerable in view of the remote character of some of the stations in the options. In San Juan and the Virgin Islands, commercial power is available. All other stations were assumed to be isolated sites and that they would have to generate their own power. The monitor and control station at San Juan was considered to be installed in existing facilities at the Coast Guard Base.

The total investment costs were assumed to be obligated within a one year period; that is, in the year of program initiation. O & M costs for the first year following program initiation were assumed to be accrued at 25 percent of the full annual rate. This assumption was based on the fact that the station would be undergoing a transition to operational status during that period and that some maintenance costs would be covered under equipment warranties. This assumption was consistent with that used in Reference 19. In the subsequent years, O & M costs were accumulated at the full annual rate.

Life cycle costs reflected station operations through the year 2000.

Two cost structures were used: current (1982) dollars and discounted dollars. A discount rate of ten percent was used to determine present value costs in accordance with OMB Circular A-94 (Reference 20). The use of discounting tends to reduce the cost impact of major systems acquired late in the time stream. In this study, the major investments are made early in the time stream, and hence, the relative impacts between discounted and current dollar investments are slight. The major differences between them are attributable to O & M costs.

7.2 GROUND STATION TOTAL COSTS

7.2.1 Discounted Dollars

Cost comparisons among the three alternatives for the discounted dollars case are shown in Figure 7-1. Two options are shown for the High Power and Maxi Chain configurations. These options reflect a configuration with full U.S. participation (i.e. all stations built, manned and operated by U.S.) and a configuration with host nation(s) participation. In the latter configuration, it is assumed that the U.S. will provide the equipment and some support in the station construction, and that the host nation will provide the major construction costs and all of the operation and maintenance costs. The costs for the High Power Chain with Venezuelan participation and the Midi Chain are similar (approximately $22 million). The Maxi Chain with host nation participation is slightly greater ($28 million) due principally to an increased investment cost. The most costly alternative is the Maxi Chain with the U.S. constructing and operating the system and it is over twice as expensive as the least costly options ($56 million vs. $22 million).

7.2.2 Current Dollars

The current dollar costs are shown in Figure 7-2. All alternatives and options retain their same relative positions as compared with the discounted dollars examples. The investment costs for the two cost configurations are similar. The

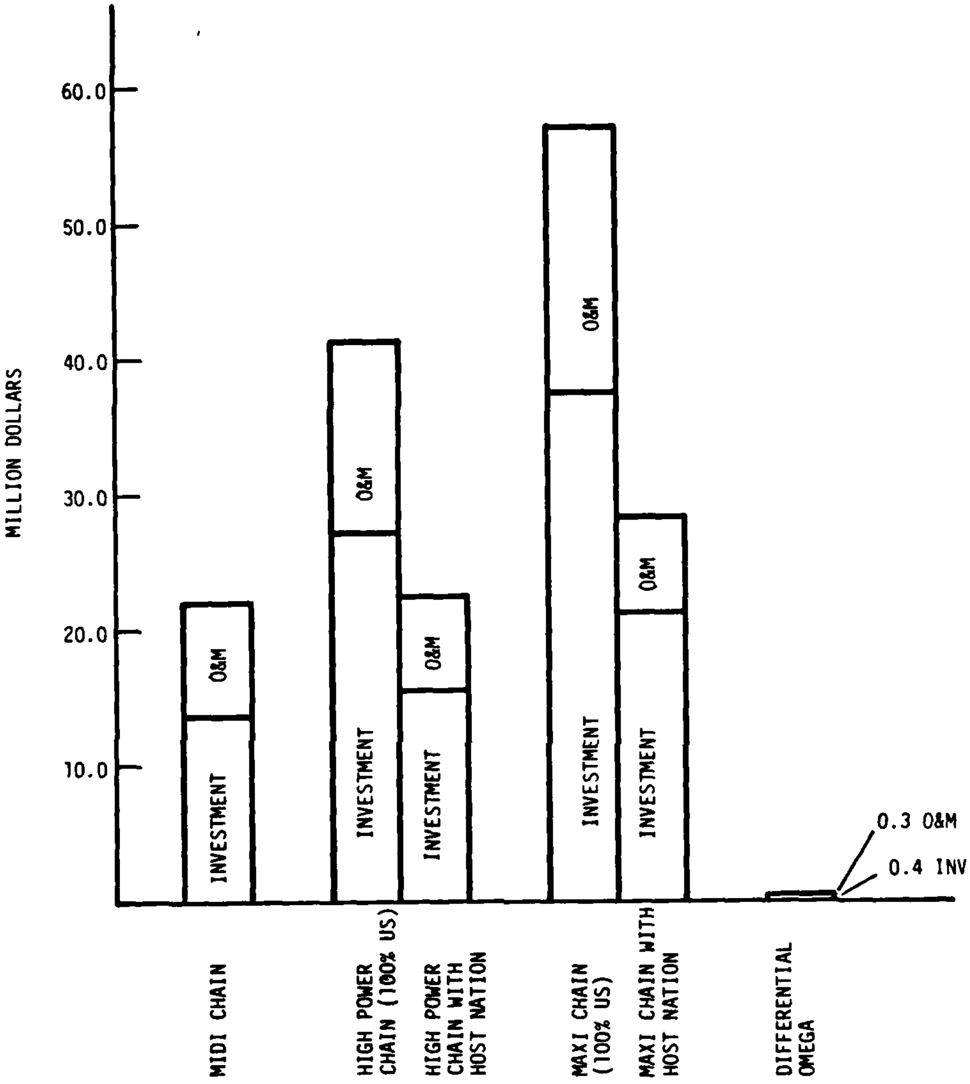

FIGURE 7-1 SYSTEM ALTERNATIVES COSTS DISCOUNTED DOLLARS (10%)

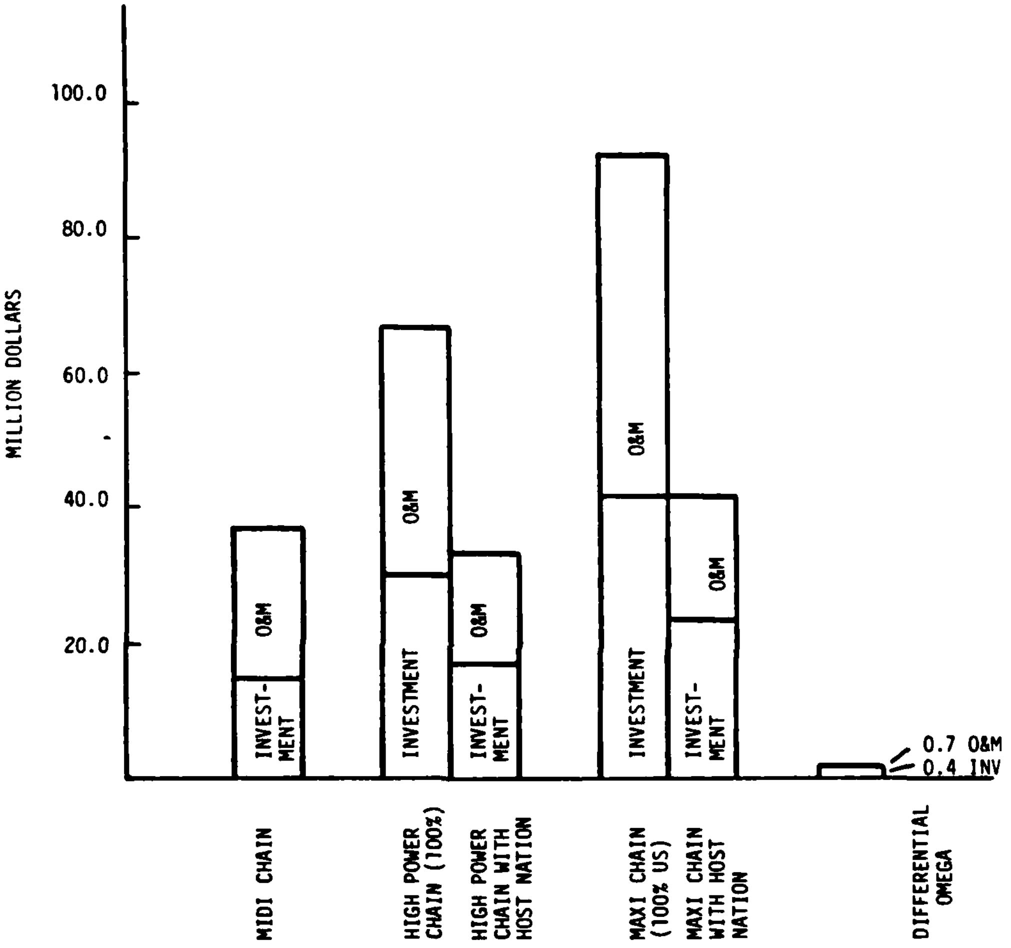

FIGURE 7-2 SYSTEM ALTERNATIVES COSTS CURRENT DOLLARS

principal differences are in the O & M costs. The effect of discounting can be seen, since these latter costs are time dependent. In the constant dollar case the O & M costs represent approximately half of the total, while in the discounted dollars, they are one third of the total.

With respect to total current dollar costs, the High Power Chain with host nation participation is slightly less than the Midi costs ($33 million vs. $37 million). The Maxi Chain with host nation participation is slightly higher at $42 million total cost. On the other hand, the Maxi and High Power Chain costs with full U.S. operation are $92 and $67 million, respectively.

7.3 GROUND STATION COST/COVERAGES

7.3.1 Unit Area Costs

Dollar costs per square mile of coverage area shown in Figure 7-3 for the discounted dollars case. The costs for the Midi Chain are significantly greater than for the other alternatives and options. The former costs are greater than $600/square mile as compared to a high of $91/square mile for the Maxi Chain and $76/square mile for the High Power Chain, both of which assume full U.S. operation. With host nation participation the latter coverage costs are similar - approximately $45/square mile for each option. In all of the cases, the investment costs are approximately two thirds of the total costs since discounting has reduced the impact of O & M costs.

Using current dollars, costs per square mile of coverage were determined. These results are shown in Figure 7-4. The Midi Chain is approximately $1100/square mile, the High Power and Maxi Chains are $123 and $146 respectively, assuming full U.S. construction and operation costs. These latter costs are reduced by approximately fifty percent when host nations participate in the system. In all cases, costs are approximately equally distributed between investment and O & M costs.

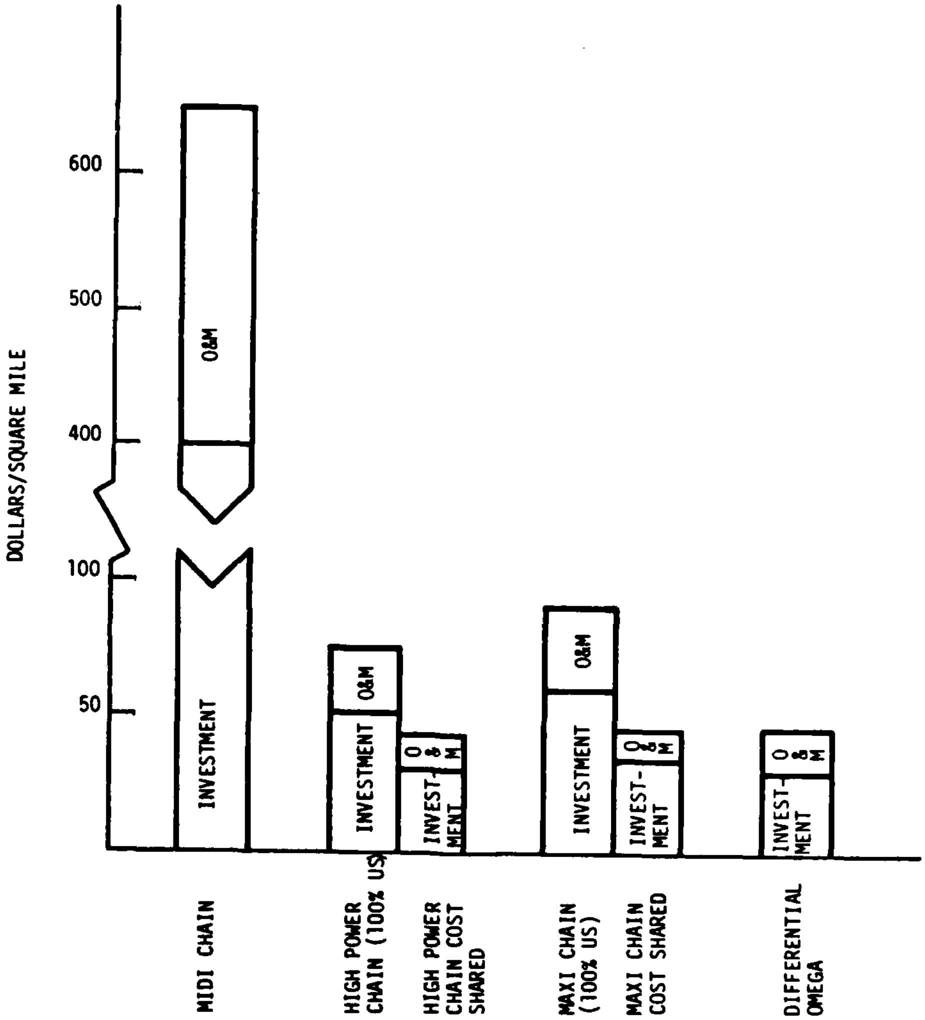

FIGURE 7-3 SYSTEM ALTERNATIVES COSTS PER SQUARE MILE DISCOUNTED DOLLARS

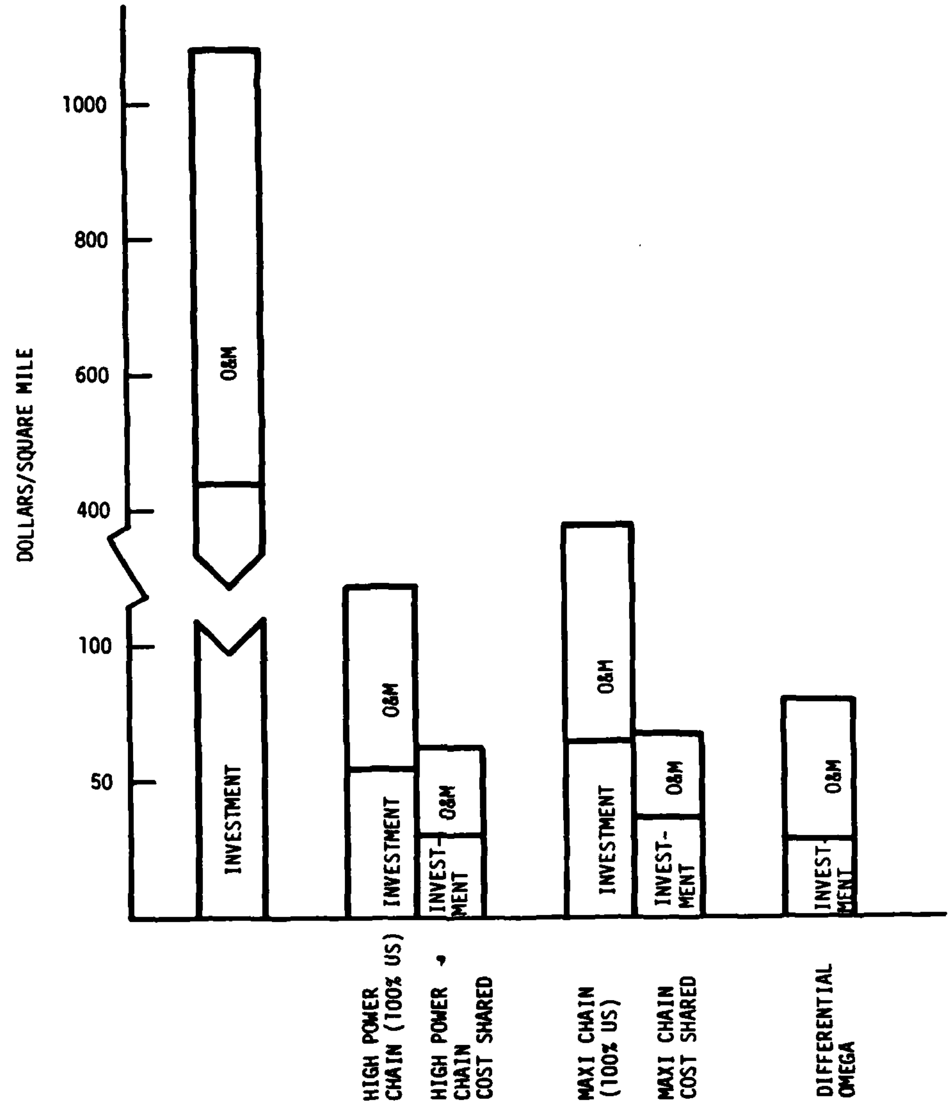

FIGURE 7-4 SYSTEM ALTERNATIVES COSTS PER SQUARE MILE CURRENT DOLLARS

7.4 GROUND STATION PERSONNEL REQUIREMENTS

7.4.1 LORAN-C Alternatives

Included in the O & M costs for the various LORAN-C configurations are the personnel costs for manning and operating the stations. Aside from the costs attributable to the three alternatives, there are also personnel requirements generated in terms of Coast Guard billets and increased manning levels. Based on Coast Guard supplied information increased billet requirements were determined for the three LORAN-C expansion alternatives. These requirements are shown in Figure 7-5. Only the requirements for full U.S. participation are shown. If there is host nation participation, the billet requirements for isolated foreign stations will be reduced. However, these billets may not be totally eliminated, since there may be a requirement for advisory or supervisory personnel to assist in station operation and maintenance. In all alternatives, the personnel shown are minimum requirements.

The Midi Chain has the lowest personnel requirement (1 officer, 21 enlisted) since all of the stations are on U.S. territory, however, the Mona Island station is isolated and requires more frequent personnel rotation. It is assumed that personnel from the monitor and control station at San Juan will be rotated with the Mona Island facility. The greatest personnel requirements are for the Maxi Chain with the majority of personnel assigned to the isolated, foreign stations. Of the 75 billets estimated for the Maxi Chains, 57 are required for the isolated stations. Similarly, in the High Power Chain, 38 out of 56 billets are assigned to foreign stations. Host nation participation would reduce these requirements greatly. In all alternatives, four enlisted billets are assumed to be assigned to the Coast Guard Greater Antilles Section (GANTSEC) in San Juan for overall system support. In addition, the requirements for the monitor and control station in San Juan are considered to be identical for the three alternatives. These billets consist of one officer (commanding officer) and five enlisted.

	Midi Chain				High Power Chain				Maxi Chain			
	Officer	Warrant	Enlisted	Total	Officer	Warrant	Enlisted	Total	Officer	Warrant	Enlisted	Total
LORAN STATIONS												
San Juan					0	1	7	8	0	1	7	8
St. Thomas	0	0	4	4								
St. Croix	0	0	4	4								
Mona Island	0	0	4	4								
Maracaibo, Ven.					1	1	17	19				
Carpuano, Ven.					1	1	17	19				
Barcelona, Ven.									1	1	17	19
South Caicos									1	1	17	19
Barbuda									1	1	17	19
MONITOR & CONTROL												
San Juan	1	0	5	6	1	0	5	6	1	0	5	6
GANTSEC												
San Juan	0	0	4	4	0	0	4	4	0	0	4	4
TOTALS	1	0	21	22	3	3	50	56	4	4	67	75

FIGURE 7-5 BILLET REQUIREMENTS - LORAN-C EXPANSION ALTERNATIVES

As well as the additional billets required for the LORAN-C expansion alternatives, there are additional system support functions which will impact on existing Greater Antilles Section and Seventh District personnel. These impacts may be covered by expanding the duties of assigned personnel or may generate the requirement for additional billets at these facilities.

At the Section level the additional support is estimated to include:

Officer

1 LCDR (Electronics Engineering)

1 LCDR (Civil Engineering)

Warrant Officer

2 CWO (Electronics)

1 CWO (Finance and Supply)

1 CWO (Engineer)

Enlisted

1 TTC (Teletype, Chief)

1 EMC(Electrician Mate, Chief)

1 SK (Storekeeper)

2 YN (Yeoman)

At the District level the additional support is estimated to include:

1 LT (Operations)

1 LT (Electronics Engineering)

1 LT (Civil Engineering)

1 LT (Law)

1 CWO (Electronics)

The additional impact upon headquarters personnel has not been included, but may also generate additional billet requirements.

7.4.2 Differential Omega Configuration

The impact of Differential Omega upon Coast Guard manning levels is expected to be slight. At the station level, there may be a requirement for an additional electronics technician, although it is quite probable that the maintenance duties could be handled by the current GANTSEC personnel. At the headquarters level, the personnel requirements have not been determined although it is not expected to be substantial.

7.5 USER COSTS AND IMPACTS

7.5.1 LORAN-C Alternatives

The impact of receiver costs upon the marine user was determined based upon data collected in the Caribbean region and discussions with representatives of various user groups in Puerto Rico and the Virgin Islands. Those data are presented in detail in the appendices. The small, locally oriented user, such as the recreational boater, small marine operator and the local fisherman, while small in size, are large in number. If they decide to purchase navigation receivers, either NAVSTAR GPS or LORAN-C or other contending systems, they could represent a significant market. Thus, an assessment of the purchasing plans and proclivities of these groups is essential to the outcome of this study.

On the other hand, the large marine operators are few in number and are generally willing to adopt improved navigational systems as a means of enhancing productivity of their vessels. Further, those vessels which call at mainland U.S. ports are required by regulation to carry LORAN-C receivers or other authorized equipment (i.e. Transit) (Reference 2).

Based on the data collected certain judgments can be made with respect to the procurement and employment of navigation systems by the marine users.

- Most of the large marine operators carry a combination of LORAN (either A or C) and global (Transit or Omega) navigation systems as well as radar. Some have elected to use Transit until NAVSTAR GPS become available and because of uncertainty concerning the future of LORAN-C in the Caribbean. However, the new purchases of sets attributable to LORAN-C availability in the Caribbean is expected to be slight, since most of these users are already equipped or would wait for NAVSTAR GPS. The principal purchases of LORAN-C sets would be replacements for those already in place.

- The large commercial fishermen, particularly the tuna fishermen travel great distances from Puerto Rico, frequently to the Pacific and South Atlantic. Most of these users are equipped with state-of-the-art electronic equipment, including LORAN-C and Omega and would not be a significant new purchaser of LORAN-C. However, the local fisherman, should the industry expand as discussed in Appendix D, could be a substantial purchaser of LORAN-C in the latter decade. These purchases could amount to several hundred sets.

- Most of the small commercial vessels engaged in inter-island trade generally operate within sight of land. These operators rely upon their knowledge of the region for navigation and rarely carry any navigation equipment more sophisticated than a compass. They are generally slow to change methods of operating and did not avail themselves of LORAN-A when it was available. It would be extremely unlikely if many would use LORAN-C if it should become available.

- Most of the large tugs operating in the Puerto Rico - Virgin Islands region are equipped with LORAN-C (as well as LORAN-A) and radar. In addition, there are a few who have Transit or Omega. These are seagoing vessels whose range extends to the Gulf and East Coasts and Panama Canal, and since they are already equipped with LORAN-C, their purchases will be constrained to replacements in kind.

- The recreational boaters (870) who own vessels of large size and who cruise from the East Coast, through the Bahamas and the Antilles are equipped with sophisticated navigation receivers including LORAN-C, Transit and Omega. Should LORAN-C become available in the Eastern Caribbean, it is probable that this category would be the largest user of LORAN-C in the near future. However, many of these users have already purchased LORAN-C receivers and hence, they may not account for substantial additional purchases. On the other hand, those boaters who are permanently based in the Puerto Rico-Virgin Islands area will probably avail themselves of LORAN-C and will constitute the single largest category of purchasers. Such purchases could amount to over 900 sets by the year 2000.

Overall, it appears that the influence of LORAN-C expansion into the Caribbean upon users who may purchase LORAN-C receivers will be slight. Most large marine users are already equipped and the smaller users have not perceived requirement for this, or any other, electronic navigation system.

7.5.2 Differential Omega

The initial high cost ($14,000) assumed for the Differential Omega receivers coupled with its limited coverage constrains these purchases to relatively few vessels.* Most of the Differential Omega coverage today exists in Europe, the Mediterranean, and the West Coast of Africa as well as French territories in the Western Hemisphere. Initial purchases of this system will be confined to vessels principally engaged in the trade between Puerto Rico-Virgin Islands and these regions. Large commercial vessels will adopt the system initially, followed by high value small commercial vessels engaged in inter Caribbean trade. The more cost-insensitive recreational boater will acquire these sets at a more rapid rate than the other user categories; however, the overall rate will not equal that postulated for LORAN-C.

*more recent information (October 1980) indicates that these costs have been reduced to $10-12,000. However, for purposes of this study, the $14,000 figure was used.

8. SYSTEM BENEFITS

8.1 INTRODUCTION

The principal thrust of this study has been to identify and quantify system benefits. While many benefit measures immediately come to mind which can be related to improved navigational accuracy, the determination of a numerical value for these measures was the subject of considerable investigation. This section addresses the benefit measures used in the analysis and the methods and data sources used for their quantification.

Improved navigation affects two principal areas: Productivity and Safety. Within the area of productivity are such benefits as reduction in trip time, closer adherence to desired or optimum track with resultant fuel savings and more efficient operations through improved arrival scheduling. In the area of safety there are benefits to be gained by a reduction of the potential for groundings, strandings and rammings and a reduction in insurance premiums through lowered regional loss experience. Ancillary to these safety benefits is a reduction in the probability of pollution.

As well as the civil user- related benefits which are identified above, there are other benefits which impact upon government functions, particularly Coast Guard functions. These may be broadly categorized as improved efficiency of Coast Guard operations. Specifically such areas include reduction in effort in responding to and/or accomplishing Search and Rescue (SAR) missions; improved accomplishment of Enforcement of Laws and Treaties (ELT) and Marine Environmental Protection (MEP) Missions; and, the possible introduction of vessel traffic monitoring in narrow or congested seaways.

8.2 QUANTITATIVE BENEFIT MEASURES

Based upon a review of the available literature, discussions with knowledgable individuals in the marine community and in the Eastern Caribbean and on a review of the vessel data base which had been amassed in support of this study, four major quantifiable benefit measures were identified which could be attributable to improved navigation. These measures were: Vessel fuel savings, port scheduling savings, vessel casualty reductions and insurance premium reduction. These measures are discussed below. Benefit measures for improved Coast Guard Operations are discussed in Section 9.

8.2.1 Vessel Fuel Savings

Previous studies (References 21, 22, 23) have indicated that there is a potential fuel savings attributable to improved navigational accuracy. These savings can be derived through better shiphandling, more economical routing and better knowledge of the effect of set and drift upon vessel course and speed. In the above studies, the economic effect of improved navigational accuracy was determined as a function of shortened trip times, trip distances or fuel economics. These savings have ranged from a high of 1.5 percent to a low of 0.17 percent for various regions of the world and assumed navigational accuracies. For 0.25 nm navigational accuracy, the savings ranged from 0.17 percent to 0.64 percent for trade routes through the Caribbean. For the determination of the benefits accruing to the Eastern Caribbean expansion alternatives, it was assumed that the average savings would amount to 0.25 percent. Further, 0.1 percent was also assumed to be a minimum value for comparison purposes and to provide a range of benefits.

8.2.2 Port Scheduling Savings

Based on discussions with shipping companies and port authorities (Appendix F), it appears that savings are possible through better scheduling of port services and more accurate determination of vessel arrival times. These productivity improvements can include reduced waiting times for pilotage and berths and more efficient scheduling of longshoremen services. However, the most costly element of a vessel's operating expenses is in port cargo handling. This element amounts to approximately 23 percent of the vessels total operating expenses and is second only to crew wages. Further, payment for longshoremen services begins when the vessel is scheduled to arrive, not when the vessel actually arrives and hence the delay of an hour in scheduled arrival can have a significant impact upon vessel operating expenses. Thus, savings in this area appeared to be most promising. By comparison, pilotage and berthing savings appeared to be minor.

Savings would accrue from the ability of a vessel to arrive at a certain place at a scheduled time with greater accuracy (e.g., arrival at a sea buoy or harbor entrance closer to a designated time). Two separate cases were examined to provide a range of values for savings due to improved navigational accuracy. It was assumed for those cases that navigational accuracies in the Caribbean are either 4.0 nm or 2.0 nm and that all system expansion alternatives would provide an improvement of those accuracies to 0.25 nm or better. In each case, it was assumed that half of the vessels would arrive either early or on time and hence no benefits would accrue to them. In the first case, the remaining half of the vessels would miss their arrival point by 2.0 nm and in the second case by 1.0 nm. These results were based on the assumption that they will be late by one-half of the maximum error of the system (e.g., 2.0 nm for accuracies of 4.0 nm). When 0.25 nm accuracies were introduced, similar logic prevailed, however the numbers were too small to enter into the analysis and hence the final savings for all vessels were 1.0 nm and 0.5 nm per vessel, respectively. These figures were then converted into the times required for a vessel to cover these distances.

8.2.3 Vessel Casualty Reduction

Savings attributable to the reduction in casualties due to faulty navigation are an obvious benefit from improved navigational accuracies. These savings include not only the reductions in vessel losses and damages, but also, the indirect and less obvious savings. This latter category include the savings in the costs include in refloating or salvaging the vessel, such as tug costs, deballasting and lighterage costs, divers inspection and drydocking costs. In addition, there are losses incurred while the vessel is aground and in a non productive status.

In this analysis of radionavigation expansion alternatives, a study of marine casualties in the Eastern Caribbean was conducted. The results of this study are given in Appendix B. These results include the probable impact of improved radionavigation accuracy and the expected savings both in casualty costs and in lost productivity.

8.2.4 Insurance Premium Savings

The effect of improved radionavigational capability also impacts upon the operating costs of the vessel, particularly in terms of the reduction of the premiums for hull and machinery insurance. Discussions with underwriters at the American Hull Insurance Syndicate (Appendix F) have indicated that as a rule, no insurance premium reduction is made for vessels or regions with improved navigation capability. On the other hand, a certain minimum level of navigational capability is presumed. Vessels which do not meet these standards are assigned to a higher premium rate. On the other hand, if the loss history of the vessel is favorable, a proportionate reduction in premium can be gained.

In Reference 21, an estimate of the premium reduction was determined using a favorable loss history due to improved radionavigation accuracy. It was estimated that 1.5 percent of the hull losses due to grounding could be avoided by the use of improved navigation. This loss avoidance can be translated into an insurance savings. After reductions for overhead and profit, this reduction was determined to be 0.825 percent. This factor was applied to the premiums for those vessels which normally operate in the Caribbean and who would be the principal users of the system expansion alternatives.

8.3 DETERMINATION OF USER BENEFITS

8.3.1 Vessel Fuel Savings

Benefits due to improved navigational accuracy were determined as a function of vessel fuel savings. In this determination only the large commercial vessels (tanker and cargo) were considered since these operators are the principal quantifiable beneficiaries of LORAN-C. The traffic projections, traffic patterns and densities, trade route segments and system alternatives coverages discussed in previous sections were used to determine the number of vessels (transits) and route distances affected by improved navigational accuracy. The accuracy improvement factors discussed above were used in this determination (0.1 and 0.25 percent). This resulted in annual savings in nautical miles as a function of vessel type and system configuration. These determinations were made for each year from 1985 - 2000.

Two variables were introduced into these calculations: First, the price of oil was considered to be a separate, independent variable and was assumed to escalate 50 percent every 5 years. Assuming a price of $28.00 a barrel for Saudi crude in April 1980, this results in a price of $141.75 a barrel by 2000. This approach was used since the escalating price of oil represents an unusual event which impacts directly only upon the benefits element of this analysis. No other inflation-based variables were used since overall inflation impacts equally upon the cost and benefits elements. Secondly, traffic projections for the region have indicated a fairly low rate of growth, based on the assumption that while the number of vessels remain reasonably constant, their size will increase. Hence, larger vessels were assumed to enter the Caribbean fleet between 1985 and 1995.

Using MARAD-supplied estimates (Reference 24) of average vessel speeds and fuel consumptions for the various categories and tonnages of vessels, together with the estimated fuel costs, fuel savings were determined on an annual basis for cargo and tank vessels, for the four system configurations. These results are shown in Table 8-1, aggregated through the year 2000, in discounted dollars. As can be seen, the savings attributable to this benefit element are not substantial for any system alternative.

In addition, the benefits attributable to the Midi LORAN-C Chain are greater than those attributable to the Differential Omega System since it is assumed that virtually all large marine operators will have LORAN-C receivers by 1985 and hence can avail themselves of the signal. On the other hand, it is assumed that initially there will be few users of Differential Omega (10 percent), and that these users will not increase to over 50 percent until after 1990 (see Section 5.0).

8.3.2 Port Scheduling Savings

Port scheduling savings were determined based on inbound traffic scheduled to arrive at Eastern Caribbean ports. Only large commercial vessels were considered since optimum unloading and rapid port turn around is a critical element in these vessels' operations. Small, inter-island operations were not included since these operations are informal with much of the cargo handling being done by the crew.

TABLE 8-1 CUMULATIVE NAVIGATIONAL IMPROVEMENT SAVINGS - DISCOUNTED DOLLARS (MILLIONS)

	SYSTEM ALTERNATIVES			
VESSEL	MIDI CHAIN	MAXI CHAIN	HIGH-POWER CHAIN	DIFFERENTIAL OMEGA
TANKER	0.3-0.7	2.9-7.3	2.5-6.3	0.1-0.2
CARGO	0.3-0.8	1.8-4.4	1.3-3.2	0.1-0.3
TOTALS	0.6-1.5	4.7-11.7	3.8-9.5	0.2-0.5

The projections for large marine traffic from the U.S. given in Section 5. were reduced by 50 percent to account for the fact that the scheduling for only inbound traffic would be affected by system improvements.

Large marine intra-Caribbean traffic was not so reduced. The expected values attributable to improved accuracy discussed in 8.2.2 were used (0.5 - 1.0 nm). In all cases vessel speed was assumed to be 15 knots which resulted in time savings of 2 and 4 minutes respectively. Based on discussions with port authorities, cargo handling costs generally run between $3,000 - $4,000 per hour and are charged for at scheduled arrival time. Hence, small improvements in arrival scheduling can result in several hundred dollars' savings. In this case, the expected value savings are $167 and $233, respectively.

Using those planning factors and estimated vessel populations, savings were determined for the four system configurations. These results are shown in Table 8-2. No distinction was made between the Maxi and High Power Chain since both of these systems provide similar coverage of the major Caribbean ports. On the other hand, there are greater benefits attributable to the Midi Chain than to the Differential Omega system since there will be more users of the former system due to the reasons ennumerated above. Overall, in this benefit element, as with the fuel improvement saving, no large savings can be attributed to enhanced navigational accuracy.

8.3.3 Vessel Casualty Reduction

The results of the Eastern Caribbean casualty analysis performed for the five year period 1974 - 1979 (Appendix B) have indicated that the area is generally free from major navigation-related vessel incidents. Further, of those incidents that were navigation-related. Enhanced LORAN-C or Differential Omega coverage would have played a significant role and might have prevented the

TABLE 8-2 CUMULATIVE PORT ARRIVAL SAVINGS - DISCOUNTED DOLLARS (MILLIONS)

	SYSTEM ALTERNATIVES			
ACCURACY IMPROVEMENT	MIDI CHAIN	MAXI CHAIN	HIGH-POWER CHAIN	DIFFERENTIAL OMEGA
4.0NM to 0.25NM	5.4	15.3	15.3	1.9
2.0NM to 0.25NM	2.6	7.6	7.6	1.0

grounding in only 4 out of 84 cases. In 13 other cases, such coverage would have played a supporting role and might have contributed to prevention of the incident. Included in these incidents are all categories of vessel classes including not only the large and small commercial, but also the fishing and recreational boats as well.

In Appendix B the costs of these incidents were determined. Included in such costs were not only vessel loss and damage costs, but also loss in productivity, refloating, salvage and inspection costs where appropriate. In those 13 incidents where improved radionavigation coverage would have played a supporting role, these costs were reduced by a factor of 50 percent to account for the uncertain impact of such coverage. In the four cases where radionavigation would have played a significant role, the costs were not so reduced.

Based on this five-year loss experience, vessel population projections were made using the predicted increases given in Section 5. These assumptions are Caribbean-specific and were based on MARAD projections and discussions with the Puerto Rico Economic Development Commission (Reference 15, Appendix F). In addition, projections were made by MIT in support of the Offshore Vessel Traffic Management Study (Reference 25). These latter projections indicate a somewhat higher annual growth rate (3 percent) than used in this analysis. Therefore both growth projections were used in estimating the future vessel casualties in order to provide a range of values. In both estimates, a linear relationship was assumed to exist between vessel population growth and vessel casualties.

The estimated savings in vessel casualty costs due to LORAN-C expansion and Differential Omega are given in Table 8-3. No difference is noted between the Maxi and High Power Chain savings since both of these chains cover the same casualty regions. The Midi Chain covers approximately 92 percent of the

TABLE 8-3 CUMULATIVE VESSEL CASUALTY SAVINGS - DISCOUNTED DOLLARS (MILLIONS)

	SYSTEM ALTERNATIVES			
PROJECTED GROWTH	MIDI CHAIN	MAXI CHAIN	HIGH-POWER CHAIN	DIFFERENTIAL OMEGA
WORLDWIDE TRAFFIC GROWTH	5.2	5.6	5.6	1.5
CARIBBEAN TRAFFIC GROWTH	3.2	3.5	3.5	0.9

vessel groundings. The savings due to Differential Omega are considerably reduced since it is assumed that few vessels would be equipped with these receivers initially. In all of these savings, it is presumed that the vessel master, captain or boat owner uses and trusts his radionavigation equipment and that operations are conducted with prudence and good judgment. In most of the navigation-related groundings examined, it appears that the latter two elements were missing.

8.3.4 Insurance Premium Savings

Insurance premium savings were estimated using the loss avoidance reduction factor identified above (0.825 percent). MARAD-supplied estimates identified the vessel insurance costs as a function of vessel class, size, tonnage and flag ownership (Reference 24). These estimates range from $154,000 for a 25,000 ton, foreign flag cargo vessel to $470,000 for a 60,000 ton U.S. flag tanker. From these figures were extracted those elements attributable to Hull and Machinery (approximately 30 to 40 percent) premiums. The premiums for the Tanker and Cargo vessel were determined based on the size projections given in Section 5. and compatible with those used in Section 8.3.1. In this analysis vessel populations were used since savings were determined as a function of the individual vessels and not as a function of traffic flows. Because of the differential that exists between U.S. and foreign flag insurance rates, determinations were made for both of these categories. The foreign flag vessels used in the estimates were either U.S.-owned or engaged in U.S. commerce (including Puerto Rico and the U.S. Virgin Islands).

These savings in discounted dollars are shown in Table 8-4 for the four system expansion options. The High Power and Maxi Chain options are identical since both of these alternatives provided coverage of the same casualty area.

TABLE 8-4 CUMULATIVE INSURANCE PREMIUM SAVINGS - DISCOUNTED DOLLARS (MILLIONS)

	SYSTEM ALTERNATIVES			
VESSEL	MIDI CHAIN	MAXI CHAIN	HIGH-POWER CHAIN	DIFFERENTIAL OMEGA
US CARGO	0.3	0.4	0.4	0.3
US TANKER	0.1	0.1	0.1	0.1
TOTAL	(0.4)	(0.5)	(0.5)	(0.4)
FOREIGN CARGO	0.2	0.2	0.2	0.2
FOREIGN TANKER	0.4	0.4	0.4	0.4
TOTAL	(0.6)	(0.6)	(0.6)	(0.6)
TOTALS	1.0	1.1	1.1	1.0

Similarly, the premium savings attributable to the Midi Chain and to Differential Omega were assumed to be the same since the coverages are similar. It was assumed that the regional availability of Differential Omega both from Puerto Rico and Guadeloupe would cause a reduction in premium even though not all potential users adopted the system at the time of its implementation. From these results, it can be seen that although some insurance savings will accrue from improved navigational accuracy, they will be slight.

8.4 QUALITATIVE BENEFITS

In addition to those quantified benefits and savings identified above, there are certain qualitative benefits which contribute to the overall well-being of the mariner on the open ocean, out of sight of land. Chief among these is the assurance that the vessel's location can be accurately and rapidly determined. Further, there is the assurance that in times of distress, the location provided by such a system (either in Latitude and Longitude or in time-difference coordinates) can be broadcast to search and rescue elements, and will provide a reference point for the initiation of the rescue mission. Such an attribute is of particular benefit to the recreational boater whose skills in navigation may not be as great as those of the seasoned mariner, particularly in times of stress and distress.

The political benefits associated with radionavigation cannot be measured, however, they can be significant. The availability of a radionavigation signal is not discriminatory, and can be used by any mariner with the proper equipment. As such, this signal reflects the presence of the originating country and provides a constant reminder of the country's contribution to international safety at sea. While the worth of such benefits in the Caribbean can not be measured, the availability of a LORAN-C or Differential Omega signal may provide a measure of international good will in an area where United States' presence and policies have been under criticism.

9. COAST GUARD OPERATIONS AND BENEFITS

9.1 INTRODUCTION

The effect of the expansion of LORAN-C or the introduction of Differential Omega on Coast Guard operations in the Eastern Caribbean is assessed in this section. Only those elements of the Coast Guard mission which will be affected by improved navigational accuracy are considered. Where those effects can be quantified in terms of benefits, cost savings or personnel reductions, these missions are discussed in detail. The benefits which have been quantified are directly attributable to a LORAN-C expansion or Differential Omega installation and, it is felt, constitute the principal direct Coast Guard savings. Other effects which serve to improve the Coast Guard's mission are indirect benefits, not as readily quantifiable, and require a detailed operations analysis of missions, effectiveness and accuracy in greater depth than possible in this study. In addition, there are certain disbenefits which relate negatively to radionavigation improvements either through environmental impacts or constraints upon operational effectiveness. These effects are also considered.

9.2 EASTERN CARIBBEAN OPERATIONS

Coast Guard operations in the Eastern Caribbean are under the cognizance of the Commandant Seventh Coast Guard District, Miami, Florida. Administratively, the Eastern Caribbean is designated as the Greater Antilles Section (GANTSEC) with headquarters at the Coast Guard Base, San Juan, Puerto Rico (Figure 9-1). Other Coast Guard facilities in the region are the Coast Guard Air Station, Borinquen, Puerto Rico, site of the former Ramey Air Force Base, the LORAN-A stations at Cabo San Juan, Puerto Rico, San Salvador Island and South Caicos Island. Since LORAN-A is scheduled for termination on December 31, 1980, these latter stations will become candidates for deactivation.

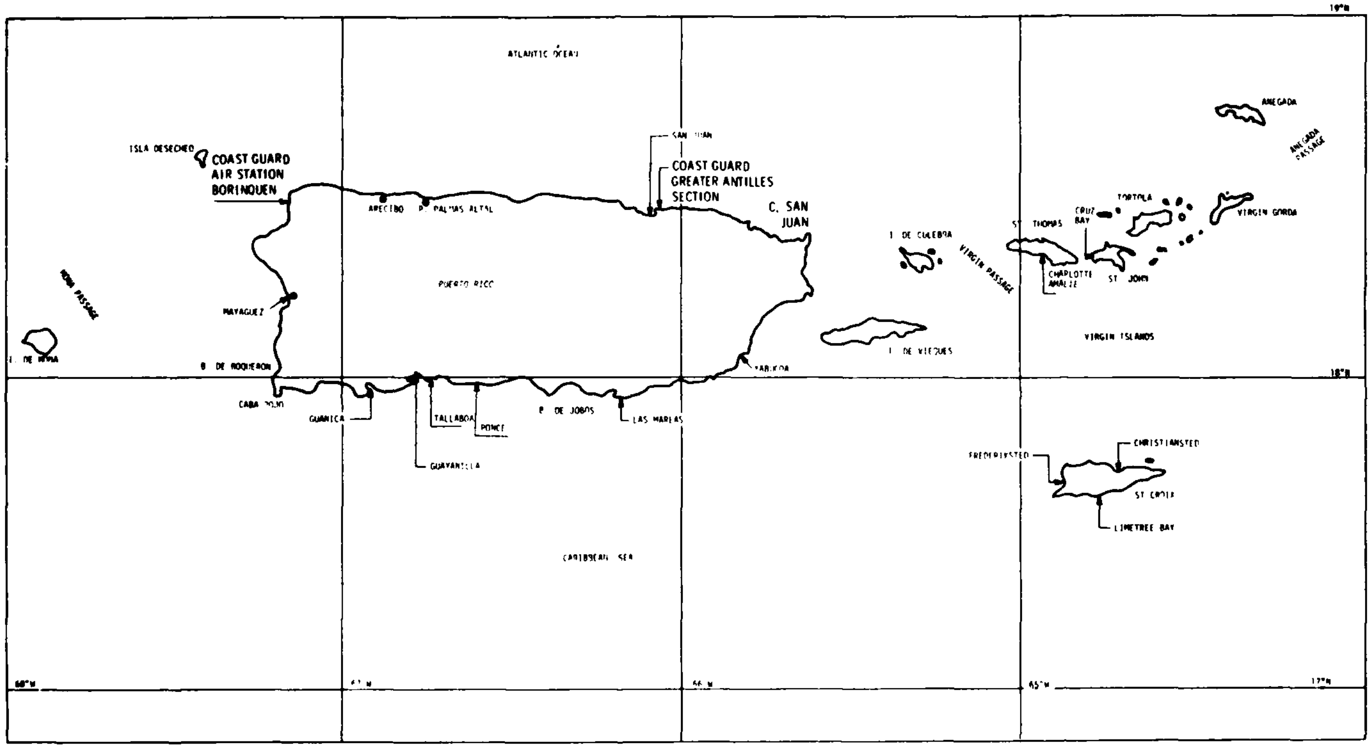

FIGURE 9-1 COAST GUARD FACILITIES - EASTERN CARIBBEAN

The operating units permanently assigned to the region consist of 3 HH-3 helicopters at Borinquen Air Station, a buoy tender and 82 ft patrol boat at San Juan and an 82 ft patrol boat at Charlotte Amalie, St. Thomas, Virgin Islands. Operations in the region are augmented by cutters on detached assignment from East and Gulf Coast Districts. In addition, HC-130 aircraft are occasionally detached from the St. Petersburg/Clearwater Air Station to supplement helicopter operations.

The areas of operation for these units consist of not only the Eastern Caribbean including the Coastal Confluence Zone and the Fishery Conservation Zone, but may extend to specific regions for extended search operations. ELT operations cover not only anti-smuggling and anti-alien activities in the Puerto Rico-Virgin Islands Region, but also drug interdiction and blocking operations in the major passages - particularly those in the Western Portions of the Caribbean including the Yucatan Channel and the Windward Passage as well as Mona Passage in the East. Protection of the marine environment includes operations in support of anti-dumping and anti-pollution including oil spill surveillance in the Coastal Confluence Zone and adjacent waters. In support of vessel traffic safety, traffic separation lanes and vessel monitoring systems, while not currently employed, are potential activities which may be introduced into Eastern Caribbean operations. All of the above missions in the Eastern Caribbean have an element which is related either directly or indirectly to enhanced navigational accuracy.

Navigation by Coast Guard vessels permanently assigned to the Eastern Caribbean is principally performed by radar, visual and celestial means. Radionavigation equipment on these vessels consist of LORAN-A and Radio Direction Finder receivers. In addition, the buoy tender has an Omega receiver installed as well as LORAN-C. The question of installation of LORAN-C for the 82 ft. patrol boats is currently under study. On the other hand, the HH-3 helicopters at Borinquen until recently have had no wide area electronic navigation equipment installed. As a result, navigation-related problems have often developed with these aircraft with the resulting degradation in mission effectiveness. In addition, HC-130 aircraft with inertial navigation packages aboard have had to be dispatched to provide improved navigation in SAR cases when the HH-3's have been deficient. In FY 1980, Omega receivers were installed on the HH-3's on an experimental basis with considerable success after some initial problems. As a result Omega is now the principal means of electronic navigation in the Eastern Caribbean for these aircraft. Cutters serving in the Caribbean on detached duty, principally those from East and Gulf Coast Districts generally have LORAN-C receivers aboard. Depending upon the skill of the operator and the sophistication of the receiver, LORAN-C skywaves can be used successfully north of Puerto Rico and Hispaniola. South of Puerto Rico, reception and tracking varies from terrible to nonexistent (Reference 26). In this area celestial means are used exclusively when out of radar range of land.

9.3 SEARCH AND RESCUE (SAR)

9.3.1 General

The magnitude of the Search and Rescue effort is defined in terms of the number of cases investigated over the past two years by units of the Seventh Coast Guard District, particularly those operating in the Greater Antilles section. These cases are summarized in Table 9-1, are identified as a function of the various system expansion alternatives and were derived from Reference 54. In terms of number of cases, these responses reflect less than 4 percent of the

TABLE 9-1 EASTERN CARIBBEAN SAR CASES WITHIN SYSTEM COVERAGE AREAS

SYSTEM ALTERNATIVE / YEAR		SAR CASES			SQUARE MILES PER CASE
		1978	1979	TWO YEAR AVERAGE	
LORAN-C	MAXI CHAIN	504	361	432	1449
	HIGH POWER CHAIN	445	332	388	1391
	MIDI CHAIN	425	239	332	102
DIFFERENTIAL OMEGA		~400	~200	~300	46

Seventh's District SAR workload. Further, in both years approximately 15 percent of the cases occurred greater than three miles offshore. Table 9-1 also indicates the number of square miles of system coverage per case as a measure of alternative radionavigation system capacity and SAR case load. Thus, while this region is marked by a relatively low case load, the area it encompasses is large enough to make the amount of searching per case substantial, particularly in those cases occurring beyond the sight of land.

The impact of the large area requirements upon the search load can be seen in the SAR Statistics for Air Station at Borinquen (Table 9-2). In this table, the HH-3 hours flown in support of the SAR missions are shown in terms of actual hours and percent of total resource hours. Also shown is the percent of the service-wide resource hours employed in the SAR mission. As can be seen, on a comparable four year basis HH-3 employment is over one-third greater than the service-wide average. Further, in FY 1979, helicopter SAR operations at Borinquen increased to 43 percent of the total workload. In addition, over the past five years, helicopter hours flown in support of the Coast Guard mission have consistently exceeded the programmed hours by approximately 20 percent. Thus, it appears that LORAN-C expansion might give benefits in this area and hence the effect of improved navigational accuracy was examined for impact not only on the SAR effort, but also as a means of reducing excess helicopter flight hours.

A review of the 1979 SAR data files was made at the Greater Antilles Section in San Juan to determine if a pattern exists between navigation-related SAR incidents and the availability of LORAN-C. Of the over 500 SAR cases in the data file, approximately one-half were for medical evaluation or other similar assistance; further, 20 percent of the cases involved vessels lost or overdue. The navigation-related incidents comprised twenty-eight cases, most of which involved

TABLE 9-2 COAST GUARD AIR STATION, BORINQUEN, P.R. - SAR STATISTICS

SAR WORKLOAD	FISCAL YEAR					FOUR YEAR AVERAGE ('75-'78)
	1975	1976	1977	1978	1979	
HOURS	948	884	961	837	1031	907
PERCENT OF TIME	36	36	38	33	43	36
SERVICE-WIDE SAR PERCENT	26	28	26	25	-	26

vessels aground in the harbor or harbor entrances, or aground on unmarked shoals or coral heads. There were twelve incidents involving pleasure craft where the vessel was disoriented, aground or in distress solely due to the inability of the owner to navigate. An analysis of these incidents indicated that the individuals piloting the pleasure craft should not have ventured out on the high seas, that they lack the basic knowledge of navigation and did not demonstrate prudence or good seamanship in their handling of the vessel. By their actions, these individuals demonstrated a total lack of nautical competence such that they would ultimately become a SAR statistic. Thus, with respect to pleasure craft, it is highly unlikely that the availability of LORAN-C coverage would have prevented any of these incidents.

9.3.2 Search and Rescue Benefits

The role of improved LORAN-C coverage in the Eastern Caribbean for the Search and Rescue program is predicated upon an improvement in Coast Guard efficiency, particularly in searching, an overall increase in maritime safety thereby reducing the number of SAR cases, and an improvement in the detection and location of the cases that do occur. Only the first of these issues is addressed since the magnitude of the current search effort can be accurately determined and quantified and estimates exist as to the effect of improved navigational accuracy upon the search effort. While the effect of improved navigation upon overall maritime safety has been addressed to some extent in the casualty analysis, the impact of such improvements upon reduction of the SAR effort is unknown. Finally, while the ability of the distressed vessel to provide accurate positional information is an extremely critical element of the search mission the quantitative value of such information in the reduction of search cost is open to conjecture.

The principal quantitative benefit ascribed to improved navigational accuracy is the reduction in the amount of effort required to obtain a particular level of mission effectiveness. In this case, mission effectiveness is defined as the probability of detection (POD). While the relationship of navigational accuracy to the SAR mission is the subject of continuing studies and experiments, flight tests have shown that by utilizing LORAN-C a 78 percent POD can be obtained with a reduction in effort of approximately 31 percent as compared to navigation by dead reckoning (Reference 27). While these results are experimental, they are used in this analysis to obtain order-of-magnitude estimates which may be attributable to navigational improvements. For purposes of this analysis it is assumed that similar results can be obtained for Differential Omega within the coverage area for this latter system. Further, it is assumed that Differential Omega will be available for Coast Guard aircraft in the Eastern Caribbean.

While a 31 percent reduction in the SAR effort appears to be a substantial savings, it may be realistic in the Eastern Caribbean because of the continuing navigation problems experienced by the HH-3 helicopters in the region. Because of these problems and because of the larger areas of responsibility, the amount of such effort expended in the area has consistently exceeded service-wide coverages as discussed above. In this analysis, a 31 percent savings in aircraft utilization was assumed to be the upper limit obtainable; further, for purposes of comparison, a lower limit of 9 percent was also assumed.

The average annual utilization of aircraft at Borinquen for the SAR mission for the period 1975 - 1979 is 934 hours. A 31 percent reduction in effort is equivalent to 289 hours saved per year. These savings were then translated into annual fuel savings and the benefits determined. A burn rate of 187 gallons per hour was assumed, the cost of fuel was $1.32 per gallon, the current Defense Supply Agency cost, although open market purchases have been as high as $2.00 per gallon this year (Appendix F). Using the same rationale discussed in Section 8., fuel costs were assumed to inflate by 50 percent every 5 years. Other costs were not so affected. The hourly operating cost for the HH-3 was assumed to be $1200 in 1980 and would escalate based on increased fuel costs.

As well as savings due to improved helicopter utilization, there are other savings due to the reduction in the number of HC-130 flights from St. Petersburg/Clearwater. As noted previously, navigational problems with the HH-3's have required HC-130 aircraft to be dispatched to augment the helicopter search. During the past several years, there have been one to two of these flights each year. It was assumed that improved navigational accuracy would cause these flights to be eliminated. It was further assumed that these savings would range between 25 and 50 flight hours per year. These savings were then translated into dollars using the rationale for increased fuel and other costs discussed previously. The burn rate for the C-130 in low level flight was assumed to be 750 gallons per hour and the overall costs in 1980 were $2000 per hour.

The results of these determinations are given in Table 9-3 for both the high and low ranges of benefits and for the HH-3 and the HC-130 aircraft. These results are in discounted dollars and cumulated through the year 2000. This table also indicates the expected benefits for each of the four system alternatives. These benefit figures are based not only upon the system coverage factors, but also the number of cases expected to be covered by each system. The number of cases are the average of the FY 78 and FY 79 figures. The case coverage for Differential Omega is assumed to be the same as for the Midi Chain. As can be seen the life cycle benefits range from a high of $3.3 million to a low of $1.0 million depending on the expected savings and system option selected. These results are included in the overall benefits summarized in Section 10.

TABLE 9-3 CUMULATIVE SEARCH AND RESCUE BENEFITS - DISCOUNTED DOLLARS (MILLIONS)

	SYSTEM ALTERNATIVES			
AIRCRAFT	MAXI CHAIN	HIGH POWER CHAIN	MIDI CHAIN	DIFFERENTIAL OMEGA
HH - 3F	0.8- 2.4	0.7- 2.1	0.6- 1.9	0.6- 1.9
HC - 130	0.4- 0.9	0.4- 0.9	0.4- 0.7	0.4- 0.7
TOTAL	1.2- 3.4	1.1- 3.0	1.0- 2.6	1.0- 2.6

9.4 MARINE ENVIRONMENT PROTECTION (MEP)

The Marine Environmental Protection Program includes both oil spill surveillance, detection and monitoring as well as monitoring of the Ocean Dumping Program. While the role of improved radionavigation could indirectly affect the oil spill detection activities through reduced groundings and diminished potential for pollution, the benefits directly accruing to the Coast Guard could not be quantified. (However, the effects on the total results of a major marine disaster directly attributable to improved navigation are discussed in Section 11.) On the other hand, there are benefits to be derived from the application of LORAN-C in the Ocean Dumping Program. By implication, these benefits are also applicable to Differential Omega.

The Ocean Dumping Program involves EPA-authorized waste disposal at sea in certain designated disposal sites. Monitoring of this waste disposal is the responsibility of the Coast Guard. Monitoring is generally accomplished by labor-intensive methods such as aircraft surveillance, and shipriders. In the Eastern Caribbean, there is one authorized disposal site 50 nm off the North Coast of Puerto Rico (Figure 9-2) and monitoring of the dumping activities is performed by personnel from the Coast Guard Base at San Juan and aircraft from the Coast Guard Air Station at Borinquen.

Under a notice of proposed rulemaking published on December 13, 1979, the Coast Guard has announced its intention to require the installation of an electronic surveillance device on vessels engaged in ocean dumping. This device called the Ocean Dumping Surveillance System (ODSS) is based on LORAN-C inputs, dump station sensors and a digital recorder. The system is capable of recording the vessel movements and dump operations and can be used to

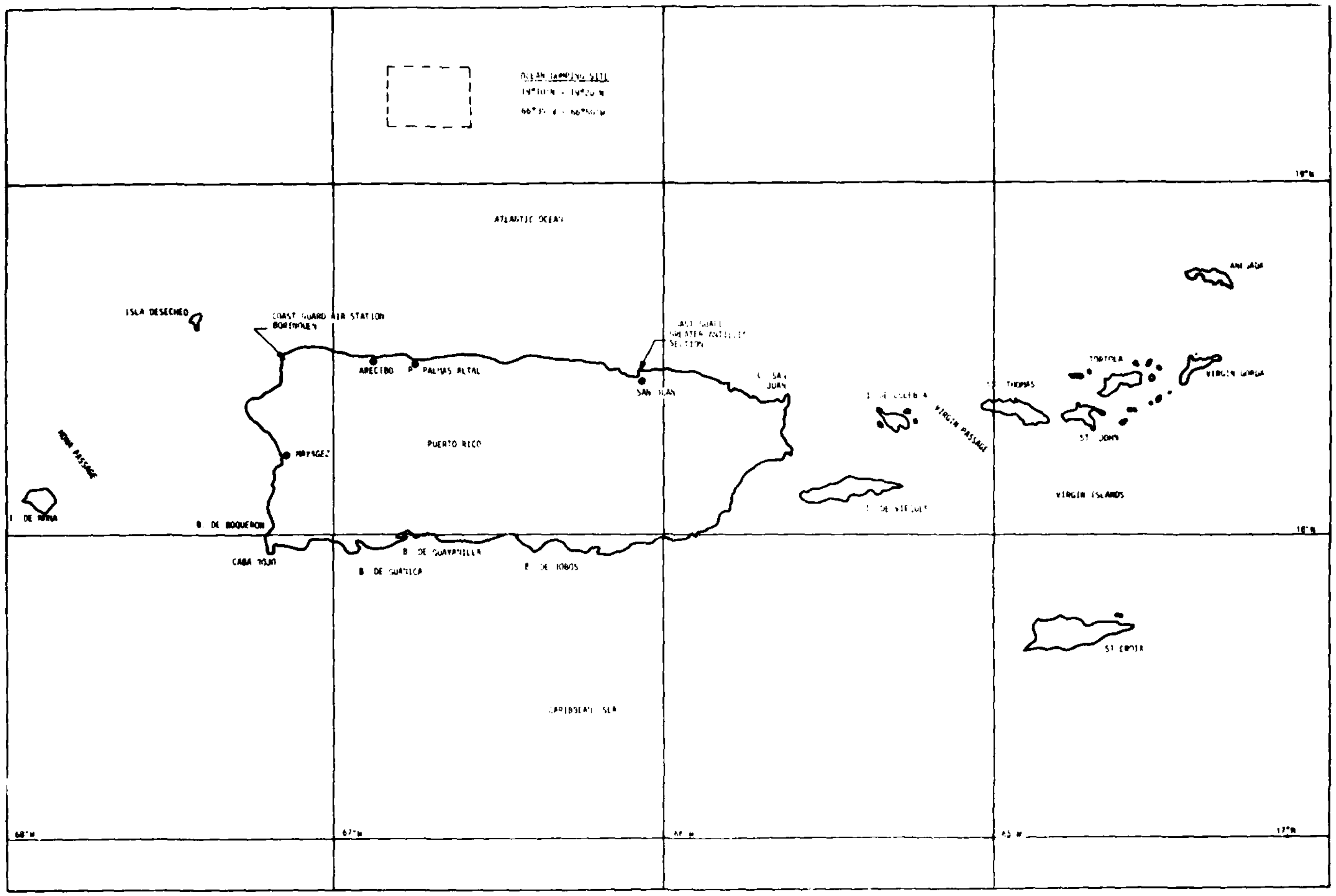

FIGURE 9-2 OCEAN DUMPING SITE - EASTERN CARIBBEAN

electronically reconstruct a vessel's voyage thereby obviating the need for labor intensive, on site monitoring. In addition, this system provides for full surveillance of dump operations. However, since no LORAN-C Coverage exists in the Caribbean, this region is specifically exempt from these requirements.

Should LORAN-C coverage be expanded into the Caribbean, it is probable that ODSS will be required. Hence a determination of benefits that can be ascribed to both this system and to LORAN-C as well was conducted. It was assumed that a similar system, employing Differential Omega inputs is also possible and would be required should Differential Omega be implemented instead of LORAN-C.

In order to determine the benefits, the following information was obtained from the Marine Safety Office, San Juan with respect to the Eastern Caribbean Dumping Program for the period August 1978 - January 1980.

Total dumps	167
Dumps under Coast Guard surveillance by shipriders, aircraft, or both	42
Percent of dumps under surveillance	25%
Manhours of surveillance	1133
Aircraft surveillance - Hours	22.2

Using the above data the cost of shiprider and aircraft surveillance was determined. The costs of the HH-3 helicopters were as discussed previously. Shiprider costs were based on a rate of $19,000 per year. Fuel costs were assumed to escalate at the rate of 50 percent every five years. Other cost elements were not affected. Since these costs reflected a current 25 percent surveillance factor, the results were multiplied by four to include not only the cost avoidance attributable to LORAN-C expansion, but also the benefits in improved mission capability. The life cycle benefits in discounted dollars was 0.9 million dollars. This benefit was valid for all four system options since it was assumed that all options provided coverage of the dump site. This result is included in the total system benefits.

9.5 ENFORCEMENT OF LAWS AND TREATIES (ELT)

The role of increased LORAN-C coverage in the Enforcement of Laws and Treaties (ELT) mission area lies principally in the improvement of the operational capability of the Coast Guard units involved. The quantification of these benefits is dependent upon a detailed analysis of this mission area and as such is properly the subject of a specific study oriented toward operational efectiveness and system performance. However, certain subjective conclusions can be made toward improved radionavigational accuracy over that currently obtainable by visual, radar and celestial means.

The law enforcement activities of the Coast Guard include various responsibilities for the enforcement of laws concerning living resources through a range of acts covering controlled substances, smuggling, vessel theft and hijacking, and other activities affecting maritime law. All of these activities are conducted to some degree in the Eastern Caribbean region.

There are two missions on which the ELT resources are principally focused. These are the enforcement of the Fishery Conservation Zone (FCZ) and drug interdiction. On a service-wide basis, approximately 82 percent of the ELT resource time and operating expenses are devoted to fisheries enforcement, the balance is for general law enforcement, primarily drug interdiction (Reference 28). However projected future trends indicate that drug interdiction activities will be increased while the fisheries enforcement effort will be proportionately reduced.

In the Eastern Caribbean, the Fishery Conservation Zone extends approximately 200 miles north and south of Puerto Rico and includes all of the Mona Passage to the west and all of the U.S. Virgin Islands to the east (see Section 4.2.2). However, as indicated in Appendix D, fishing in Puerto Rico and the Virgin Islands is small, locally organized and principally concentrated in inshore areas. A few vessels venture far off shore to Saba Bank, Nevis Island, Anegada Passage and the coast of Venezuela. Most of the fishing activities are conducted by small (10 - 15 ft.) vessels in Vieques Sound and the Mona Passage. While these latter areas are within the Fishery Conservation Zone, because of the species sought and the gear used, they are not subject to overfishing. Hence, the Eastern Caribbean Fishery Conservation Zone is not considered an active fishing area (as compared to the Puget Sound and Georges Bank areas) and no enforcement activities are conducted, nor are they necessary. It is possible, however, that the fishing industry will grow and expand in the future such that the Coast Guard will be required to enforce the Fishery Conservation and Management Act in the region. Improved LORAN-C coverage would be useful in defining the limits of the Fishery Conservation Zone and for a more accurate determination of position by both the Coast Guard cutter and the fishing vessel as well. At this time, however, it appears that there is no role for LORAN-C or Differential Omega in the enforcement of this Coast Guard mission area in the Eastern Caribbean.

With respect to drug interdiction activities in the Eastern Caribbean, the Coast Guard's role is more pronounced. Barrier patrols and blocking activities are established in areas where historically smuggling activity has taken place. In the Caribbean, these activities chiefly take place in the Yucatan Channel, Windward and Mona Passages. However, only the latter passage is in the area of interest for this study. The nature of these blocking activities involve the stopping, boarding, search and possible seizure of vessels suspected of drug trafficking. The authority for this activity lies in the Coast Guard's overall right to search vessels subject to United States law, including both United States vessels and foreign vessels in waters over which the United States has jurisdiction (14 U.S. 89). On the high seas, the Coast Guard's jurisdiction over foreign vessels is not so clear. In the latter case, the jurisdiction is derived from the Single Convention of Narcotic Drugs, 1961 and boarding requires authority from the country of registry, obtained by special request through the Department of State. Operations in the Mona Passage and contiguous areas include waters over which the United States exercises jurisdiction as well as areas of the high seas. Hence, in this region, the accurate establishment of the enforcement vessel's and the contraband vessel's position is critical with respect to the rapid and timely determination of the legalities of boarding and seizing. Thus, a potential role exists for LORAN-C (and Differential Omega), in this region of the Caribbean whereby improved positional accuracy can enhance the effectiveness of the drug interdiction mission.

9.6 OFFSHORE VESSEL TRAFFIC MANAGEMENT (OVTM)

An additional benefit from enhanced LORAN-C and Differential Omega coverage under the Marine Environment Protection (MEP) mission area lies in the contribution of these systems to the vessel surveillance system effort.The Offshore

Vessel Traffic Management (OVTM) Study (Reference 25) addresses, among other measures, the role of LORAN-C in the prevention of tanker casualties. These measures are discussed here as potential supplementary benefits to be gained from LORAN-C expansion. With these measures, it is assumed that Differential Omega can be used to derive comparable benefits.

The most apparent measure, and one that can be readily implemented is the application of those systems to vessel traffic separation schemes. Such schemes are aimed at reducing the risk of collision in congested or converging areas by separating vessel traffic proceeding in opposite or nearly opposite directions through the use of a separation lane or buffer zone. The use of traffic separation schemes is not now compulsory and it is entirely discretionary with the ships' masters as whether to follow the recommended routes or not. However, vessels which elect not to follow the separation routes are advised to keep outside the boundaries of established schemes and not hamper the organized traffic (Reference 7). Implicit in any traffic separation scheme is the ability of the vessel to navigate within 0.25 nm accuracy or better (Reference 8). All traffic separation schemes are approved by IMCO.

In the Eastern Caribbean, confined waters under the jurisdiction of the United States are possible candidates for traffic separation schemes should LORAN-C or Differential Omega be introduced into the region. The Virgin Passage between the Islands of Culebra and St. Thomas is a potential area for traffic separation. A concept for such a scheme is shown in Figure 9-3. In this concept, the traffic is constrained to north-south lanes two miles wide separated by a one mile buffer zone between them. In accordance with customary usage, northbound traffic adheres to the starboard lane while southbound traffic uses the port lane.

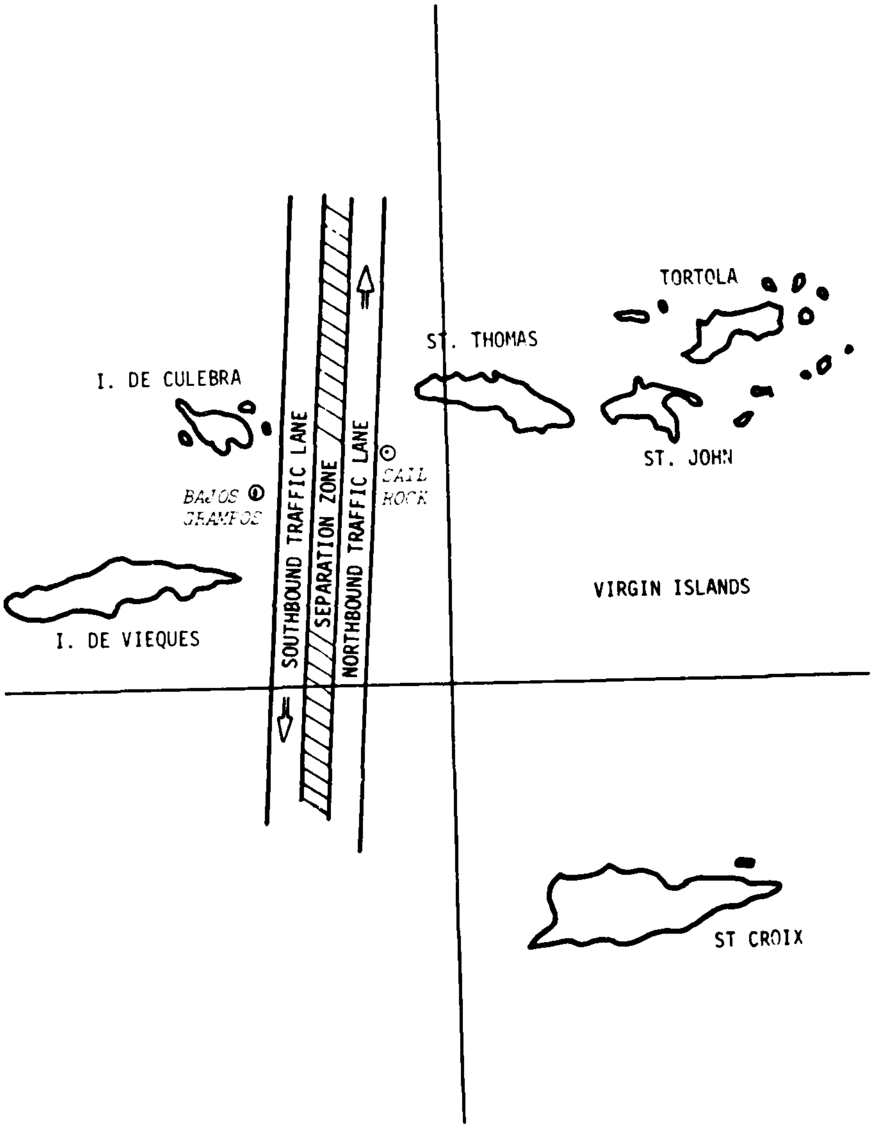

FIGURE 9-3 TRAFFIC SEPARATION CONCEPT - VIRGIN PASSAGE

The Virgin Passage is five miles wide at its narrowest part and is bounded in the east by Sail Rock and in the west by the shoal water surrounding Bajos Grampus. Both of these hazards are marked by lighted buoys. Depths range between 11 and 21 fathoms. The Virgin Passage is a likely candidate for traffic separation since two-way traffic is prevalent through the area and the potential for collision exists. Further such traffic is characterized by considerable tanker traffic from the St. Croix and the North Coast of South America, raising the possibility for an oil spill should such a collision occur. The coverage and accuracy provided by either Differential Omega or any of the LORAN-C options would permit such a benefit to be derived.

As well as traffic separation schemes, the Offshore Vessel Traffic Management Study considers other concepts which are based on the availability of LORAN-C , Differential Omega or other radionavigation systems of comparable accuracy and update rate. Among these are an automatic monitoring system which involves a passive retransmission of the vessel's position, course and speed to a local shore station. No action is required of the vessel master other than system activation.

The shore station tracks all vessels, plots projected courses and positions and advises vessels which are standing into danger. Critical to the operation of such a system is an advisory or control center which provides 24 hour staffing, communications, data processing and displays. Such a system using retransmitted LORAN-C is currently in commercial operation in the Suez Canal.

The above two examples are indicative of the types of additional capability which might be derived from increased availability of LORAN-C or Differential Omega. However, the benefits to be obtained from the OVTM systems and concepts are secondary to the costs and benefits directly attributable to LORAN-C and Differential Omega. The critical point to consider is that the availability of these or comparable radionavigation system coverages permit such OVTM concepts to be employed, if required. Hence, these LORAN-C and Differential Omega benefits are not quantified but lie in the enhanced operational flexibility provided for the reduction of collisions groundings and strandings.

9.7 LORAN-C DISBENEFITS

9.7.1 Enforcement of Laws and Treaties (ELT)

The availability of LORAN-C in the Eastern Caribbean would also impact upon certain users and areas in a negative sense. While these impacts may not be substantial when viewed in the aggregate, they can be disruptive upon marine operations and environmental quality. These impacts affect principally Coast Guard operations and the ecology of the islands.

The LORAN-C signal cannot be denied specifically to any user and hence vessels involved in the contraband and smuggling trade are as free to use the system as any legitimate enterprise. Such a vessel equipped with a LORAN-C receiver can remain outside the territorial waters and reduce exposure to detention, search and arrest. Further, the ability of such vessels to rendezvous accurately, in darkness and in remote and isolated locales will be enhanced, thereby increasing the difficulty of enforcement by the Coast Guard.

A specific example of the role that LORAN-C or Differential Omega could have played in alien smuggling operations was identified during the analysis of groundings in the Eastern Caribbean (Appendix B) . On October 4, 1978, the 62 ft. motor sailer "DOGSTAR" ran aground at night on a reef east of Buck Island at St. Croix, Virgin Islands. Aboard were seven illegal aliens who were attempting to be smuggled ashore at the eastern trip of St. Croix. The grounding caused the attempt to be thwarted and, in addition, caused $15,000 damage to the vessel. It is speculative as to whether the vessel would have used LORAN-C or Differential

Omega had it been available. However, had it been available and in use it probably would have permitted the smuggling attempt to be carried out successfully. Such an incident is illustrative of the type of disbenefit which may be attributed to improved navigation.

9.7.2 Environmental Impacts

As well as disbenefits specifically related to navigation, there are others related to the environment and ecology. The Caribbean Islands are regions of great natural beauty and represent extremely desirable areas in terms of tourism and retirement. Land, particularly in the Virgin Islands commands a premium price and its availability is limited. The negative effect of the acquisition, construction and operation of a LORAN-C station can only be surmised, yet could prove to be significant. Further, the power requirements of these stations may tax the ability of the local power entities. Where self contained power is used, the noise and pollution of the diesel generators could be objectionable. While these impacts may not be measurable, they may be obnoxious in terms of the inhabitants and environment of the islands. Similar disbenefits are not attributable to Differential Omega since this system is predicated upon the utilization of existing radiobeacon sites and the additional requirements for space and power would be slight.

10. BENEFIT/COST RESULTS

10.1 INTRODUCTION

The synthesis of the benefits and costs determined in the preceding sections are presented in this section. These results are presented in three levels of detail. First, the summary results which defined the overall merits of the four system alternatives. Secondly, the comparative results which analyze the relative merits of the three LORAN-C options and finally, the detailed results which provide time stream data on each of the four systems.

10.2 SUMMARY RESULTS

The overall results of the benefit/cost analysis are presented in Figure 10-1. In this figure, the results of the Differential Omega alternative are compared against all LORAN-C alternatives. In this case as in all others presented in this section, the benefits consist of not only the productivity and safety benefits, but also the Government (Coast Guard) benefits. As can be seen from this figure, Differential Omega appears sufficiently promising as to merit further, detailed analysis. This system, in its most optimistic configuration, has a benefit/cost ratio of 13.0 while the least optimistic configuration is approximately 8.0. Further, this analysis assumes that the potential users will be slow to adopt Differential Omega and hence, the benefits were slow to accrue and accrued late in the benefits stream. A more rapid acquisition of Differential Omega sets may not affect the results since although the benefits may be accrued early, they may be offset in part by the higher accrued costs of the receivers.

The underlying reason for the results favoring Differential Omega lie in its low Government investment and O&M costs. Hence, even relatively small benefits can readily meet the capital recovery costs and cause this system to be displayed favorably.

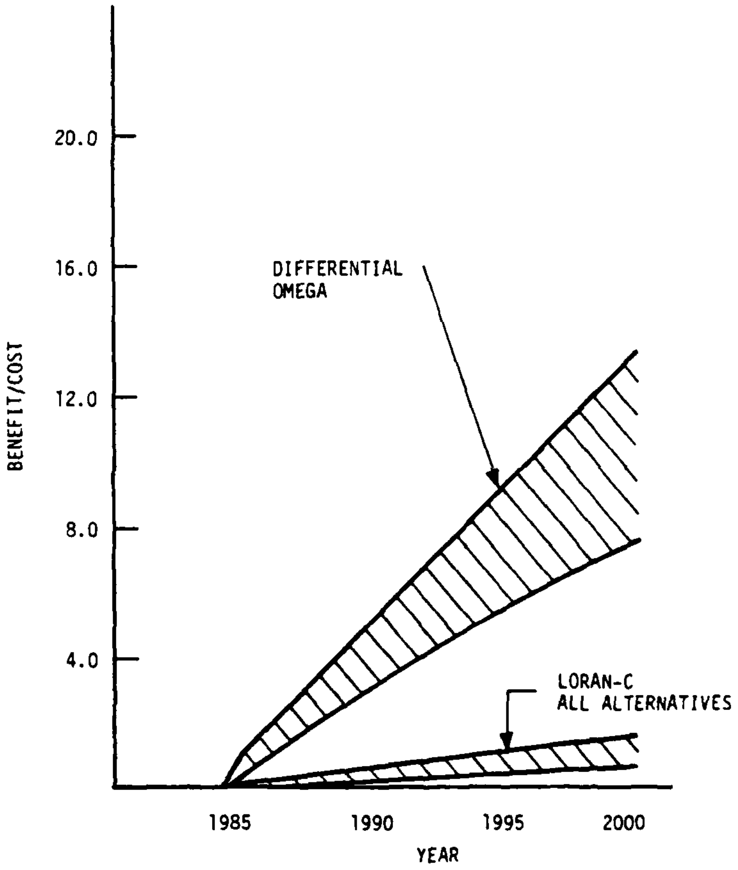

FIGURE 10-1 SYSTEM ALTERNATIVES BENEFIT/COST BEST-WORST COMBINATIONS

On the other hand, all of the LORAN-C alternatives appear as a narrow, constrained band with a maximum benefit/cost ratio of 1.6. The least-favorable alternative combination is less than 0.5. This range of values represents not only all of the LORAN-C expansion alternatives, but also all of the various cost sharing and host nation assumptions, as well as the range of determined benefits. The relatively poor showing of LORAN-C can be attributed to the relatively high initial investment and O&M costs vis a vis future benefits. Thus, using benefit/cost as a criterion, LORAN-C expansion in the Eastern Caribbean does not appear promising.

Other measures of system value can be used. Figure 10-2 shows the cumulative benefits and costs as a function of vessel traffic density. These benefits and costs are not unit values (i.e., benefits, costs per vessel), but rather are measures of system value generated by the vessel traffic and vessel populations. In this figure, histograms of the four system alternatives are shown. The shaded areas reflect ranges of values to show the affect of cost sharing or uncertainties in the level of benefits. In this figure, the LORAN-C Midi Chain appears the most promising from the stand point of benefits. This clearly shows the impact of traffic density since the coverage provided by this system is limited to one of the areas of higher traffic density. On the other hand, the benefits attributable to Differential Omega are less despite the fact that the coverage provided by this system is comparable to that provided by the Midi Chain. The benefits from the Maxi and High Power Chains are lesser still, since although in absolute values these benefits are high, they are diluted by the large number of vessels covered by their signals.

With respect to the cost per vessel covered, Differential Omega appears most favorable at less than $5.00. On the other hand, the comparatively large investment and O&M costs associated with the Midi Chain exceed the benefits captured by at least 30 percent. In addition, neither the High Power nor Maxi

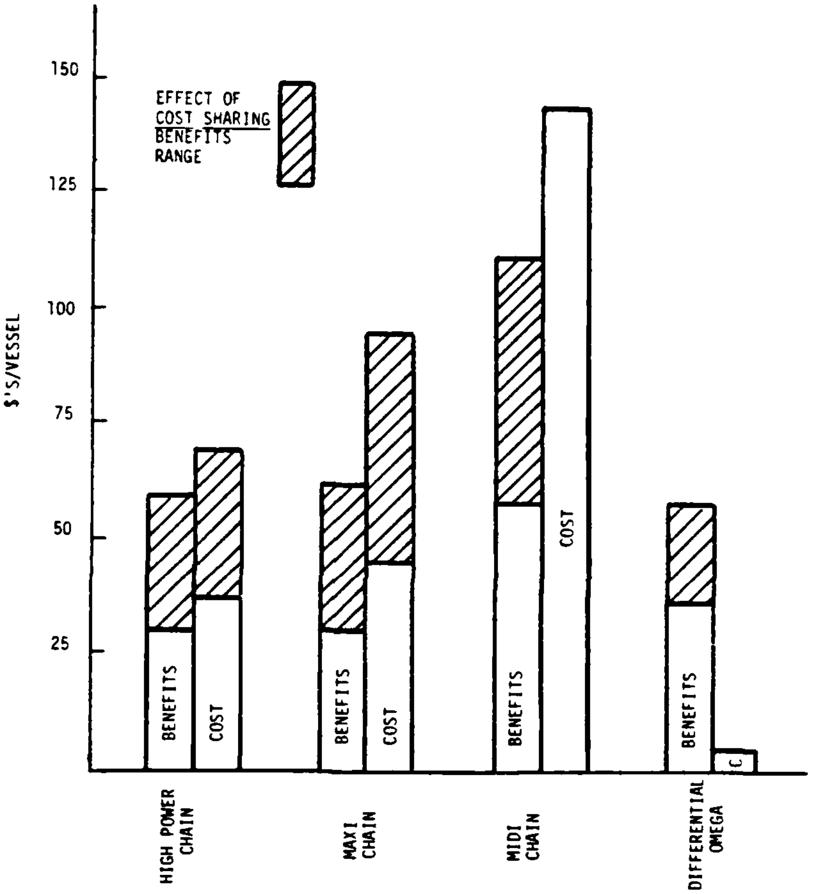

FIGURE 10-2 SYSTEM ALTERNATIVES VESSEL TRAFFIC COSTS AND BENEFITS THROUGH YEAR 2000

Chains appear favorable using this criteria since in both cases, the costs exceed the benefits.

A third measure of system value used in this analysis is the costs and benefits per square mile of signal coverage. These results are shown in Figure 10-3. Using these criteria, Differential Omega appears most favorable both with respect to benefits and costs. The Midi Chain also appears promising with respect to benefits, however, the high per square mile costs negate this. The dilution effect of the large areas covered by the high power and maxi chains serves to lower the cost threshold but also tends to minimize the benefits. Hence neither system offers much promise on a per square mile basis.

10.3 LORAN-C SYSTEM ALTERNATIVES

The preceeding section examines not only the absolute merits of all of the contending systems, but also the relative merits of these systems compared against certain measures of system value. In this section, the LORAN-C alternatives are examined in greater detail both comparatively between the three options and singly for those combinations of costs and benefits which appear either most promising or least promising.

10.3.1 Most Favorable Combinations

During the development of the costs and benefits in this study ranges of values were used. With respect to the benefits, these ranges reflected the uncertainties associated with the determinations and could be described as "most optimistic" and "least optimistic". In the cost determinations, some of the system options involved installations on foreign soil. As such, those latter alternatives were open to various cost sharing and host nation participation schemes. Hence, various combinations of costs and benefits were possible. In Figure 10-4, the most

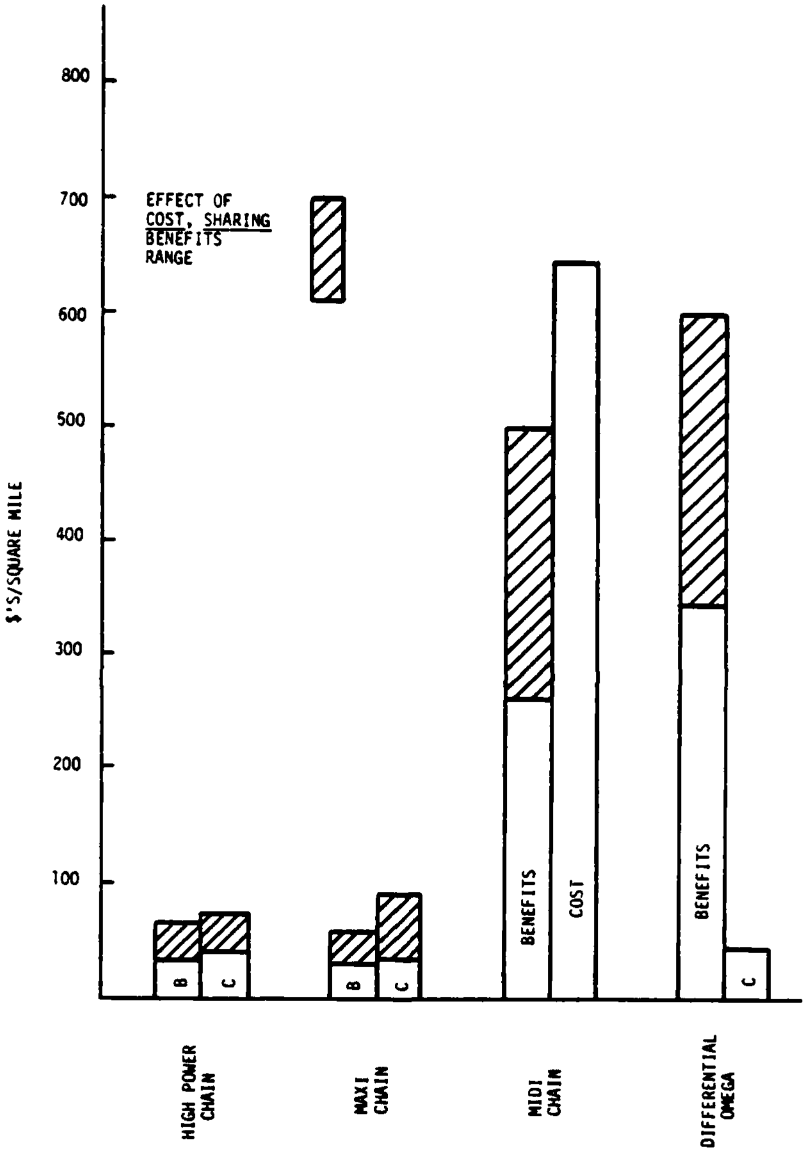

FIGURE 10-3 SYSTEM ALTERNATIVES AREA COVERAGE COSTS AND BENEFITS THROUGH YEAR 2000

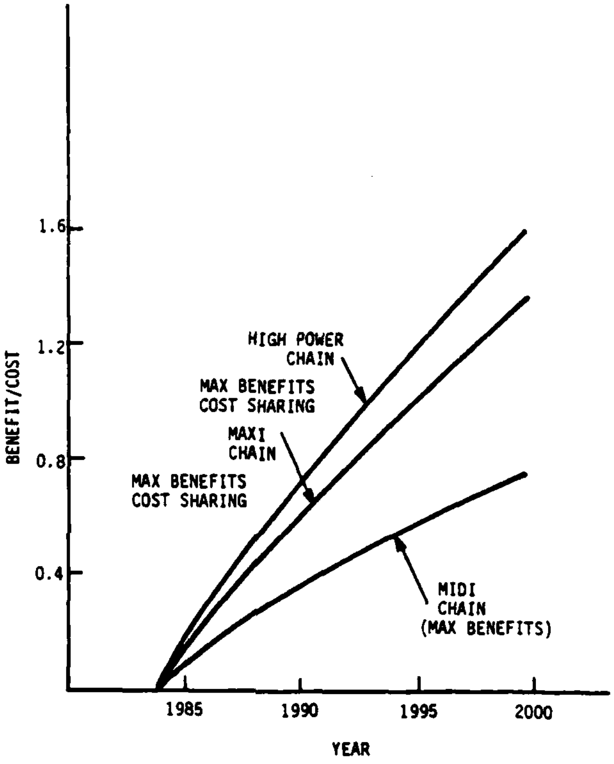

FIGURE 10-4 LORAN-C SYSTEM ALTERNATIVES BENEFIT/COST MOST FAVORABLE COMBINATIONS

favorable combinations (i.e., the highest Benefit/Cost ratios) of LORAN-C alternatives are shown. Among the options selected, the High Power Chain appears the most favorable yielding a benefit/cost ratio of 1.6. This option represents a combination of maximum benefits and U.S.-Host nation cost sharing.

The breakeven point at which this system has paid for itself is in 1992. The Maxi Chain with a similar benefit and cost combination has a ratio of 1.35 and a breakeven point of 1995. Even under the most favorable conditions, the Midi Chain does not pay for itself in the time frame of this study.

10.3.2 Least Favorable Combinations

Using a similar approach as with the most favorable LORAN-C combinations, the least favorable ones were determined. These results are shown in Figure 10-5. For the High Power and Maxi Chains these combinations represent minimum (least optimistic) benefits with the United States absorbing all of the system costs. For the Midi Chain, it reflects the least optimistic benefits only since there are no cost options in this alternative. These combinations are tightly grouped around a benefit/cost ratio of 0.4 and none of them attain a breakeven point. It is interesting to note that the Midi Chain closely approximates the Benefit/Costs of the High Power Chain and Maxi Chain, while in the most favorable combinations, the Midi Chain has the lowest ratio and is ranked a poor third.

10.3.3 Maxi Chain

The benefit/cost ratios for the best and worst combinations for the Maxi chain are shown in Figure 10-6. Only the maximum benefit, shared cost case achieves a benefit/cost ratio greater than 1.0, while the worst combination (minimum benefit, no cost sharing) is 0.3. The other two combinations are

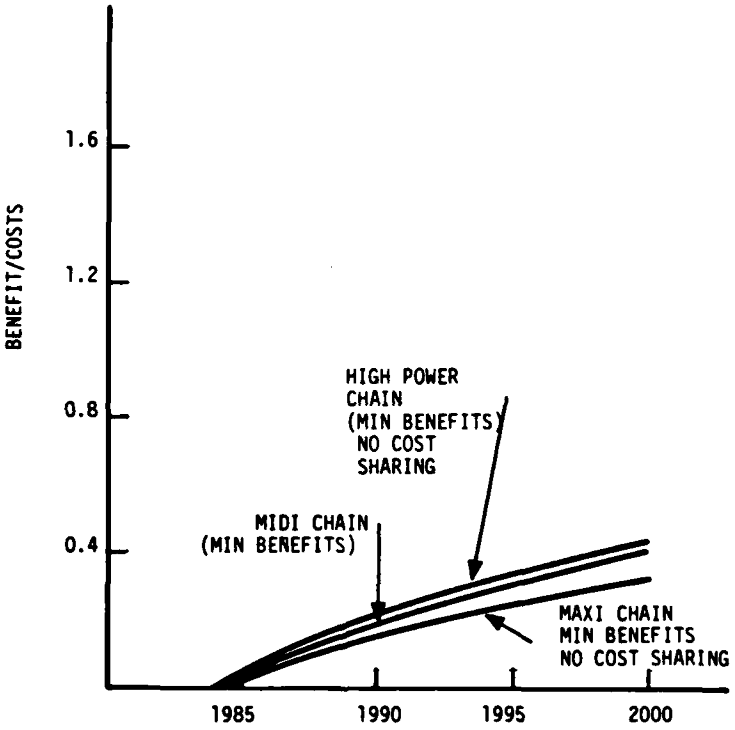

FIGURE 10-5 LORAN-C SYSTEM ALTERNATIVES BENEFIT/COST LEAST FAVORABLE COMBINATIONS

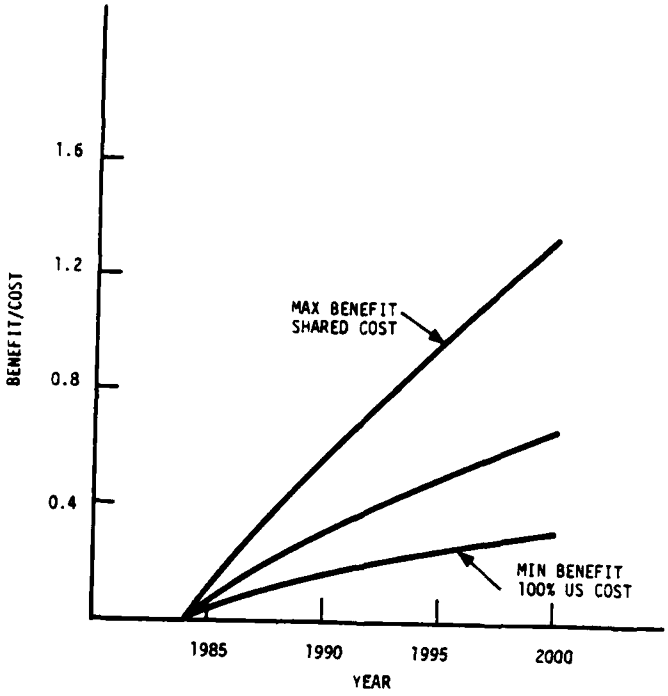

FIGURE 10-6 MAXI CHAIN BENEFIT/COST BEST-WORST COMBINATIONS

identical and appear as a single line. These combinations are high benefits with no cost sharing and low benefits with full cost sharing. However, in neither case are the benefit/cost ratios greater than 0.7.

10.3.4 High Power Chain

Similar results are obtained for the High Power Chain (Figure 10-7) as with the Maxi Chain. The maximum benefit/shared cost option is the most favorable (benefit/cost ratio = 1.6) while the minimum benefit/no cost sharing the least favorable. The remaining option combinations are nearly identical and appear as a single line between the two extreme cases. Neither mid-range option combination achieves a benefit/cost ratio greater than 0.82.

10.3.5 Midi Chain

The Midi Chain (Figure 10-8) combinations consist of two benefit/cost ratios which reflect the range of benefits determined for this option. No cost variations were considered. Neither combination provides a favorable benefit/cost ratio and extrapolating the most promising combination past the year 2000 indicates that a breakeven point would not be achieved until 2012. Further, it appears that such a breakeven point may never be attained for the minimum benefit combination.

10.4 DETAILED RESULTS

This section consists of a series of time stream curves detailing the absolute costs and benefits for the four system alternatives. These results are of a greater level of detail than those discussed earlier and are presented here for purposes of gaining greater insight into the various system combinations.

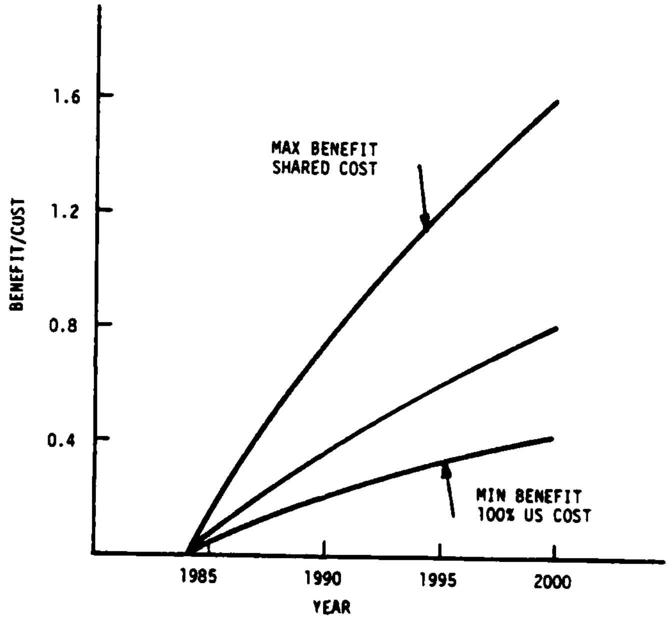

FIGURE 10-7 HIGH POWER CHAIN BENEFIT/COST BEST-WORST COMBINATIONS

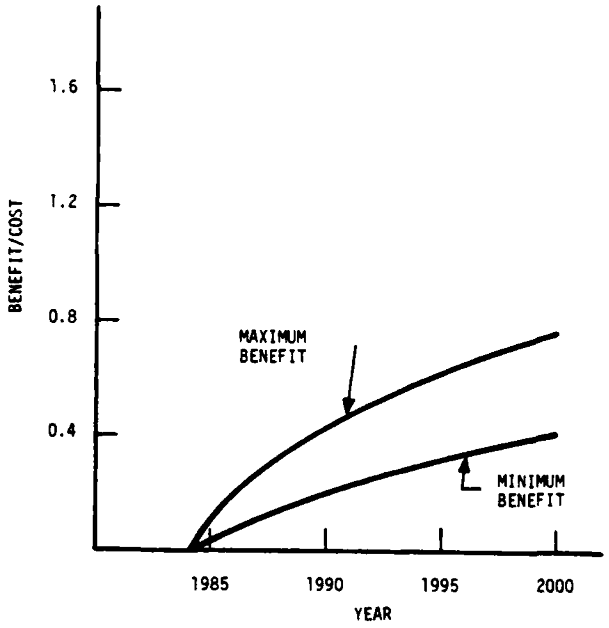

FIGURE 10-8 MIDI CHAIN BENEFIT/COST BEST-WORST COMBINATIONS

10.4.1 Maxi Chain

The costs and benefits for the Maxi chain are presented in Figure 10-9. The cost sharing option appears most attractive due to the shallow slope of the curve. This option, coupled with the most optimistic benefits indicate a breakeven point by 1995. Further extrapolation of both of these elements yields a benefit/cost ratio of approximately 7.0 by the year 2010. On the other hand, the slopes of the least optimistic benefit and the no cost sharing alternatives appear nearly parallel and hence, no reasonable time period for a breakeven point can be expected from this combination.

10.4.2 High Power Chain

The benefit and cost time streams for the high power chain given in Figure 10-10. The earliest breakeven point occurs in 1993 for the cost sharing, most optimistic benefit combination. Extrapolating from this base, it would appear that this ratio would increase to 2.0 by 2005 and to 3.0 by 2020, well beyond a reasonable equipment life and yet not sufficiently promising to warrant further consideration as a system expansion. Other combinations hold even less promise. For example, the breakeven point for the no cost sharing, most optimistic benefit case appears to be 2003 as is the case with the cost sharing, least optimistic benefit combination.

10.4.3 Midi Chain

On a basis of absolute costs and benefits, the Midi Chain does not appear promising. In Figure 10-11, it can be seen that the slope of the cost curve closely parallels that of the least optimistic benefit curve and hence no breakeven point can be attained within the lifetime of the system. On the other hand, the curve of the most optimistic benefits will not attain parity with the cost curve

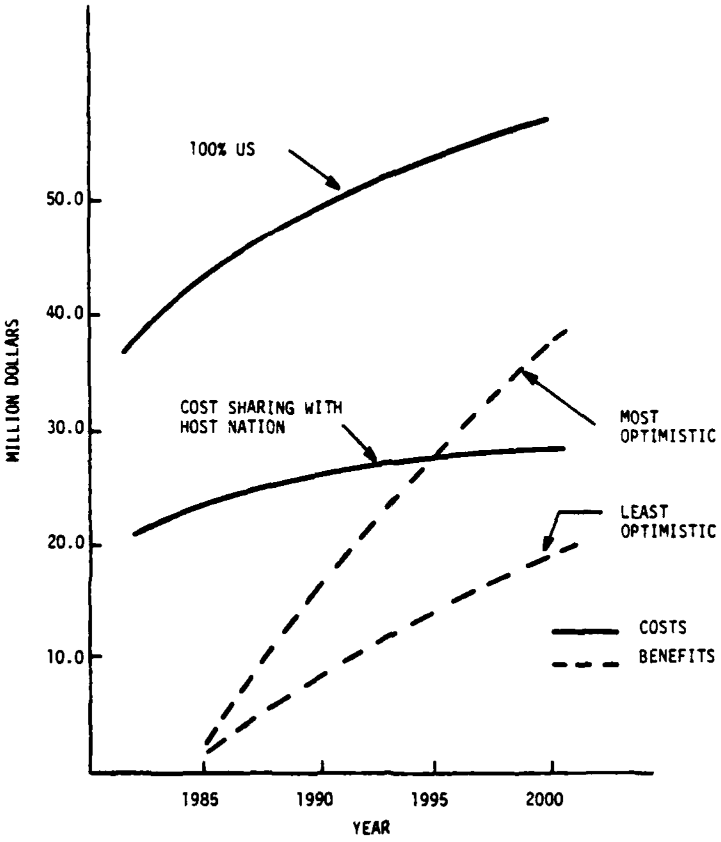

FIGURE 10-9 MAXI CHAIN CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

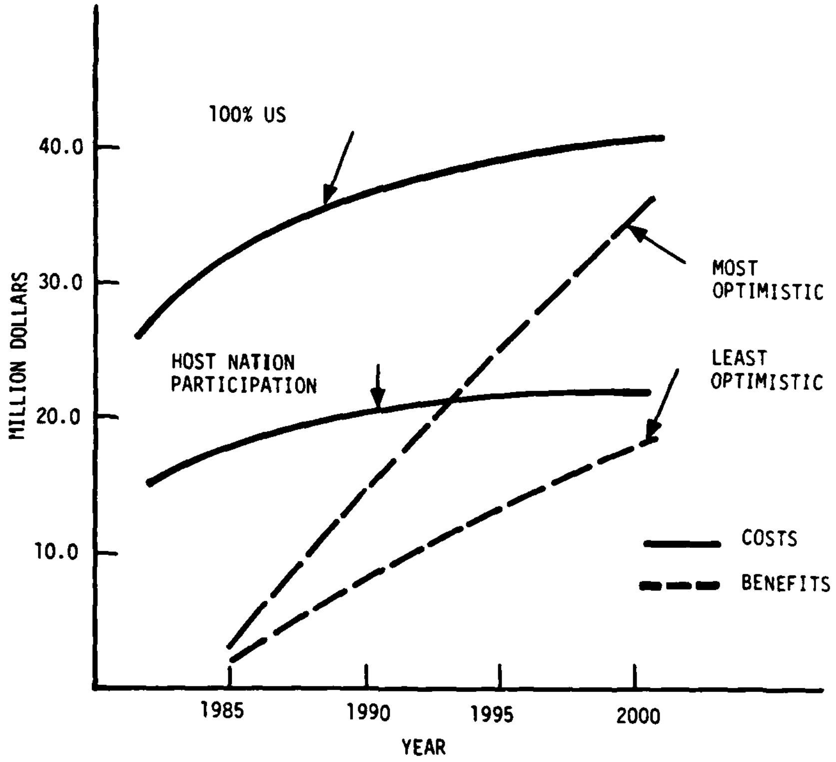

FIGURE 10-10 HIGH POWER CHAIN CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

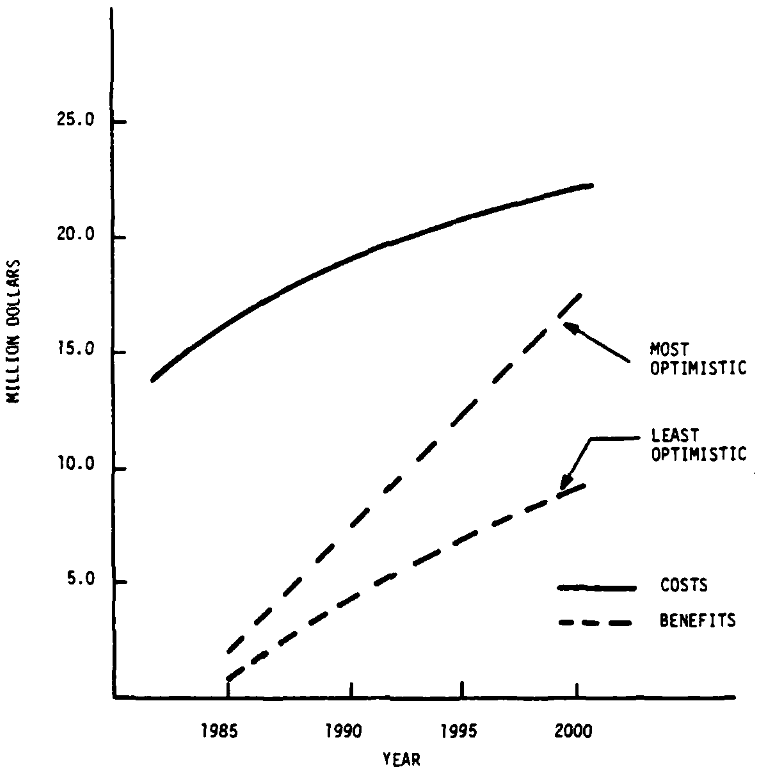

FIGURE 10-11 MIDI CHAIN CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

until well past 2005. For such a system to appear promising within the benefit enveloped assumed, costs would have to be reduced by a factor of 10. Such a reduction appears highly unlikely.

10.4.4 Differential Omega

The benefit/cost streams for Differential Omega present a wholly different pattern as compared to the LORAN-C alternatives (Figure 10-12). In the former case, for both benefit options, the breakeven point is attained early in the system life, the benefits continue to be accumulated at a fairly rapid rate while the cost curve remains essentially constant due to the relatively low O&M costs. Overall, the benefit/cost ratios are between 8.0 and 13.0 and they will continue to increase as long as the system in operational. Based on these observations, the Differential Omega option appears most promising.

10.5 IMPACT ASSESSMENT

10.5.1 Major Marine Disaster

The installation of a radionavigation system is frequently justified on the basis of, among other things, a favorable benefit/cost ratio. In all of the LORAN-C alternatives assessed in this study the life cycle benefit/cost ratio rarely exceeded the breakeven point and hence such systems do not appear promising. However, the argument is sometimes made that a navigation system could be rationalized on the grounds that it will prevent one major marine disaster. Accordingly the benefit/cost results of the LORAN-C expansion assessment were examined to determine the impact of a major navigation related marine disaster.

It is assumed that a major tank vessel grounding occurs within the Caribbean and that this disaster could have been prevented by improved radionavigation aids. It is further assumed that the losses incurred in such a disaster are $100 million, such losses to include vessel, cargo, oil spill clean up

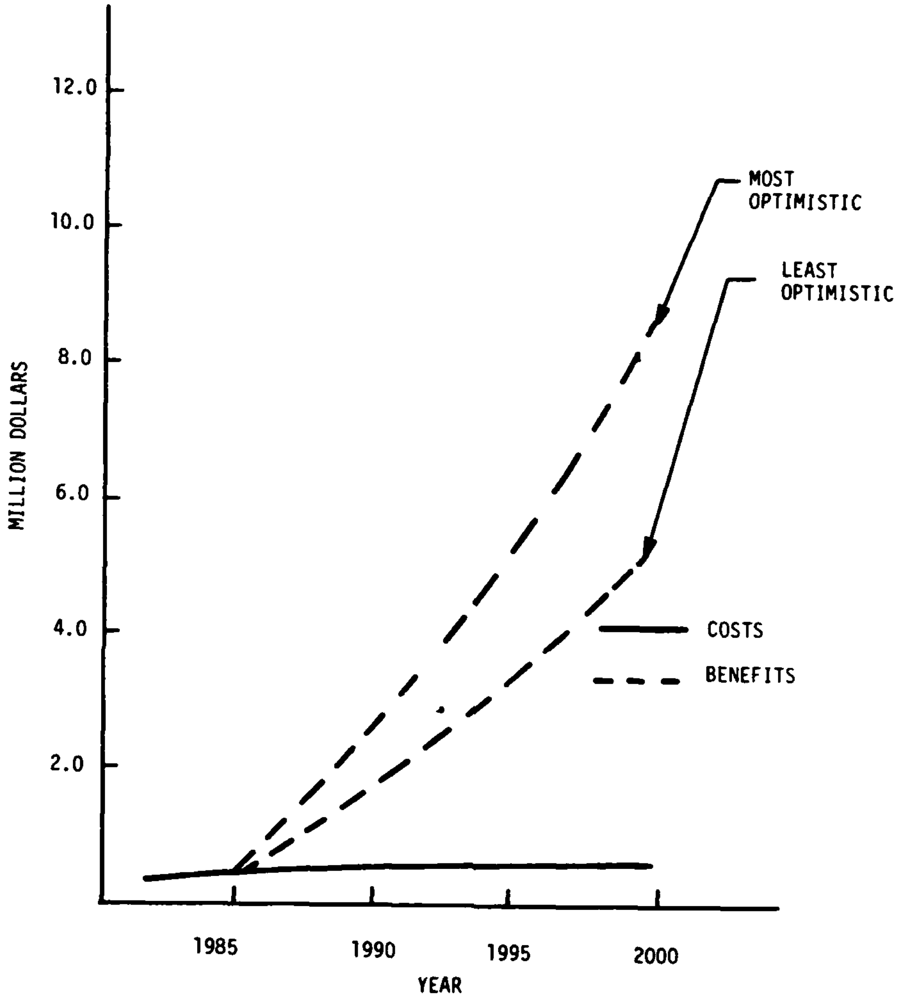

FIGURE 10-12 DIFFERENTIAL OMEGA CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

operations, property and ecological damages. (In the Argo Merchant disaster, the estimated cleanup costs including the value of the oil spilled was $52 million (Reference 25).) The probability of such an event not occurring was deemed to be a function of the area coverage provided by LORAN-C expansion alternatives. These area coverage percentages were discussed in Section 6.7. Using these percentages, the expected value of the disaster was determined for each of the LORAN-C alternatives. These values were $72, $52 and $54 million for the High Power, Maxi and Midi Chains respectively. Further, the disaster was assumed to occur in 1985, 1990, 1995 and 2000. Discounted values were determined for each time period and the effect upon the total benefit/cost ratios ascertained for the most favorable system combinations. These results are shown in Table 10-1.

As would be expected, the highest benefit/cost ratios occur when the marine disaster happens early in the system life. However, the ratio for the most promising system (High Power Chain, Early Marine Disaster) does not exceed 3.6 and the values for the other chains are correspondingly less both in 1985 and later in the time stream. Accordingly, on the basis of benefit/cost ratios, the impact of the prevention of a major marine disaster does not significantly affect any of the LORAN-C alternatives such that they warrant closer analysis for possible implementation.

TABLE 10-1 LIFE CYCLE BENEFITS/COSTS - IMPACT OF PREVENTED MARINE DISASTER

LORAN-C SYSTEM	BASE CASE	YEAR OF MARINE DISASTER			
		1985	1990	1995	2000
MAXI	1.4	2.7	2.2	1.9	1.7
HIGH POWER	1.6	3.6	2.8	2.4	2.1
MIDI	0.8	0.9	0.9	0.8	0.8

11. CONCLUSIONS AND FINDINGS

11.1 COST AND BENEFIT CONCLUSIONS

The following conclusions and findings can be made with respect to the costs and benefits of LORAN-C expansion and Differential Omega:

- In the aggregate, the benefit/cost ratios for any of the LORAN-C system alternatives or options do not reach a level commonly deemed necessary to justify a favorable investment decision. In the most favorable configuration, the life cycle benefits barely exceed the life cycle costs.
- Benefits were derived from improved vessel productivity and enhanced vessel safety; government benefits (principally Coast Guard) were obtained from service and operational savings. No single benefit was sufficiently large so as to constitute a major, overriding element in the final results.
- Productivity benefits were based on fuel savings through improved accuracy in navigation and from the ability to determine port arrival and scheduling times with greater precision. Safety benefits stemmed from reduced vessel groundings and savings in insurance premiums.
- Coast Guard benefits were attributable to savings in the search and rescue effort for a given level of capability and to cost avoidance and improvements incapability in the Marine Environment Protection mission.
- As well as benefit/cost ratios, other measures of system value were used. These were the benefits and costs generated as a function of vessel traffic density and the benefits and costs per square mile of system coverage. These measures were used to

evaluate relative system merits among alternatives. Although none of the LORAN-C alternatives are deemed cost-beneficial, the Midi chain was the most promising on the basis of benefits generated per vessel, however it is also least promising on the basis of costs per vessel. The Midi Chain is similarly rated based on the costs and benefits per square mile of coverage.

- An investment decision regarding Differential Omega appears promising from a benefit/cost criterion. Further, based on the benefits generated per vessel, it is similar to the two wide area LORAN-C chains; on the basis of vessel generated costs, it is more favorable by nearly an order of magnitude than the most promising LORAN-C system (High Power Chain). On the basis of benefits generated per square mile of coverage, it is ranked highest of all alternatives, while on the basis of costs per square mile, it is equivalent to both of the wide area chains.
- The advent of NAVSTAR GPS in 1985-87 could significantly affect the number of ships that equip with either LORAN-C or Differential Omega. This, in turn, would lower all projected benefit-cost ratios thereby making all system alternatives investigated even less promising. Some large marine operators have already indicated their intent to defer the acquisition of any additional radionavigation receivers until the availability of NAVSTAR GPS.

- As a secondary benefit, both Differential Omega and LORAN-C would provide a navigational capability which would permit the introduction of Vessel Traffic Monitoring Systems in congested seaways and passages.
- The impact on the LORAN-C benefit/cost ratio of a major navigation-related casualty was assessed. While increasing the benefit/cost ratio substantially, such impact would not raise this ratio to the level required for a favorable investment decision.
- Political benefits, while treated only peripherally in this study, may, by implication from external events, override the quantitative benefits.

11.2 USER CONCLUSIONS

The following observations have been derived regarding the impact of LORAN-C and Differential Omega on users and potential users.

- Most large commercial vessels will have LORAN-C installed within the time frame of this study, however, this installation will probably be made regardless of LORAN-C expansion in the Caribbean.
- Few small commercial vessels will install LORAN-C specifically for Eastern Caribbean operations. Most ocean-going tugs already have it installed or are in the process of acquiring it. Local inter-island cargo operators will be slow to adopt new systems particularly if few benefits are perceived.
- Should the Puerto Rican fishing industry continue as is currently structured, few fishermen will acquire LORAN-C. The current

fishing fleet consists of vessels of small size and limited endurance. These vessels rarely venture far offshore, and hence have no requirement for LORAN-C or any other radionavigation system. However, if the Caribbean fishing industry grows in vessel size and in landings as is optimistically projected, then this user category will be a substantial purchaser of LORAN-C.

- The large recreational boat owner including those from the United States mainland as well as those in Puerto Rico-Virgin Islands will be the largest user of LORAN-C and with respect to the Puerto Rico-Virgin Islands owners, probably the largest purchaser.
- The major users of Differential Omega will probably be the large commercial operators who will have installed this system for operations in Europe, the Mediterranean and West Africa. The high value small commercial user will probably acquire Differential Omega but in limited quantities and well into the system life cycle. Under current projections, commercial and commercial sport fishing vessels will probably not use this system at all. Some cost insensitive recreational boaters will be system users but in more limited numbers than LORAN-C.

11.3 VESSEL TRAFFIC AND POPULATION CONCLUSIONS

The current status and future trends for traffic and population can be characterized as follows:

- In 1979, inbound-outbound traffic between the United States and Eastern Caribbean amounted to 18,500 moves while inter-island traffic accounted for an additional 21,200 moves. Approximately

40 percent of the U.S. traffic was generated by tank vessels. There are approximately 350 large and 220 small commercial vessels who are principally engaged in United States-Eastern Caribbean trade. By the year 2000, the traffic between the U.S. and the Eastern Caribbean was projected to increase to 25,700 transits, while the traffic between Puerto Rico-Virgin Islands and other Caribbean islands would grow to 29,800 transits. Although this former traffic is expected to grow at a moderate rate, the vessel populations accounting for this traffic will remain fairly constant because of the shipbuilding trends which are toward larger and more efficient vessels.

- The Puerto Rican and Virgin Islands fishing fleets consist of 1040 and 420-450 vessels, respectively. Most of these vessels operate close inshore within sight of land. Approximately 30 vessels sail to the fishing grounds in the Caribbean and the North Coast of South America. The future trends for this industry may vary from a static or no growth condition to a dynamic situation with the fleet size remaining the same but with the trend to larger, more modern vessels of greater range and endurance.
- The current population of recreation and pleasure craft registered in Puerto Rico and the Virgin Islands amounted to 22,300 vessels. There are an additional 870 vessels which habitually cruise from the mainland to the Eastern Caribbean. By 2000, the former population is expected to grow by approximately sixty percent, however, the number of mainland vessels which cruise to this region is expected to remain fairly constant.

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APPENDIX A

RADIONAVIGATION CHARACTERISTICS AND REQUIREMENTS

1. INTRODUCTION

This Appendix addresses the characteristics, capabilities, coverages, and limitations of those radionavigation systems currently in use or under development by the United States. Also included are the current range of values for system receiver costs. Against these system characteristics are presented the requirements of the various system users in terms of vessel activity and certain performance parameters.

2. RADIONAVIGATION SYSTEMS

Only those systems which have application for marine users in the Eastern Caribbean are considered in this Study. These systems are:

- LORAN-C
- Omega
- Transit
- Radiobeacons
- NAVSTAR GPS
- LORAN-A

One of those systems (LORAN-A) has restricted application because of its imminent termination while most of the others are expected to be available through the year 2000. Caribbean coverage from those systems vary from limited areas to full coverage including worldwide availability. Finally, one of these systems (NAVSTAR GPS) is still under development with full marine coverage and operational capability (2-dimensional) not expected until the 1985-1987 time frame. These systems, their coverages, and their time-phased availabilities are shown in Figure A-1. In this study, LORAN-C is assumed to be available at least through the year 2000.

The above systems are defined in the following sections in terms of certain performance parameters. The data were derived from the Federal Radionavigation Plan (Reference 1) and modified to reflect the unique qualities and constraints of the Eastern Caribbean region.

2.1 SYSTEM CHARACTERISTICS - LORAN-C

2.1.1 General

LORAN-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than LORAN-A. It was subsequently selected as the U.S. Government-provided radionavigation system for civil marine use in the U.S. coastal areas.

LORAN-C is a pulsed, hyperbolic system, operating in the 90-110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time-difference (TD) are made by a receiver which achieves improved accuracy over LORAN-A by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain.

Navigation is based primarily on the use of the LORAN-C groundwave. Skywave navigation is also feasible but with some loss in accuracy and signal availability. There is skywave coverage in the Eastern Caribbean, but it is not a reliable signal for maritime applications. The system characteristics of LORAN-C are summarized in Table A-1.

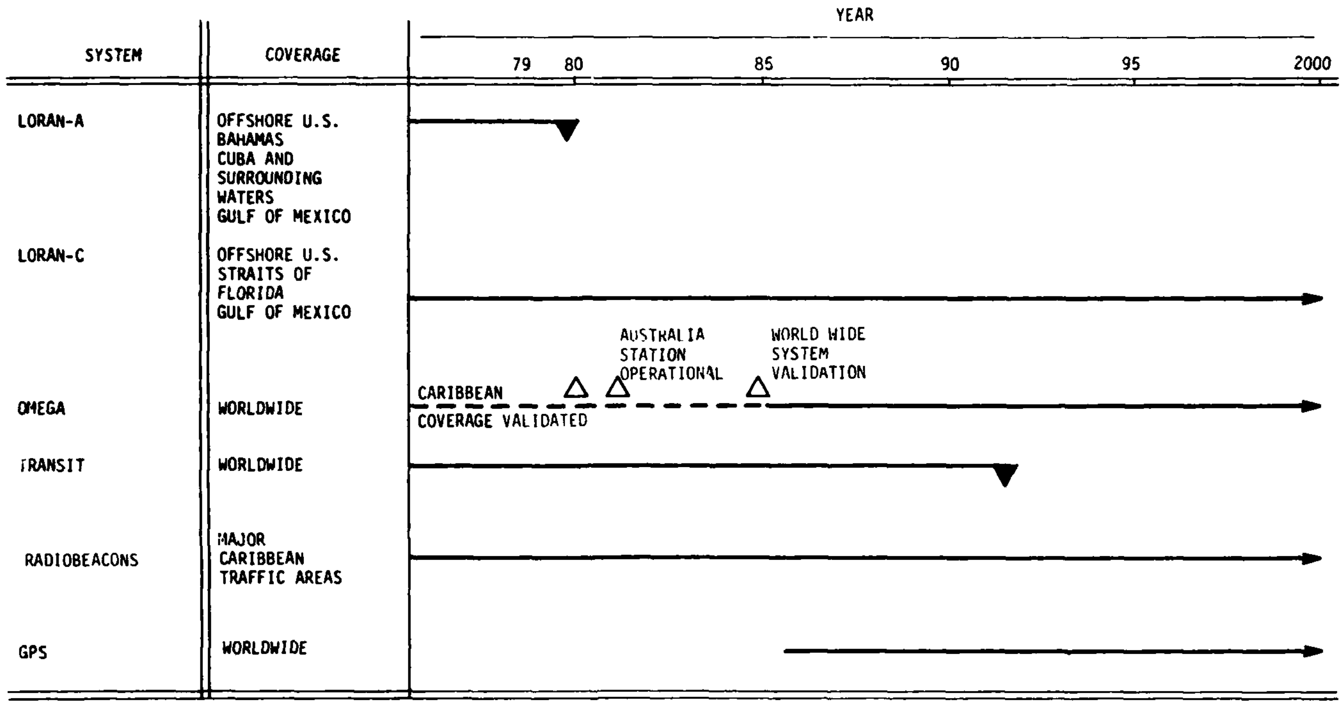


FIGURE A-1 TIME-PHASED RADIONAVIGATION SYSTEM AVAILABILITY - EASTERN CARIBBEAN

TABLE A-1 SELECTED SYSTEM CHARACTERISTICS: LORAN-C, LORAN-A, OMEGA, RADIOBEACONS

System	Accuracy (95%)			Fix Rate	Coverage	Availability	Reliability	Ambiguity Resolution
	Predictable	Repeatable	Relative					
LORAN-C	0.25NM (worst case) for 1:3 SNR (460 m)	60-300 ft. (18-90 m)	60-300 ft. (18-90 m)	25 Fixes/ Second	U.S. Coastal Areas, Continental U.S., Selected Overseas Areas	99+%	(1)	Yes, Easily Resolved
LORAN-A	1-2NM (3.7-7.4km)	300-6000 ft. (90-1800 m)	300-6000 ft. (90-1800 m)	25 Fixes/ Second	U.S. Coastal Confluence, Bahamas	99%	(1)	Yes, Easily Resolved
OMEGA	2-4NM (goal) (3.7-7.4km)	2-4NM (3.7-7.4km)	1-2NM (1.85-3.7km)	1 Fix/ 10 Seconds	Near Global (over 90%)	99%	(1)	Requires Knowledge of Approx. Position
RADIO-BEACONS	± 3°			Continuous; up to 6 min if sequenced	Worldwide stations local coverage	99+%	99+%	Reciprocal bearings possible

(1) depends upon mission time

NOTE: Each system has unlimited capacity in terms of potential user populations, and all provide two-dimensional fixes (Except Radiobeacons)

2.1.2 Coverage

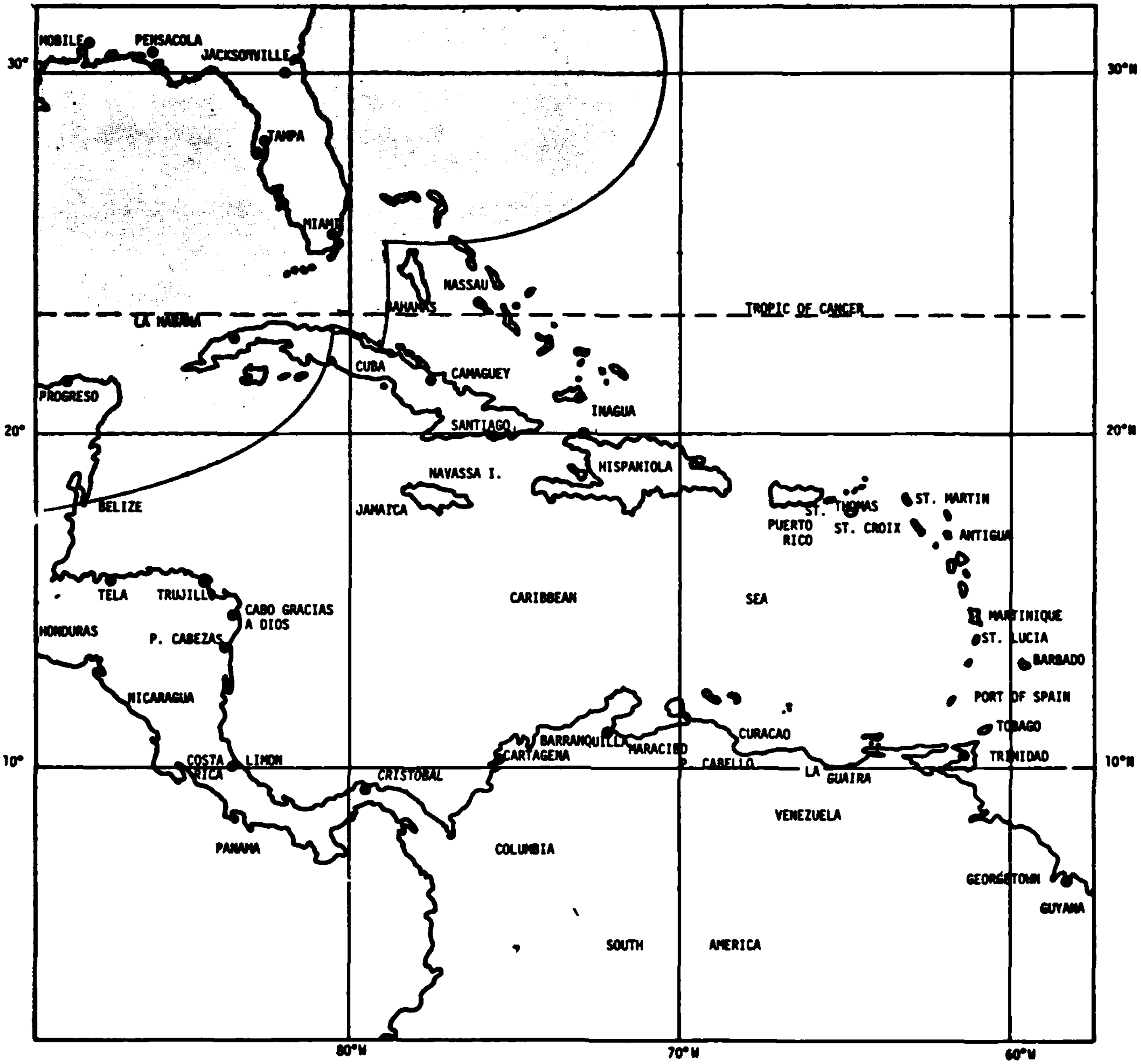
On the Pacific Coast, LORAN-C coverage extends from the U.S./Mexican border northward throughout the Gulf of Alaska and Aleutians into the Bering Sea. East Coast and Gulf of Mexico coverage is provided by expanding and reconfiguring the existing East Coast Chain and constructing additional stations to form three new chains. This reconfigured system provides coverage of the entire Eastern United States including the Great Lakes as well as the Coastal waters of Gulf and Eastern littoral States.

Limited Caribbean coverage is provided through the Southeast chain. This coverage for a signal to noise ratio of 1:3, includes the Grand Bahama and Great Abaco Island Groups in the Bahamas, the Straits of Florida and Cuba west of 80° W. At lower signal to noise ratios such as 1:10, this coverage is extended 200 to 300 miles down the Bahama Island Chain with a concomitant degradation of accuracy (fixes accurate to one mile or better). Groundwave coverage providing a single line of position is available throughout the Bahamas and the Turks and Caicos Islands. LORAN-C coverage using a signal to noise ratio of 1:3 is shown in Figure A-2.

2.1.3 Receiver Costs

Receiver costs for the individual user categories vary as a function of the sophistication of the vessel and the various requirements of the user. These costs were derived from previous studies in this area, current trade pricings and industry projections (References 19, 29, 30). These prices are subject to downward pressure as the economics of scale and the effects of competition begin to be felt. For purposes of this study, the following prices were assumed for marine LORAN-C receivers:

Large Commercial Vessels	$3800
Small Commercial Vessels	$2700



1/4 NM or Better Fix Accuracy

2 drms with Sigma = 0.1 microseconds

1:3 Signal to Noise Ratio

95% Signal Availability

58 dB Noise Limit

FIGURE A-2 CARIBBEAN LORAN-C COVERAGE

Fishing & Sport Fishing vessels	$3200
Recreational Boats	$1900

2.2 SYSTEM CHARACTERISTICS - OMEGA

2.2.1 General

The Omega system was developed by DOD to meet the need for worldwide general navigation. Omega utilizes CW phase comparison of skywaves from pairs of stations. The stations transmit time shared signals in four frequencies: 10.2kHz, 11 1/3 kHz, 13.6 kHz and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance performance. The system is comprised of seven transmitting stations situated throughout the world plus an additional temporary station located in Trinidad. Nearly worldwide position coverage will be attained when an eighth station in Australia becomes operational (1981).

The inherent accuracy of the Omega System is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be obtained in the form of predictions from tables or automatically in computerized receivers. The system has a design goal of 2 to 4 NM (95 percent CEP). This depends on location, station pairs used, time of day, and validity of the propagation corrections. In the North Atlantic Ocean Area, the Omega System has been validated to meet the above design goal (Reference 58). Omega characteristics are summarized in Table A-1.

2.2.2 Coverage

When the Omega system is fully implemented, it is expected to provide nearly worldwide position verification. Coverage in the vicinity of Puerto Rico and the Virgin Islands, provides the user with Omega positions typically accurate 1.0 - 1.5 miles or better 95 percent CEP. To obtain this accuracy, it requires a selection of those Omega stations which provide the best service at each hour of the day. In addition, a dead reckoning position must be carefully maintained and checked against the Omega-obtained position to guard against gross errors in the latter position caused by slips in the lane count.

The proximity of the Eastern Caribbean area to the Trinidad station affects the behavior of the electromagnetic waves (i.e. model interference) from this station. Within 450 nm of this transmitter, the interference is such that the use of this Omega station for navigation is not generally reliable. The best results from the Trinidad station are obtained in the northwest corner of the Caribbean, however, on 31 December 1980 service from this station will be terminated. The most commonly used stations in this area are Norway (A), Hawaii (C), North Dakota (D), and Argentina (F). Coverage from these stations varies from day to night. Coverage contours for these stations are shown in Figures A-3 through A-10. In addition, the Australian station, when activated, will provide nightime coverage. Through judicious selection of appropriate station pairs, the crossing angles between the LOP's derived from these stations is generally good. Hence, with the exception of Trinidad station coverage, this area is average for Omega applications.

2.2.3 Receiver Costs

The degree of sophistication of the Omega receivers is directly proportional to the level of receiver pricing. The manually operated receiver is the least expensive unit but requires a high degree of knowledge and skill on the part of the operator in order to employ it effectively. Because of the need for lane identification, automatic tracking is particularly desirable in Omega receivers, but this feature raises the level of sophistication and price of the unit for receivers not equipped with lane counters. Strip chart recorders are necessary for lane identification and result in a concomitantly lower level of pricing.

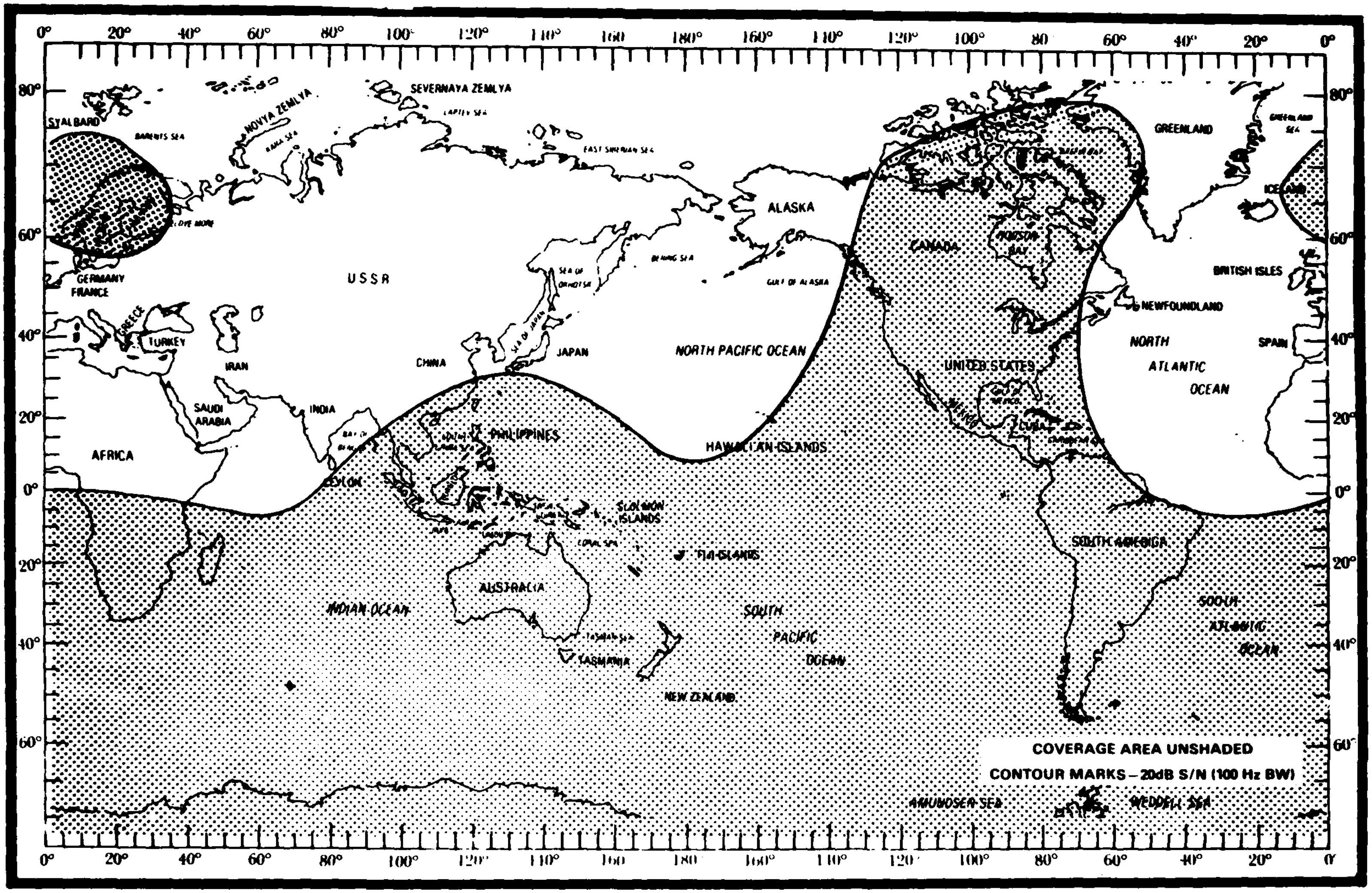


FIGURE A-3 OMEGA COVERAGE, NORWAY STATION (DAYTIME)

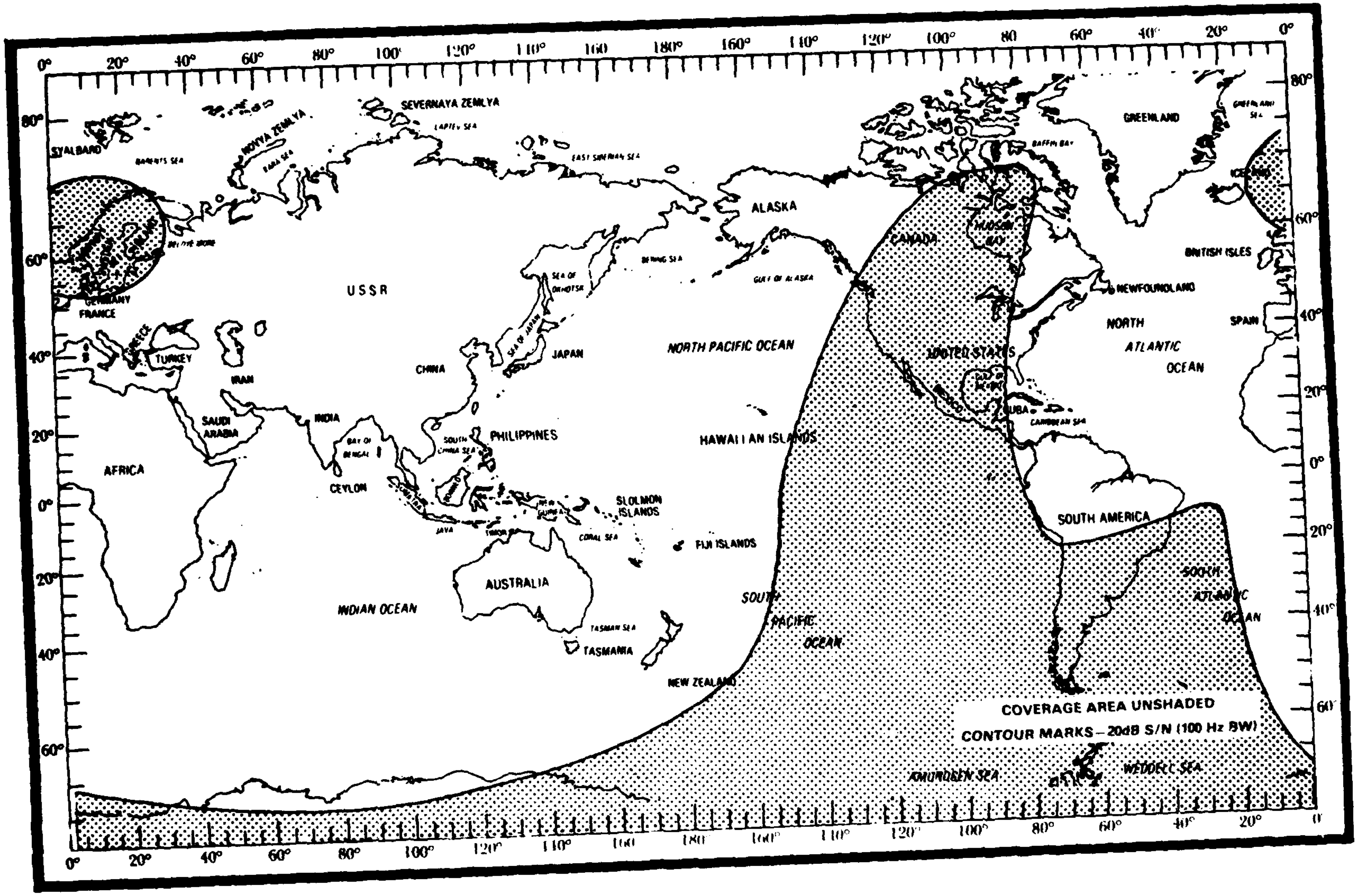


FIGURE A-4 OMEGA COVERAGE, NORWAY STATION (NIGHTTIME)

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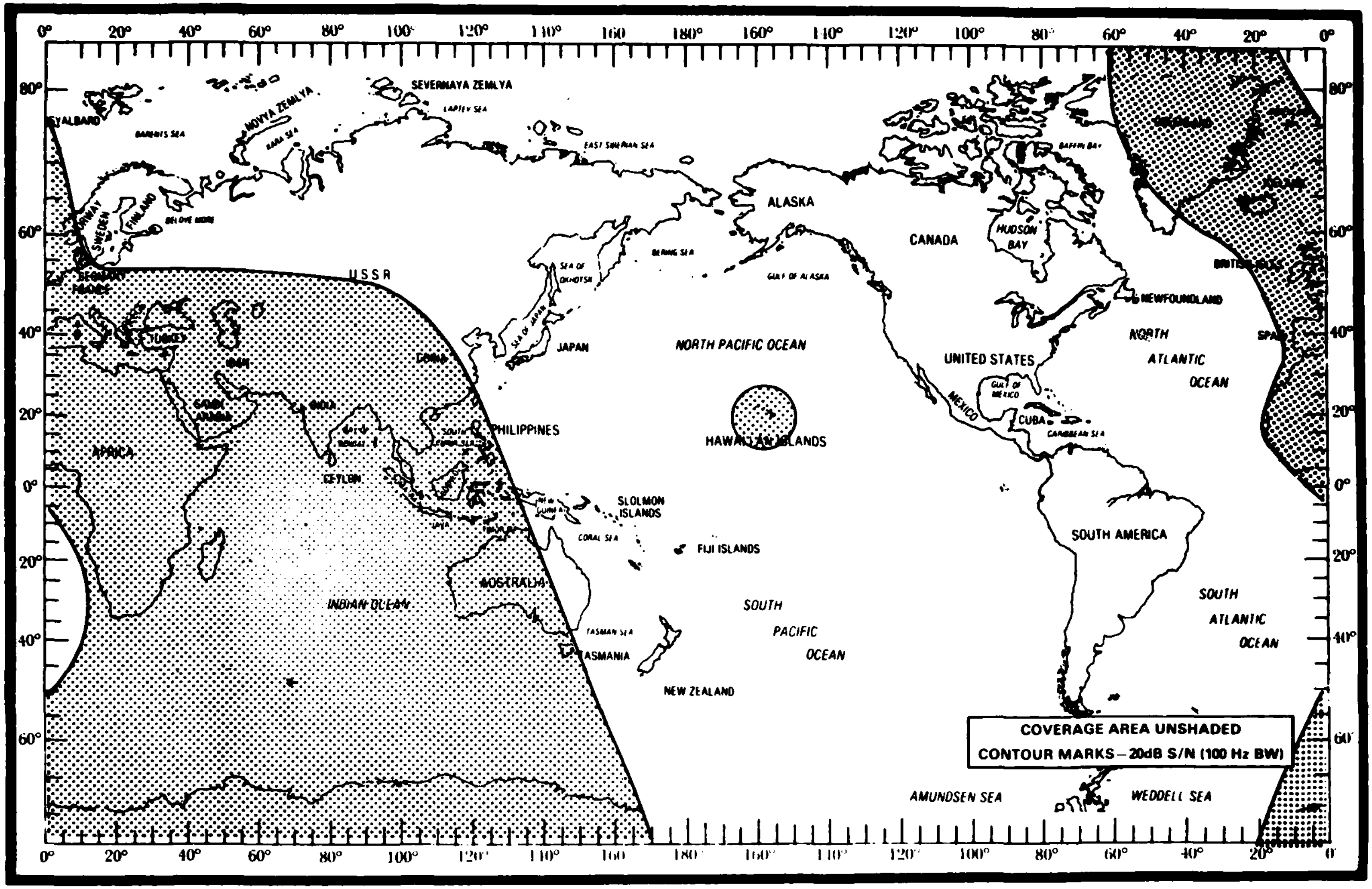

FIGURE A-5 OMEGA COVERAGE, HAWAII STATION (DAYTIME)

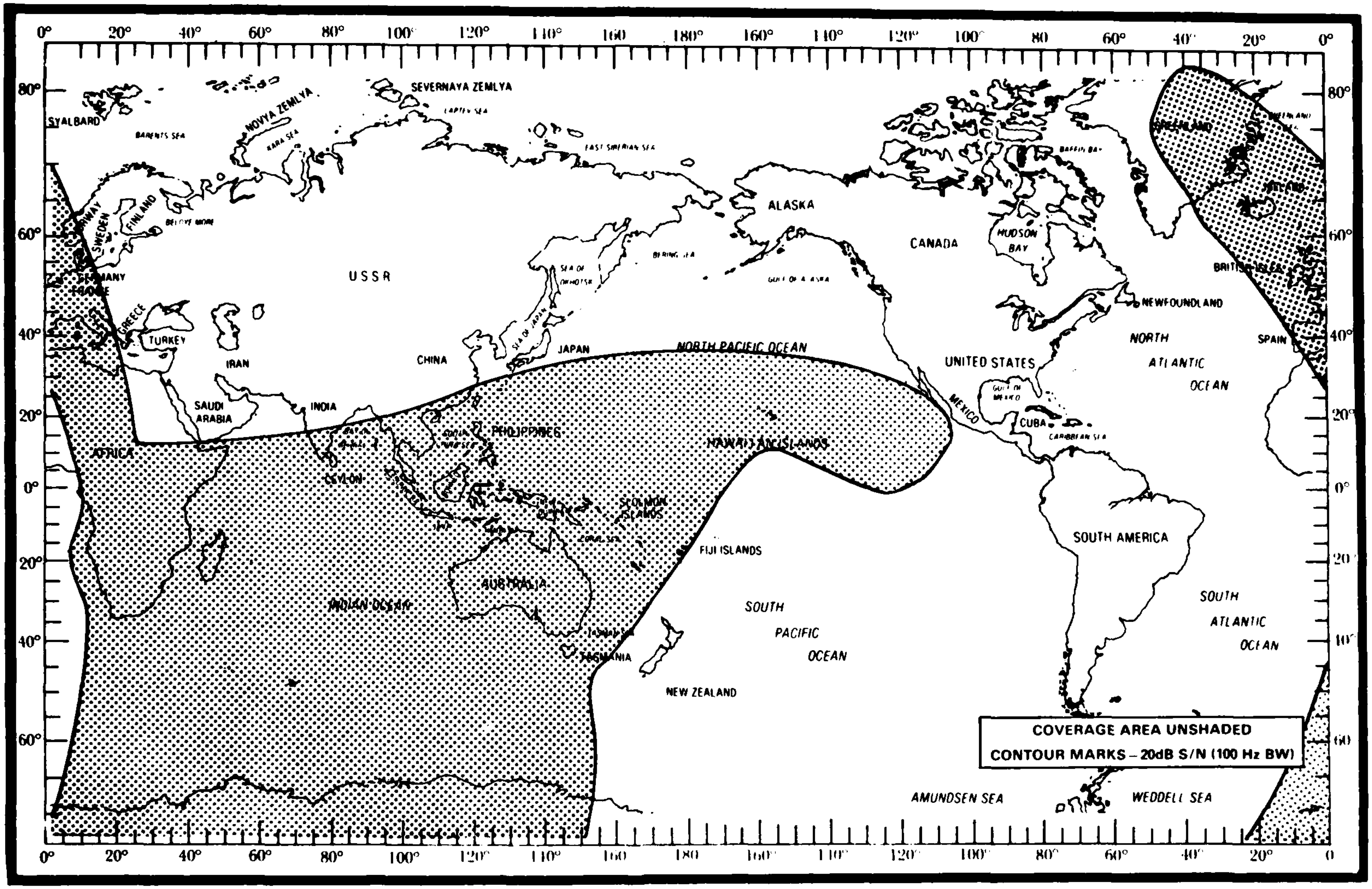

FIGURE A-6 OMEGA COVERAGE, HAWAII STATION (NIGHTTIME)

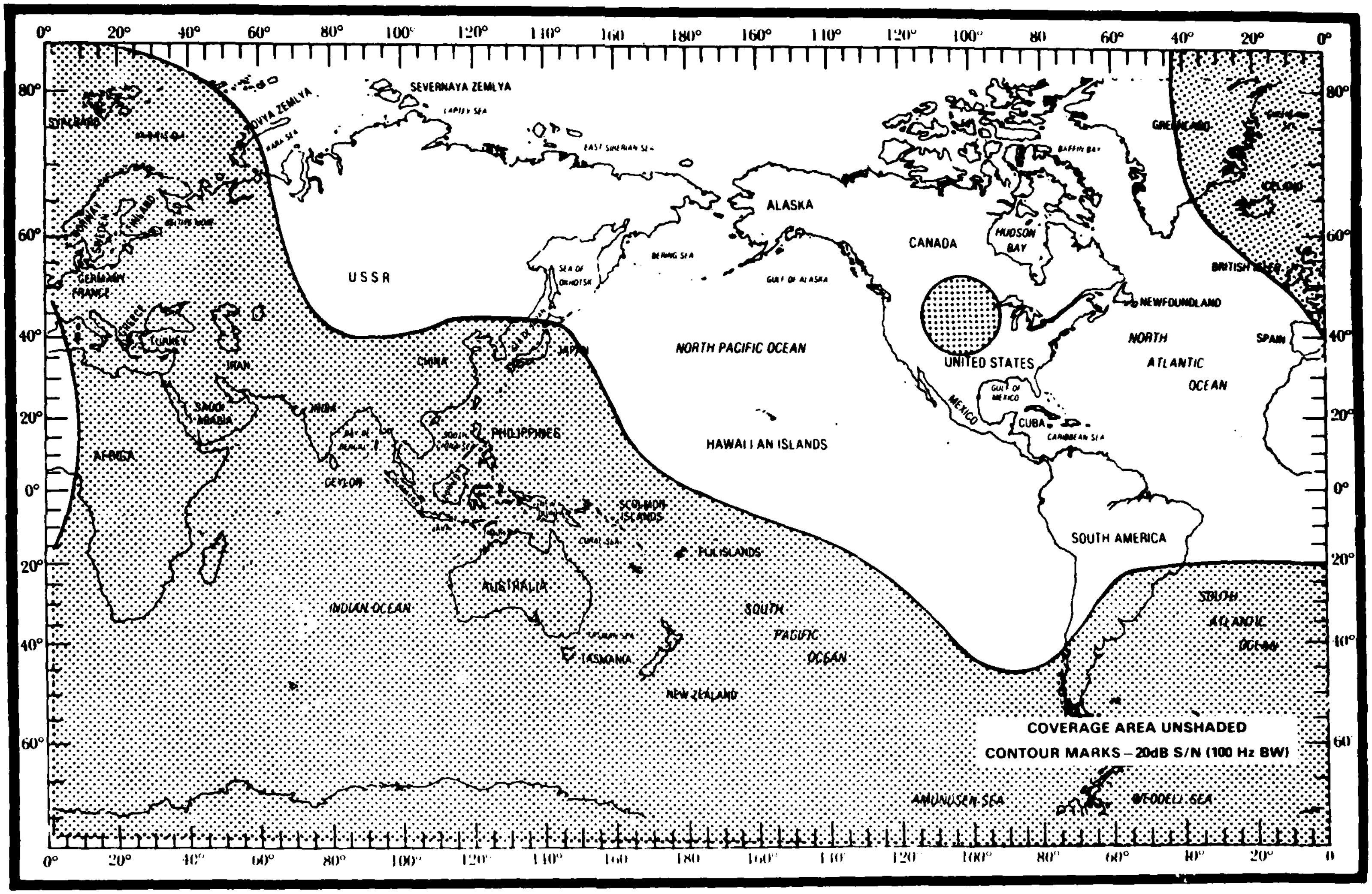

FIGURE A-7 OMEGA COVERAGE, NORTH DAKOTA STATION (DAYTIME)

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BENEFITS AND COSTS OF LORAN-C EXPANSION INTO THE EASTERN CARIBB--ETC(U)
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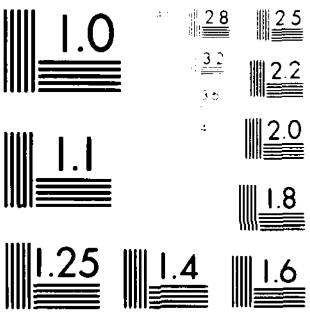

MICROCOPY RESOLUTION TEST CHART

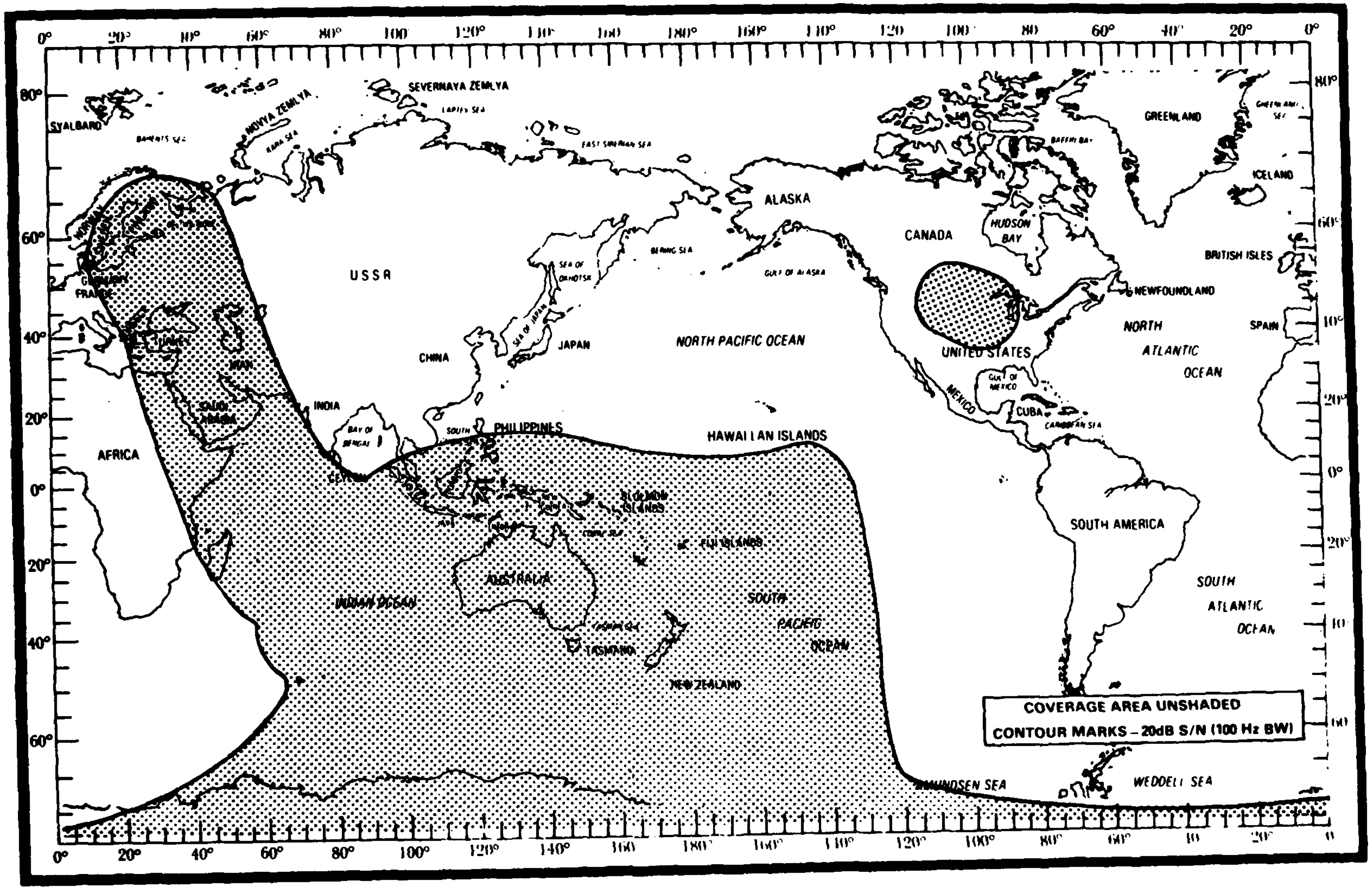

FIGURE A-8 OMEGA COVERAGE, NORTH DAKOTA STATION (NIGHTTIME)

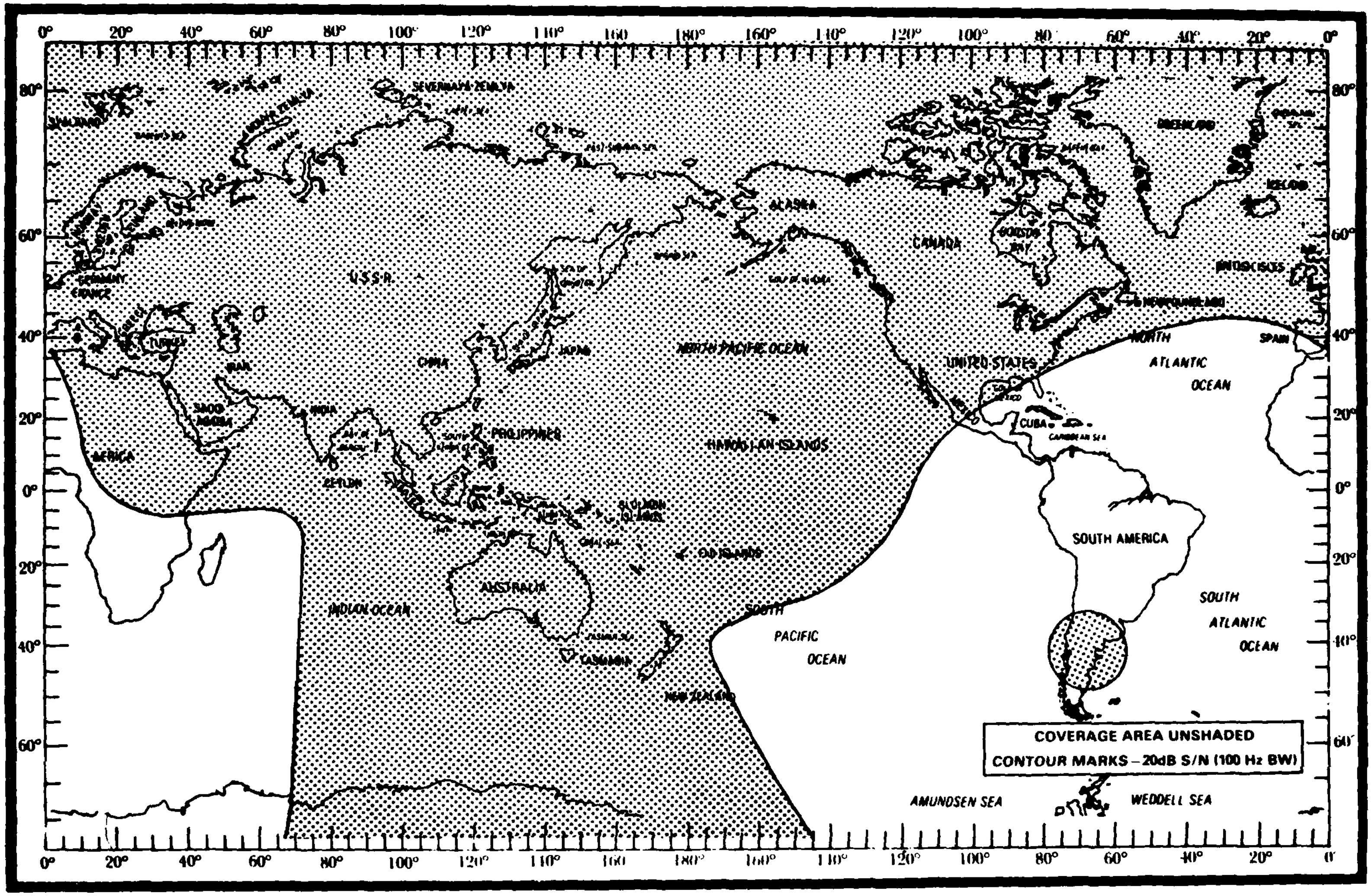

FIGURE A-9 OMEGA COVERAGE, ARGENTINA STATION (DAYTIME)

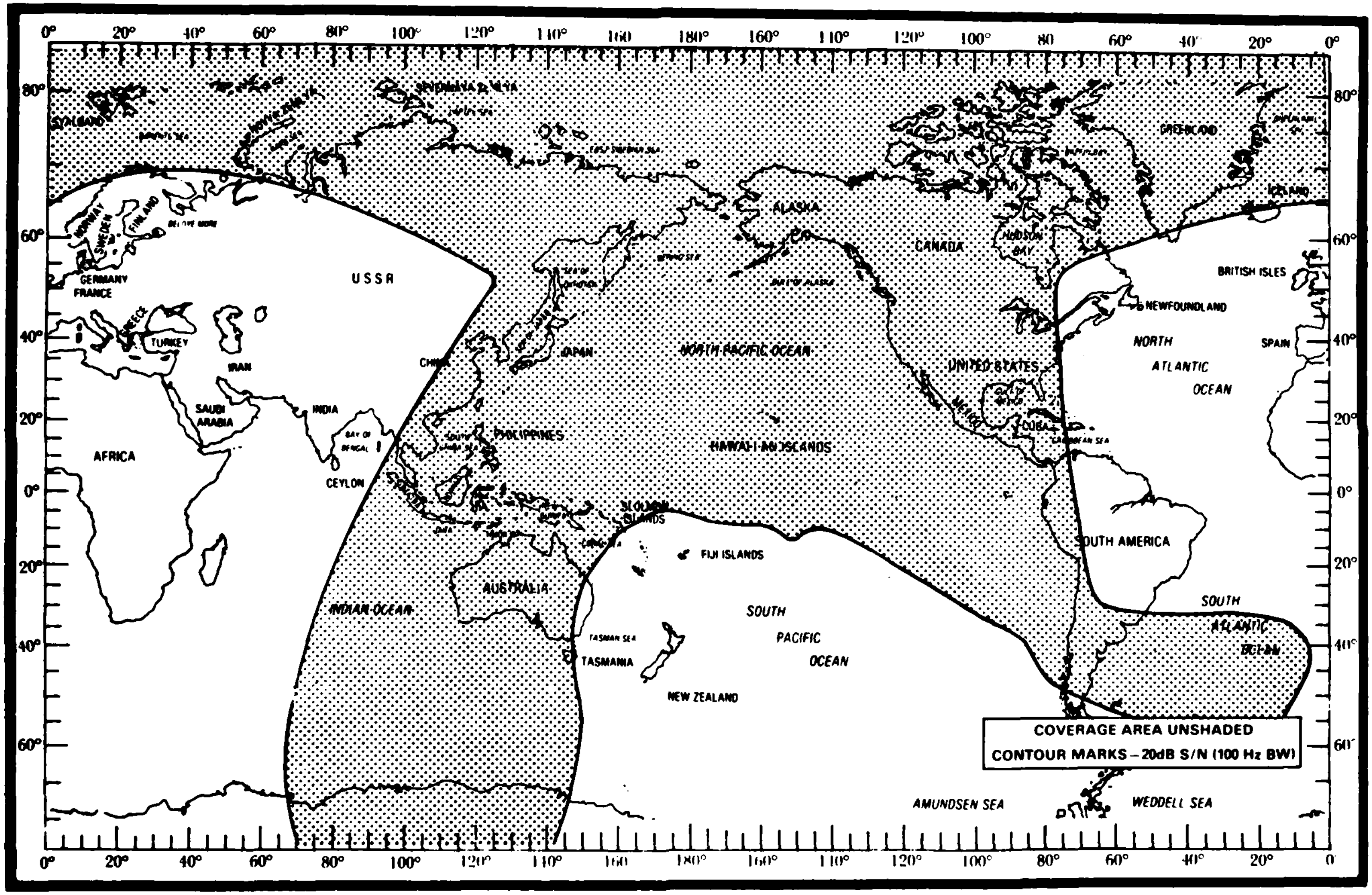

FIGURE A-10   OMEGA COVERAGE, ARGENTINA STATION (NIGHTTIME)

Omega receiver prices for the various user categories are given below and are based on the data contained in References 19 and 29.

Large Commercial Vessels	$11,900
Small Commercial Vessels	$ 3,100
Fishing & Sport Fishing Vessels	$ 9,500
Recreational Boats	$ 2,200

2.2.4 Differential Omega

Differential Omega is a scheme that permits real time corrections of Omega signal propagation and velocity deviations from nominal to be applied automatically by the Omega receiver. These corrections are derived by measuring the Omega signal at a known location such as a coastal radiobeacon station and transmitting the error correction on a subcarrier on the radiobeacon signal. This subcarrier is transparent to the radiobeacon user but is decoded by the Differential Omega receiver and automatically applied to the Omega LOP measured at the vessel's position. The spacial dependency of this process degrades accuracy as distance from the fixed site increases. Accuracies of 0.25 nm are typical at about 50 nm from the radiobeacon station. The process does not eliminate the lane ambiguity resolution problem, but does alleviate other anomalous signal propagation conditions.

The differential receiver costs more than the standard Omega receiver because it must process the radiobeacon subcarrier in addition to the normal Omega functions. However, this additinal cost is offset by its flexibility which permits the navigator to use the receiver in the standard Omega mode when the vessel is outside the limits of Differential Omega coverage. Current estimates (October 1980) indiate that the price range for Differential Omega receivers is $10,000 to $14,000.

2.3 SYSTEMS CHARACTERISTICS - TRANSIT

2.3.1 General

Transit is a space-based navigational system consisting of five satellites in 600 NM polar orbits. The phasing of the satellites is staggered to minimize time-between-fixes for users. In addition, the Transit system consists of four ground-based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

The satellites broadcast ephemeris information continuously on approximately 150 MHz and 400 MHz signals. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the use based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and a knowledge of the doppler shift of the satellite signal. Also, vessel course, speed, and time must be known in order to determine position accuratly. Transit system characteristics are in Table A-2.

2.3.2 Coverage

Coverage is worldwide but not continuous. While there is coverage in the Caribbean area and in the Bahamas, the mean time between Transit fixes is approximately 1.5 hours. This translates into a cumulative cross-track error of less than 1.5 miles at least half the time (95 percent confidence limit). In 10 percent of the time, there is at least a five hour duration between fixes and may be as great as eight hours in a limited number of cases. For these extended periods, cross-track error ranges between 2.5 and 7 miles and 2.5 to 4 miles error along-track (95 percent confidence limits). These latter errors are dependent upon vessel course, speed and quality of dead reckoned position.

TABLE A-2 SELECTED SYSTEM CHARACTERISTICS: TRANSIT NAVSTAR GPS

System	Description	Accuracy[1]			Avail.	Coverage	Rel.	Fix Rate	Fix Dim.	Capacity	Ambiguity Potential
		Pred.	Repeat.	Relative							
TRANSIT	Satellite Doppler	500m	50m	38m	99+% when Satellite is in View	Worldwide Non-Continuous	–	30 Min. at 80° lat. to 110 min. at Equator (Average)	2D	Unlimited	–
NAVSTAR GPS	Satellite, UHF Spread Spectrum Structured Navigation Signal	Horiz. 25m Vert. 30m	25m 30m	10m 8m	95%	Global Continuous	99+%	Essentially *Continuous*	3D+ *Time* and 3D Velocity	Unlimited	–

NOTE: *Horizontal* **(2 drms) and vertical (2 sigma) accuracies are available to military and selected civil users. Accuracy available to other users is estimated at: 500m (2 drms) horizontal and 430m (2 sigma) vertical.**

2.3.3 Receiver Costs

There is little variation among the capabilities of the various Transit receivers presently available. However, the number of sets sold annually is increasing and price differences are beginning to appear among these receivers. In the past, for all of the user categories, an average receiver price of $20,000 was indicative of the market environment (Reference 19,21). Now there are more Transit installations than Omega receivers on commercial vessels and, there is downward pressure on this price such that lower cost equipments are becoming available ($6000 per receiver).

2.4 SYSTEM CHARACTERISTICS - RADIOBEACONS

2.4.1 General

Radiobeacons are nondirectional radio transmitting stations which operate in the low frequency (LF) and medium frequency (MF) bands to provide groundwave signals to a receiver. A radio direction finder (RDF) is used to measure the relative bearing of the transmitter with respect to the heading of an aircraft or vessel.

Aeronautical Nondirectional Beacons (NDB) operate in the 200-415 kHz band. Marine radiobeacons operate in the 285-325 kHz band. The transmissions include a coded continuous-wave (CCW) or modulated continuous wave (MCW) signal to identify the station. Two CW carriers are spaced 1020 Hz apart, one of which is keyed intermittently to produce the code characters. Some of the longer-range marine radiobeacons operate on the same frequency and are time sequenced to prevent mutual interference. Specific characteristics of Radiobeacons are given in Table A-1.

There are approximately 25 Radiobeacon stations in the Caribbean east of longitude 80°W. These beacons extend from the Bahamas, through the Antilles to the North Coast of South and Central America. Of these beacons, there are four marine beacons which are usable only by maritime entities; the balance are aeronautical beacons which are available to both aviation and marine users. Overall, only five beacons are operated by the United States (four on Puerto Rico, one at Guantanamo Bay, Cuba), the balance are operated by the individual nations overseeing the particular territory. These beacons and their location are listed in Table A-3. A complete listing of all beacons is contained in Radionavigational Aids (DMAPUB 117A Reference 31).

2.4.2 Coverage

Radiobeacon coverage in the Eastern Caribbean is shown in Figure A-11. As can be seen, there is some radiobeacon coverage of all of the principal passages of this region. Old Bahama passage is somewhat limited in coverage as is Windward Passage. In addition, radiobeacon coverage from Cuba is erratic and should not be relied upon.

2.4.3 Receiver Costs

Radiobeacon receivers represent the lowest cost category of radionavigation equipment and because of this, are more widely used than any other category. Receiver prices range from several hundred dollars to several thousand dollars based on level of sophistication and perceived requirement on the part of the user.

TABLE A-3 CARIBBEAN RADIOBEACONS EAST OF 80 W

NAME	TYPE	LOCATION	RANGE
Bahama Islands			
West End International Settlement Pt. Grand Bahama Island	Aero	26°41'N/78°59'W	50 Miles
Bimini Island	Aero	25°42'N/79°16'W	75 Miles
Nassau International Airport New Providence Island	Aero	25°03'N/77°28'W	140 Miles
San Salvador Island	Aero	24°04'N/74°32'W	-
Great Inagua	Aero	20°58'N/73°41'W	50 Miles
Cuba and Hispanola			
Cabo Caucedo	Aero	18°25'57"N/69°40'14"W	140 Miles
Cayo Caiman Grande	Marine	22°41'N/78°53'W	90 Miles
Punta Alegre	Marine	22°22'30"N/78°47'18"N	70 Miles
Santiago di Cuba	Aero	19°57'58"N/75°50'17"W	70 MIles
Guantanamo Bay	Aero	19°54'N/75°10'W	-
Puerto Rico			
San Juan (Vega Baja)	Aero	18°28'N/66°25'W	250 Miles
San Juan	Marine	18°28'14"N/66°07'03"W	55 Miles
Roosevelt Roads	Aero	18°14'N/65°37'W	65 Miles
Punta Tuna Light Station	Marine	17°59'25"N/65°53'08"W	55 Miles
Jamaica			
Montego Bay	Aero	18°30'N/77°55'W	150 Miles
Kingston	Aero	17°58'N/76°53'W	250 Miles
Lesser Antilles			
Saint Martin (Sint Maarten)	Aero	18°03'N/68°07'W	150 Miles
Coolidge (Antigua)	Aero	17°09'N/61°47'W	150 Miles
Pointe-a-Pitre (Guadelaupe)	Aero	16°15'N/61°33'W	250 Miles
Marie-Galante/Grand Bourg (Guadelaupe)	Aero	15°52'N/61°16'W	-
Fort de France (Martinique)	Aero	14°36'N/61°06'W	100 Miles
Vigie (St. Lucia)	Aero	14°01'N/61°00'W	-
Seawell (Barbados)	Aero	13°04'N/59°29'W	150 Miles
Crown Point (Tobago)	Aero	11°09'N/60°50'W	50 Miles
Trinidad			
Piarco	Aero	10°35'N/61°25'W	150 Miles

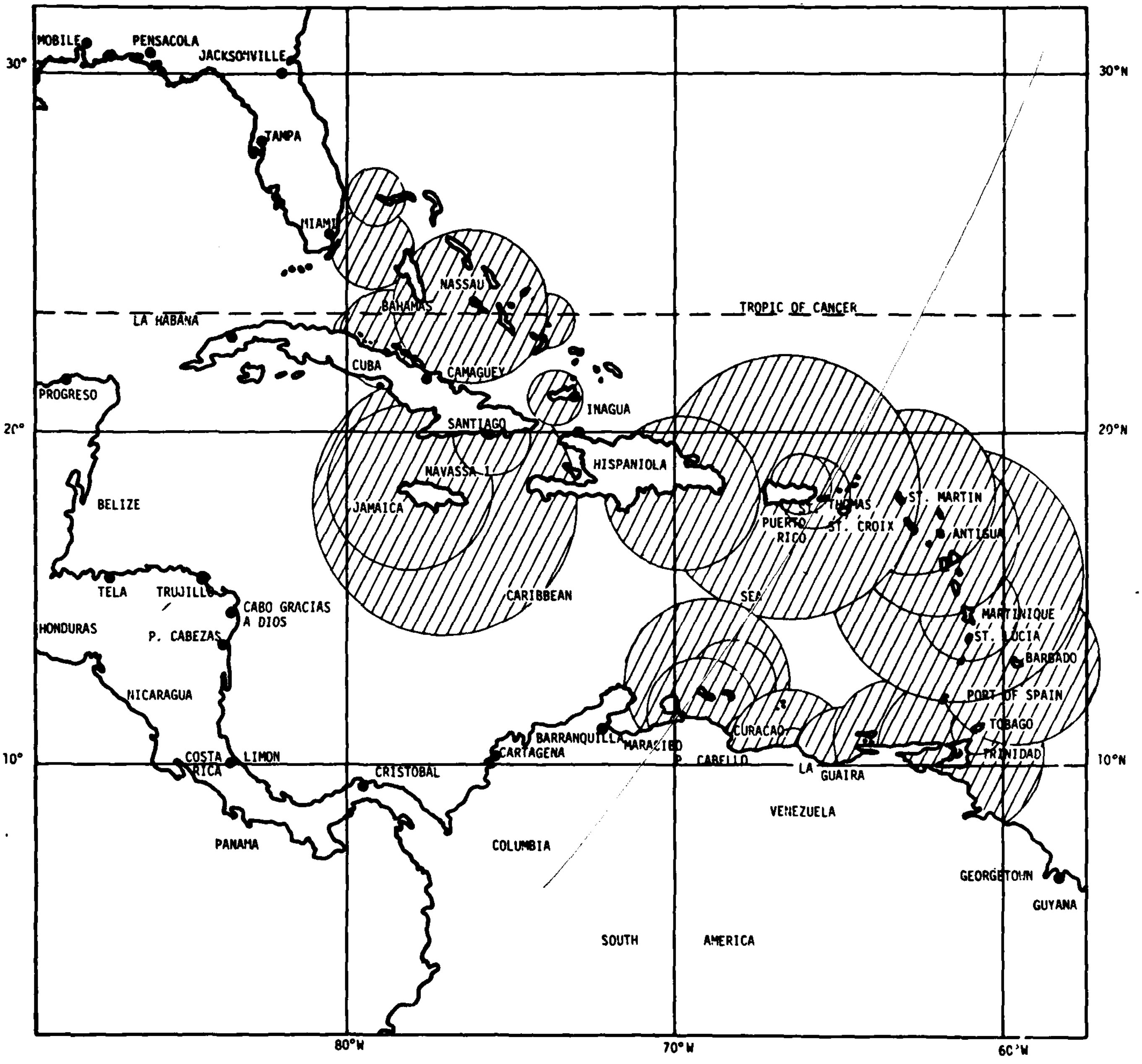

FIGURE A-11 EASTERN CARIBBEAN RADIOBEACON COVERAGE

2.5 SYSTEM CHARACTERISTICS - NAVSTAR GPS

2.5.1 General

NAVSTAR GPS is a space-based radionavigation system being developed by the Department of Defense under Air Force management. The concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite in the system with respect to time and distance from the transmitting satellite to the user. Each satellite transmits its ephemeris data. This is periodically updated by the master control station based upon data obtained from the monitors. The fully deployed operational system is intended to provide highly accurate positional information in three dimensions and precise time and velocity information on a global basis continuously, to an unlimited number of properly-equipped users. It will be unaffected by weather and will provide a worldwide coverage with a common grid reference system. While the system was initially conceived to meet the requirements of a wide spectrum of military missions, current policy calls for civil availability with a degradation in system accuracy required to protect national security interests.

The user system automatically selects appropriate signals from each of four satellites (selected from those in view with respect to optimum satellite-to-user geometry). It then solves the three time-of-arrival difference quantities to obtain distance between user and satellites. This information establishes the user position with respect to the satellite system. A time correction factor then relates the satellite system to earth coordinates. Each satellite will continuously transmit a composite signal at 1227.6 and 1575.42 MHz consisting of a precise navigational signal, a coarse/acquisition navigational signal, data such as satellite ephermis, atmospheric propagation correction data and clock bias information. User equipment measures four independent pseudoranges and range-rates and translates these to three-dimensional position, velocity and system time. Worldwide full operational capability is expected by 1987. The characterisics of NAVSTAR GPS are summarized in Table A-2.

2.5.2 Receiver Costs

Receiver costs for the civil user have been estimated in several previous studies (Ref. 19, 29, 32, 33). These costs are highly speculative and dependent upon the assumptions made with respect to the level of technology employed, the degree of technical sophistication incorporated into the receiver, production quantities, market split and user demand, to name a few. Further, most of these studies addressed only the civil aviation user. Reference 19 represented the only attempt to translate aviation equipment costs into marine equipment costs. The results of this study indicated that GPS marine receiver prices would lie between $3100 and $16,600 depending upon the needs of the user and degree of receiver sophistication. These prices were based upon 1977 dollars and production base of 3000 units. Specifically, for the various user categories, these prices were:

Large Commercial Vessels	$6200-$16,600
Small Commercial Vessels	$4400
Fishing and Sport Fishing Vessels	$5300
Recreational Boats	$3100

2.6 SYSTEM CHARACTERISTICS - LORAN-A

2.6.1 General

LORAN-A was developed to provide a long range radionavigation capability. It is a pulsed hyperbolic system operating in the 1700 to 2000 kHz band and is based on measurement of the difference in time of arrival of RF pulses radiated by a pair of synchronized transmitters which are separated by several hundred miles. The difference in time is shown as a line of position (LOP) on a LORAN-A chart or derived from LORAN tables. The TD measurements from two station pairs yields two LOP's and their intersection defines a position fix.

LORAN-A has been extensively used by civil air and marine craft at all levels of sophistication and requirements. It is principally used out to the limit of groundwave coverage; beyond this range the skywave is used when available. Those vehicles interested in returning to the same location or traversing the same path, such as fishing vessels, utilize LORAN-A in the repeatable mode. LORAN-A has been used extensively in civil intercontinental air carrier operations for transoceanic flights including flights to the Bahamas, Puerto Rico and the Virgin Islands.

LORAN-A coverage for the eastern U.S. including Gulf of Mexico and Atlantic Coast is provided by the East Coast, Gulf of Mexico and West Indies chains. The West Indies chain also provides fix coverage to the Eastern Caribbean north of the Islands of Cuba and Hispanola. The West Indies chain consists of stations at Jupiter, Florida; San Salvador, BWI, South Caicos, BWI, and Cape San Juan, PR. All of the above chains are scheduled for termination on December 31, 1980. LORAN-A characteristics are summarized in Table A-1.

2.6.2 Coverage

Coverage of the system is dependent upon the station power and propagation conditions. The ground wave range varies from 600-800 nm. Skywave range extends up to 1500 nm at night. LORAN-A coverage in the Caribbean is shown in Figure A-12. Eastern Caribbean coverage includes all of the Bahama Islands and the principal passages between the Bahamas, Cuba, and Hispanola including

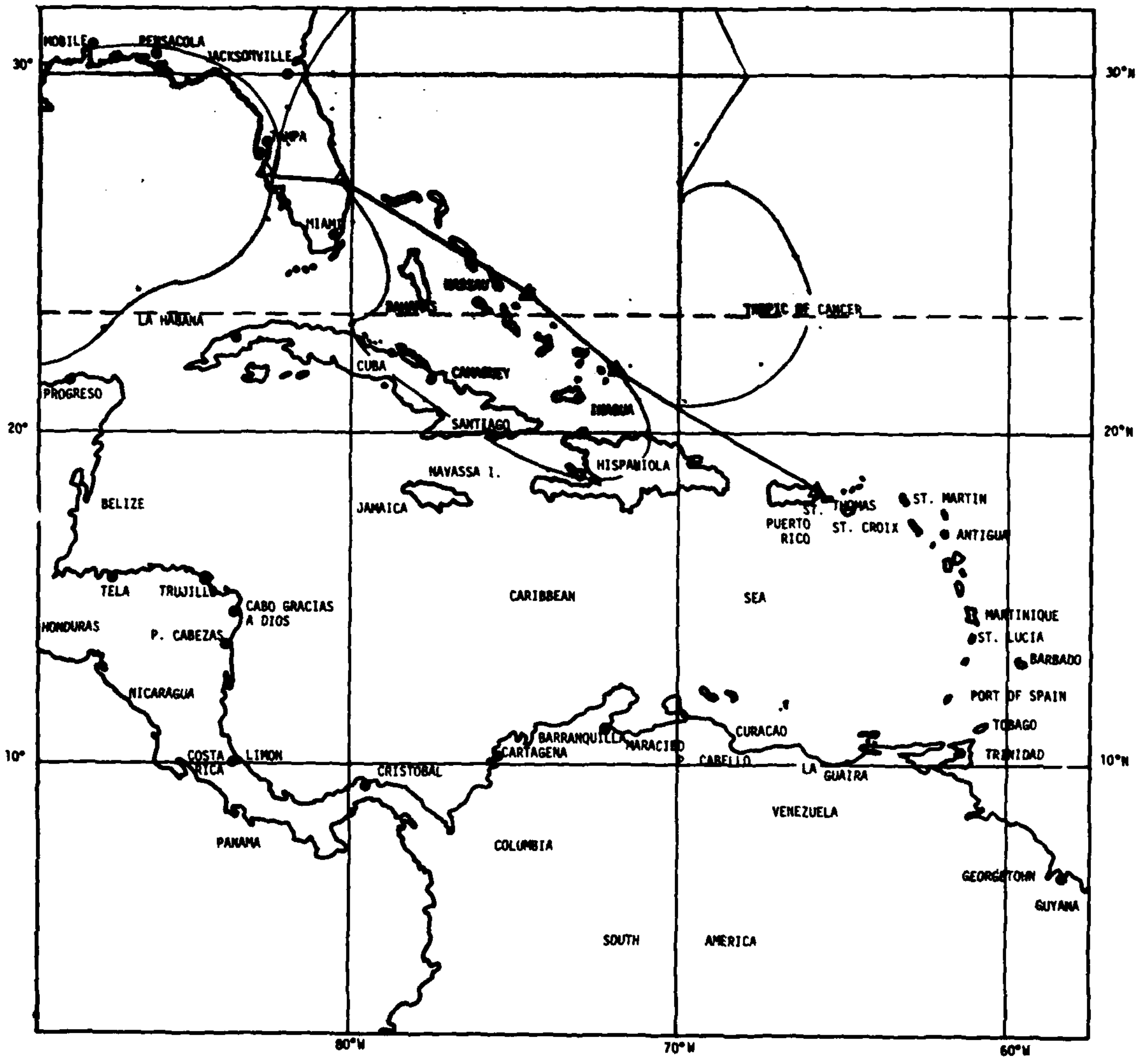

FIGURE A-12 CARIBBEAN LORAN-A COVERAGE

Windward, Caicos and Crooked Island passages and the Old Bahama Channel. However, there is no coverage of the eastern section of the Straits of Florida including the lower Gulf of Mexico. A single, groundwave line of position is available from South Caicos Island in the Bahamas to Puerto Rico. The baseline extension of this station pair runs through the Virgin Islands and therefore does not provide a line of position for the sea lanes east of Puerto Rico, including the Virgin Passage. The land masses of Hispaniola and Puerto Rico prevent groundwave coverage to the waters south of these islands.

2.6.3 Receiver Costs

Receiver costs for LORAN-A sets have been under downward pressure since the announcement of the termination of LORAN-A system. As a result of this, high performance LORAN-A sets can be purchased now for as little as $200; against this low investment cost, the perspective purchaser must weight a finite system availability. Nevertheless, over the past several years, LORAN-A sets have been purchased in large quantities by the marine users; in quantities so large that they have exceeded prior yearly purchases. The reason for this purchasing strategy can only be surmised, however, it must be assumed that while the perceived user benefits (and disbenefits of imminent system termination) have remained constant, the costs have decreased to the extent that the benefit-cost were not considered, since this system will not be a valid alternative for potential users in the near future.

3. USER REQUIREMENTS

3.1 GENERAL

The radionavigation requirements for vessels operating in the Eastern Caribbean are based on the generalized requirements detailed in the Federal

Radionavigation Plan (Reference 1). Because of the lack of hazards to navigation and due to the relatively benign weather conditions, there are few Caribbean-specific requirements which exceed those of the general requirements. Those that do exist are related to the specific function of the user, e.g., fishing. These requirements are discussed in detail in Appendix D.

The navigational requirements of a vessel depend upon its type and size, the activity in which the ship is engaged, e.g., point-to-point transit, fishing; the geographic region in which it operates, e.g., ocean, coastal; and other factors. Safety requirements for navigation performance are dictated by the physical constraints imposed by the environment and the vessel, and the need to avoid the hazards of collision, ramming and grounding.

In this study, system performance parameters are identified based on the need to satisfy current maritime user requirements or to achieve special benefits on the high seas (ocean phase) and in the coastal waters. These parameters are divided into two categories. There are unique requirements needed to provide special benefits to the various classes of navigation users, and there are those related to safety of navigation. The requirements are categorized in terms of performance characteristics which represent the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

3.2 OCEAN NAVIGATION REQUIREMENTS

The requirements for safety of navigation on the high seas is given in Table A-4. For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position-fixing on the high seas are not very strict. All position accuracy requirements are 2 drms. As a minimum, these requirements include a predictable accuracy of 2-4 nm coupled with a maximum fix interval of two hours or less. These minimum requirements would permit reasonable safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy for 1-2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95 percent of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 0.99.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many (perhaps most) of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost. In addition, many of the recreational ocean sailers for whom sailing is a serious avocation shun the more precise electronic systems and choose to rely on celestial navigation because this method is more in keeping with the traditions of the sea.

Economic efficiency in transoceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that need for safety in routine point-to-point ocean voyages. These requirements are summarized in Table A-4. The predictable accuracy requirements may be as stringent as 0.1 nm for special maritime activities and large, economically efficient vessels; and may range to 0.25 nm for all of the above categories, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table A-4, the required fix rate may range from as low as once per five minutes to as high as once per

Table A-4 Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Ocean Phase

(Reference 1)

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)			Coverage	Availability	Reliability	Fix Rate	Fix Dimension	Capacity	Ambiguity
	Predictable	Repeatable	Relative							
Safety of Navigation – All Craft	2-4NM(3.7-7.4km) Minimum 1-2NM(1.8-3.7km) DESIRABLE	–	–	Worldwide	95% full cap. 99% Fix at least every 12 hours	(2)	15 Mins. or Less Desired; 2 hrs Maximum	Two	Unlimited	Resolvable with 99% Confidence

Benefits	Measures of Minimum Performance Criteria to Achieve Benefits									
Large Ships Maximum Efficiency	0.1-0.25NM (185-460M) (1)	–	–	Worldwide, except Polar Regions	99%	(2)	5 min.	Two	Unlimited	Resolvable with 99% Confidence
Hydrography Science, Resource Exploitation	0.1-0.25NM (185-460M)	Maximum Possible	–	Worldwide	95%	(2)	1 min.	Two	Unlimited	Resolvable with 99% Confidence
Search Operations	0.25NM (460M.)	0.25NM	185 M.	National Maritime SAR Region (NPAC, NWLAN)	99%	(2)	1 min.	Two	Unlimited	Resolvable with 99% Confidence

(1) Requirement subject to confirmation by additional study
(2) Dependent upon mission time

minute. Signal availability must be at least 95 percent and approach 99 percent for search and rescue operations and large, high-efficiency ships. These requirements are based on current estimates and are to be used for the purposes of system planning. There has not been sufficient analysis to establish definitive, quantitative relationships between navigational accuracy and economic efficiency, however, estimates have been made for purposes of this study in order to derive ranges of benefits (see Sections 8. and 9.).

The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, oceangoing fishing vessels is evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

3.3 COASTAL NAVIGATION REQUIREMENTS

Requirements for position fixing accuracy for coastal navigation are based upon the need for larger vessels to navigate at safe distances from shallow water, on the need to remain in the designated traffic separation lane at the approaches to many ports and in fairways established through offshore oil fields. Only the first requirement is applicable to the Eastern Caribbean region. Further, there is a need for accurate definition for enforcement purposes of the boundaries of the Fishery Conservation Zone, the U.S. Customs Zone and the territorial waters of the U.S.

It has been established that a navigation system providing a capability to fix position to an accuracy of 0.25 nm will satisfy the minimum safety requirements if a fix can be obtained at least every fifteen minutes. As indicated in Table A-5, these requirements may be relaxed slightly for the recreational boat and other small vessels.

Table A-5 Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Coastal Phase
(Reference 1)

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)			Coverage	Availability	Reliability	Fix Rate	Fix Dimension	Capacity	Ambiguity
	Predictable	Repeatable	Relative							
Safety of Navigation – All Ships	0.25NM (460M)	–	–	U.S. Coastal Waters	99.7% Minimum	(1)	2 Min.	Two	Unlimited	Resolvable with 99.9% Confidence
Safety of Navigation – Recreational Boats & Other Smaller Vessels	0.25NM-2NM (460-3700 M)	–	–	U.S. Coastal Waters	99% Minimum	(1)	5 Min.	Two	Unlimited	Resolvable with 99% Confidence

Benefits	Measures of Minimum Performance Criteria to Achieve Benefits									
Commercial Fishing (including Commercial Sport Fishing)	0.25NM (460 M.)	50-600 ft. (15-180M)	–	U.S. Coastal/ Fisheries Areas	99% Minimum	(1)	1 Min.	Two	Unlimited	Resolvable with 99.9% Confidence
Hydrography Science, Resource Exploitation	150 M.	20-600 ft. (15-180M)	–	U.S. Coastal Area	99% Minimum	(1)	1 Min.	Two	Unlimited	Resolvable with 99.9% Confidence
Search Operations, Law Enforcement	0.25NM (460 M.)	300-600 ft. (90-180M)	300 ft. (90M)	U.S. Coastal/ Fisheries Areas	99.7% Minimum	(1)	1 Min.	Two	Unlimited	Resolvable with 99% Confidence
Recreational Sports Fishing	0.25NM (460 M.)	100-600 ft. (30-180M)	–	U.S. Coastal Areas	99% Minimum	(1)	5 Min.	Two	Unlimited	Resolvable with 99.9% Confidence

(1) Dependent on mission time

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as naval operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. As shown in Table A-5, the most rigid requirement of any of this general group of special operations is for position measurement with a repeatable accuracy on the order of 20 - 50 feet (2 drms), a signal availability of at least 99 percent, and a fix rate of once per minute for most applications.

3.4 SPECIFIC EASTERN CARIBBEAN REQUIREMENTS

Based on discussions with marine interests in the Eastern Caribbean (Appendix F) no user requirements could be identified which exceeded or differed from those already discussed above.

APPENDIX B

VESSEL CASUALTY ANALYSIS

1. INTRODUCTION

This appendix addresses and analyzes the marine casualty history in the Caribbean area. The objective of this analysis is to obtain a profile of the incidents and accidents which have occurred in this region and could be attributable in any manner to navigational causes. Only those casualties in which navigation could be deemed a contributing or primary causal factor have been considered. The underlying objective was to determine what role, if any, the availability or non availability of electronic and/or visual navigation aids played in the casualty, and further, to characterize such casualties in terms of personal injuries and loss of life, vessel and cargo costs, oil pollution costs and other costs stemming from such elements as loss of vessel productivity.

The casualty data base used was derived in part from that amassed for the Offshore Vessel Traffic Management (OVTM) Study (Reference 25). This data base is subject to certain limitations due to the nature of the primary data sources and screening criteria used. These data were augmented and expanded by a review of all of the vessel incidents in the files of the U.S. Coast Guard Marine Safety Office in San Juan, Puerto Rico.

The principal source for the OVTM data base was the U.S. Coast Guard Merchant Vessel Casualty Reports (MVCR). These reports contain the causal factors, a narrative description of the incident, vessel(s) and personnel data, location, time and environmental conditions, deaths, injuries and dollar value of loss and damage. These reports are required to be filed for each stranding or grounding, physical damage to property in excess of $1,500, material damage affecting the vessels seaworthiness or loss of life or severe injury. These reports are required to be filed by all U.S. and foreign flag vessels for casualties which occur within the navigable waters of the U.S. (3-mile limit). Further, U.S. vessels are required to report on each casualty, regardless of location. Hence, this data base is deficient in data on casualties involving foreign flag vessels in international or foreign waters. For example, because of these limitations and constraints, this data base would not contain a report on the grounding of the Liberian Tanker Argo Merchant on December 15, 1976 on Nantucket Shoals. This vessel was of foreign registry and the incident occurred 29 miles from shore.

The information derived from the files of the Marine Safety Office in San Juan contained additional data with respect to incidents which occurred in the entire Caribbean area. While some of the incidents were already reported on in the Merchant Vessel Casualty Reports, this information provided background and amplifying data. Further, the Marine Safety Office data provided information on recent incidents which did not appear in the Merchant Vessel Casualty Reports or which were initially excluded because of the screening criteria used in the OVTM Study.

For information on foreign flag casualties, particularly those which occurred in international and foreign waters, Casualty Returns from Lloyd's Registry of Shipping were consulted, but this latter source is limited with respect to causal factors and loss and damage factors.

2. CASUALTY CHARACTERIZATION

In order to develop a profile of the impact of navigation aids and the navigational capability of a vessel upon the causes of marine casualties, the type of casualty descriptors in the Merchant Vessel Casualty Report file were analyzed and reduced to those in which faulty or deficient navigation might possibly have a role.

These casualty descriptors were further refined to those applicable to the Eastern Caribbean. These descriptions were:

- Grounding and Strandings

- Collisions including
  - meeting, crossing and overtaking
  - anchored
  - fog and low visibility

- Rammings
  - offshore rigs
  - floating or submerged objects
  - aids to navigation
  - fixed objects

Other data parameters used to limit the number of cases examined included:

- U.S. Caribbean waters specifically those surrounding Puerto Rico and the Virgin Islands.

- Tankships, tank barges and foreign flag tankers greater than 1,000 GT.

- Non tankers greater than 5,000 GT.

The above restrictions imposed by the OVTM study would have constrained this analysis to incidents which had a potential for oil spillage and not have considered all accidents wherein faulty navigation played a major role. Thus, all incidents involving smaller vessels and pleasure craft were initially eliminated from this analysis. Further, this analysis would have been constrained to events which occurred only within the navigable waters of the U.S. and not those in international or foreign waters. In all of these cases, the vessels would have been in regions of potential LORAN-C coverage. Accordingly, the files of the Marine Safety Office in San Juan were used as the principal source of those casualties which were initially eliminated from the analysis.

In both data bases, casualties which occurred in channels and restricted waterways were excluded since it was deemed that LORAN-C would not avert these casualties.

3. MARINE CASUALTY ANALYSIS

3.1 INCIDENT IDENTIFICATION

The total casualty file for the period FY 1972 through FY 1977 contained 20,047 entries. Applying the initial screening criteria discussed in Section 2.0 above, the number of marine casualties which occurred in the Puerto Rico and Virgin Islands totaled 19. An additional 65 casualties were identified using information from the Marine Safety Office, San Juan. The Merchant Vessel Casualty Reports and Marine Safety Office data were reviewed to gain insight into the causative factors underlying these incidents and to derive sufficient information to determine if there was an underlying role for radionavigation in the cause, prevention, or aversion of any of these casualties. In addition, this review was also used to derive the data parameters which would characterize the incident.

The results of this preliminary screening and review process indicated that there were no collisions involving U.S. vessels in the Caribbean Sea. There was one ramming incident involving an unmarked wellhead in the Gulf of Paria. Of the identifiable casualties, the rest were attributable to groundings. These groundings and the single ramming are summarized in Figure B-1 by vessel category, casualty location and vessel ownership. The vessel categories and ownership are discussed here; the analysis of locales is discussed in Section 3.3.

Approximately seventy-five percent of these incidents involved U.S. flag or U.S. owned, foreign flag vessels. However, this percentage may be somewhat misleading since no substantive data could be readily obtained on incidents involving foreign flag vessels which occurred in foreign or international waters. Further, no attempt was made to derive these figures since the benefits to be gained from the prevention of a navigation-related incident involving those vessels was outside the scope of those benefits considered in this study. The foreign vessels which are included are those which grounded in U.S waters and they are presumed to be in support of U.S. commerce.

The largest category of vessels involved in the groundings are the tank vessels. This category amounted to thirty incidents or over one-third of the total incidents. Of the thirty groundings, 12 involved foreign flag vessels. The second largest category of incidents were those involving tugs and barges. There were twenty incidents in this category; virtually all (17) involving U.S. owned or U.S. owned foreign flag vessels. The large number of tug barge incidents is not surprising since much of the local maritime commerce is conducted in this mode. This is emphasized by the fact that most of these incidents occurred throughout the region and were not localized in any one area. The third most prevalent category consisted of both the large cargo vessels and the small, interisland vessels and the number of these incidents were almost identical (10 and 11, respectively).

The least number of incidents involved the fishing vessels. These are generally small vessels (10-15 feet), and fish close inshore. Those that do run

VESSEL CATEGORY	APPROXIMATE CASUALTY LOCATION	GUAYANILLA BAY, P.R.	SAN JUAN, P.R.	LA PARGUERA, P.R.	LAS MAREAS LAGOON, P.R.	JOBOS BAY, P.R.	YABUCOA, P.R.	OTHER PUERTO RICO	VIEQUES SOUND	ST. THOMAS, V.I.	ST. CROIX, V.I.	OTHER E. CARIBBEAN	TOTAL VESSELS
LARGE COMMERCIAL	CARGO		3 3					1 0	1 0		2 0		7 3
	TANKER	12 5	2 1	0 1	2 1		2 0				0 4		18 12
	PASSENGER		1 0										1 0
SMALL COMMERCIAL	TUG/BARGE	2 0	2 1			2 0	1 0		4 0	0 1	4 1	2 0	17 3
	INTER-ISLAND ETC.							1 1	2 0	1 1	2 1	1 1	7 4
FISHING	COMMERCIAL			1 0				2 0					3 0
	RECREATIONAL SPORT											1 0	1 0
RECREATIONAL	MOTOR VESSEL								1 0	1 0			2 0
	SAIL VESSEL			1 0					1 0	2 0		1 0	5 0
OTHER	MILITARY		1 0										1 0
TOTAL BY LOCATION		14 5	9 5	2 1	2 1	2 0	3 0	4 1	9 0	4 2	8 6	5 1	62 22

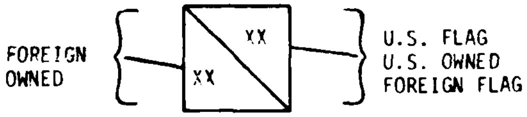

FIGURE B-1 U.S. AND FOREIGN VESSEL INCIDENTS aground sustain slight damage and, thus, do not appear on the vessel casualty reports. The ones that do appear in the reports are those groundings in which the vessel is a total loss or there is loss of life involved, or both. In the 84 grounding incidents indicated in Figure B-1, there were only two that involved loss of life. Both of these were fishing vessels and neither could have been prevented by improved radionavigation aids.

3.2 CAUSAL FACTORS

Merchant Vessel Casualty Reports, Marine Safety Office and other related data were reviewed to determine if there were patterns and trends in the incidents which would indicate causes which could be averted through the installation of improved radionavigation aids, specifically, LORAN-C or Differential Omega. Investigating officers' reports, masters' and pilots' statements and other supporting information were screened to collect any and all factors which caused or contributed to the casualty. These causal factors were listed and then consolidated to eliminate redundancies and similarities. The results of this process reduced the number of causal factors to manageable proportions.

Four principal categories were used:

1) External Causes - Those causes generally beyond the control of the master or of the vessel itself. These causes included those attributable to navigation aids, pilotage and environmental factors such as visibility, wind, and uncharted hazards.

2) Master Related Causes - Those causes over which the master had direct control and for which he was responsible. Included in those causes are such master-related elements as inaccurate plotting of vessel position, faulty ship handling, or failure to use a proper chart.

3) Vessel Related Causes - These causes are directly attributable to a material failure within the vessel which was either a principal or contributing factor (e.g., gyro repeater failure, radar failure).

4) Intentional Causes - These causes where the master deliberately grounds his vessel to prevent further damage or sinking.

As a result of this review 14 separate causal factors relating to the Caribbean vessel casualties were identified. These factors were:

- navigation aids inoperative
- navigation aids out of position
- pilotage available but not used
- pilotage unavailable
- restricted visibility
- wind
- nighttime visibility
- uncharted hazard
- failure to maintain a plot of vessel position
- inaccurate plot of vessel position
- turned too early or too late
- misjudged set/drift
- no chart available or used improper chart
- vessel related material casualty

Only one of the above factors were subsequently found to be unrelated to the incidents and was not used (i.e., unavailability of pilotage). In most of the incidents, two or more of the above factors contributed to the casualty. The results of this analysis are given in Figure B-2. The most frequent cause (and master related cause) is inaccurate plotting of the vessel position (16 instances). This cause is rarely unrelated and is generally tied to other master related or external factors. There were 14 instances of groundings due to uncharted shoals or other hazards and 12 instances involving material casualties. These latter instances are events over which improved navigational aids would have little effect. Other contributing causes were failure to use pilotage when available, inoperative navigational aids and wind effect; of the remaining factors, most were related to shiphandling, although this factor by itself may have been sufficiently severe so as to be the principal reason for the casualty (e.g., turned early or late).

3.3 LOCALE-RELATED CASUALTIES

A similar analysis of vessel casualties was performed to determine if there were certain locales which would be amenable to the installation of improved radionavigation aids. In each case, the vessel's position at time of grounding was plotted on the appropriate large scale chart. This position and information concerning the movement of the vessel was examined for hydrographic and topographic effects upon the causes of the grounding. The results of this analysis are given both in Figure B-1 and B-2.

There were 10 areas identified in the Puerto Rico-Virgin Islands region where incidents occurred as well as an additional category covering incidents outside of the region but in the area of potential LORAN-C coverage. Five of these locales were on the south or southeast coast of Puerto Rico. One was in the Vieques Sound close inshore to the east coast of Puerto Rico. Of these locations, one location, Guayanilla Bay, was marked by a preponderance of incidents. Nineteen groundings were cited in this area which represented nearly one-quarter of the total

SELECTED CAUSAL FACTORS		APPROXIMATE CASUALTY LOCATION	GUAYANILLA BAY, P.R.	SAN JUAN, P.R.	LA PARGUERA, P.R.	LAS MAREAS LAGOON, P.R.	JOBOS BAY, P.R.	YABUCOA, P.R.	OTHER PURETO RICO	VIEQUES SOUND	ST. THOMAS, V.I.	ST. CROIX, V.I.	OTHER E. CARIBBEAN	TOTAL CAUSES
EXTERNAL CAUSES	NAVIGATION AIDS	INOPERATIVE	3							1	1			5
		OUT OF POSITION									1	1		2
	PILOTAGE	NOT USED	5	4										9
		UNAVAILABLE												
	ENVIRON-MENTAL	VISIBILITY WEATHER		1	1	1				1				4
		WIND/WAVE	2	1		1		1	2	3		2	2	14
		NIGHTTIME										1	1	2
		UNCHARTED HAZARD	2	1		2	1	1		1	2	2	2	14
MASTER RELATED	VESSEL POSITION	FAILED TO MAINTAIN PLOT	2	1							1	3	1	8
		INNACURATE PLOT	8	2	2					2		1	1	16
	SHIP HANDLING	TURNED EARLY OR LATE	1	2			1			1		3		8
		MISJUDGED SET/DRIFT	1	6					1	1				10
	CHART	NONE OR IMPROPER	1											1
VESSEL RELATED		MATERIAL CASUALTY		2	1			2	1	1	2	2	1	12
OTHER-INTENTIONAL GROUNDING									1			1		
TOTAL INCIDENTS			19	14	3	3	2	3	5	9	6	14	6	

FIGURE B-2 CAUSAL FACTORS AND INCIDENT LOCATIONS groundings in the Caribbean region. In addition, 30 groundings occurred off the south coast of Puerto Rico (including Guayanilla Bay).

The south coast of Puerto Rico is marked by low lying ground with heavy mangrove growth which is conducive to a poor radar return. While this characteristic could be cited as a reason for the frequent groundings in this area, a review of the causal factors indicates otherwise. In this region, vessels ran aground most frequently due to inaccurate plotting of the vessel's position and failure to use pilotage when available.

San Juan on the north coast of Puerto Rico and St. Croix in the Virgin Islands were also areas of frequent groundings. In San Juan, the predominant causes of groundings were failure to use pilotage when it was available and poor shiphandling, particularly misjudgment of the effects of set and drift. The frequency of these causes would indicate that San Juan may be subject to crosscurrents and should be approached with extreme caution by a mariner unfamiliar with the area. On the other hand, in St. Croix, there appears to be no pattern among the causal factors with groundings being attributed to all major categories, including intentional grounding.

3.4 POTENTIAL ROLE FOR RADIONAVIGATIONAL AIDS

Using the matrix formed by the causal factors and the location of the casualties, each incident was reviewed to determine if a radionavigation aid with an accuracy of 0.25 nm would have helped to avert the casualty. This determination was based on engineering judgment and on the data given in the casualty reports. The results of review are presented in Figure B-3.

In most of the incidents, it was deemed that an improved radionavigational capability would not have averted the grounding. This was due principally to the facts that these casualties were caused by poor shiphandling, vessel master

CAUSAL FACTORS		CASUALTY LOCATION	GUAYANILLA BAY, P.R.	SAN JUAN, P.R.	LA PARGUERA, P.R.	LAS MAREAS LAGOON, P.R.	JOBOS BAY, P.R.	YABUCOA, P.R.	OTHER PUERTO RICO	VIEQUES SOUND	ST. THOMAS, V.I.	ST. CROIX, V.I.	OTHER E. CARIBBEAN
EXTERNAL CAUSES	NAVIGATION AIDS	INOPERATIVE	▤					░		▨	▨		
		OUT OF POSITION									▨	▨	
	PILOTAGE	NOT USED	▨	▨									
		UNAVAILABLE											
	ENVIRON-MENTAL	VISIBILITY WEATHER	░	▤	░	▨				░			
		WIND /WAVE	▨	▨		▨		▨	▨	▨		▨	▨
		NIGHTTIME										▤	▤
		UNCHARTED HAZARD	▨	▨			▨	▨		▨	▨	▨	▨
MASTER RELATED	VESSEL POSITION	FAILED TO MAINTAIN PLOT	▨	▨ ░							▨	▨	▨
		INACCURATE PLOT	▤		░					░		▤	▤
	SHIP HANDLING	TURNED EARLY OR LATE	▨	▨			▨			▨		▨	
		MISJUDGED SET/DRIFT	▨	▨					▨		▨		
	CHART	NONE OR IMPROPER	▨	▨									
VESSEL RELATED		MATERIAL CASUALTY		▨	▨			▨	▨	▨	▨	▨	▨
TOTAL INCIDENT-RELATED NAVAID REQUIREMENTS		UNLIKELY	11	13	1	3	2	3	5	8	6	11	5
		POSSIBLE	0	1	0	0	0	0	0	0	0	3	1
		PROBABLE	0	1	2	0	0	0	0	1	0	0	0

POTENTIAL ROLE FOR RADIO NAVAIDS:

▨ - UNLIKELY
▤ - POSSIBLE
░ - PROBABLE

FIGURE B-3 INCIDENT-RELATED RADIONAVAID REQUIREMENTS blunders, and unavoidable environmental factors. There were however, 17 incidents where a radionavigation system might have contributed to a better understanding by the master of his vessel's proximity to danger, and hence, assisted in avoiding the grounding. It is conjectural whether in fact this would have occurred.

There are four incidents however where improved radionavigational accuracy would probably have helped to avoid the grounding. The first incident was the grounding of the "S.S. Daphne" off LaParguera on the south coast of Puerto Rico on 12 November 1974. This vessel was a 708 foot Liberian tanker owned by Intermaritime Transportation Ltd. of Panama. The Daphne was carrying 45,340 tons of crude oil from La Salina, Venezuela to Guayanilla, Puerto Rico at the time of the casualty. The incident occurred at night with poor visibility due to heavy rains. The master was navigating using radar bearings and ranges, but because of the heavy weather and low lying terrain the signal was attenuated and unreliable. LORAN-A was aboard, but could not be used. The vessel grounded in shoal water approximately 3.25 nm away from the nearest safe water. While the stated cause of the grounding was "failure of the master to ascertain his exact position while operating in adverse weather conditions", it was principally caused by the failure to use all navigational aids available. In addition, the availability of LORAN-A coverage might have averted this grounding.

The second incident occurred in the same approximate position and involved the yacht "Milare II" which grounded on Margarita Reef on July 21, 1977. This 42 ft. sailing vessel was enroute from the Dominican Republic to Ponce in Puerto Rico. The owner was navigating by celestial and visual means. The last plotted position was a sunline at 1530. In nighttime, the owner was using what he thought was Cabo Rojo Light, however, this was in error because subsequently, the vessel grounded at approximately 2100. This error placed the vessel approximately five miles off its desired course. The incident occurred in calm seas with light wind and little current. No surf was breaking over Margarita Reef. The owner was an experienced yachtsman and would probably have used all navigational aids available to him.

The third incident involved the Tug "Puerto Rico Sun" and the Tank Barge "Peck Slip". The barge grounded in Vieques Passage on the night of July 28, 1977. Rain squalls limited visibility to 0.5 miles and the radar was inoperative. Further, the light on Cabeza de Perro Buoy No. 7 was out. The master of the tug, although familiar with the area was unable to fix his position because of the combination of factors and grounded in shoal water south of buoy no. 7. A radionavigation system with 0.25 nm accuracy would have provided the additional position reference needed to avert this incident.

The fourth incident occurred in March 3, 1976 and involved the Dutch Tug "Gelderland" which was grounded and wrecked to the West of Isla de Cabras on the approach to San Juan Harbor. The master did not have a pilot aboard, was unfamiliar with the entrance and was not using LORAN-A even though it was aboard. The vessel was a total loss and approximately 1000 gallons of fuel oil were spilled on the shoreline. Had LORAN-C been available and used, it probably would have prevented the incident. However, the failure to use LORAN-A even though available, questions the prudence and judgment of the master.

Other incidents where improved radionavigation aids could have contributed to its prevention included:

- Sportsfisherman "Bette Louise" (US) Grounded and wrecked off northeast Coast of Dominican Republic, August 28, 1974.
- M/V "Cumulus" (Dominican Republic) grounded and sunk on White Horse Reef, St. Croix, Virgin Islands, October 15, 1977.

- Sailing Vessel "Dogstar" (US) grounded Buck Island Reef, St. Croix, Virgin Islands, October 4, 1978.
- M/V "Barcola" (Liberian) grounded on charted, unmarked shoal in entrance to Guayanilla Bay, January 15, 1979.

The above casualties are indicative of the type of incidents which are related to faulty or deficient navigation. However, the presence of any sophisticated navigation system does not provide assurance that it will be used by the vessel's master and, hence, casualties will occur as long as masters fail to use prudence as well as all means available to navigate their vessel.

4. LOSS AND DAMAGE COSTS

In order to obtain an estimate of the potential savings which might accrue if LORAN-C or other navigation systems with an accuracy of 0.25 nm or better, were installed in the Eastern Caribbean, all navigation related incidents were evaluated. Those that were related to vessel position or visibility were identified. It was assumed that these two categories were most amenable to prevention through improved radionavigation aids.

Those incidents were then quantified based upon the data available in the casualty reports plus a determination of all associated costs using various planning factors. The costs associated with a grounding included the following elements:

- number of hours aground
- number of tugs used
- tug use time
- lighters and barges used
- divers inspection costs
- dry docking costs

- cargo loss
- vessel loss (less salvage value)
- oil spill costs

Hourly vessel operating costs were obtained from MARAD (Reference 22) and were used to determine the loss in vessel productivity while aground. Hourly tug operating costs were obtained from several tug companies (Appendix F) and were used for tug, lighter and barge costs. Divers inspection and dry dock inspection costs were obtained from comparable organizations (Appendix F). The cargo loss was based upon statements in the vessel casualty reports, owners statements and newspaper accounts. Vessel losses were based on current selling prices for similar vessels (in the case of pleasure craft) or estimated original prices minus depreciation in the case of larger vessels. Oil spill costs were generally available in the casualty documents.

Each of the incidents was then quantified based on the above cost elements and planning factors. Further, each incident was evaluated for the role of improved radionavigation aids and assigned a value of 0.5 or 1.0 depending on the perceived role. For those incidents where radionavigation would have played a supporting role, 0.5 was used. Where radionavigation would have had a significant impact, 1.0 was used. The quantified losses were than reduced where necessary. This process resulted in a net estimated loss of $3.3 million (Current Dollars) for the period 1974-1979. This value was used as the base for future estimates of casualty savings as indicated in Section 8.

APPENDIX C COMMERCIAL VESSELS TRAFFIC AND POPULATIONS

1. INTRODUCTION

The purpose of this section is to provide an estimate of the traffic between the U.S. and the Eastern Caribbean, a determination of the number of large and small commercial vessels generating the traffic, and an identification of the users of LORAN-C navigation equipment. A second objective is to project traffic, vessel population and LORAN-C users from 1980 to 2000. This information will be utilized to quantify the costs and benefits derived from expanding LORAN-C coverage into the Eastern Caribbean.

Due to data limitations, the traffic and population of vessels passing through the Caribbean were not estimated. Thus, excluded from the estimates presented in Appendix C were the following traffic and population estimates:

- U.S. flag vessels transiting through the Eastern Caribbean, i.e., vessels which do not call at Caribbean ports
- Foreign flag vessels transiting through the Eastern Caribbean
- Foreign flag vessels engaged in foreign trade calling at Caribbean ports

Included in this category are large (over 1,600 gross tons) and small (less than 1,600 gross tons) commercial vessels which operate in the Caribbean. Included in the large vessel category are merchant/passenger type ships, freighters, bulk carriers, tankers, barges and containerships. Included in the small vessel category are tug/tow boats, barges, scow and small cargo vessels.

2. DATA SOURCES AND METHODS USED

2.1 Data Sources

An extensive literature search was performed to identify data sources for this study. Major data sources, as well as secondary or alternate ones, were identified and classified according to their source. The data sources utilized were as follows:

Department of Commerce
U.S. Army Corps of Engineers
U.S. Coast Guard
Department of the Navy
International Statistics
Maritime and Trade Associations
Journals and Directories
Maritime Private Research Organizations

Additionally, key individuals within many organizations were contacted to obtain supplementary information. A list of contacts is shown in Appendix F.

2.2 Methods Used

The Foreign Trade Division of the Bureau of the Census provided the principal data source used to develop traffic estimates and determine the number of vessels (Reference 34). These data were compiled from U.S. Customs documents which contain vessel, movement, and cargo information on all U.S. vessels engaged in foreign trade and foreign vessels engaged in U.S. trade. This information is obtained from manifest documents supplied to the U.S. customs by vessel masters and shipping agents. The Bureau of the Census utilizes this information to compile traffic statistics by U.S. port on a monthly basis. This information is presented in two forms: vessel clearances (AE 750) and vessel entrances (AE 350). Figure C-1 shows the type of information which is contained in these forms.

The U.S. to Eastern Caribbean traffic was determined from these forms by referring to the column, country and subdivision or U.S. port and identifying all vessels which cleared U.S. ports en-route to the Caribbean. The traffic from the Caribbean to the U.S. was determined in a similar manner. The method used to determine the vessel population generating the traffic was straightforward. Vessels sailing to the Caribbean ports or from the Caribbean to U.S. ports were identified and counted by name. In the event that a vessel made more than one trip it was counted only once.

The U.S. to Puerto Rico traffic was estimated from statistics provided by the Puerto Rico Port Authority (References 35, 36). This traffic information could not be obtained from the forms AE 350 and AE 750 because U.S. flag vessels sailing directly from U.S. to U.S ports are not required to clear with U.S. Customs. However, foreign flag vessels are required to clear with U.S. Customs, and information for these vessels and the traffic they generated was obtained from the census forms.

All vessels which enter or depart from the U.S. Virgin Islands are required to clear customs because the U.S. Virgin Islands is a free port. Thus, the U.S. to U.S. Virgin Islands traffic was estimated from census forms AE 350 and AE 750.

Date:Month
Year
Day

Passengers

Army engineer channel

Customs district and port

Vessel manifest

Vessel name

Flag

Type service

Rig

Net registered tonnage

Ballast or cargo

Country and subdivision or U.S. port

Type vessel

Type cargo

Trip

Draft (feet)

O-Entrance code

Census use only

Month and serial number (Census use only)

FIGURE C-1. AE 350 PART 2 MONTHLY VESSEL ENTRANCES IN DISTRICT, PORT, AND MANIFEST ARRANGEMENT

EXPLANATION OF CODES

Type of Service

1. Liner or berth
4. Tanker
5. Irregular or tramp

Rig

1. Motor dry cargo, steam dry cargo
2. Motor tanker, steam tanker
3. Tug
4. Barge (other than tanker), scow
5. Tanker barge
6. Other, including yacht, gas, sloop, schooner, sailboat, houseboat, rowboat, research vessel

Ballast or Cargo

1. Vessel cleared direct to foreign ports in ballast
2. Vessel cleared direct to foreign ports with bulk cargo
3. Vessel cleared direct to foreign ports with general cargo
4. Vessel cleared via other domestic ports in ballast
5. Vessel cleared via other domestic ports with bulk cargo
6. Vessel cleared via other domestic ports with general cargo

Country and Subdivision or U.S. Port

Indicates first foreign country clearing direct to (destination of outbound voyage) in terms of Schedule C code. Where "country to" has marked coastal differences a further distinguishing sub-country code is added - otherwise sub-country code is always "0". If clearing via domestic ports, indicates first U.S. port vessel entered in terms of Schedule D code.

FIGURE C-1. (Cont.)

EXPLANATION OF CODES (Cont.)

Type Vessel

0. Vessels to other domestic ports, Navy operated vessels, vessels in for repairs or crew changes, and all other types excluded by reason of FT 975 coverage.
1. All vessels except tanker cleared direct to foreign ports
2. Tankers cleared direct to foreign ports

Type Cargo

0. All vessels coded "0" under type vessel
1. Bulk or general cargo
3. Ballast

Trip

0. No U.S. or in-transit cargo laden at this port
1. U.S. or in-transit export cargo laden at this port
9. Vessels under 26 net registered tons

FIGURE C-1. (Cont.)

3. TOTAL VESSEL TRAFFIC BETWEEN THE U.S. AND THE EASTERN CARIBBEAN

To develop accurate traffic estimates and determine their densities, the U.S. to Eastern Caribbean traffic was identified separately for three regions. These were:

- U.S. to Eastern Caribbean exclusive of Puerto Rico and the U.S. Virgin Islands (pattern one)
- U.S. to Puerto Rico (pattern two)
- U.S. to U.S. Virgin Islands (pattern three)

The total traffic between the U.S. and the Eastern Caribbean was calculated by aggregating all three estimates obtained from each region.

3.1 U.S. to Eastern Caribbean Inbound/Outbound Traffic

Forms AE 350 and AE 750 were utilized to develop estimates for this pattern. To provide a greater level of detail and accuracy, the U.S. was divided into four geographic regions as follows:

- New England - Maine to Bridgeport, Connecticut
- Mid-Atlantic - New York to Baltimore
- South - Norfolk, Virginia to the Port of Miami
- Gulf - Tampa, Florida to Galveston, Texas

To determine traffic by trade route, the Eastern Caribbean was divided into three geographic regions. These were:

- The Greater Antilles - Jamaica, Haiti, Dominican Republic
- The Lesser Antilles - Leeward and Windward Islands. The Leeward Islands consist of the British Virgin Islands, St. Christopher, Nevis, Anguilla, Sombrero, Antigua, Barbuda, Redonda, French West Indies, and Montserrat. The Windward Islands include: Dominica, St. Lucia, St. Vincent, Grenadine Islands and Grenada.
- The North Coast of South America-Trinidad and Tobago, Barbados, Netherlands Antilles (including Curacao, Aruba, Bonaire, Saba, St. Eustatin, and St. Martin), and the North Coast of Venezuela.

Table C-1 shows the traffic between the U.S. and Caribbean Islands and the north coast of South America. The heaviest traffic occurred between the Gulf ports and the north coast of South America, accounting for almost one-fourth of the total traffic. New England experienced the lowest traffic volume, only 952[1] vessel moves.[2] Traffic between the U.S. and the north coast of South America accounted for almost 75 percent of the total volume. Approximately 85 percent of the total traffic was generated by 170 large commercial vessels and 15 percent by 100 small commercial vessels.

TABLE C-1. U.S. TO EASTERN CARIBBEAN INBOUND/OUTBOUND TRAFFIC IN 1979

	CARIBBEAN ISLANDS			
U.S. REGIONS	GREATER ANTILLES	LESSER ANTILLES	NORTH COAST OF SOUTH AMERICA	TOTAL
New England	60	0	892	952
Mid-Atlantic	276	264	2,412	2,952
South	1,248	468	2,184	3,900
Gulf	984	108	3,974	5,066
TOTAL	2,568	840	9,462	12,870

[1] Vessel moves may not necessarily represent the actual number of movements for 1979. Calculations were not rounded for consistency purposes.

[2] A vessel move is defined as the movement of a vessel transiting a given region or sector of the Eastern Caribbean.

3.2 U.S. to Puerto Rico Traffic

This traffic estimate consisted of two vessel categories: U.S. flag and foreign flag vessels.

The traffic generated by the U.S. flag vessels was estimated from statistics provided by the Puerto Rico Port Authority (References 35, 36). This traffic information could not be obtained from the forms AE350 and AE750 because U.S. flag vessels sailing directly from U.S. to U.S. ports are not required to clear with U.S. Customs. However, foreign flag vessels are required to clear with U.S. Customs, and information for these vessels and the traffic they generated was obtained from the census forms.

Table C-2 shows the U.S. to Puerto Rico inbound/outbound traffic. The traffic consisted of approximately 4,214 vessel moves. Of these, 3,350 were generated by U.S. flag vessels and 864 by foreign flag ships. Traffic between San Juan and U.S.ports comprised approximately half of the total traffic. Approximately 1,515 moves between San Juan and the U.S. were generated by U.S. flag vessels and 552 moves were generated by foreign flag vessels. Large vessels* (above 1,000 gross tons) generated approximately 1,477 trips, or 35 percent of the total traffic. The majority of the total traffic, 2,645 moves, or 63 percent, was generated by small commercial vessels (less than 350 tons).

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* A large vessel for the U.S. to Puerto Rico traffic is defined as any vessel greater than 1,000 gross tons as opposed to 1,600 gross tons. This adjustment was necessary due to the way the statistics are compiled by the Puerto Rico Port Authority.

TABLE C-2. U.S. TO PUERTO RICO INBOUND/OUTBOUND TRAFFIC IN 1979 U.S. AND FOREIGN FLAG VESSELS

PUERTO RICAN PORTS	LARGE		LESS THAN 350 G.T.		350 TO 999 G.T.		TOTAL	
	U.S.	FOREIGN	U.S.	FOREIGN	U.S.	FOREIGN	U.S.	FOREIGN
San Juan	551	250	955	292	9	10	1,515	552
Ponce	20	12	130	24	16	12	166	48
Mayaguez	18	15	255	30	8	3	281	48
Guanica	4	6	50	20	3	10	57	36
Guayanilla	195	60	109	12	3	--	307	72
Las Mareas	77	--	263	--	16	--	356	-
Yabucoa	251	18	157	6	2	--	410	24
Other Ports	--	--	258	84	--	--	258	84
TOTAL	1,116	361	2,177	468	57	35	3,350	864

3.3 U.S. to U.S. Virgin Islands Inbound/Outbound Traffic

All vessels which enter or depart from the U.S. Virgin Islands are required to clear customs because U.S. Virgin Islands is a free port. Thus, the U.S. to U.S. Virgin Islands traffic was estimated from census forms AE 350 and AE 750. Table C-3 shows that the total traffic generated consisted of 1,440 moves. The majority of the traffic, 95 percent, was generated by large vessels; only five percent was generated by vessels less than 1,600 gross tons. The total traffic was generated by approximately 300 vessels, of which 280 were large vessels greater than 1,600 gross tons.

TABLE C-3. U.S. TO U.S. VIRGIN ISLANDS INBOUND/OUTBOUND TRAFFIC IN 1979

	CHARLOTTE AMALIE	CHRISTIAN-STED	FREDRIK-STED	TOTAL
New England	--	216	--	216
Mid-Atlantic	--	420	--	420
South	204	252	108	564
Gulf	--	240	--	240
TOTAL	204	1,128	108	1,440

3.4 Total U.S. to Eastern Caribbean Traffic

The total U.S. to Eastern Caribbean traffic was obtained by aggregating all three traffic pattern estimates. Table C-4 shows that the total traffic consisted of approximately 18,524 vessel moves. Traffic between the U.S. and the north coast of South America comprised more than half the total traffic generated, or 9,362 moves. Traffic between the U.S. and the U.S. Virgin Islands comprised only eight percent of the total traffic. The U.S. to Puerto Rico traffic accounted for 23 percent and the U.S. to the Greater Antilles comprised 14 percent of the total traffic. The Gulf ports handled the majority of the traffic, 29 percent or 5,306 moves. Southern ports ranked second, accounting for 24 percent, or 4,464 moves. New England ports handled only six percent, or 1,168 moves of the total 18,524 moves.

TABLE C-4. TOTAL U.S. TO EASTERN CARIBBEAN INBOUND/OUTBOUND TRAFFIC IN 1979

	PATTERN ONE			PATTERN TWO	PATTERN THREE	
TO/FROM U.S. REGION	GREATER ANTILLES	LESSER ANTILLES	NORTH COAST OF SOUTH AMERICA	PUERTO RICO	VIRGIN ISLANDS	TOTAL
New England	60	0	892	--	216	1,168
Mid Atlantic	276	264	2,412	--	420	3,372
South	1,248	468	2,184	--	564	4,464
Gulf	984	108	3,974	--	240	5,306
All U.S. Regions	—	—	—	4,214	--	4,214
TOTAL U.S.	2,568	840	9,462	4,214	1,440	18,524

3.4.1 Tanker Traffic

Oil tanker traffic comprised approximately 43 percent of the total traffic, or 7,962 moves of a total 18,524. Refined oil from Aruba was shipped primarily to the Mid-Atlantic ports. Crude oil from Venezuela, Trinidad and Tobago was shipped to the Gulf ports and refined oil to the Mid-Atlantic, New England and Southern ports. The Hess Oil Refinery in St. Croix shipped most of its oil to New Jersey, and the oil refineries in Puerto Rico shipped most of their product to the Gulf ports. Of a total 7,962 tanker moves, foreign flag tankers handled 7,400 shipments, and U.S. flag tankers accounted for only 562 moves. The capacity of tankers transporting crude oil ranged from 20,000 to 100,000 gross tons. Tankers shipping refined product ranged from 18,000 to 40,000 gross tons in capacity. Table C-5 shows the oil traffic pattern between the U.S. and the Eastern Caribbean.

3.4.2 General Cargo Traffic

General cargo traffic generated approximately 10,562 moves accounting for 57 percent of the total traffic. Table C-6 shows that the U.S. to Puerto Rico traffic accounted for 4,106 moves, or 59 percent of the total traffic. Personnel at the Puerto Rico Port Authority indicated that the majority of that traffic was handled by Southern Ports. The U.S. to U.S. Virgin Islands traffic was very low, only 312 shipments were generated. This traffic was handled exclusively by Southern ports, principally by smaller vessels less than 1600 gross tons. The majority of the traffic between the U.S. and the north coast of South America was again handled by Southern ports.

TABLE C-5. TOTAL U.S. TO EASTERN CARIBBEAN INBOUND/OUTBOUND
OIL TANKER TRAFFIC IN 1979

	PATTERN ONE		PATTERN TWO	PATTERN THREE		
TO/FROM U.S. REGION	GREATER ANTILLES	NORTH COAST OF LESSER ANTILLES	SOUTH AMERICA	PUERTO RICO	VIRGIN ISLANDS	TOTAL
New England	0	0	892	--	216	1,108
Mid Atlantic	0	12	2,004	--	420	2,436
South	12	0	684	--	252	948
Gulf	84	0	3,038	108	240	3,470
TOTAL U.S.	96	12	6,618	108	1,128	7,962

TABLE C-6. TOTAL U.S. TO EASTERN CARIBBEAN INBOUND/OUTBOUND GENERAL CARGO TRAFFIC IN 1979

	PATTERN ONE			PATTERN TWO	PATTERN THREE	
TO/FROM U.S. REGION	GREATER ANTILLES	LESSER ANTILLES	NORTH COAST OF SOUTH AMERICA	PUERTO RICO	VIRGIN ISLANDS	TOTAL
New England	60	--	--	--	--	60
Mid Atlantic	276	252	408	--	--	936
South	1,236	468	1,500	--	312	3,516
Gulf	900	108	936	--	--	1,944
All U.S.	--	--	--	4,106	--	4,106
TOTAL U.S.	2,472	828	2,844	4,106	312	10,562

4. LARGE AND SMALL COMMERCIAL VESSEL POPULATIONS

4.1 Large Commercial Vessels

Census forms AE 350 and AE 750 were utilized to identify the names of U.S. vessels greater than 1,600 gross tons which generated the total traffic presented in Table C-4. This process revealed that approximately 100 large commercial U.S. vessels generated ten percent of the total U.S. to Eastern Caribbean traffic. Of those, approximately 75 were general cargo vessels and 25 were oil tankers. Table C-7 summarizes the vessels identified.

The number of large foreign flag vessels which accounted for approximately 56 percent of the total traffic could not be estimated accurately because these vessels operate irregularly. It was estimated, however, that approximately 200 to 250 foreign flag vessels were in this group.

TABLE C-7. U.S. LARGE COMMERCIAL VESSELS IDENTIFIED

TYPE OF VESSEL	NUMBER OF VESSELS
Tanker	25
Ore Carrier	4
Barge	6
Containership	25
General Cargo	20
Bulk Carrier	20
TOTAL	100

4.2 Small Commercial Vessels

Census forms AE 350 and AE 750, as well as the Transportation Lines Series (published by the U.S. Army Corps of Engineers) and other data sources, were used to identify U.S. small commercial vessels (less than 1,600 gross tons) which generated the total U.S. to Eastern Caribbean traffic. It was estimated that small commercial U.S. vessels accounted for approximately 15 percent of the total traffic. This represents 2,763 moves out of a total 18,526. It was determined that approximately 70 vessels operate in the area. Included in the identified small commercial vessels were tug/tow, barge, scow, small cargo and small tanker.

Small commercial foreign flag vessels generated approximately 19 percent of the total traffic. No firm estimate could be obtained of their population because they operate on an irregular basis. A two month sample from the AE 350 and AE 750 forms was taken and 150 small foreign flag vessels were identified. Most of the vessels appeared in both months, and it seems that there is a specific group of small vessels that serve the U.S. to Eastern Caribbean traffic.

5. PUERTO RICO AND U.S. VIRGIN ISLANDS TRAFFIC TO FOREIGN PORTS

5.1 Puerto Rico Traffic

The inbound/outbound traffic for Puerto Rico was estimated from the AE 350 and AE 750 forms, as well as shipping statistics provided by the Puerto Rico Port Authority. Excluded from this traffic pattern was the U.S. to Puerto Rico vessel traffic which was presented in Table C-2. Table C-8 shows that the total Puerto Rico inbound/outbound traffic consisted of approximately 8,556 vessel moves. The San Juan port handled 63 percent of the total traffic, representing 5,628 vessel moves. The port of Fajardo accounted for 14 percent of the total traffic, or 1,236 moves. The port of Guanica handled the lowest traffic volume, 36 vessel moves. Intra-Caribbean traffic accounted for 62 percent of the total traffic representing 5,400 vessel moves. This traffic was handled exclusively by small commercial vessels such as tug/tow boats, barges, scow and small cargo vessels. Traffic from Puerto Rico to the north coast of South America represented 21 percent of the total, and it was generated by 1,908 vessel moves.

Table C-9 shows the distribution of traffic between general cargo and oil tanker vessels. Approximately 87 percent of the traffic was generated by general cargo vessels, approximately 7,452 moves. The ports of San Juan, Jobos, Humacao and Guayanilla handled 75 percent of the oil tanker traffic. Venezuela, Trinidad and Tobago, and Aruba accounted for almost 41 percent of all oil tanker traffic generated between Puerto Rico and foreign ports. The port of Fajardo accounted for 264 oil shipments, which were handled by small oil barges.

5.2 U.S. Virgin Islands Traffic

Since all vessels which enter or depart from the U.S. Virgin Islands are required to clear customs, the U.S. Virgin Islands inbound/outbound traffic was estimated from the AE 350 and AE 750 forms. Excluded from this traffic pattern

TABLE C-8. PUERTO RICO INBOUND/OUTBOUND TRAFFIC IN 1979 EXCLUSIVE OF U.S. TRAFFIC

PUERTO RICAN PORTS	INTRA-CARIBBEAN	NORTH COAST OF SOUTH AMERICA	BAHAMAS	AFRICA	EUROPE	OTHER	TOTAL
Fajardo	1,116	96	--	--	--	24	1,236
Guanica	24	12	--	--	--	--	36
Humacao	12	24	--	--	12	108	156
Mayaguez	108	48	--	--	--	96	252
Ponce	492	96	--	12	72	84	756
San Juan	3,564	1,344	60	36	144	480	5,628
Jobos	24	120	24	--	--	24	192
Guayanilla	60	168	24	24	24	--	300
TOTAL	5,400	1,908	108	72	252	816	8,556

TABLE C-9. PUERTO RICO INBOUND/OUTBOUND GENERAL CARGO VS OIL TANKER TRAFFIC IN 1979

	INTRA-CARIBBEAN		NORTH COAST OF SOUTH AMERICA		BAHAMAS		AFRICA		EUROPE		OTHER		TOTAL	
PUERTO RICAN PORTS	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER
Fajardo	852	264	96	--	--	--	24	--	--	--	--	--	972	264
Guanica	24	--	12	--	--	--	--	--	--	--	--	--	36	--
Humacao	12	--	--	24	--	--	--	--	--	12	12	96	24	132
Mayaquez	108	--	48	--	--	--	--	--	--	--	96	--	252	--
Ponce	492	--	96	--	--	--	12	--	60	12	84	--	744	12
San Juan	3,444	120	1,188	156	60	--	36	--	144	--	468	12	5,340	288
Jobos	12	12	--	120	--	24	--	--	--	--	--	24	12	180
Guayanilla	60	--	12	156	--	24	--	24	--	24	--	--	72	228
TOTAL	5,004	396	1,452	456	60	48	48	24	204	48	684	132	7,452	1,104

was the U.S. to U.S. Virgin Islands traffic which was presented in Table C-3. Table C-10 shows that the total inbound/outbound traffic was generated by 16,884 vessel moves. The port of Cruz Bay handled 40 percent of the total traffic, or 6,756 vessel moves. It was determined that this traffic was exclusively generated by recreational boats, small ferries, small cargo vessels, tug/tow boats and small barges. The majority of this traffic, approximately 90 percent, was generated by recreational and small passenger ferries. The Charlotte Amalie port generated 6,684 vessel moves, or 39 percent of the total traffic. The majority of this traffic was also generated by local recreational boats and small ferries. Included in this traffic were approximately 600 moves generated by large passenger cruise ships (References 3, 34). The Christiansted port handled 19 percent of the total traffic, accounting for 3,168 vessel moves.

Table C-11 indicates the distribution of general cargo and oil tanker traffic. The Cristiansted port handled 82 percent of all the oil tanker traffic, or 864 moves. The majority of the oil tankers shipping this oil were large tankers, ranging from 18,000 to 100,000 gross tons.

Table C-12 indicates the number of vessels which generated traffic in August; 184 vessels generated a total of 597 moves. Of those, 150 were small vessels (mainly recreational boats and passenger ferries), four large cargo vessels and 30 tankers. Of the 184 vessels, 91 made only one move while 93 vessels made

TABLE C-10. U.S. VIRGIN ISLANDS INBOUND/OUTBOUND TRAFFIC IN 1979 EXCLUSIVE OF U.S.

U.S. VIRGIN ISLANDS PORTS	INTRA-CARIBBEAN	NORTH COAST OF SOUTH AMERICA	BAHAMAS	AFRICA	EUROPE	PERSIAN GULF	OTHERS	TOTAL
Charlotte Amalie	6,432	204	36	--	--	--	12	6,684
Cruz Bay	6,732	--	12	--	--	--	12	6,756
Coral Bay	12	--	12	--	--	--	--	24
Christiansted	2,400	156	12	132	96	132	240	3,168
Fredriksted	228	12	--	--	--	--	12	252
TOTAL	15,804	372	72	132	96	132	276	16,884

TABLE C-11. U.S. VIRGIN ISLANDS INBOUND/OUTBOUND GENERAL CARGO VS OIL TANKER TRAFFIC IN 1979

	INTRA-CARIBBEAN		NORTH COAST OF SOUTH AMERICA		BAHAMAS		AFRICA		EUROPE		OTHER		TOTAL	
U.S. VIRGIN ISLANDS PORTS	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER	GENERAL CARGO	TANKER
Charlotte Amalie	6,252	180	192	12	36	--	--	--	--	--	12	--	6,480	192
Cruz Bay	6,732	--	--	--	--	--	--	--	--	--	12	--	6,744	--
Coral Bay	12	--	--	--	--	--	--	--	--	--	--	--	12	--
Christiansted	2,208	192	60	96	--	12	--	132	--	96	36	336	2,304	864
Fredriksted	228	--	12	--	--	--	--	--	--	--	12	--	252	--
TOTAL	15,432	372	264	108	60	12	--	132	--	96	72	336	15,792	1,056

TABLE C-12. POPULATION OF VESSELS GENERATING TRAFFIC IN THE U.S. VIRGIN ISLANDS IN AUGUST 1979

NUMBER OF MOVES MADE BY SAME VESSEL	SMALL VESSELS	LARGE CARGO VESSELS	OIL TANKERS
1	73	--	18
2	23	--	5
3	15	--	3
4	7	--	1
5	9	1	2
6	6	--	4
7	3	1	--
8	4	--	--
9	1	--	--
Over 10	9	2	--

Total No. of Moves = 597

Vessel Population = 184
Small Vessels = 150
Large Cargo = 4
Oil Tankers = 30

more than one move. Two large cargo vessels and nine small vessels made more than ten moves each. Thus, nine small vessels generated more than 90 moves and two large vessels accounted for over twenty moves.

6. VESSEL TRAFFIC PROJECTIONS: 1980 TO 2000

6.1 Approach

The approach utilized to project the vessel traffic for the years 1980 to 2000 consisted of three steps. These were:

The first step was to examine historical trade data between the U.S. and the Caribbean countries. This process revealed that the level of trade between the U.S. and these Caribbean Islands has not changed substantially over the last five years. An average trade growth rate of two percent per year was assumed for all Caribbean Islands except Puerto Rico and the U.S. Virgin Islands. Puerto Rican economic planners have projected that trade between Puerto Rico and the U.S., as well as other countries, will grow by 4.5 percent per year from 1980 to 2000 (Reference 15). The same growth rate was also assumed for the U.S. Virgin Islands.

The second step consisted of examining the impacts of improved vessel operating efficiency and shipbuilding trends on vessel traffic. These trends can be summarized as follows:

- Increasingly larger ships will be built in every vessel category.
- The number of vessels in the world fleet required to serve the U.S. foreign trade, including U.S. flag vessels, is projected to grow by only 379 vessels, or about 2.5 percent, between 1980 and 2000. Since trade is projected to grow by over 130 percent, there is a trend towards larger and more efficient vessels (Reference 14).
- The number of general cargo vessels is expected to decrease from 1980 to 2000 by 60 percent. (Reference 14.)
- From 1980 to 2000 the average increase in deadweight per vessel for the world fleet is expected to be 71 percent (Reference 14).

- The average annual increase in productivity of newly built vessels is expected to be over one percent. Full and partial containerships will experience an increase of 1.9 and 2.0 percent, respectively, and the smallest increase, 0.02 percent, will be experienced by combination carriers (Reference 14).
- Rising fuel costs will force ship operators to further improve their scheduling and other operational aspects.

The third step consisted of developing traffic growth factors which were utilized to project traffic. Because each traffic pattern and further the distribution of the general cargo versus oil tanker traffic is not expected to grow at a similar rate various adjustments were necessary. For instance, the oil tanker traffic from the north coast of South America to the U.S. was projected to increase by 17.5 percent, as opposed to a five percent increase projected for the general cargo traffic. Table C-13 shows the values of the growth factors which were utilized to project the traffic.

6.2 Projected Total U.S. to Eastern Caribbean Traffic

The U.S. to Eastern Caribbean traffic will change modestly over the twenty-year period. From Table C-5 and Table C-14 it can be obtained that the traffic by 2000 will increase by 7,300 moves, or 40 percent. Approximately 5,171 moves, or 71 percent of the increased traffic volume, will be generated in the U.S. to the north coast of South America trade. This substantial traffic growth is due to a 17.5 percent increase anticipated in oil tanker traffic. Tables C-15 and C-16 show the breakdown of general cargo and oil tanker traffic. Traffic between the U.S. and Puerto Rico will increase by 1,387 moves, or 24 percent. This increase will be generated by general cargo vessels, as opposed to oil tankers.

TABLE C-13. FACTORS APPLIED TO PROJECT U.S. TO EASTERN CARIBBEAN TRAFFIC: 1980-2000

	TRAFFIC PERCENTAGE CHANGE PER FIVE YEAR PERIOD							
	GENERAL CARGO				OIL TANKERS			
PATTERN	1985	1990	1995	2000	1985	1990	1995	2000
Pattern One								
o Greater Antilles	5.0	3.5	3.5	2.5	4.0	4.0	3.0	3.0
o Lesser Antilles	5.0	3.5	3.5	2.5	4.0	4.0	3.0	3.0
o North Coast of South America	5.0	5.0	5.0	4.5	17.5	16.0	12.0	10.0
Pattern Two	10.0	7.5	7.5	5.0	4.0	4.0	3.0	2.0
Pattern Three	4.0	4.0	3.5	2.0	4.0	4.0	3.0	2.0

TABLE C-14. PROJECTED U.S. TO EASTERN CARIBBEAN INBOUND/OUTBOUND TRAFFIC FROM 1980 TO 2000

	PATTERN ONE												PATTERN TWO				PATTERN THREE			
	GREATER ANTILLES				LESSER ANTILLES				NORTH COAST OF SOUTH AMERICA				PUERTO RICO				U.S. VIRGIN ISLANDS			
U.S.	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
New England	63	65	67	69	0	0	0	0	1,060	1,229	1,376	1,513	--	--	--	--	224	233	240	245
Mid Atlantic	290	300	310	318	290	304	319	335	2,783	3,181	3,531	3,858	--	--	--	--	437	454	468	477
South	1,310	1,356	1,404	1,440	491	508	526	539	2,379	2,586	2,780	2,930	--	--	--	--	586	597	616	629
Gulf	1,032	1,068	1,106	1,135	113	117	121	124	4,553	5,173	5,722	6,234	--	--	--	--	250	260	268	273
TOTAL	2,695	2,789	2,887	2,962	894	929	966	998	10,775	12,169	13,409	14,535	4,628	4,970	5,337	5,601	1,496	1,544	1,592	1,624

TABLE C-15. PROJECTED U.S. TO EASTERN CARIBBEAN INBOUND/ OUTBOUND GENERAL CARGO TRAFFIC FROM 1980 to 2000

	PATTERN ONE												PATTERN TWO				PATTERN THREE			
	GREATER ANTILLES				LESSER ANTILLES				NORTH COAST OF SOUTH AMERICA				PUERTO RICO				U.S. VIRGIN ISLANDS			
U.S.	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
New England	63	65	67	69	0	0	0	0	12	13	14	15	--	--	--	--	--	--	--	--
Mid Atlantic	290	300	310	318	277	290	304	319	428	449	471	492	--	--	--	--	--	--	--	--
South	1,297	1,342	1,389	1,424	491	508	526	539	1,575	1,653	1,735	1,813	--	--	--	--	324	325	336	343
Gulf	945	978	1,012	1,037	113	117	121	124	983	1,032	1,084	1,133	--	--	--	--	--	--	--	--
TOTAL	2,595	2,685	2,778	2,848	881	915	951	982	2,998	3,147	3,304	3,453	4,516	4,854	5,218	5,479	324	325	336	343

TABLE C-16. PROJECTED U.S. TO EASTERN CARIBBEAN INBOUND/ OUTBOUND OIL TANKER TRAFFIC FROM 1980 to 2000

	PATTERN ONE												PATTERN TWO				PATTERN THREE			
	GREATER ANTILLES				LESSER ANTILLES				NORTH COAST OF SOUTH AMERICA				PUERTO RICO				U.S. VIRGIN ISLANDS			
U.S.	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
New England	0	0	0	0	0	0	0	0	1,048	1,216	1,362	1,498	--	--	--	--	224	233	240	245
Mid Atlantic	0	0	0	0	13	14	15	16	2,355	2,732	3,060	3,366	--	--	--	--	437	454	468	477
South	13	14	15	16	0	0	0	0	804	933	1,045	1,117	--	--	--	--	262	272	280	286
Gulf	87	90	94	98	0	0	0	0	3,570	4,141	4,638	5,101	--	--	--	--	250	260	268	273
TOTAL	100	104	109	114	13	14	15	16	7,777	9,022	10,105	11,802	112	116	119	122	1,172	1,219	1,256	1,281

Puerto Rico is not expected to alter substantially its output of refined oil in the near future and, therefore, the oil tanker traffic was kept constant in the projections (Reference 37). The U.S. to U.S. Virgin Islands traffic is not expected to change substantially.

The Hess Oil Refinery in St. Croix, Virgin Islands, operates close to full capacity and, unless the current facilities are expanded, the oil traffic will not change (Reference 16). Projections for the general cargo traffic between the U.S. and the U.S. Virgin Islands indicated that this traffic will only change by approximately 180 moves since the additional tonnage will be shipped on larger vessels.

The traffic between the U.S. and the Greater and Lesser Antilles was projected to change by approximately 550 vessel moves. The new traffic will be generated by general cargo vessels.

The population of large and small commercial vessels will not be affected by the additional trade created because of the improvements in the operating efficiency of vessels and the larger vessels utilized to carry the additional tonnage. Thus, the populations of large and small commercial vessels will be approximately 350 and 220 respectively.

6.3 Projected Puerto Rico Traffic

The methodology utilized to project the U.S. to Eastern Caribbean traffic was also used to project the traffic for Puerto Rico. However, to develop more accurate traffic projections an additional factor was taken into account. Approximately 63 percent of all traffic generated in Puerto Rico represents Intra-Caribbean traffic. This traffic is generated mostly by tug/tow boats, oil barges, scows, barges, ferries, and small cargo ships. In general, operators of these ships are not likely to respond immediately to shipbuilding or operating efficiency improvement trends of the industry. This finding was based on the fact that small operators adopt technological improvements at a slower pace than large operators due to financial constraints.

Since small vessels will not be affected by technological breakthroughs, the Intra-Caribbean traffic was assumed to grow by ten percent every five years. Traffic to the north coast of South America was assumed to grow by five percent because this traffic is also partially handled by small vessels. The traffic to Africa, Europe and other areas was assumed to increase by two percent every five years. Table C-17 summarizes the Puerto Rico inbound/outbound traffic from 1980 to 2000, and Table C-18 shows traffic projections by port.

TABLE C-17. SUMMARY: PROJECTED PUERTO RICO INBOUND/ OUTBOUND TRAFFIC: 1980-2000

	PERIOD				
REGION	1979	1985	1990	1995	2000
Intra-Caribbean	5,400	5,938	6,526	7,113	7,701
North Coast of South America	1,908	2,003	2,098	2,192	2,290
Bahamas	108	113	116	119	122
Africa	72	75	78	81	84
Europe	252	262	270	276	283
Other	816	849	883	926	959
TOTAL	8,556	9,240	9,971	10,707	11,439

TABLE C-18. PROJECTED PUERTO RICO INBOUND/OUTBOUND TRAFFIC FROM 1980 TO 2000

PUERTO RICAN PORTS	INTRA-CARIBBEAN				NORTH COAST OF SOUTH AMERICA				BAHAMAS				AFRICA				EUROPE				OTHER			
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Fajardo	1227	1343	1459	1575	101	106	111	117	0	0	0	0	0	0	0	0	0	0	0	0	26	28	30	32
Guanica	26	29	31	33	13	14	14	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humacao	13	14	15	17	25	26	27	28	0	0	0	0	0	0	0	0	13	14	15	16	110	113	115	117
Mayaguez	119	131	143	155	50	52	54	57	0	0	0	0	0	0	0	0	0	0	0	0	98	100	102	104
Ponce	541	595	649	703	101	106	111	117	0	0	0	0	13	14	15	16	76	78	80	82	86	88	100	102
San Juan	3920	4312	4704	5096	1411	1478	1545	1612	63	66	69	73	37	38	39	40	148	152	154	157	504	528	552	576
Jobos	26	29	32	35	126	132	138	144	25	26	27	28	0	0	0	0	0	0	0	0	25	26	27	28
Guayanilla	66	73	80	87	176	184	192	200	25	26	27	28	25	26	27	28	25	26	27	27	0	0	0	0
TOTAL	5938	6526	7113	7701	2003	2098	2192	2290	113	118	123	129	75	78	81	84	262	270	276	283	849	883	926	959

Table C-18 indicates that the total traffic by 2000 will be 11,439 moves, an increase of almost 34 percent from 1979. The Intra-Caribbean traffic, which is generated by small commercial vessels, will account for approximately 80 percent of the total traffic increase. The traffic from Puerto Rico to the north coast of South America was projected to increase by 13 percent, or 382 vessel moves.

6.4 Projected U.S. Virgin Islands Traffic

The methodology utilized to project the Puerto Rico Inbound/Outbound traffic was also utilized to project the U.S. Virgin Islands traffic. Table C-19 summarizes the traffic from 1980 to 2000, and Table C-20 presents the projections by port. In 1979, the traffic was estimated to consist of 16,884 moves; projections to 2000 indicate an increase of 6,452 vessel moves, or 38 percent. Most of this traffic increase was projected to account for the Intra-Caribbean traffic; in 1979 it accounted for 15,804 vessel moves, in 2000 it was projected at 22,124 moves, a gain of 6,320 moves. This traffic increase will account for approximately 98 percent of the total traffic gains.

The oil tanker traffic was projected to increase by only 30 to 40 moves. This small increase in oil traffic was based on two facts. First, the tankers which are currently being built, as well as those to be built, will be larger and more efficent. Second, the oil refinery in St. Croix operates close to full capacity and, therefore, the current level of traffic it generates can not be increased substantially.

TABLE C-19. SUMMARY: PROJECTED U.S. VIRGIN ISLANDS INBOUND/OUTBOUND TRAFFIC: 1980-2000

	PERIOD				
REGION	1979	1985	1990	1995	2000
Intra-Caribbean	15,804	17,384	18,964	20,414	22,124
North Coast of South America	372	391	410	429	448
Bahamas	72	77	82	87	89
Africa	132	134	136	138	138
Europe	96	98	100	102	102
Persian Gulf	132	134	136	138	138
Others	276	282	289	295	297
TOTAL	16,884	18,500	20,017	21,733	23,336

TABLE C-20. PROJECTED U.S. VIRGIN ISLANDS INBOUND/ OUTBOUND TRAFFIC FROM 1980 TO 2000

U.S. VIRGIN ISLANDS PORTS	INTRA-CARIBBEAN				NORTH COAST OF SOUTH AMERICA				BAHAMAS				AFRICA			
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Charlotte Amalie	7,075	7,718	8,361	9,004	214	224	234	244	38	40	42	44	0	0	0	0
Cruz Bay	7,405	8,078	8,751	9,424	0	0	0	0	13	14	15	15	0	0	0	0
Coral Bay	13	14	15	16	0	0	0	0	13	14	15	15	0	0	0	0
Christiansted	2,640	2,880	3,120	3,360	164	172	180	188	13	14	15	15	134	136	138	138
Fredriksted	251	274	297	320	13	14	15	16	0	0	0	0	0	0	0	0
TOTAL	17,834	18,964	20,544	22,124	391	410	429	448	77	82	87	89	134	136	138	138

TABLE C-20. (Cont.)

U.S. VIRGIN ISLANDS PORTS	EUROPE				PERSIAN GULF				OTHER			
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Charlotte Amalie	0	0	0	0	0	0	0	0	13	14	15	16
Cruz Bay	0	0	0	0	0	0	0	0	13	14	15	16
Coral Bay	0	0	0	0	0	0	0	0	0	0	0	0
Christiansted	98	100	102	102	134	136	138	138	244	248	251	251
Fredriksted	0	0	0	0	0	0	0	0	12	13	14	14
TOTAL	98	100	102	102	134	136	138	138	282	289	295	297

7. LORAN-C USERS

7.1 Approach

An extensive literature search was conducted to determine sources containing information on navigation equipment carried aboard large and small commercial vessels. However, none of the sources examined contained this type of information. Thus, it was decided to obtain this information directly from shipping companies which operate vessels in the study area.

7.2 Large Commercial Vessel LORAN-C Users

Seven companies which own or operate 62 vessels were contacted to obtain information on the type of navigation equipment carried aboard their vessels and the principal means by which the vessels navigate (References 38, 39, 40, 41, 42, 43, 44). This information is summarized in Tables C-21 through C-28.

Of the 62 vessels surveyed 35, or 56 percent, carry LORAN-C receivers. Omega equipment is carried by 24 vessels, or 39 percent. Many of the vessels which are not equipped with LORAN-C equipment carry satellite navigation receivers. A few companies indicated that instead of installing LORAN-C equipment they will, or have already, install satellite equipment. A consideration for choosing satellite equipment, as opposed to LORAN-C, is cost. Operators think that Loran-C will be outdated in a short time period and, therefore, they will not recover the costs associated with buying and installing the equipment.

Individuals contacted within these companies indicated that the vessels utilize electronic navigation receivers as the principal means of navigation because they provide more efficient operation and enhance safety.

TABLE C-21. SURVEYED LARGE MARINE VESSELS (CONTAINERSHIPS)

1.	Type of Vessel	Containers
2.	Range of Deadweight Tonnage	Low 9,349 High 18,172
3.	Number of Vessels Surveyed	13
4.	Number of Vessels Carrying LORAN-A Equipment	None
5.	Number of Vessels Carrying LORAN-C Equipment	13
6.	Number of Vessels Carrying Additional Equipment	13
7.	Principal Means of Navigation	Electronics

TABLE C-22. SURVEYED LARGE MARINE VESSLES (BARGE CARRIERS) U.S. GULF TO S. AMERICA PORTS

1.	Type of Vessel	Barge Carrier
2.	Range of Deadweight Tonnage	Low 41,048 High 50,023
3.	Number of Vessels Surveyed	4
4.	Number of Vessels Carrying LORAN-A Equipment	4
5.	Number of Vessels Carrying LORAN-C Equipment	None
6.	Number of Vessels Carrying Additional Equipment	4
7.	Principal Means of Navigation	Electronics

TABLE C-23. SURVEYED LARGE MARINE VESSELS (CONTAINERSHIPS) EAST COAST OF THE U.S. VIA PANAMA CANAL TO S. AMERICA

1.	Type of Vessel	Container
2.	Range of Deadweight Tonnage	Low 20,015 High 28,058
3.	Number of Vessels Surveyed	9
4.	Number of Vessels Carrying LORAN-A Equipment	None
5.	Number of Vessels Carrying LORAN-C Equipment	9
6.	Number of Vessels Carrying Additional Equipment	9
7.	Principal Means of Navigation	Electronics

TABLE C-24. SURVEYED LARGE MARINE VESSELS (CONTAINERSHIPS) OPERATING FROM U.S. GULF TO CARIBBEAN PORTS

1.	Type of Vessel	Container
2.	Range of Deadweight Tonnage	Low 11,049 High 13,800
3.	Number of Vessels Surveyed	7
4.	Number of Vessels Carrying LORAN-A Equipment	7
5.	Number of Vessels Carrying LORAN-C Equipment	7
6.	Number of Vessels Carrying Additional Equipment	7
7.	Principal Means of Navigation	Electronics

TABLE C-25. SURVEYED LARGE MARINE VESSELS (BULK CARRIERS) PASSING THROUGH CARIBBEAN SEA

1.	Type of Vessel	Bulk Carrier
2.	Range of Deadweight Tonnage	Low 11,000 High 13,800
3.	Number of Vessels Surveyed	7
4.	Number of Vessels Carrying LORAN-A Equipment	7
5.	Number of Vessels Carrying LORAN-C Equipment	None
6.	Number of Vessels Carrying Additional Equipment	7
7.	Principal Means of Navigation	Electronics

TABLE C-26. SURVEYED LARGE MARINE VESSELS (FREIGHTERS) U.S. GULF TO S. AMERICA PORTS

1.	Type of Vessel	Freighter
2.	Range of Deadweight Tonnage	Low 11,329 High 13,595
3.	Number of Vessels Surveyed	14
4.	Number of Vessels Carrying LORAN-A Equipment	14
5.	Number of Vessels Carrying LORAN-C Equipment	None
6.	Number of Vessels Carrying Additional Equipment	14
7.	Principal Means of Navigation	Electronics

TABLE C-27. SURVEYED LARGE MARINE VESSELS (OIL TANKERS) U.S. GULF TO S. AMERICA AND CARIBBEAN PORTS

1.	Type of Vessel	Oil Tanker
2.	Range of Deadweight Tonnage	Low 17,000 High 38,000
3.	Number of Vessels Surveyed	6
4.	Number of Vessels Carrying LORAN-A Equipment	5
5.	Number of Vessels Carrying LORAN-C Equipment	6
6.	Number of Vessels Carrying Additional Equipment	6
7.	Principal Means of Navigation	Electronics

TABLE C-28. STATISTICS ON VARIOUS NAVIGATION EQUIPMENT

NO.	TYPE OF EQUIPMENT	NO.
1.	Number of Vessels Surveyed	62
2.	Number of Vessels Carrying LORAN-A Equipment	32
3.	Number of Vessels Carrying LORAN-C Equipment	30
4.	Number of Vessels Carrying LORAN-A and LORAN-C Equipment	7
5.	Number of Vessels Carrying LORAN-A and Omega Equipment	24
6.	Number of Vessels Carrying LORAN-A and Satellite Equipment	27
7.	Number of Vessels Carrying LORAN-A, Omega and Satellite Equipment	5
8.	Number of Vessels Carrying LORAN-C and Omega	5
9.	Number of Vessels Carrying LORAN-C and Satellite	19
10.	Number of Vessels Carrying LORAN-A, LORAN-C and Omega	5
11.	Number of Vessels Carrying LORAN-A, LORAN-C and Satellite	12
12.	Number of Vessels Carrying LORAN-A and Other Equipment	62
13.	Number of Vessels Carrying LORAN-C and Other Equipment	62

7.3 Small Commercial Vessel LORAN-C Users

Eleven companies, which operate 173 vessels, were identified and four of them were contacted to obtain information on navigation equipment (References 45, 46, 47, 48). Table C-29 shows various data obtained for 21 barges and tug vessels and for four small ferries. Of the 21 barges or tug boats, 11 carry Loran-A and ten carry LORAN-C. Ten vessels carry both LORAN-A and C equipment, one vessel carries only LORAN-A and two vessels carry only LORAN-C equipment. Ten vessels do not carry Loran equipment, but utilize other electronic means of navigation, such as radar and radio direction finders. The four small ferries operated by the Puerto Rico Port Authority carry only communication equipment because they operate close to the shore.

Additional information for vessels which operate exclusively in Puerto Rico and the U.S. Virgin Islands was obtained during the trip to the Caribbean (Appendix F). Approximately 10 to 15 small cargo vessels were surveyed, and it was found that none of these vessels utilize either LORAN-A or C to navigate. These vessels mainly utilize radio direction finders and radars when necessary. It can be assumed that many small vessels which operate in the Puerto Rico and U.S. Virgin Islands do not use Loran equipment. These vessels operate on a local basis, where the weather conditions and the familiarity of the masters with the waters make it unnecessary to use sophisticated electronic navigation equipment.

TABLE C-29. SURVEYED SMALL COMMERCIAL VESSELS

1.	No. of Vessels Surveyed	73
2.	No. of Operators Contacted	4
3.	No. of Vessels for Which Information Was Obtained	21
4.	No. of Vessels Carrying LORAN-A Equipment	11
5.	No. of Vessels Carrying LORAN-C Equipment	10
6.	No. of Vessels Carrying Both LORAN-A and LORAN-C Equipment	10
7.	No. of Vessels Carrying Neither LORAN-A nor LORAN-C Equipment	10

7.4 Projected LORAN-C Users: 1980 to 2000

All U.S. flag commercial vessels which are over 1,600 gross tons are required to carry LORAN-C or its equivalent (Reference 2). Similarly, all foreign flag vessels over 1,600 gross tons which call at U.S. ports are required to carry Loran-C or its equivalent. Thus, projections for the 350 large U.S. and foreign flag commercial vessels were not necessary because these vessels will always carry navigation equipment, as specified by Federal regulations.

Projections for the small commercial vessels were based on the type of equipment these vessels currently carry, as well as attitudes expressed by vessel operators. Vessels which are over 100 gross tons are likely to be equipped with LORAN-C or its equivalent. Vessels which are less than 100 gross tons usually are engaged in Intra-island trade. These vessels are not likely to obtain Loran-C equipment because their operators cannot justify the additional cost, relative to the benefits they will derive.

Based on these assumptions, it was estimated that approximately 60 percent of all the U.S. small commercial vessels which operate in the Eastern Caribbean will be equipped with LORAN-C or its equivalent.

APPENDIX D THE FISHING INDUSTRY IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

1. INTRODUCTION

The purpose of this section is to describe the current status, as well as to indicate the probable future course of the fishing industry in Puerto Rico and the U.S. Virgin Islands. The analysis is based on information obtained from interviews and discussions with the following organizations:

- Caribbean Fishery Management Council (Appendix F)
- Southeast National Fishery Center (Appendix F)
- Island Resources Foundation (Appendix F)

Additional information pertinent to fishing boat characteristics; such as installed navigation equipment, fishing locations and others; were obtained from discussions with individuals in Puerto Rico and the U.S. Virgin Islands (Appendix F).

2.0 CURRENT STATUS

Thus far, there has not been any conclusive evidence suggesting that the fishing stock throughout the Caribbean is poor. However, the Puerto Rican and the U.S. Virgin Islands fishing fleets have performed poorly. In 1975, the latest available statistics, 181 million pounds of fish worth $47 million were landed in Puerto Rican fisheries (Reference 49). Puerto Rican fishermen landed only 4.0 million pounds of fish worth $2.3 million. The balance was landed by vessels from the U.S. mainland, mainly tuna boats. These tuna landings amounted to $44 million of the total landings. The poor performance of the Puerto Rican and U.S. Virgin Islands fishing industry is attributed to several factors. First, the majority of the vessels comprising the two fleets are small, outdated and inadequately equipped. Second, approximately 84 percent of the Puerto Rican and 90 percent of the U.S. Virgin Islands vessels, because of their small size, fish in areas close to the shore. Thus, they are limited by the amount of stock and species that exist in these areas. Third, the current fishing locations have been overfished and as a result the productivity of the fishermen has decreased. The current status of Puerto Rico and the U.S. Virgin Islands fishing industry can be characterized as follows:

- Small boats, 15 to 20 feet, (83.3 percent) fish close to the shore. The major fishing spots for these boats are located between San Juan and Vieques, as well as the Culebra Islands. The distance between San Juan and the two islands is approximately 47 nautical miles. These boats are engaged in trap and line fishing, and the species most frequently sought are lobster, silk snapper, snapper and other reef fish.

- Boats 20 to 30 feet (12.4 percent) usually travel distances up to 140 nautical miles to fish seabass, hogfish, mackerel, yellow-tail snapper and others. These boats are engaged in line fishing and net fishing. The major fishing spots for these boats are the waters of the Dominican Republic and areas near the Mona Passage.

- Boats 30 to 40 feet (2.8 percent) fish in St. Martin, Saba Bank and Nevis Island. These boats usually travel a maximum distance of approximately 225 nautical miles. The major fish species sought are wahoo, mutton snapper, mackerel and others. The fishing methods utilized are line and net fishing.

- The very few large boats (1.7 percent), 40 to 50 feet, may travel as far as the coast of Venezuela, a distance of approximately 490 miles from San Juan, to seek shrimp and lobster. These 18 vessels are engaged in trolling and trap fishing.

Table D-1 summarizes this information and Figure D-1 illustrates the fishing locations. Productivity, the catch and the ultimate value of the catch depend on the following factors:

- ability of fisherman to locate the fish fairly quickly
- number and type of species available
- stock quantity
- expertise to land various available species
- availability of proper gear

Though it is recognized that there are other variables affecting productivity and landings, the above-mentioned are the most important. All of the variables, except for the first, are dependent to some extent on the location selected by the vessel. On the other hand, selection of the location depends primarily on the size of the vessel which determines its sailing range. Since the majority of the Puerto Rican and the U.S. Virgin Islands fishing fleet, 84 and 90 percent respectively, consist of small boats, 10-20 feet in length, they are constrained to fish in locations close to the shore. The problems associated with the status of the fishing industry have been recognized and addressed in Puerto Rico, the U.S. Virgin Islands and the U.S. mainland. The next section describes the measures to be taken

TABLE D-1. VARIOUS FISHING DATA FOR PUERTO RICAN FISHERIES

NUMBER OF BOATS	BOAT LENGTH IN FEET	FISHING LOCATIONS	SPECIES SOUGHT	GEAR	DISTANCE FROM SAN JUAN (NAUTICAL MILES)
863	10-18	Culebra, Vieques	spiny lobster, silk snapper,	beach seine, hand seine, traps, lines porgy, parrotfish	up to 50
129	19-30	Dominican Republic, Mona Passage	seabass, hogfish, mackerel, yellowtail snapper, mutton snapper, sardine	beach seine, hand seine, gill nets, lines	up to 140
30	30-40	St. Martin, Saba Bank, Nevis Island	mullet, goatfish, snapper trigger-fish	traps, gill nets, troll	up to 225
18	Over 40	Coast of Venezuela	shrimp, spiny lobster	traps, troll	up to 490

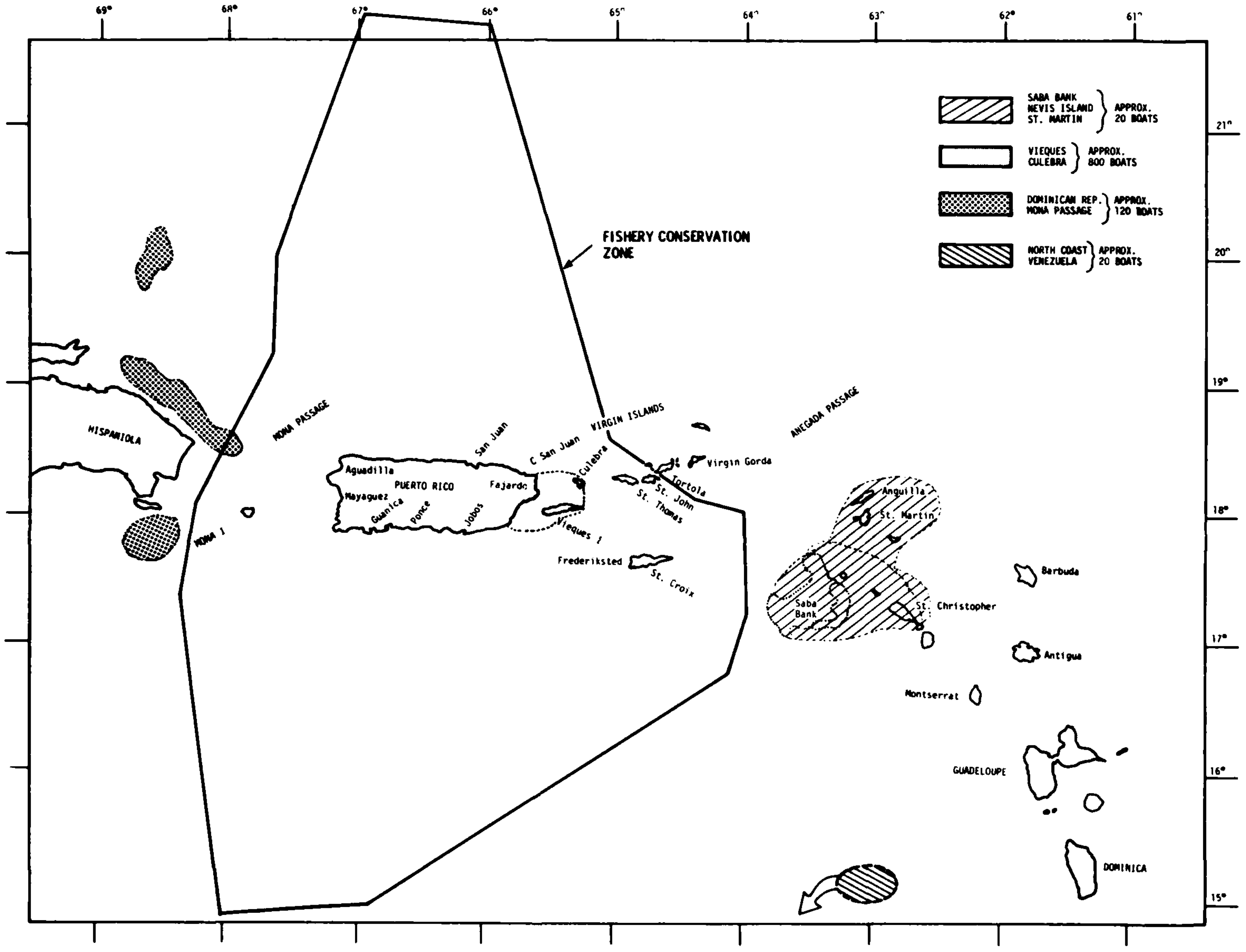

FIGURE D-1 FISHING LOCATIONS IN THE CARIBBEAN to improve the fishing industry. The plans which are described refer primarily to Puerto Rico and were developed by the Caribbean Fishery Management Council in collaboration with the Southeast National Fishery Center. No similar plans exist for the U.S. Virgin Islands.

3. FUTURE DIRECTION

The Caribbean Fishery Management Council and the Southeast National Fishery Center are currently working towards the objective of improving the status of the fishing industry. The main objectives, as outlined by these organizations, consist of upgrading the fishing fleets, replacing the small boats with larger more sophisticated ones and diversifying the species sought. Accomplishment of these objectives are based on the following key elements:

- Transfer of Technology and Expertise - The Puerto Rican government is taking steps to create a fishing boat construction industry. Japan and Spain have expressed interest in this venture. Initially the boats produced will be operated by the foreign countries which manage the boat building yards, but the crew will be drawn from both countries. After a certain period of time, both boat yards and the boats already in operation will be transferred to the Puerto Rican government. It is hoped that Puerto Ricans will acquire the type of boats and expertise required to fish various species.
- Diversify Species Landed - various efforts are being made to determine whether or not the Caribbean Sea is rich in sharks and squid. Some preliminary evidence indicates that Caribbean fishing grounds may be rich in these two species. Thus, included in the plans to upgrade the fishing fleet are provisions to construct boats for squid and shark fishing. Japanese and European markets will most likely consume these species because they are not popular in the U.S.
- Collaboration with other Caribbean islands to exchange information on fishing techniques.

- Financial and technical assistance from the U.S. to improve the fishing fleet and fishing techniques.

At this time, all of the above-mentioned plans are not well defined and contain many unknown elements which make it unlikely that the industry will change its current status in the next five to ten years. The plan for transfer of technology and expertise contains many unknown elements, such as the number of boat construction yards that will be built, what their output will be and when these boat yards will become operational. The implementation date of this plan could vary from three to seven years from 1980. Collaboration with other Caribbean islands may increase productivity and landings, but it is not expected to alter substantially the composition of the Puerto Rican commercial fishing fleet. The only short-run positive assistance may be provided by the U.S. in the form of technical and financial aid. The U.S. government, however, has not firmly established its role in this project nor has it disclosed the level of assistance which it will provide to Puerto Rico.

Based on this evidence, it can be concluded that major changes are not likely to occur in the short-run. However, when the improvement plans materialize, the fishing industry is expected to undergo structural changes and become a contributing factor to the welfare of the local people.

4. POPULATION OF COMMERCIAL AND COMMERCIAL SPORT FISHING VESSELS

The fishing vessels which operate in Puerto Rico and the U.S. Virgin Islands were classified into two categories: commercial fishing vessels and commercial sport fishing vessels. The former category refers to those vessels whose operator and crew members derive their primary income from the fish they land. The latter category includes vessels whose operators charter them to private parties for a fee.

4.1 Commercial Fishing Vessels

The fishing fleets of Puerto Rico and the U.S. Virgin Islands consist of 1040 and 420 to 500 boats, respectively (Appendix F). Table D-2 shows the distribution of the boat population by length. This table shows that the majority of the boats are small in size. Only 116 boats are greater than 22 feet in length and very few are over 36 feet. The organizations contacted in the U.S. Puerto Rico and the U.S. Virgin Islands could not provide detail information pertaining to the composition of the U.S. Virgin Islands fleet. At the present time the Caribbean Fishery Management Council, and the Island Resources Foundation, in collaboration with the Southeast National Marine Fishery Center are carrying out programs to estimate more accurately the population as well as to determine other characteristics such as length, fishing equipment carried aboard and others.

The Puerto Rican and the U.S. Virgin Islands boats are not equipped with any sophisticated electronic navigation equipment. Some of the large boats, over 35 feet in length, may be equipped with depth finders or fathometers. The majority of the Puerto Rican fishermen fish close to the shore or in reefs located near the Culebra and Vieques islands. The fishermen operating these boats are familiar with most fishing grounds and therefore, have no incentives to equip their boats with sophisticated electronic navigation receivers. Additionally, the majority of the fishing boats, 90 percent, are 10 to 20 feet and do not have the capability to sail long distances to seek fish in less explored areas, where Loran C (because of its repeatable mode) would help them to relocate the fishing grounds on future trips. Approximately 200 U.S. tuna vessels operate occasionally in the waters of Puerto Rico. These vessels fish predominantly off the coast of Costa Rica, Ecuador, the Pacific coast and the east coast of Africa. The 200 U.S. tuna vessels are equipped with all available navigation equipment, such as radar, depth finders, Omega, LORAN-C and Transit.

TABLE D-2. POPULATION OF COMMERCIAL FISHING VESSELS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

LENGTH IN FEET	NUMBER OF VESSELS	
	PUERTO RICO	U.S. VIRGIN ISLAND
10-21	924	-
22-30	71	-
31-36	27	-
36 and over	18	-
TOTAL	1040	420-500

4.2 Commercial Sport Fishing Vessels

Estimates of the number of operating boats were obtained from dockmasters and other individuals related to sport fishing activities in Puerto Rico and the U.S. Virgin Islands (Appendix F). It was estimated that approximately twenty and forty boats operate throughout Puerto Rico and the U.S. Virgin Islands, respectively. These boats are currently equipped with depth finders or fathometers. Individuals indicated that none are equipped with LORAN . These vessels navigate three to 100 nautical miles from shore seeking to land white marlin, blue marlin, tuna and other pelagic species.

5. PROJECTED POPULATION: 1980 - 2000

5.1 Commercial Fishing Vessels

In order to develop reliable projections for the fishing fleet of Puerto Rico, information obtained in the U.S. (mainland) and in Puerto Rico was utilized. Due to many uncertainties associated with the future plans to improve the quality of the fishing fleet, it seemed reasonable to develop projections according to two scenarios:

A. Conservative - The conservative projections were based on the following assumptions:

   - The growth rate of the fleet from 1980 to 2000 is 0.07 percent or seven boats per year. This growth rate was determined by examining historical data as well as current and expected profits made by the fishing industry in Puerto Rico.
   - Availability of LORAN-C coverage may or may not induce commercial fishermen to equip their boats with LORAN-C sets. This assumption was based on the fact that availability of partial LORAN-A coverage did not convince commercial fishermen to buy LORAN-A sets. However, availability of LORAN-C coverage, in conjunction with low LORAN-C equipment prices (achieved by continuous market expansion), will be a positive incentive to commercial fishermen to buy LORAN-C equipment and thus increase their productivity, landings and profits.
   - The seven boats added to the population per year are equipped with LORAN-C equipment.

B. Optimistic - The optimistic projections were based on the following assumptions:

- Two boat construction yards will produce eight boats per year. o- The boats built will be equipped with all the available navigation equipment. Included are depth finders, radio direction finders, radar, satellite, Omega and LORAN-C.

- U.S. financial assistance to Puerto Rico will be in the form of one fully equipped boat per year from 1985 through 2000.

- U.S. technical assistance to Puerto Rico will increase productivity and landings and thus it will serve as an incentive to Puerto Ricans to improve their boats at their own expense.

Table D-3 (conservative projections) shows that by the end of year 2000 the fishing fleet will consist of 1,072 boats. Approximately 89 boats will be equipped with LORAN-C receivers. Table D-4 (optimistic projections) indicates that the population of the commercial fishing fleet will be 1,174 boats and 217 of these will be equipped with LORAN-C receivers.

The Puerto Rico "conservative" scenario was employed to project the population and the LORAN-C users in the U.S. Virgin Islands commercial fishing fleet. This approach was selected because there are no specific plans to increase the number of boats, or improve its composition. Provisions for credit allowances to fishermen are being studied, but it is not known whether they will be implemented and how effective they will be. Table D-5 indicates the population and number of LORAN-C users from 1980 through 2000.

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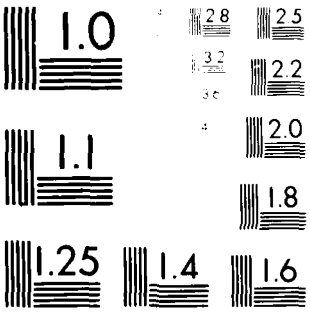

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TABLE D-3. CONSERVATIVE PROJECTIONS OF PUERTO RICAN COMMERCIAL FISHING BOAT POPULATION AND LORAN-C USERS

		NUMBER OF BOATS					LORAN-C USERS				
NO.	LENGTH IN FEET	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
1	10-20	924	924	924	897	871	--	--	--	--	--
2	21-30	71	86	101	104	109	--	5	15	23	29
3	30-36	27	42	57	60	62	--	5	18	28	36
4	36 and Over	18	23	28	29	30	--	5	10	17	24
	TOTAL	1,040	1,075	1,110	1,090	1,072	--	15	43	68	89

TABLE D-4. OPTIMISTIC PROJECTIONS OF PUERTO RICAN COMMERCIAL FISHING BOAT POPULATION AND LORAN-C USERS

		NUMBER OF BOATS					LORAN-C USERS				
NO.	LENGTH IN FEET	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
1	10-20	924	924	924	897	871	--	--	--	--	--
2	21-30	71	86	96	99	103	--	5	20	30	40
3	30-36	27	42	52	54	57	--	5	25	35	42
4	36 and Over	18	23	63	103	143	--	5	45	90	135
	TOTAL	1,040	1,075	1,135	1,153	1,174	--	15	90	155	217

TABLE D-5. PROJECTED U.S. VIRGIN ISLANDS COMMERCIAL FISHING FLEET AND LORAN-C USERS

YEAR	NUMBER OF BOATS	LORAN-C USERS
1980	420-500	--
1985	430-520	10
1990	440-540	25
1995	450-550	40
2000	460-550	60

5.2 Commercial Sport Fishing Vessels

Projections for the population and the number of LORAN-C users in this group were based on the assumption that the number of tourists that visit Puerto Rico and the U.S. Virgin Islands in 2000 will be approximately twice as many as they were in 1980 (Reference 50). Availability of LORAN-C coverage will induce these operators to equip their boats with such receivers because in its repeatable mode it provides for the rapid and accurate relocation of good fishing grounds. Table D-6 shows the number of boats and the users of LORAN-C from 1980 to 2000.

Table D-7 summarizes the commercial and commercial sport fishing boat population for both Puerto Rico and the U.S. Virgin Islands. It also indicates the total number of navigational-aid users.

TABLE D-6. PROJECTED POPULATION OF SPORT FISHING BOATS AND NAVIGATION USERS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS: 1980 - 2000

		POPULATION		NAVIGATION USERS		TOTAL	
NO.	YEAR	PUERTO RICO	U.S. VIRGIN ISLANDS	PUERTO RICO	U.S. VIRGIN ISLANDS	POPU-LATION	NAV-IGATION USERS
1	1980	21	43	--	--	64	-
2	1985	25	48	5	10	73	15
3	1990	30	55	20	25	85	45
4	1995	35	60	30	40	95	70
5	2000	40	65	40	60	105	100

TABLE D-7. PROJECTED TOTAL POPULATION AND LORAN-C USERS OF COMMERCIAL AND COMMERCIAL SPORT FISHING BOATS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

	NUMBER OF BOATS		LORAN-C USERS	
YEAR	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
1980	1,559	1,639	--	--
1985	1,578	1,658	40	40
1990	1,635	1,760	93	160
1995	1,635	1,798	178	265
2000	1,657	1,829	249	377

6. BENEFITS

The preceeding sections pointed out the current status, as well as indicated the probable future course of the fishing industry in Puerto Rico and the U.S. Virgin Islands. In light of this discussion, the issue that must be addressed is whether the fishing industry will benefit if LORAN-C coverage is expanded into the Eastern Caribbean.

Several studies have shown, though not conclusively, that mature fishing fleets (i.e., Pacific Northwest) may raise the value of their catch, depending on the gear and species by 7.4 to 50 percent if they use LORAN-C (Reference 57). Assuming that all Puerto Rican fishing vessels in 1984 (LORAN-C operational year) will be equipped with LORAN-C equipment and will raise their catch by 100 percent (because initially they will take advantage of the non-explored fishing areas), the increase would still be minimal. In 1975, total Puerto Rico landings was valued at $47 million; however, landings by the local fishermen were valued at only $2.4 million. Thus, a 100 percent increase in 1984 would raise the value of the landings to $4.8 million, which is not substantial in light of the total value of the landings. Table D-8 shows the value of the landings for major species sought in Puerto Rico and the accuracy requirements by specie and gear.

Nevertheless, it should be noted that the assumption that all Puerto Rican fishing vessels in 1984 will be equipped with LORAN-C equipment is questionable. First, 84 percent of the fleet does not need LORAN-C because of the visual aids that fishermen use to relocate good fishing areas between the coast and the Islands of Culebra and Vieques. Second, these vessels, because of their size, do not have the capability to sail out of Puerto Rico and the U.S. Virgin Islands FCZ's to seek

TABLE D-8. CATCH BY MAJOR SPECIES AND ACCURACY REQUIREMENTS BY GEAR AND SPECIES (1975)

Species	Pounds	Value in Dollars	Method of Catch	Accuracy Requirement N.M.
Goatfish	294,000	$ 91,000	Pots	0.025
Grouper	426,000	218,000	Pots 97%	0.025
Grunt	697,000	244,000	Pots 97%	0.025
Hogfish	36,400	20,000	Pots 99%	0.025
Jack	50,000	22,000	Hand Lines 50% Beach Lines 4%	0.2
Mackerel	125,000	74,000	Troll Lines 87%	0.2
Mullet	53,000	25,000	Gill Nets 64% Beach Seines 36%	-
Parrotfish	313,000	75,000	Pots	0.025
Porgy	47,000	22,000	Hand Lines 39% Beach Seines	0.2
Snappers	836,000	611,000	Pots 34-75% Beach Seines 2-7% Hand Lines 26-66%	0.2
Triggerfish	75,000	25,000	Pots 100%	0.025
Tuna	137,000	55,000	Troll Lines 97%	-
Spiny lobster	311,000	513,000	Traps 100%	0.025
Conch	186,000	100,000	Hand Lines	0.2
Shrimp	-	-	Shrimp Trawl Nets	0.5

new fishing grounds and to possibly land non-traditional species such as tuna. Third, only the larger boats, approximately 50 vessels, presently fishing in the north coast of South America, Nevis Island and Saba Bank could benefit from LORAN-C. These and later vessels could raise their productivity and landings by 100 percent.

Based on this evidence it can be concluded that under the current conditions the fishing industry of the two islands is not likely to benefit in any substantial manner if LORAN-C coverage is expanded into the Eastern Caribbean. On the other hand it should be recognized that LORAN-C could be a beneficial element if the industry changes its current status. If the plans pertinent to the improvement of the fleet materialize, the fishing industry would change substantially.

The new fishing locations would most likely lie out of the FCZ. Tuna boats would probably fish in locations out of the Caribbean (Pacific, Ecuador and east coast of Africa) as the U.S. mainland vessels do. Shrimp and lobster vessels would fish off the north coast of South America. Squid boats are likely to search for rich squid areas throughout the Caribbean. All these new vessels would fish in areas where utilization of visual aids to relocate fishing grounds would not be possible. Additionally, the fishermen would no longer be familiar with the new fishing areas. Once the new fishing areas are discovered, LORAN-C will be essential for their accurate and rapid relocation.

APPENDIX E RECREATIONAL BOATING IN THE EASTERN CARIBBEAN

1. INTRODUCTION

The purpose of this section is to estimate the population of pleasure vessels in Puerto Rico and the U.S. Virgin Islands, determine the traffic between the U.S. and Puerto Rico and the U.S. Virgin Islands and project the number of pleasure vessels and potential LORAN-C users from 1980 to 2000.

2. POPULATION OF PLEASURE CRAFT IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

This population group includes all pleasure boats which are registered and documented* in Puerto Rico and the U.S. Virgin Islands, such as sailboats, cabin cruisers, and other power boats.

2.1 Puerto Rico

The population of pleasure craft in Puerto Rico was estimated from four sources:

- U.S. Coast Guard, "Boating Statistics" (Reference 51)
- Clapp and Mayne, Inc., "Fishermen in Puerto Rico, a Socio-Economic Profile" (Reference 52)
- National Association of Engine and Boat Manufacturers, "Boating Registration Statistics" (Reference 53)
- Interviews with marina dockmasters and personnel engaged in boating activities in Puerto Rico (Appendix F)

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*Documented yachts are not registered. A documented yacht is one of at least five net tons capacity.

Table E-1 shows the population of Puerto Rico's pleasure craft in 1978 (latest available estimate). The population of this group in 1978 consisted of 17,468 craft. Approximately 15,496, or 89 percent, were up to 26 feet, 1,972 boats, or 11 percent were over 26 feet and only 192 boats were greater than 40 feet. None of these vessels carried LORAN-A or LORAN-C equipment.

TABLE E-1. PUERTO RICO PLEASURE BOAT POPULATION IN 1978

	INBOARD	OUTBOARD	TOTAL
Under 16 Feet	393	5,722	6,115
16 to Less Than 26 Feet	3,351	6,030	9,381
26 to Less Than 40 Feet	1,471	309	1,780
40 to 65 Feet	192	--	192
TOTAL	5,407	12,061	17,468

The type of navigation equipment the Puerto Rican boats carry was determined by visiting all major marinas in San Juan and Fajardo. All dockmasters indicated that the vast majority of boats do not carry any sophisticated electronic navigation receivers. Some of the large boats are equipped with depth finders and even fewer boats are equipped with radar or radio direction finders.

Dockmasters and other marina personnel provided four possible explanations for why Puerto Rican pleasure craft do not carry electronic equipment. These were:

- The good weather conditions prevailing year round;
- The existence of numerous visual aids which greatly facilitate navigation;
- Most Puerto Rican pleasure craft do not operate in the open sea;
- The majority of the boats navigate during daytime using visual navigation means.

2.2 U.S. Virgin Islands

Included in this category were all pleasure boats which are registered and documented in the U.S. Virgin Islands. The pleasure craft population was estimated from three sources:

- U.S. Coast Guard, "Boating Statistics" (Reference 51)
- National Association of Engine and Boat Manufacturers, "Boating Registration Statistics" (Reference 53)
- Interviews with marina dockmasters and experts on recreational boating activities in St. Thomas (Appendix F)

Table E-2 shows the population of pleasure craft and LORAN-C users in the U.S. Virgin Islands. In 1978 the population of this group consisted of 2,567 craft. Approximately 1,011 boats were 16 to 26 feet and 672 boats were 26 to 40 feet. Over 10 percent of the total population, or 264 craft, consisted of boats over 40 feet in length.

TABLE E-2. POPULATION OF PLEASURE CRAFT AND LORAN-C USERS IN THE U.S. VIRGIN ISLANDS IN 1978

LENGTH IN FEET	INBOARD	OUTBOARD	TOTAL	LORAN-C USERS
Under 16 Feet	1	619	620	-
16 to Less Than 26 Feet	245	766	1,011	-
26 to Less Than 40 Feet	598	74	672	-
40 to 65 Feet	244	7	251	-
65 Feet and Over	13	—	13	-
TOTAL		2,567	25	

Navigation equipment carried aboard vessels registered in the U.S. Virgin Islands was determined by visiting marinas and contacting vendors of electronic navigation equipment in St. Thomas. In general, pleasure craft do not carry sophisticated navigation equipment. Individuals contacted in St. Thomas indicated that approximately one to two percent (nearly 25 vessels) of the boat population are equipped with LORAN-C receivers and eight to ten percent of the pleasure craft carry depth finders or radio direction finders. Boats which are equipped with LORAN-C equipment are owned mostly by U.S. mainland residents.

These individuals were also asked why local boats do not carry electronic navigation equipment. They offered the same reasons as their Puerto Rican counterparts. In addition, they furnished two more factors: a) most oceangoing sailboat operators are accustomed to navigating by celestial means and b) the Puerto Rico-Virgin Island area is a region of relatively safe navigation conditions. Thus, boat owners apparently do not perceive any benefits from the utilization of sophisticated navigation equipment.

3. PROJECTED POPULATION OF PLEASURE CRAFT IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS: 1980 - 2000

3.1 Puerto Rico

To estimate the pleasure craft population through the year 2000, historical data pertaining to the pleasure craft population and its composition were examined. Table E-3 shows the population by length and its absolute and percentage growth rate for a six-year period.

In the period 1973 to 1978, the 16 to 26 foot craft category increased by 4,219 boats, or 81.7 percent. This growth accounted for 55 percent of the total population increase. The craft population under 16 feet increased by 2,380 boats and accounted for 31 percent of the total population growth. The two craft categories, 26 to 40 feet and 40 to 65 feet, together experienced a moderate growth of only 1,058 boats and accounted for 13.8 percent of the total population growth.

TABLE E-3. POPULATION OF PLEASURE CRAFT IN PUERTO RICO FROM 1973 TO 1978

YEAR	UNDER 16 FEET			16 TO LESS THAN 26 FEET			26 TO LESS THAN 40 FEET			40 TO 65 FEET		
	POPULA-TION	ABSO-LUTE CHANGE	PERCENT CHANGE	POPULA-TION	ABSO-LUTE CHANGE	PERCENT CHANGE	POPULA-TION	ABSO-LUTE CHANGE	PERCENT CHANGE	POPULA-TIOON	ABSO-LUTE CHANGE	PERCENT CHNAGE
1973	3,735	--	--	5,162	--	--	799	--	--	115	--	--
1974	4,244	509	12.0	6,137	975	15.8	1,011	212	20.9	141	2.6	18.4
1975	4,901	657	13.4	7,203	1,066	14.8	1,212	201	16.5	161	20	12.4
1976	5,390	489	9.0	8,029	826	10.2	1,390	178	12.8	169	8	4.7
1977	5,768	378	5.0	8,799	770	8.7	1,576	186	11.8	182	13	7.1
1978	6,115	345	5.6	9,381	582	6.2	1,780	204	11.4	192	10	5.2
Population Increase From 1973 to 1978	2,380			4,219			981			77		
Average Percentage Yearly Change From 1973 to 1978			9			11.4			14.7			9.5
Average Percentage Yearly Change From 1976 to 1978			6.5			8.3			12			5.6

The average yearly growth rate for the period 1973 to 1978 was calculated to be 9, 11.4, 14.7, and 9.5 percent for the under 16 feet, 16 to 26 feet, 26 to 40 feet and 40 to 65 feet categories, respectively. These growth rates decreased substantially when they were calculated for the last three-year period, 1976 to 1978.

The growth rates, however, for the year 1978 were the lowest for the three craft categories. From 1977 to 1978 only one category (under 16 feet) experienced a modest increase, 0.6 percent. These declining growth rates were attributed to several factors. First, rising fuel costs discouraged prospective buyers from entering the boat market. Personal income was rising at a slower rate than inflation, making recreational boating a more expensive activity than before. In addition, real income of Puerto Ricans declined between 1973 and 1977 (References 36). Table E-5 illustrates that the only gain in real income occurred in 1976 with a moderate increase of 0.9 percent from the preceding year. Second, the real income of Puerto Ricans is very low relative to U.S. standards. Thus, only a small fraction of Puerto Ricans have the purchasing power to buy large expensive boats. The evidence, slight growth rates of the boat population from 1973 to 1976 (presented in Table E-3), suggests that affluent individuals bought craft in the early and mid 70's. Once this group acquired craft, the growth rates decreased substantially. For these reasons, projections were based on the last year's growth rate as opposed to applying the average growth rate for the five year period.

It is assumed that the cost of fuel will continue to rise and as a result, the craft growth rates will decrease further. The impact of this factor upon the growth rates was projected as follows:

TABLE E-4. PROJECTED POPULATION OF PLEASURE CRAFT IN PUERTO RICO: 1980-2000

PERIOD	UNDER 16 FEET	16 TO LESS THAN 26 FEET	26 TO LESS THAN 40 FEET	40 TO 65 FEET	TOTAL
1978-1980	6,763	10,469	2,168	212	19,612
1981-1985	8,383	13,189	3,138	262	24,972
1986-1990	10,003	15,909	4,108	312	30,332
1991-1995	10,153	16,144	4,153	317	30,767
1996-2000	10,303	16,379	4,198	322	31,202

TABLE E-5. PAST, CURRENT AND PROJECTED PERSONAL INCOME FOR PUERTO RICANS IN CONSTANT (1954) DOLLARS

			PROJECTED PERSONAL INCOME		
YEAR	PERSONAL INCOME IN $	PERCENTAGE CHANGE	YEAR	PERSONAL INCOME IN $	PERCENTAGE CHANGE
1973	1,165	—	1985	1,483	+3.7
1974	1,125	-3.5	1990	1,776	+3.7
1975	1,114	-0.9	1995	2,127	+3.7
1976	1,125	+0.9	2000	2,548	+3.7
1977	1,120	-0.4			
1978	1,150	+2.6			
1979	1,194	+3.6			

- Under 16 feet - 0.30 percent per year
- Sixteen to less than 26 feet - 0.40 percent per year
- Twenty-six to less than 40 feet - 0.50 percent per year
- Forty to 65 feet - no effect; boat owners or potential boat buyers of this craft type are price inelastic, i.e., fuel cost does not have an impact on these individuals.

A third factor taken into account was that by the year 1990 the population of pleasure craft will have reached its major growth and thereafter it will increase by a moderate rate of half a percent per year. To avoid upward biased estimates, the growth rates were applied against the year 1978 as opposed to applying them to the population of each consecutive year. Equation (1) illustrates the method used to estimate the population under 16 feet category for 1985.

$$1985\ P_1 = BYP_1\left[1 + YEARS\,(PGR_1 - FCAF_1)\right] \qquad (1)$$

where:

$1985\ P_1$ = Craft population under 16 feet by end of 1985

BYP_1 = Craft population under 16 feet at base year (1978)

YEARS - Number of years from 1978 to 1985

PGR = Growth rate of craft population (under 16 feet)

$FCAF_1$ = Fuel cost adjusting factor for craft population under 16 feet

The values of these variables are:

BYP_1 = 6115 boats
PGR_1 = 5.6 percent

$FCAF_1 = 0.30$ percent

then

$1985\ P_1 = 8{,}383$

The population for the other three categories was projected in a similar manner.

3.2 U.S. Virgin Islands

To project the craft population from 1980 to 2000, historical data pertaining to annual growth for five years was examined. Table E-6 shows the craft population by length as well as their absolute and percentage growth rates from 1974 to 1978.

The data examined did not provide a consistent trend in which the projections could be based. For instance, from 1974 to 1975 the population increased by 143 boats, and from 1976 to 1977 certain categories experienced a moderate growth rate and some others declined. Due to this inconsistency, historical data could not constitute the basis for the projections. Thus, information obtained in St. Thomas and San Juan was applied to project the population of this group. The following information was used:

- In the last several years, the number of charter boats in the U.S. Virgin Islands has increased dramatically. At the present time there are approximately 600 boats available for renting or chartering. Two to three years ago there were only 150 boats available for this purpose.

TABLE E-6. POPULATION OF PLEASURE CRAFT IN THE U. S. VIRGIN ISLANDS

	UNDER 16 FEET			16 TO LESS THAN 26 FEET			26 TO LESS THAN 40 FEET			40 TO 65 FEET			
YEAR	POPULATION	ABSOLUTE CHANGE	PERCENT CHANGE	POPULATION	ABSOLUTE CHANGE	PERCENT CHANGE	POPULATION	ABSOLUTE CHANGE	PERCENT CHANGE	POPULATIOON	ABSOLUTE CHANGE	PERCENT CHNAGE	OVER 65 FEET
1974	251	--	--	524	--	--	288	--	--	110	--	--	--
1975	319	+ 68	+27	548	+ 24	+ 4.5	318	+ 30	+10	131	+21	+19	--
1976	697	+378	+218.5	761	+213	+38.8	616	+298	+93	221	+90	+68	--
1977	590	-107	-15.4	834	+ 73	+ 9.6	630	+ 14	+ 2	223	+ 2	+ 2	--
1978	620	+ 30	+ 5	1,011	+177	+21.2	672	+ 42	+ 6.5	251	+28	+12.5	13

- Due to many tax exemptions granted by the government of the U.S. Virgin Islands to boat owners, many individuals from the U.S. mainland register their boats in the islands.

- The number of tourists that will visit the U.S. Virgin Islands by 2000 is expected to double.

Table E-7 shows the projected population of pleasure craft in the U.S. Virgin Islands from 1980 to 2000. By 2000 the population will consist of 4,275 boats, an increase of 1,556 boats from 1980.

TABLE E-7. PROJECTED POPULATION OF PLEASURE CRAFT IN THE U.S. VIRGIN ISLANDS: 1980-2000

PERIOD	UNDER 16 FEET	16 TO LESS THAN 26 FEET	26 TO LESS THAN 40 FEET	40 TO 65 FEET	OVER 65 FEET	TOTAL
1978-1980	640	1,100	700	265	14	2,719
1981-1985	700	1,300	750	280	17	3,047
1986-1990	760	1,550	790	300	20	3,420
1991-1995	810	1,830	850	320	23	3,833
1996-2000	870	2,100	940	340	25	4,275

4. PROJECTED LORAN-C USERS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS: 1980 - 2000

4.1 Puerto Rico

Based on discussions with dockmasters and surveys taken in Puerto Rico, it was determined that locally moored boats are not equipped with LORAN-C receivers. This can be explained by the fact that LORAN-C coverage is not currently available. It is not known how the pleasure craft owners will respond if LORAN-C becomes available. Projections for this group were based on an examination made for the pleasure craft operating in the Miami and Fort Lauderdale area. Discussions with dockmasters and other experts related to boating activities, in Miami, the Bahamas, San Juan and St. Thomas revealed the following trends:

- The majority of pleasure boats operating in Miami and Fort Lauderdale which are less than 35 feet in length, do not carry LORAN-C sets.
- Approximately 70 to 80 percent of the pleasure craft, 40 feet and over in length, operating in these two areas are equipped with all available navigation aids including LORAN-C;
- In general the weather conditions that prevail in the Caribbean are favorable to navigators;
- The majority of the Puerto Ricans stay within sight of land when they navigate;
- Local navigators utilize visual navigation means extensively;
- Due to numerous unmarked reefs and shallow waters that exist throughout the coast of Puerto Rico, local navigators do not sail at night.

The above-mentioned information was used to formulate the methodology that was applied to project LORAN-C users in Puerto Rico from 1980 to 2000. The approach consisted of four steps.

The first step was to use Table E-4 to determine the number of Puerto Rican boats over 35 feet in length. Approximately 20 percent of the boats in the 26 to 40 feet category are over 35 feet in length. Thus, in 1985 the population of pleasure craft over 35 feet in length will consist of 889 boats.

The second step consisted of multiplying the Miami estimate (percentage of boats over 35 feet which carry LORAN-C sets) by the number of Puerto Rican boats over 35 feet. The product of this multiplication represents the potential users of LORAN-C equipment in Puerto Rico.

The third step was to take into account the differences that exist between the Miami and the Puerto Rican recreational boating activities. In general, U.S. mainland citizens have a higher economic standard, own more sophisticated craft (better equipped and larger in length), take longer trips, and use their boats more often. It was estimated that these factors would lower Puerto Rican LORAN-C users, calculated in step two, by approximately 40 percent.

The fourth step consisted of estimating the time lag between availability of LORAN-C coverage and usage of that system by Puerto Rican recreational boaters. Assuming that LORAN-C becomes available in 1984, it is not likely that all potential users will respond immediately. It was estimated that approximately

55 percent of all potential users will equip their boats with LORAN-C receivers by the year 2000. The values of the response factor were assumed to be:

1985 = 2 percent,

1990 = 25 percent,

1995 = 45 percent, and

2000 = 45 percent

The three step approach is summarized in equation (2):

$$PLCU_{year\ n} = (P_{1x0.20} + P_2)(0.80 - 0.40)\ Z_n$$

where:

$PLCU_{year\ n}$ = Projected LORAN-C users in year n

$P_{1x0.20}$ = Estimated population in the 26 to less than 40 feet category

P_2 = Population in the 40 to 65 feet category

0.80 = Percentage of Miami boats over 35 feet which are equipped with LORAN-C sets

0.40 = Factor to adjust for differences between Miami and Puerto Rico

Z_n = Response rate in year n

Table E-8 indicates that approximately 240 boats will utilize LORAN-C.

TABLE E-8. PROJECTED PLEASURE CRAFT LORAN-C USERS IN PUERTO RICO

	UNDER 16 FEET		16 TO LESS THAN 26 FEET		26 TO LESS THAN 40 FEET		40 TO 65 FEET	
PERIOD	POPULATION	PROBABLE LORAN-C USERS	POPULATION	PROBABLE LORAN-C USERS	POPULATION	PROBABLE LORAN-C USERS	POPULATION	PROBABLE LORAN-C USERS
1984-1985	8,388	--	13,189	--	3,138	5	262	2
1986-1990	10,003	--	15,909	--	4,108	33	312	25
1991-1995	10,153	--	16,144	--	4,153	149	317	46
1996-2000	10,303	--	16,379	--	4,198	184	322	57

4.2 U.S. Virgin Islands

The methodology applied to estimate the users of LORAN-C in Puerto Rico was also used to determine the Loran-C users in the U.S. Virgin Islands. To develop more accurate estimates, an additional factor was added based on the finding made in St. Thomas that some individuals from the U.S. mainland bring their boats into the U.S. Virgin Islands on a permanent basis and some of these boats are equipped with LORAN-C sets.

Table E-9 shows the users of LORAN-C from 1980 to 2000. Approximately 226 boats will utilize LORAN-C if coverage is made available. However, if Loran-C is not made available only a small fraction of boat owners are likely to equip their boats with receivers because the current LORAN-C groundwave signal coverage in the U.S. Virgin Islands is marginal.

Table E-10 shows the population and LORAN-C users of pleasure craft in Puerto Rico and the U.S. Virgin Islands from 1980 to 2000. The population of the pleasure craft by 2000 will consist of approximately 35,477 boats, and nearly 467 craft will utilize LORAN-C.

TABLE E-9. PLEASURE CRAFT PROBABLE LORAN-C USERS IN THE U.S. VIRGIN ISLANDS

PERIOD	UNDER 16 FEET		16 TO LESS THAN 26 FEET		26 TO LESS THAN 40 FEET		40 TO 65 FEET		65 FEET AND OVER	
	POPU-LATION	PROBABLE LORAN-C USERS	POPU-LATION	PROBABLE LORAN-C USERS	POPU-LATION	PROBABLE LORAN-C USERS	POPU-LATION	PROBABLE LORAN-C USERS	POPU-LATION	PROBABLE LORAN-C USERS
1984-1985	700	--	1,300	--	150	14	280	24	17	8
1986-1990	760	--	1,550	--	790	34	300	57	20	14
1991-1995	810	--	1,830	--	850	58	320	95	23	20
1996-2000	870	--	2,100	--	940	79	340	122	25	25

NOTE: Included in the Loran-C users are the current Loran-C users (25).

TABLE E-10. POPULATION AND LORAN-C USERS OF PLEASURE CRAFT IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS: 1980-2000

YEAR	UNDER 16 FEET	16 TO LESS THAN 26 FEET	26 TO LESS THAN 40 FEET	40 TO 65 FEET	OVER 65 FEET	TOTAL	LORAN-C USERS
1980	7,403	11,569	2,868	477	14	22,331	-
1985	9,803	14,489	3,888	542	17	28,019	53
1990	10,763	17,459	4,898	612	20	33,752	163
1995	10,963	17,974	5,003	637	23	34,600	368
2000	11,173	18,479	5,138	662	25	35,477	467

5. POPULATION OF U.S. MAINLAND PLEASURE CRAFT CRUISING TO PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Two approaches were taken to estimate the number of U.S. pleasure craft which cruise from various regions of the U.S. mainland to Puerto Rico and the U.S. Virgin Islands.

The first approach consisted of utilizing various publicly available data sources. The primary data sources used were "AE 350" (inbound traffic) and "AE 750" (outbound traffic) forms published by the Bureau of the Census Foreign Trade Division (Appendix C). These data sources were used to determine the population of U.S. recreational boats cruising to Puerto Rico and the U.S. Virgin Islands. The method applied was as follows:

- March and August were used as a sample. These two months were selected because of the seasonal traffic variations they represent.

- Vessels entered or cleared by U.S. Customs Offices in Puerto Rico and the U.S. Virgin Islands were identified. Included were small commercial tug/tow, ferries and pleasure vessels up to 100 gross tons.

- From these vessels the number of the U.S. pleasure boats was estimated according to the following method:

  - From the total number of vessels counted, the tug/tow boats were subtracted. Tug/tow boats were easily identified from their code number.

  - The vessels which operate locally were also subtracted from the total number of vessels. Included in this group were ferries, small cargo vessels engaged in intra-island commerce, charter boats, and recreational boats moored locally. The small cargo vessels were identified by their code number. The ferries were identified by the frequency with which they cleared or entered the Puerto Rican and the U.S. Virgin Islands ports. For instance a typical ferry cleared at least 12 times per month. The locally moored boats were also identified by the frequency with which they were cleared by Port Authorities in a certain month. Local boats were defined as those which were cleared at least three times a month. Thus, all other vessels which were cleared less than three times in a month were classified as boats cruising to Puerto Rico and the U.S. Virgin Islands from the United States (mainland).

This process is summarized in equation (3):

$$USRC = T_{S100} - F - C_b - S_c - TT_b \qquad (3)$$

where

$USRC$ = U.S. mainland recreational craft

T_{S100} = Total number of vessels up to 1,000 gross tons clearing or entering a given port

F = Local ferries

C_b = Charter boats and locally moored boats

S_c = Small commercial vessels

TT_b = Tug/Tow vessels

In August, 1979, 21 boats cruised to Puerto Rico and 65 boats cruised to the U.S. Virgin Islands. All craft which sailed to Puerto Rican ports also cruised to the U.S. Virgin Islands. Thus, the total number of U.S. boats which sailed to Puerto Rico and the U.S. Virgin Islands in August consisted of 65 craft.

In March 1979 16 U.S. boats sailed to Puerto Rico and 80 craft sailed to the U.S. Virgin Islands. However, the total number of boats sailing to both Puerto Rico and the U.S. Virgin Islands consisted of 80 craft. Again this was due to the tact that all craft which sailed to Puerto Rico also cruised to the U.S. Virgin Islands.

The total number of U.S. mainland boats cruising to these two locations in a year was estimated to be approximately 870 craft. This estimate was obtained by calculating the average number of boats that sail to Puerto Rico and the U.S. Virgin Islands in the two month period (80 + 65 = 145, 145/2 = 72.5) and multiplying it by 12.

The second approach consisted of utilizing information obtained in U.S. (mainland), Bahamas, Puerto Rico and the U.S. Virgin Islands to estimate the number of U.S. mainland boats which sail to Caribbean. This information revealed that approximately 800-1000 boats sail to the Caribbean. Thus, the two estimates appear to be identical.

5.1 LORAN-C Users

Information on the type of navigation equipment carried aboard U.S. recreational boats was obtained from three sources:

- Marina dockmasters in the Bahamas, Miami, San Juan and St. Thomas (Appendix F);
- Vendors of electronics navigation equipment in Miami, Fort Lauderdale and St. Thomas (Appendix F);
- Editors of fishing and boating periodicals (Appendix F).

These individuals furnished the following information pertinent to U.S. boats which cruise in the Caribbean:

- Due to increasing fuel costs in recent years the number of power boats cruising to the Caribbean has been reduced substantially;
- Approximately 40 to 60 percent of the U.S. to Eastern Caribbean traffic is generated by sailboats;

- Approximately 80 percent of the large power boats are equipped with all available navigation equipment such as radio direction finders, radar, depth finders, LORAN-C, Omega and Transit;
- Nearly 40 percent of sail boats which are 50 feet and over carry LORAN-C receivers.

From these discussions it was concluded that of the 870 U.S. mainland boats which cruise to Puerto Rico and the U.S. Virgin Islands approximately 270 are equipped with LORAN-C sets.

5.2 Projected Population

Projections concerning the U.S. mainland boats which will sail to Puerto Rico and the U.S. Virgin Islands from 1980 to 2000 were based on numerous discussions with experts on boating activities in Miami, Fort Lauderdale, San Juan and St. Thomas. Individuals contacted in these places indicated several trends of interest. These were:

- Due to increasing fuel costs in recent years, the number of power boats cruising to the Caribbean has been reduced substantially;
- Individuals usually fly to the Caribbean and charter a boat, rather than sailing from Florida or other U.S. ports to the Caribbean;
- Marina managers in San Juan and St. Thomas indicated that they do not anticipate the U.S. to Puerto Rico and U.S. to the U.S. Virgin Islands traffic to increase in the short term.

These trends point out that pleasure boat traffic will not increase over the next few years. Fuel costs are the major operating expense of pleasure boats, and high fuel prices will tend to decrease the average trip length of pleasure craft. A boat 40 feet in length consumes approximately 60 to 70 gallons of fuel per hour. This represents a cost of $60 to $70 per hour at $1.00 per gallon fuel prices. Assuming an average speed of 14 knots, a craft sailing from Miami to San Juan will consume approximately 1,600 to 1,850 gallons of fuel, or spend $1,600 to $1,850 on fuel cost. Thus, a round trip to Puerto Rico will cost nearly $3,200 to $3,700. Some boat owners may not be able to afford this high fuel cost and decide not to sail from the U.S. to the Caribbean. Rather, they will be more inclined to fly to the Caribbean and charter a boat.

Sailboat traffic, however, may increase over time by a small percentage. This increase was assumed to offset decreasing motor boat traffic. Therefore, both traffic level and LORAN-C usage is expected to remain fairly constant.

APPENDIX F LIST OF CONTACTS

1. U.S. GOVERNMENT

- Seventh Coast Guard District, Miami, Fla.
  - Aids to Navigation Branch, Capt. Alan C. Dempsey, Chief
  - Aids to Navigation Branch, LCDR Charles M. Montanese, Asst. Chief
  - Electronics Engineering Branch, CDR Phillip J. Kies, Chief

- Coast Guard - Greater Antilles Section, San Juan, PR
  - Commanding Officer, Capt. William L. King
  - Executive Officer, CDR Robert F. Muchow
  - Search and Rescue, Lt. Michael R. Adams
  - Aids to Navigation, Lt. Paul D. Barlow

- Coast Guard - Marine Safety Office, San Juan, PR
  - Executive Officer, LCDR James R. Townley

- Coast Guard Air Station, Borinquen, PR
  - Executive Officer, CDR. William J. Wallace
  - Operations Officer, LCDR. Jerald H. Heinz

- Coast Guard R&D Center, Groton, CT.
  - Lt. S.R. Osmer

- Coast Guard Headquarters, Washington, D.C.
  - Office of Operations, Aviation Branch, LT. J.A. Brokenik
  - Office of Boating Safety, Mr. G. Steykes

  - Merchant Vessel Documentation Division, Ms. Eleanor Fischer
  - Boating Affairs Branch, Mr. Diangess
  - Port Safety & Law Enforcement Division, LCDR J. D. Bannan

- Maritime Administration
  - Office of Ship Operating Costs, Mr. F. Larson, Mr. D. Murray, Washington, - D.C.

- Army of Corps Engineers
  - Navigation Analysis Center, Mr. Max Swartch, New Orleans, Louisiana

- National Marine Fishery Services
  - Resource Statistics Division, Mr. Leslie Robinson, Washington, D.C.

- Southeast Marine Fisheries Center
  - Mr. Mike Justen, Miami, Florida
  - Mr. Kim Nwallan, Miami, Florida
  - Mr. Tom Dalloween, Miami, Florida

- Northeast Marine Fisheries Center
  - Mr. K. Terall, Gloucester, Mass.

- U.S. Customs Service
  - Mr. David Brown, St. Thomas, U.S. Virgin Islands
  - Public Affairs Office, Mr. D. Dingfelfer, Miami, Florida

2. PUERTO RICAN GOVERNMENT

- Puerto Rico Office of Economic Research and Development, Mr. Gary Martin, Mr. Pedro Dias, San Juan, Puerto Rico
- Puerto Rico Financial Council, Mr. Allen Udall, San Juan, Puerto Rico

3. U.S. VIRGIN ISLANDS GOVERNMENT

- Department of Conservation & Cultural Affairs, Mr. Joseph Sutton, St. Thomas, U.S. Virgin Islands

4. PORT AUTHORITIES

- Miami Port Authority, Mr. Carmen Lunetta, Miami, Florida
- Puerto Rico Port Authority, Mr. Fernandes Rodriguez, San Juan, Puerto Rico
- Freeport Port Authority, Capt. Leon Flowers, Nassau, Bahamas

5. MARITIME ORGANIZATIONS

- Maritime Transportation Research Board, Mr. Dave Mellor, Washington, D.C.
- National Marine Manufacturing Association, Mr. John Lamont, New York, New York
- Maritime Association of the Port of New York, Mr. Nick Cretan, New York, New York

6. SHIPPING COMPANIES

- Delta S.S. Lines, Ms. Linda Lapidus, Mr. Paul Robinson, Mr. Geoffrey Bolton, New York, New York
- U.S. Lines, Mr. G. Burich, Washington, D.C.

- o Lykes Bros S.S. Lines, Capt. Sawyer, New Orleans, LA
- o Puerto Rican Merchant Marine Inc., Mr. Lopez Manuel, Mr. Fredde Vasques, Capt. Shinner, San Juan, Puerto Rico; Elizabeth City, New Jersey
- o Amerada Hess Oil Corporation, Captain Evangelos Carvoumis, St. Croix, U.S. Virgin Islands
- o McAllister Bros., Mr. John Forsythe, New York, New York
- o Farell Lines, Mr. G. Sartor, New York, New York
- o Crowley Maritime Inc., Richard Roth, San Juan, Puerto Rico
- o South Puerto Rico Towing and Boat Service, Mr. Hector Padilla, San Juan, Puerto Rico
- o Sea-Land Lines, Mr. Prindiville, Elizabeth City, New Jersey

7. Marinas

- o U.S.
  - Castaways Docks, Miami, Florida
  - Miami Marina, Miami Florida
  - Miamarina, Miami, Florida
  - Pier 66, Fort Lauderdale, Florida
  - Bahia, Fort Lauderdale, Florida
- o Bahamas
  - Lucayan Harbour Inn and Marina, Captain Stan Lockhart, Freeport, Grand Bahamas
- o - Grand Bahama Hotel and Marina, Mr. Bruce Clark, West End, Grand Bahama
  - Running Man Marina, Freeport, Grand Bahama
  - East Bay Yacht Basin, New Providence
  - Bayshore Marina, New Providence

  - Brown's Boat Basin, New Providence
  - Nassau Harbour Club

- o Puerto Rico
  - Club Nautico de San Juan, Mr. Santos Amemzon, Mr. Santorinino Feruaity,
    San Juan
  - Isleta Marina, Mr. Julio Betances, Fajardo
  - Marina Puerto Chico, Mr. Alga Miro, Fajardo
  - Villa Marina, Mr. Alan Stowell, Fayardo
  - Sea Lovers, Fajardo
- o U.S. Virgin Islands
  - Johnny Harms Lagoon Marina, Captain John Harms, Ms. Gail McCoy, Mr. Ward Stevenson, St. Thomas
  - Ancher Marina, St. Thomas

8. Vendors of Navigation Equipment

- o U.S.
  - Decca Company, Mr. Jack Weber, Fort Lauderdale, Florida
  - Stephenson Marine Electronics Company, Mr. Stephenson, Fort Lauderdale, Florida
  - Daymar Marine Electronics Company, Fort Lauderdale, Florida
  - Jerry's Marine Elctronics Inc., Fort Lauderdale, Florida
- o U.S. Virgin Islands
  - Communications Specialists International Inc., Mr. Albert Cleland, St. Thomas
  - Electronics Shop at Ancher Marine, Mr. Osburn, St. Thomas

9. Fishing Organizations

- Caribbean Fishery Management Council, Mr. Omar Munoz-Rowe, Mr. Castillo San Juan, Puerto Rico

- Island Resources Foundation, Dr. David Olsen, St. Thomas, U.S. Virgin Islands
- Charter Tuna Fishing Inc., Mr. Louis Ayala, Mayaguez, Puerto Rico

10. Other Organizations/Individuals

o Journal of Commerce, Mr. Spina, New York

o American Hull Insurance Syndicate, Mr. William Patterson, New York, New York

o Reynolds Aluminum Corporation, Mr. Charlie Meecham

o Florida Fishing News, Mr. Joe Fisher, Miami, Florida

o Captain Harry's Fishing Supply, Captain Harry Vernon, Miami, Florida

o Southern Boating Magazine, Mr. Ship Allen, Miami, Florida

o Universitv of Miami, Pr. Bruce Aurtin, Miami, Florida

o World Bank, Ms. Morko, Washington, D.C.

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