GEORGE J. SKALIOTIS CG-NRN-1-81

ENEFITS AND OSTS OF ORAN-C XPANSION NTO THE ASTERN ARIBBEAN

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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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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.

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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

- 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

- 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.

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

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 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).

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

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

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.

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 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.

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

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.

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,

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

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 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 radio-beacon 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

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	CB 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
ORIGIN-DESTINATION	NEW ENGLAND	MID ATLANTIC	SOUTHERN	GULF	PUERTO RICO	VIRGIN ISLS	GREATER ANTILLES	LESSER ANTILLES	NORTH COAST SOUTH AMERICA

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

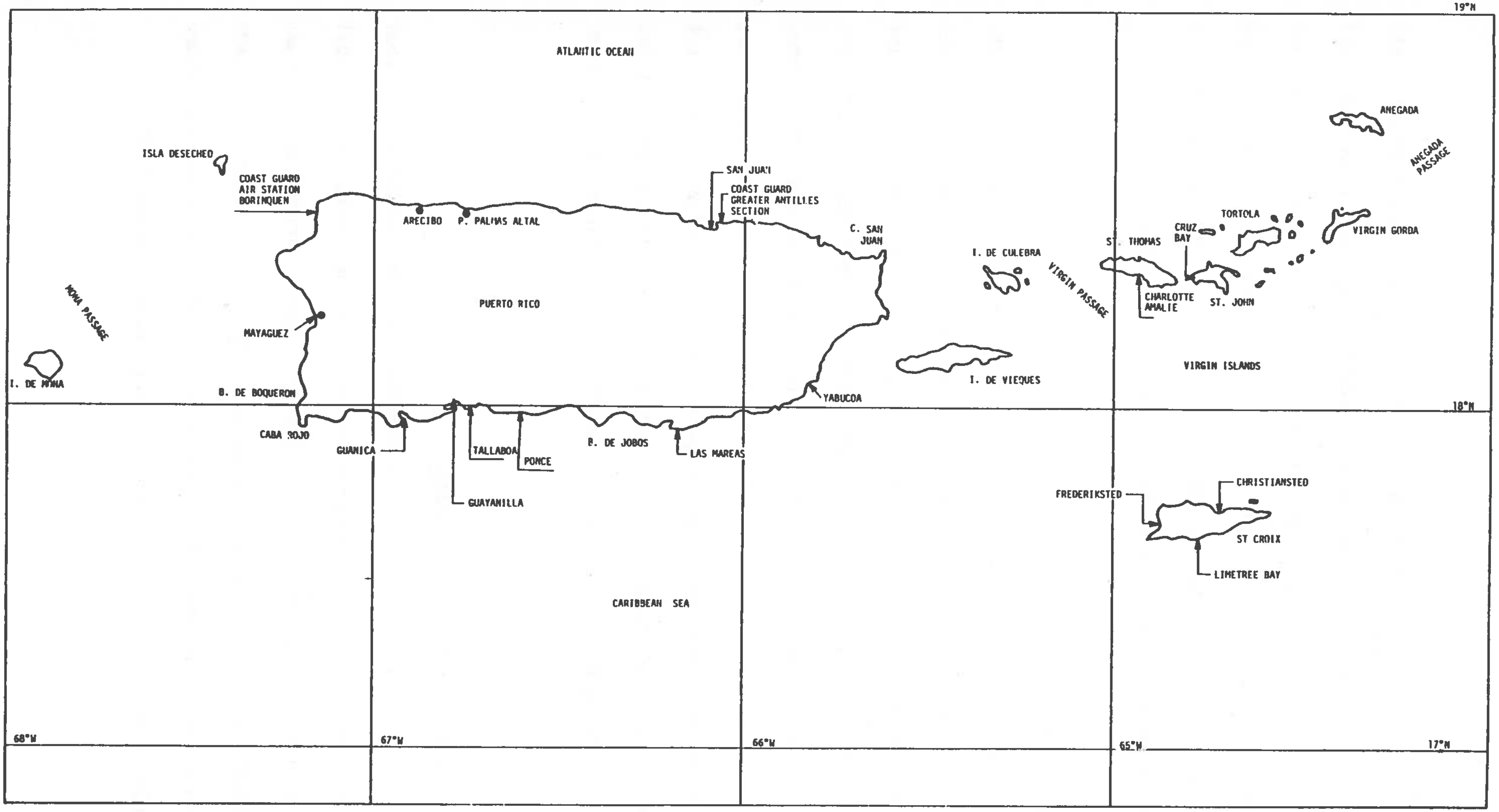


FIGURE 4-7 PRINCIPAL PORTS IN PUERTO RICO AND VIRGIN ISLANDS

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 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:

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

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

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

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 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

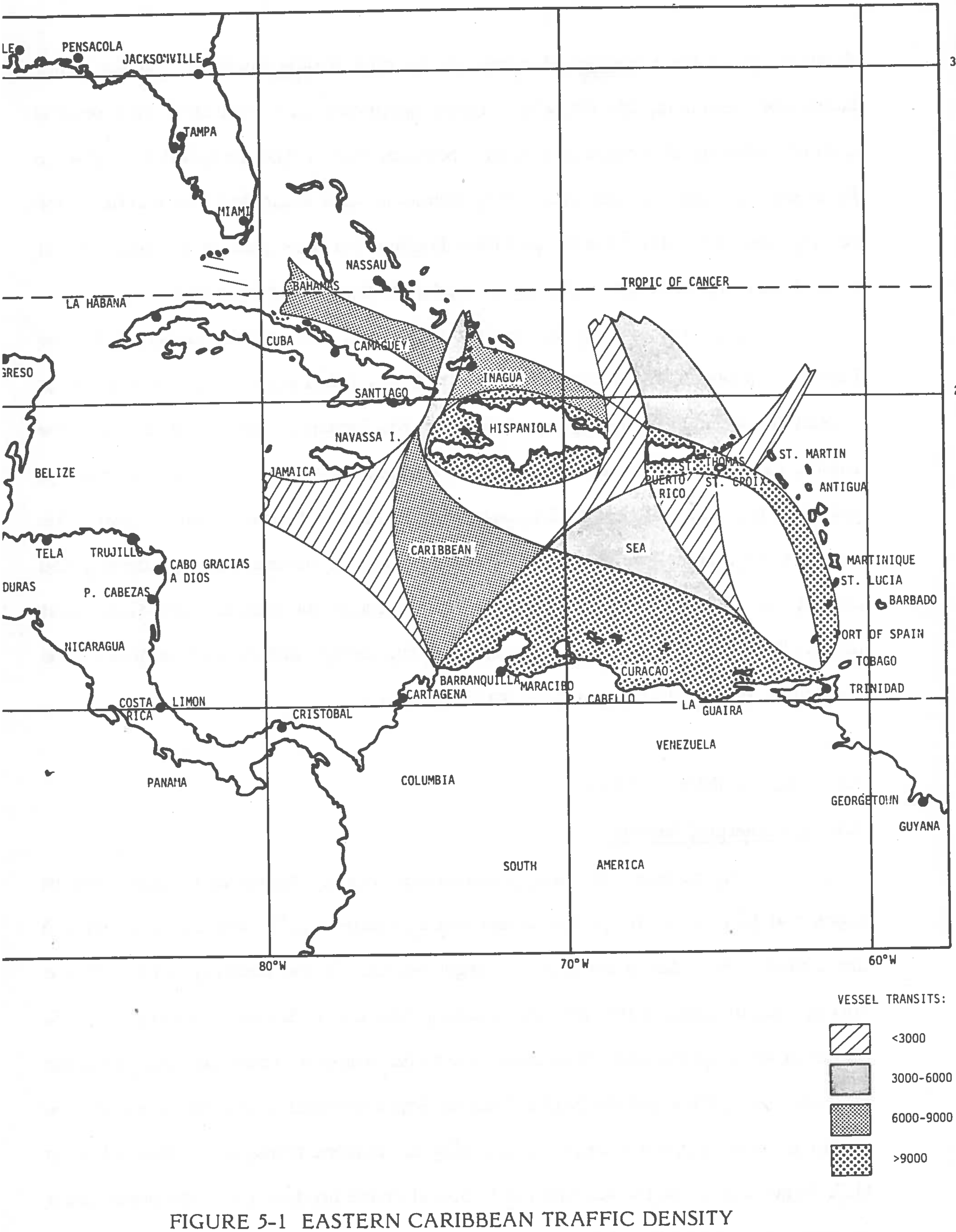


FIGURE 5-1 EASTERN CARIBBEAN TRAFFIC DENSITY

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

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

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.

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.

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

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.

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

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

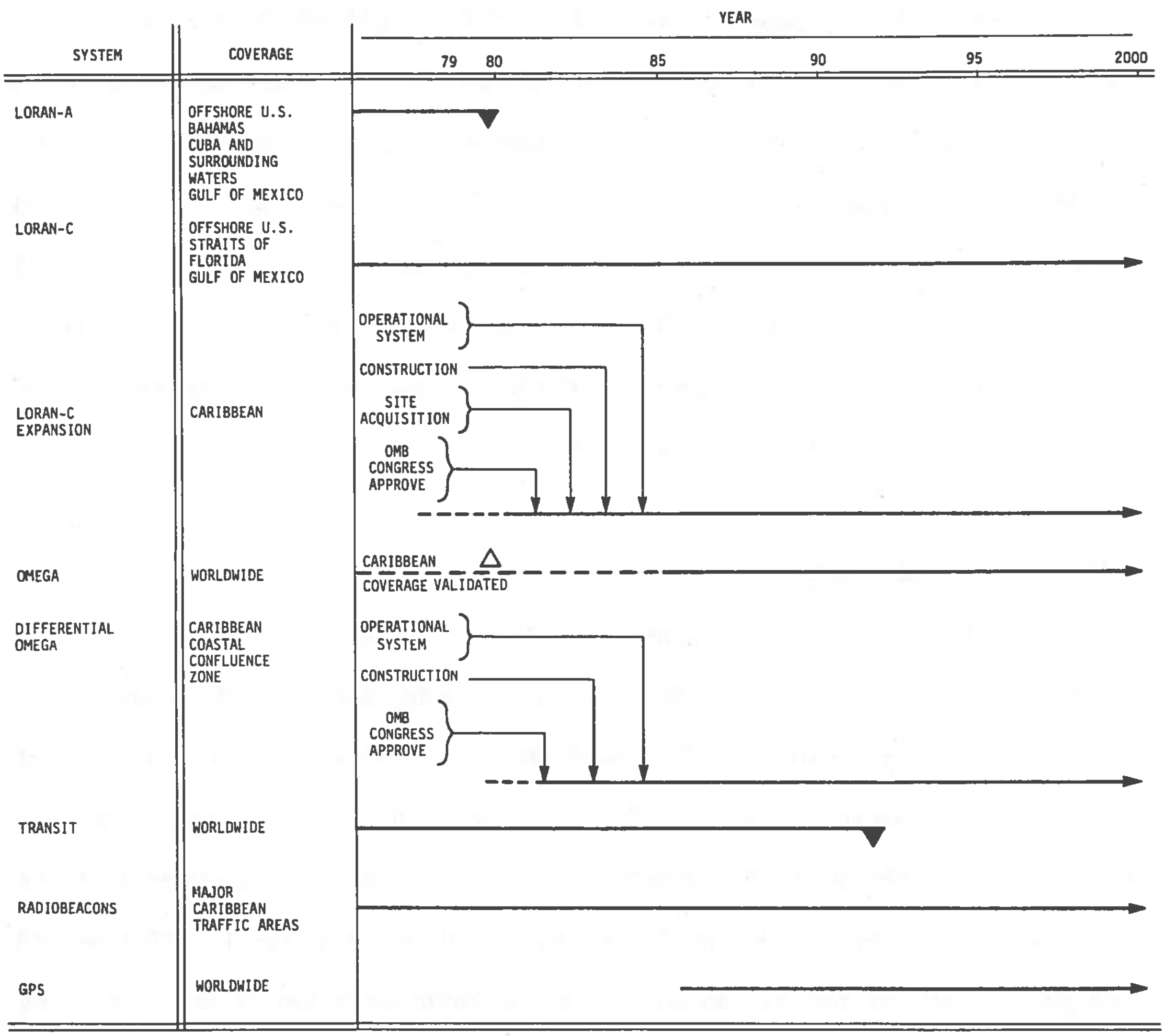


FIGURE 6-1 TIME PHASED ALTERNATIVE SYSTEMS AVAILABILITIES

6.3 LORAN-C MIDI CHAIN

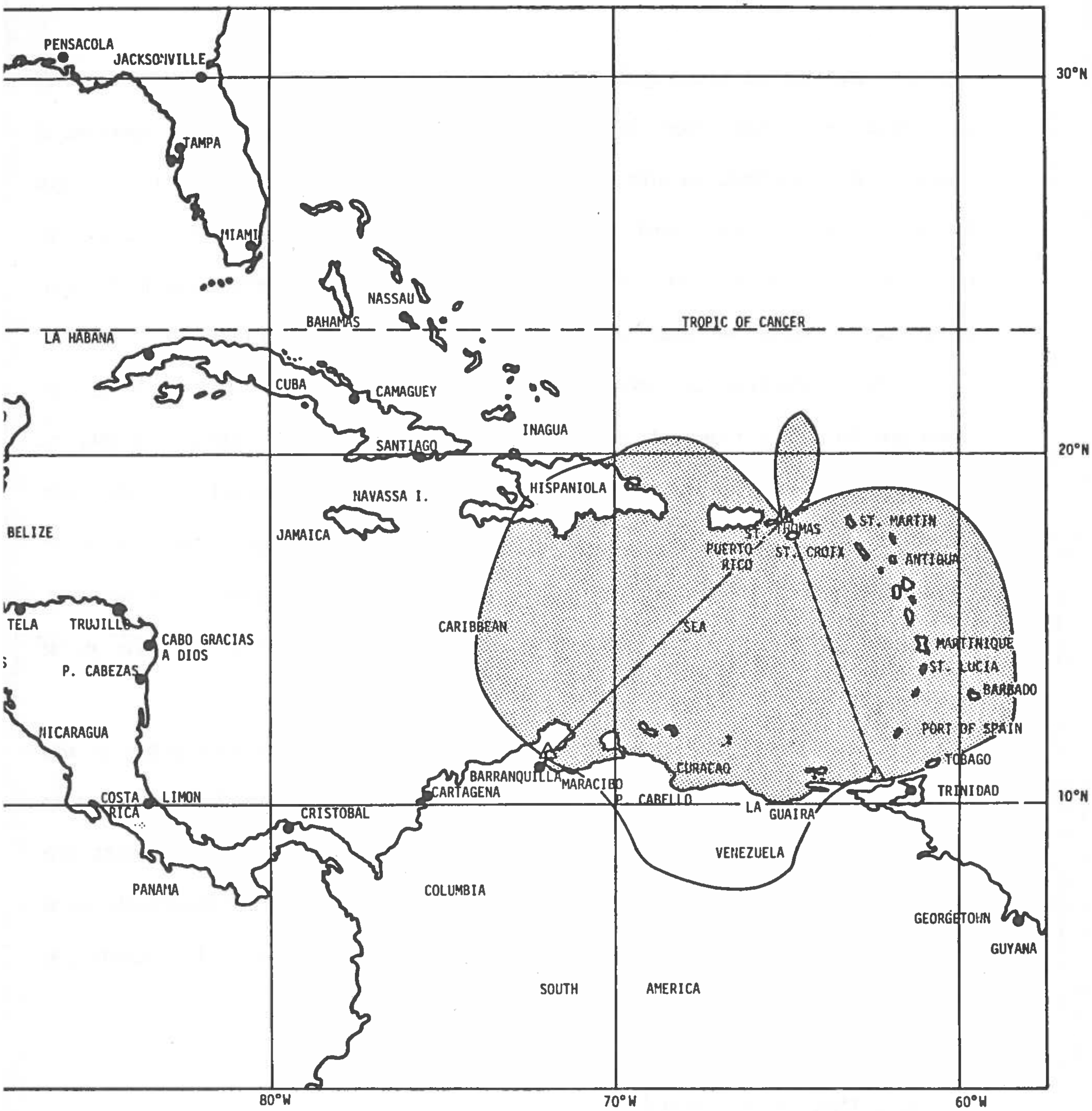
This station configuration provides coverage of most of the Caribbean Coastal Confluence Zone (approximately 34,000 square miles). It is based upon the installation of three low power (10-25 KW) transmitter stations on Mona Island, St. Croix and St. John. A monitor and control station would be located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

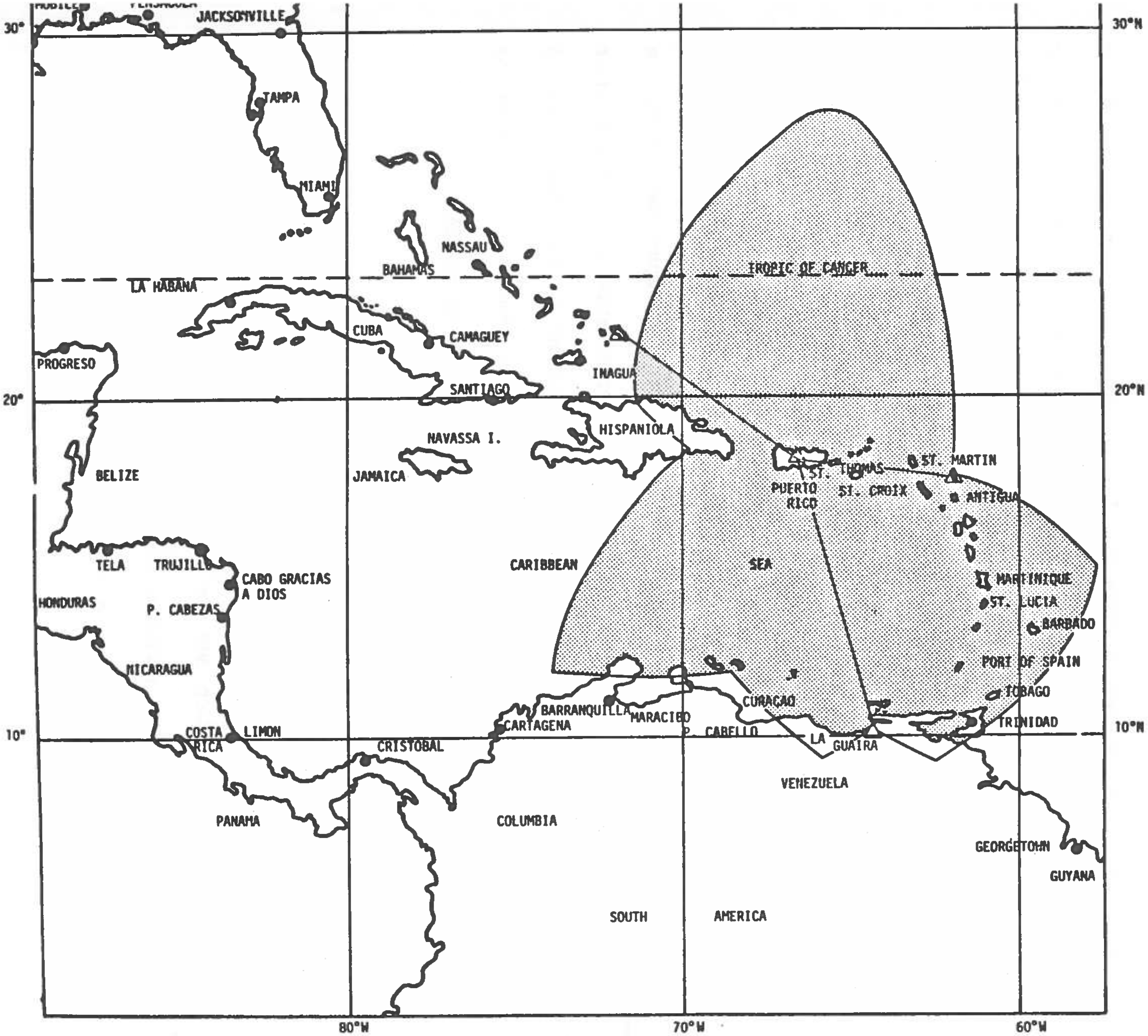
6.4 LORAN-C HIGH POWER CHAIN

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).



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

FIGURE 6-3 CARIBBEAN HIGH POWER LORAN-C CHAIN



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

2 drms with Sigma = 0.1 microseconds

1:3 Signal to Noise Ratio

95% Signal Availability

67.5 dB Noise Limit

FIGURE 6-4 CARIBBEAN LORAN-C MAXI CHAIN

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.

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.

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

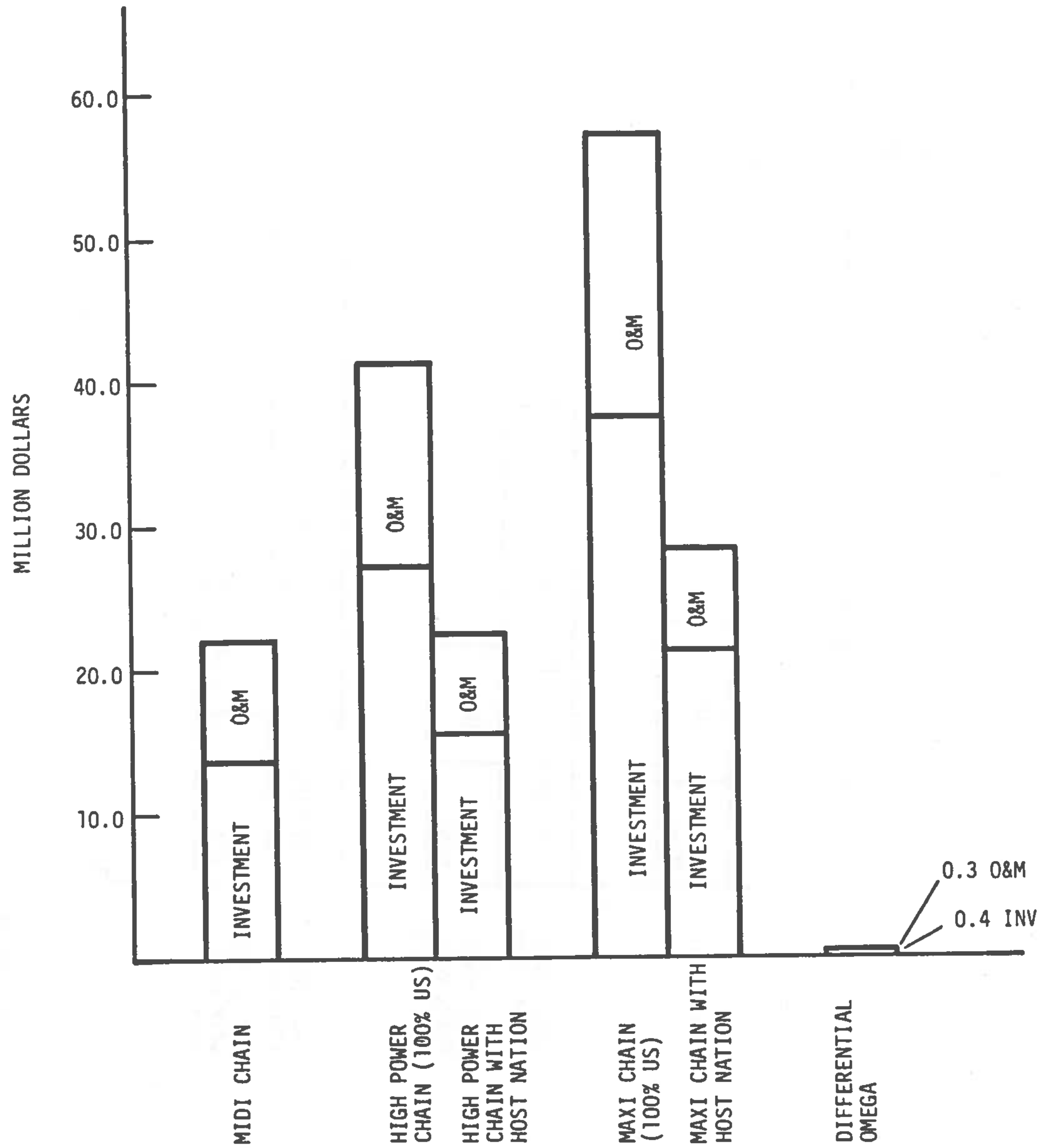


FIGURE 7-1 SYSTEM ALTERNATIVES COSTS DISCOUNTED DOLLARS (10%)

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.

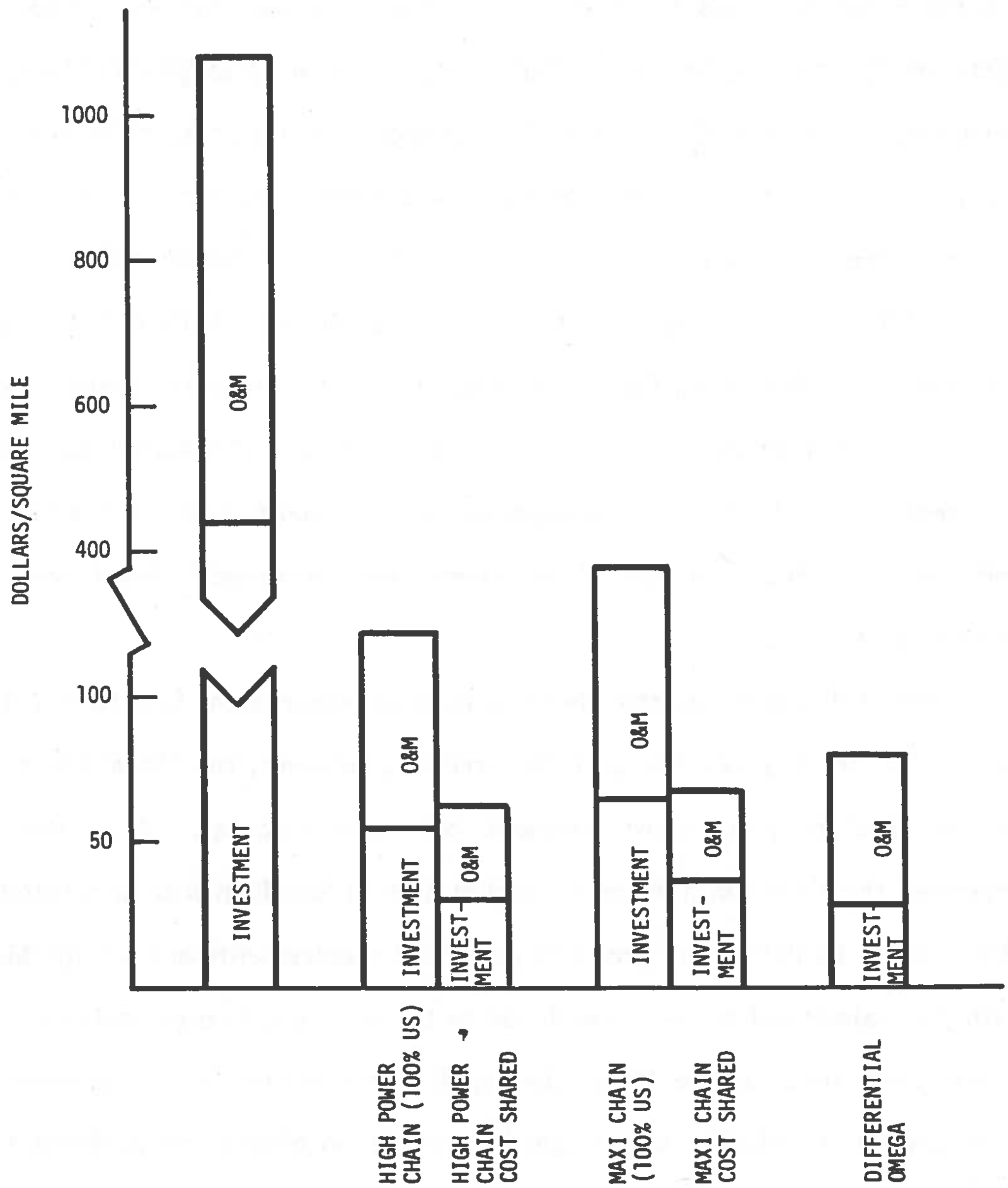


FIGURE 7-4 SYSTEM ALTERNATIVES COSTS PER SQUARE MILE CURRENT DOLLARS

	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

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 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.

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.

8.2.2 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

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

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

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

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

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

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.

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

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

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

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

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

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

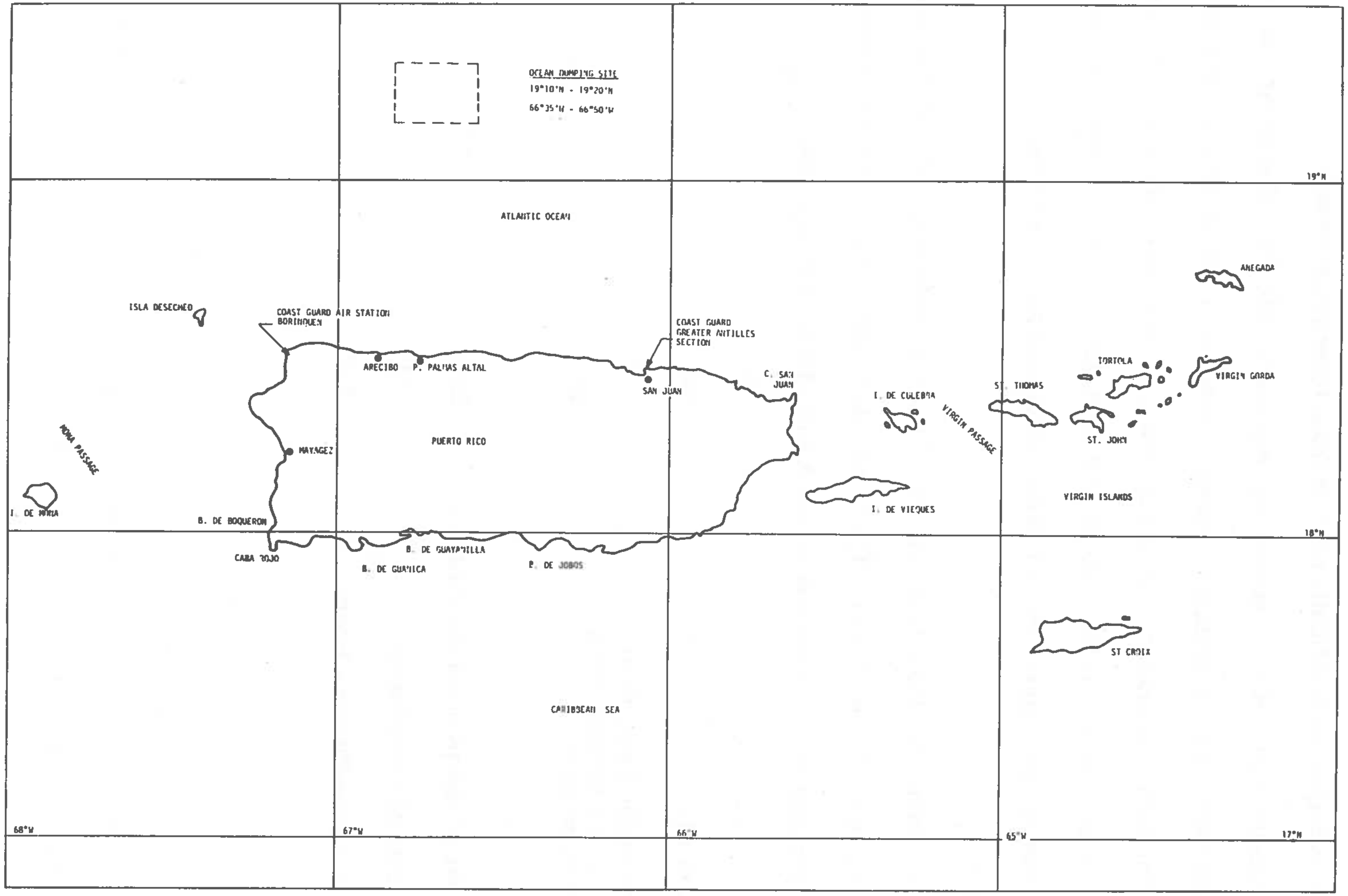


FIGURE 9-2 OCEAN DUMPING SITE - EASTERN CARIBBEAN

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.

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

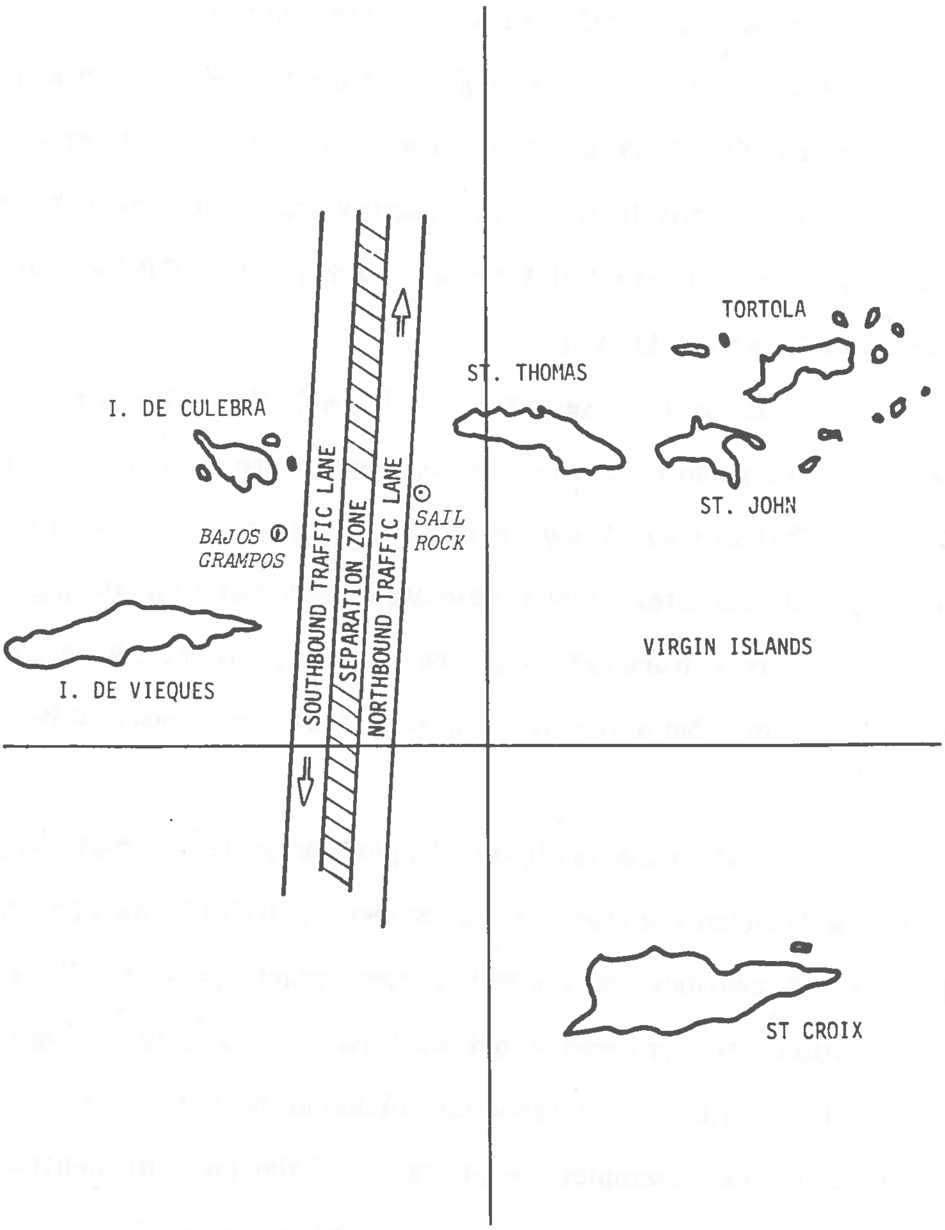


FIGURE 9-3 TRAFFIC SEPARATION CONCEPT - VIRGIN PASSAGE

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

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.

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

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

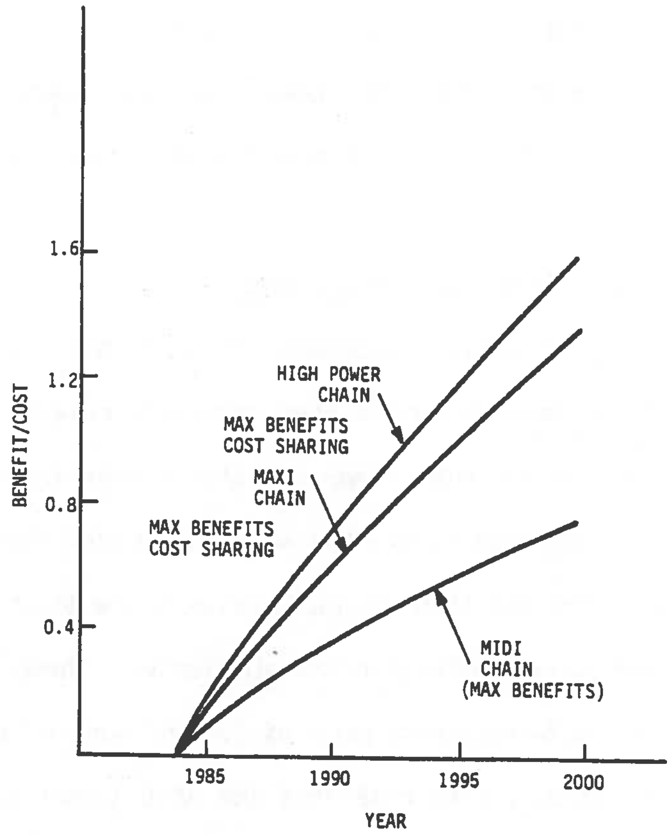


FIGURE 10-4 LORAN-C SYSTEM ALTERNATIVES BENEFIT/COST MOST FAVORABLE COMBINATIONS

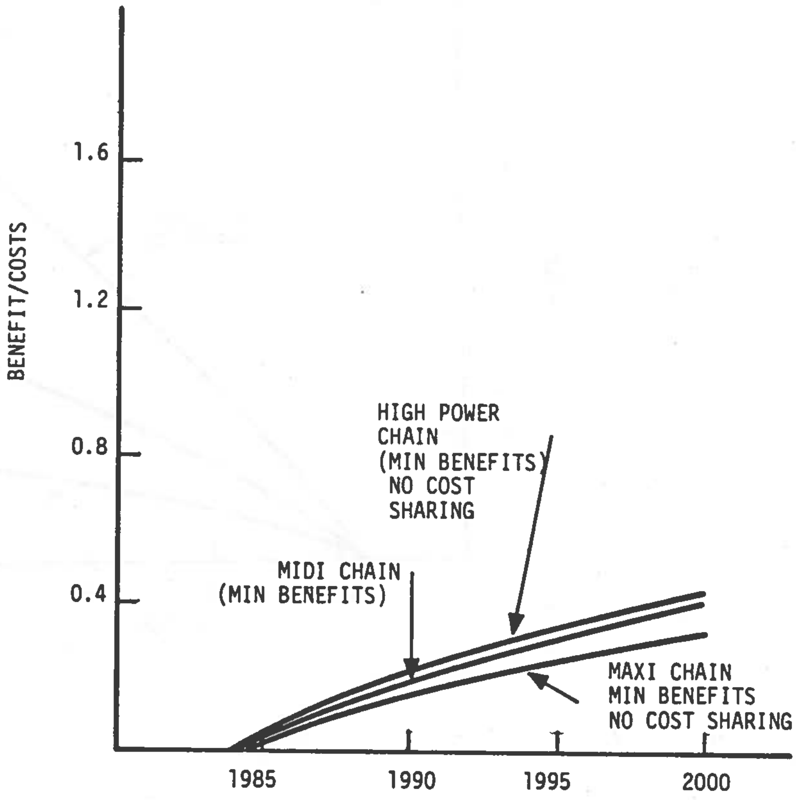


FIGURE 10-5 LORAN-C SYSTEM ALTERNATIVES BENEFIT/COST LEAST FAVORABLE COMBINATIONS

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.

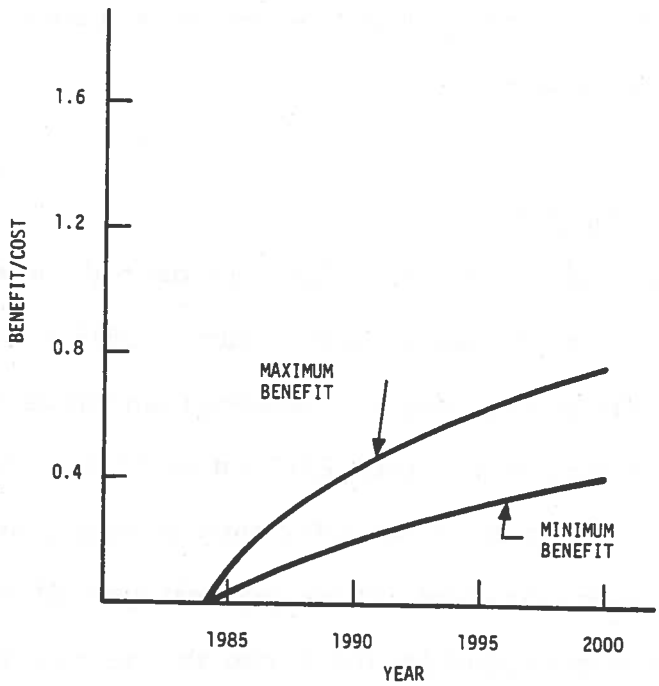


FIGURE 10-8 MIDI CHAIN BENEFIT/COST BEST-WORST COMBINATIONS

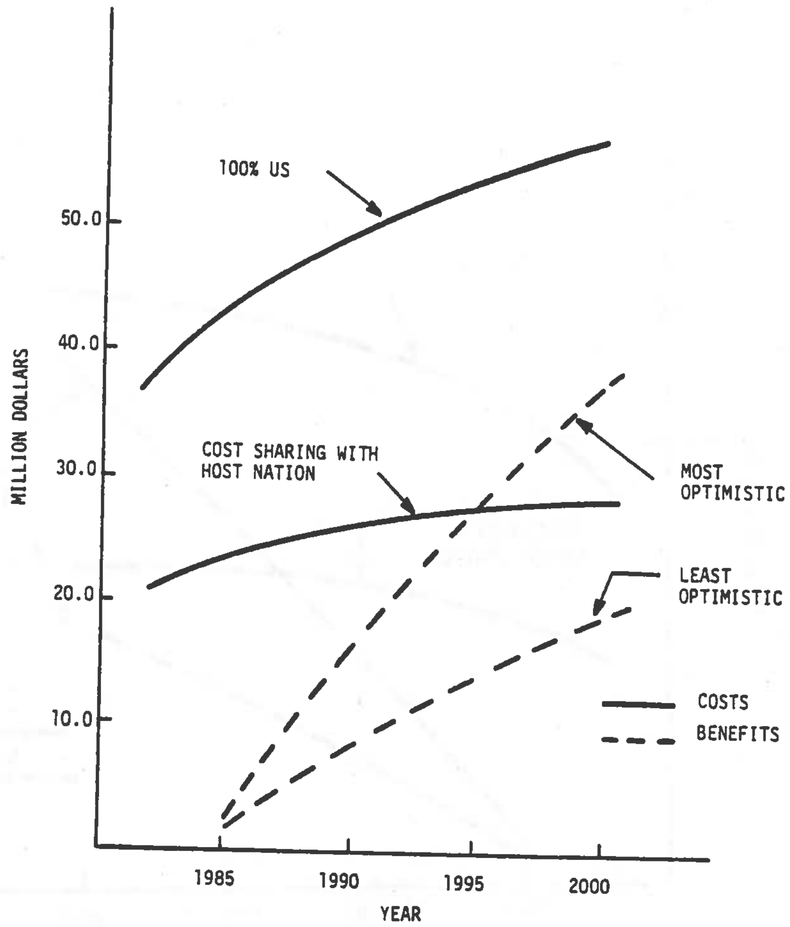


FIGURE 10-9 MAXI CHAIN CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

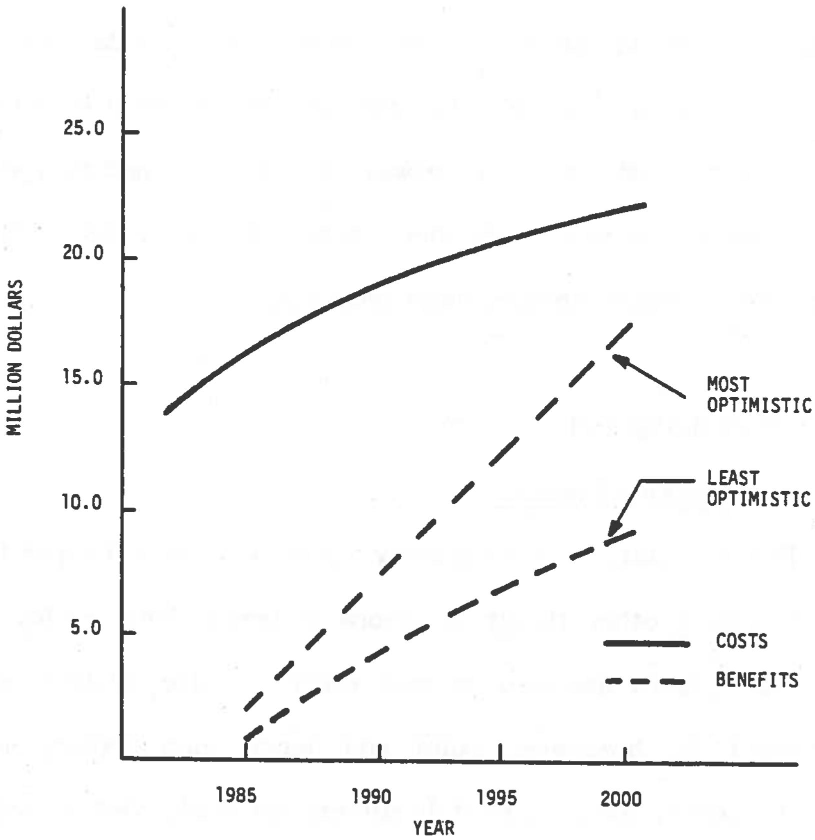


FIGURE 10-11 MIDI CHAIN CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

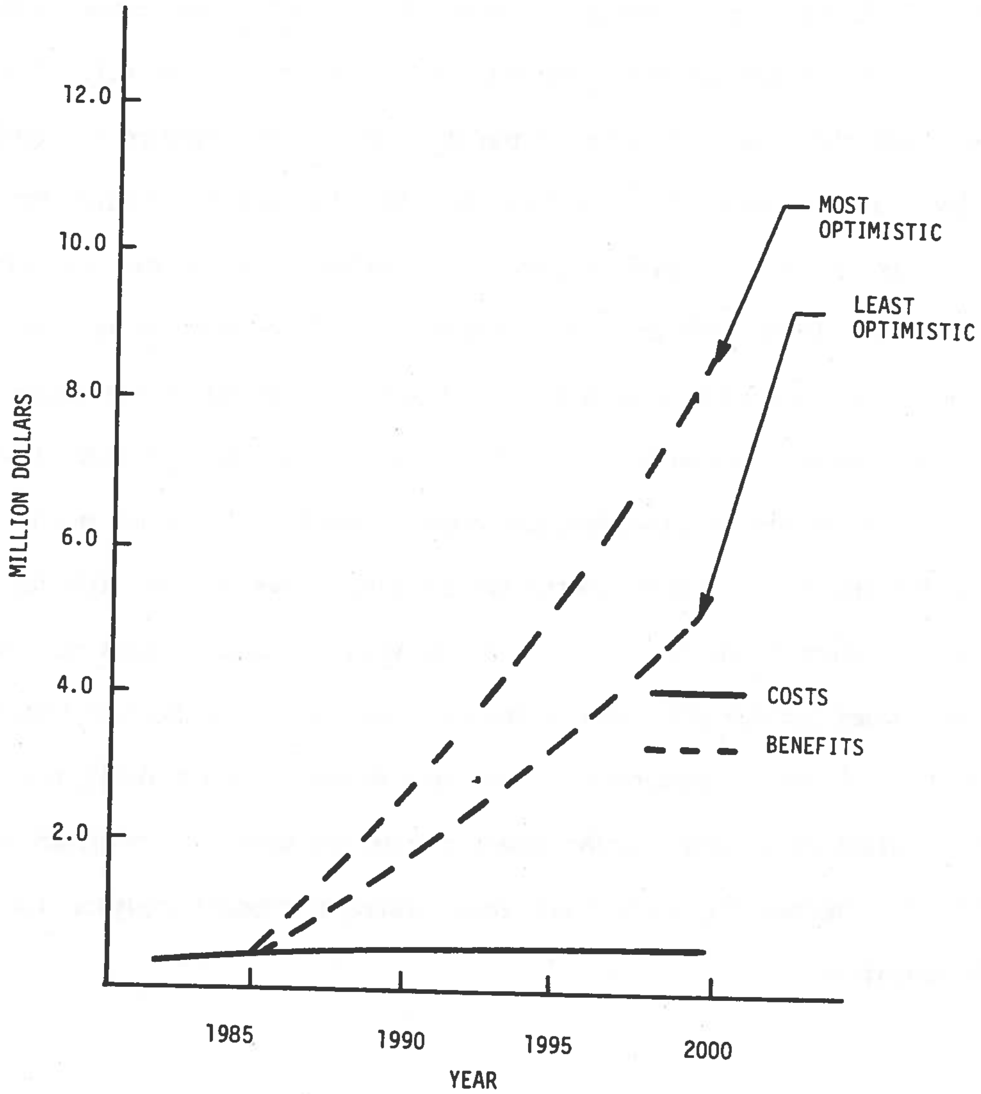


FIGURE 10-12 DIFFERENTIAL OMEGA CUMULATIVE COSTS/BENEFITS DISCOUNTED DOLLARS (10%)

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

- 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

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:

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

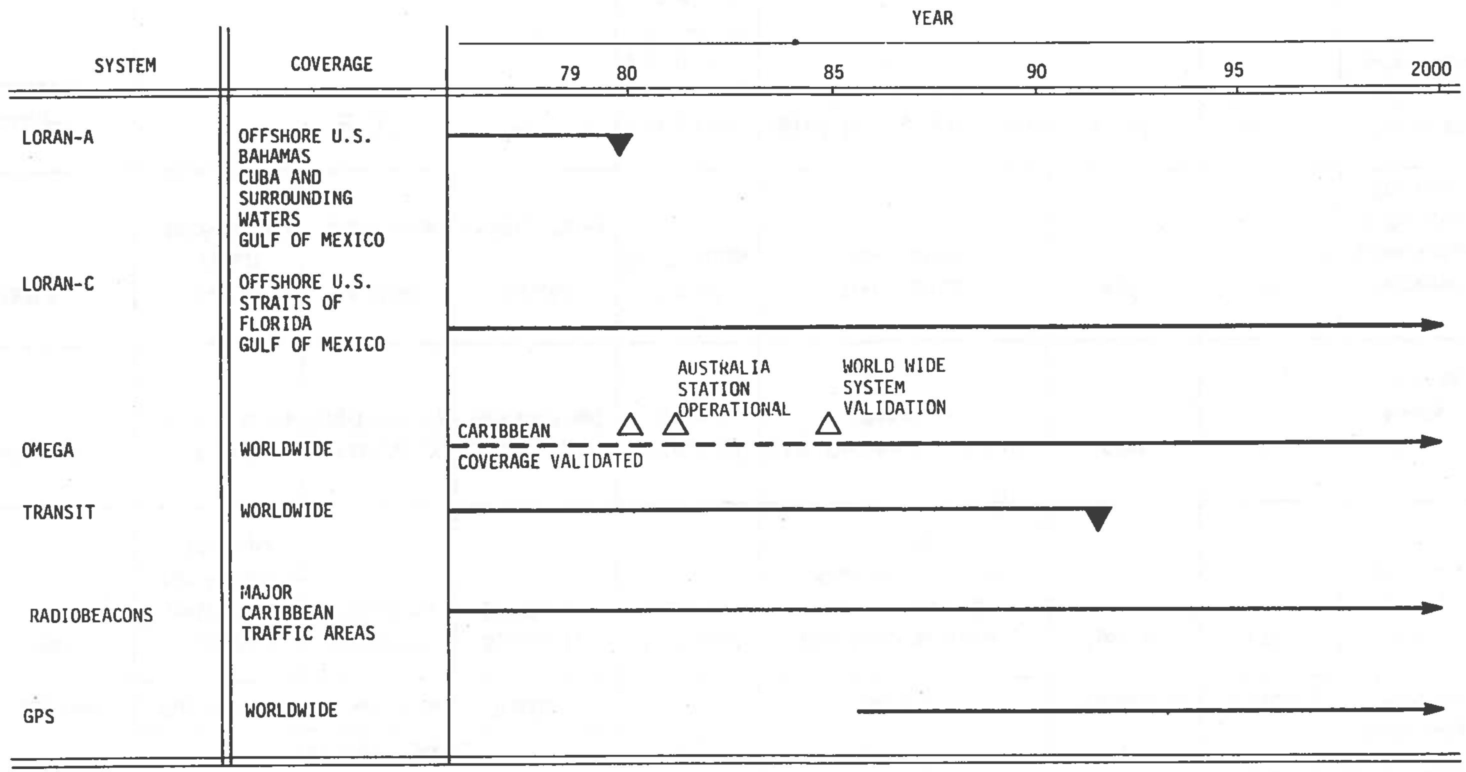

FIGURE A-1 TIME-PHASED RADIONAVIGATION SYSTEM AVAILABILITY - EASTERN CARIBBEAN

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^{o} 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

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).

define

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

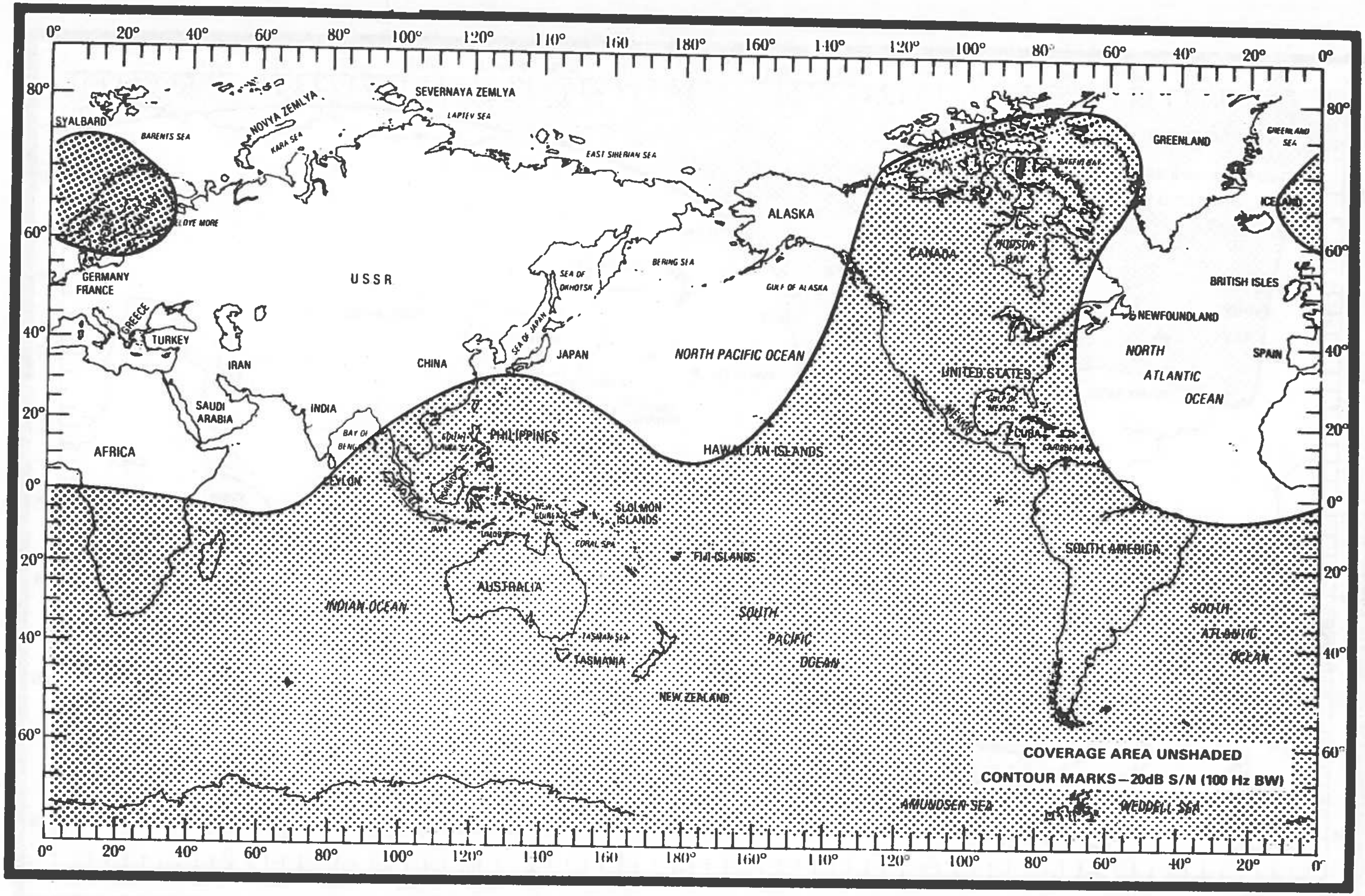

FIGURE A-3 OMEGA COVERAGE, NORWAY STATION (DAYTIME)

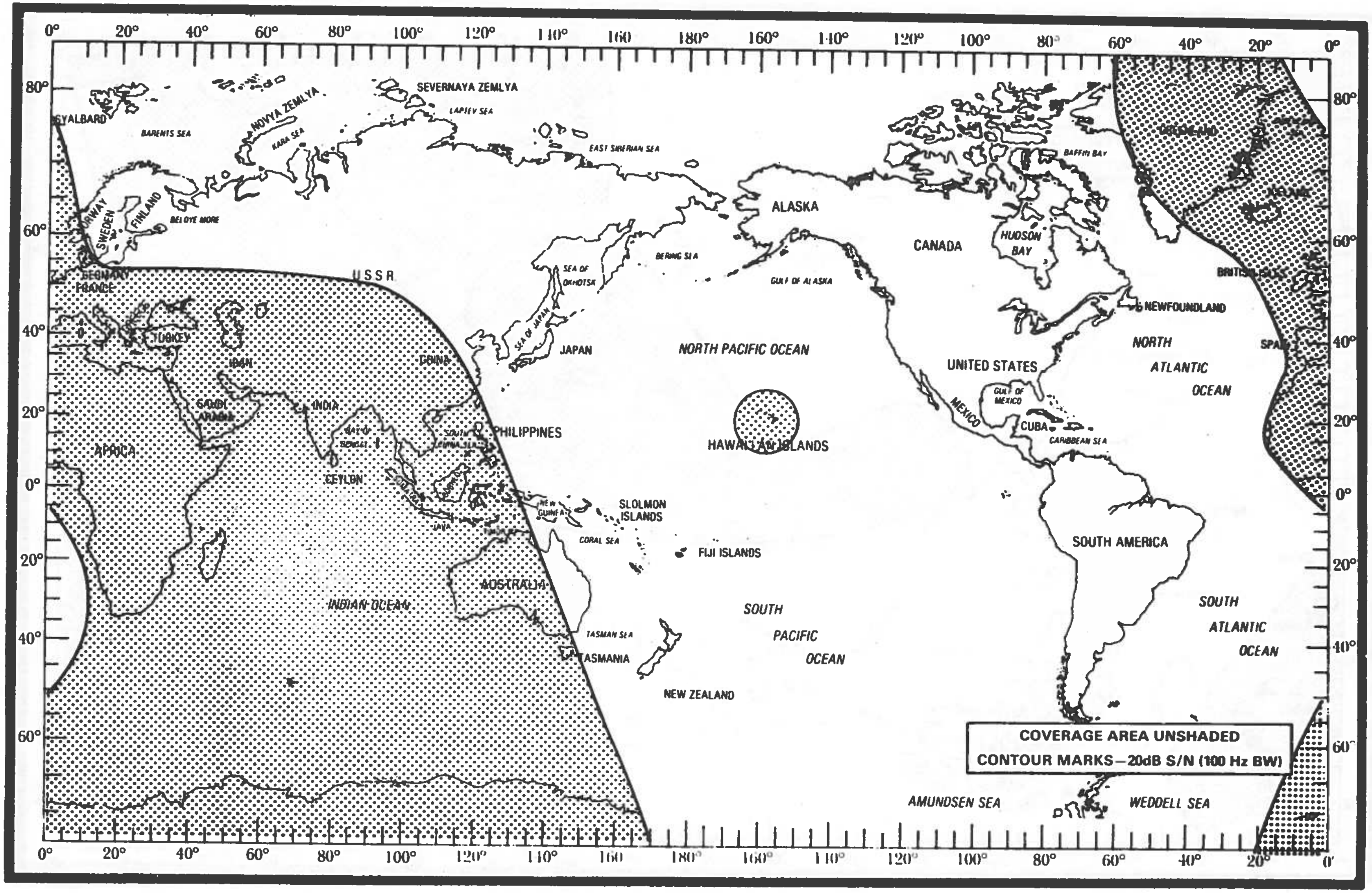

FIGURE A-5 OMEGA COVERAGE, HAWAII STATION (DAYTIME)

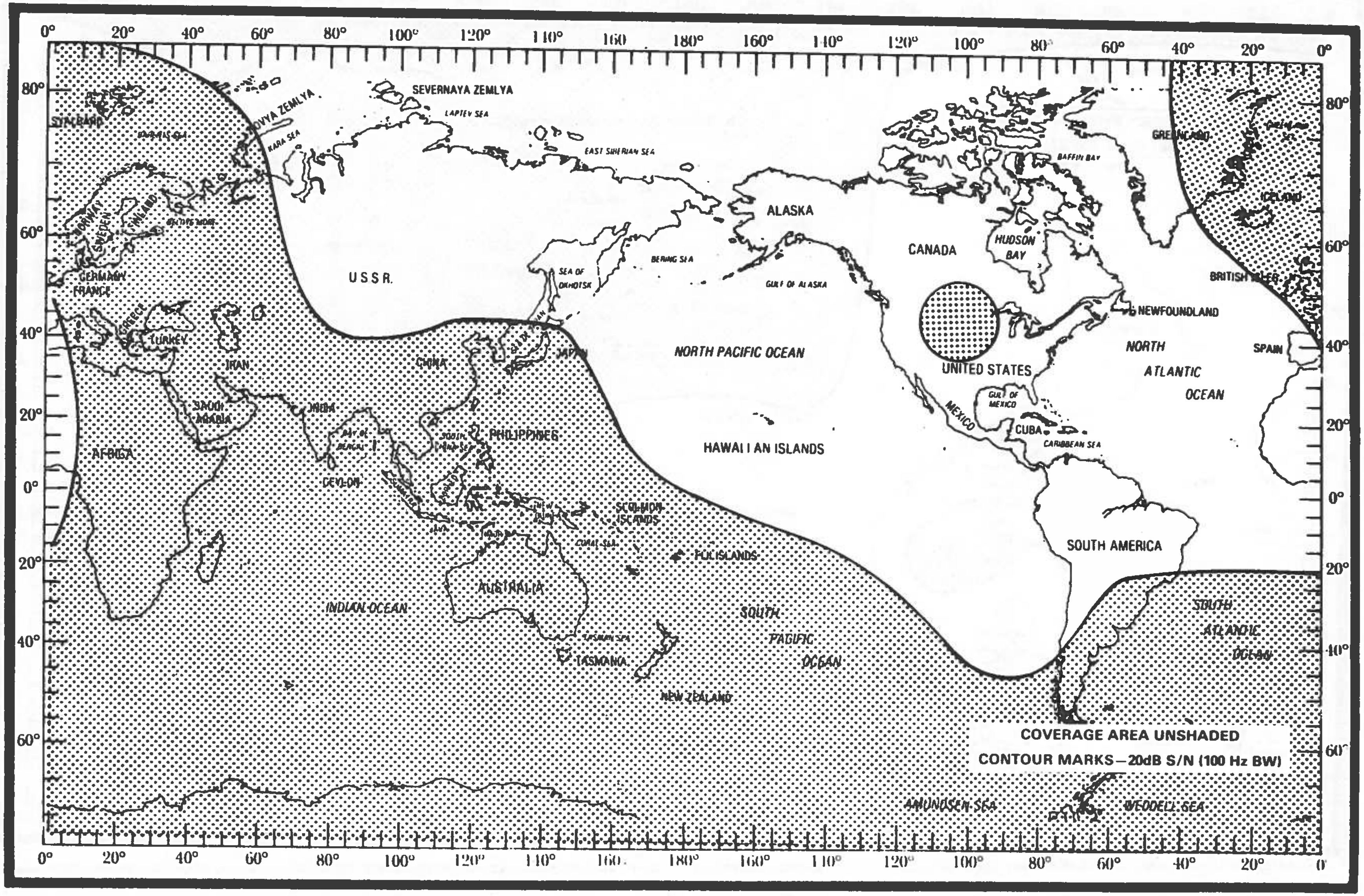

FIGURE A-7 OMEGA COVERAGE, NORTH DAKOTA STATION (DAYTIME)

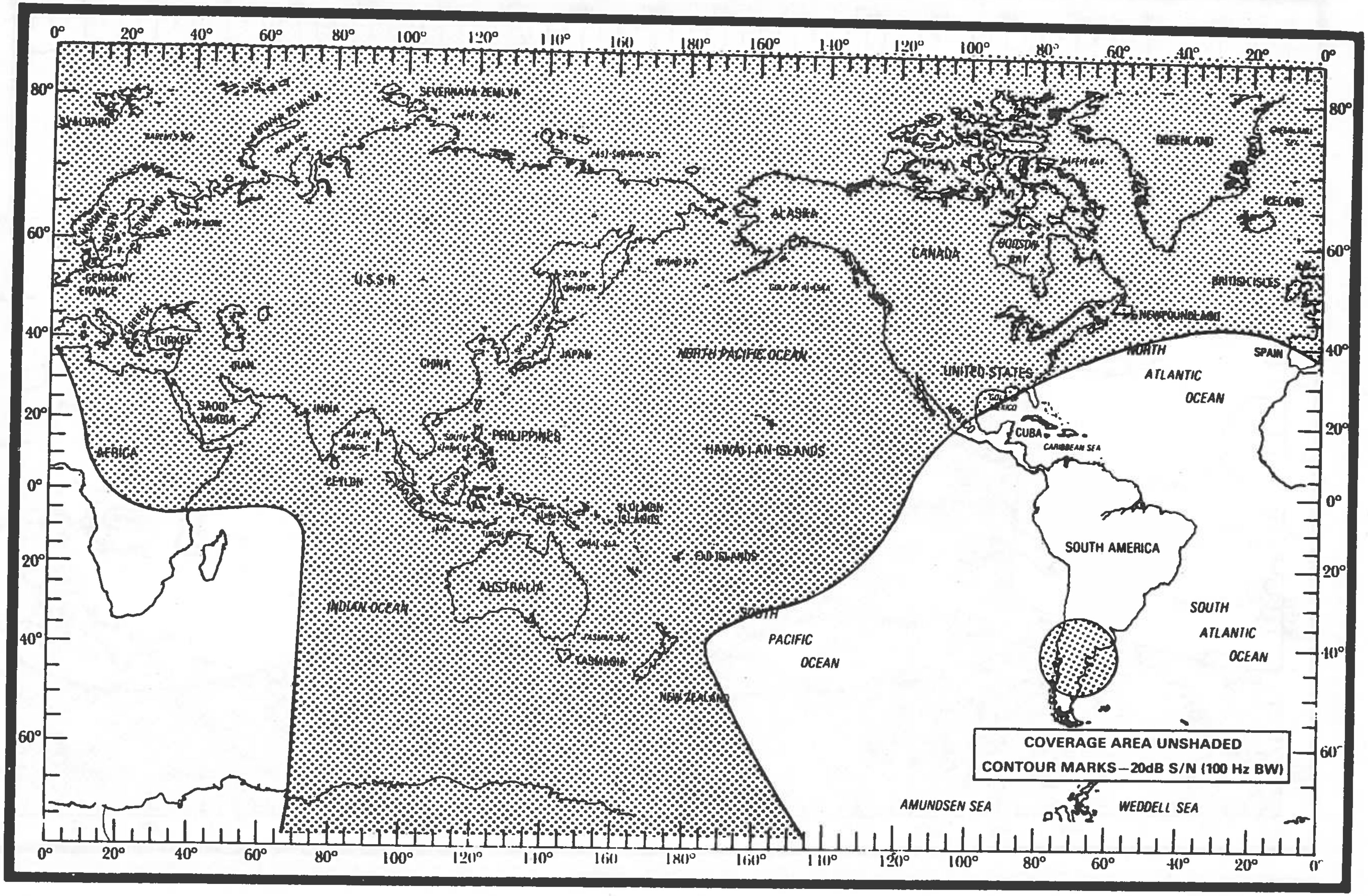

FIGURE A-9 OMEGA COVERAGE, ARGENTINA STATION (DAYTIME)

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 <u>Differential Omega</u>

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.

TABLE A-2 SELECTED SYSTEM CHARACTERISTICS: TRANSIT vs 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^o 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.

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.

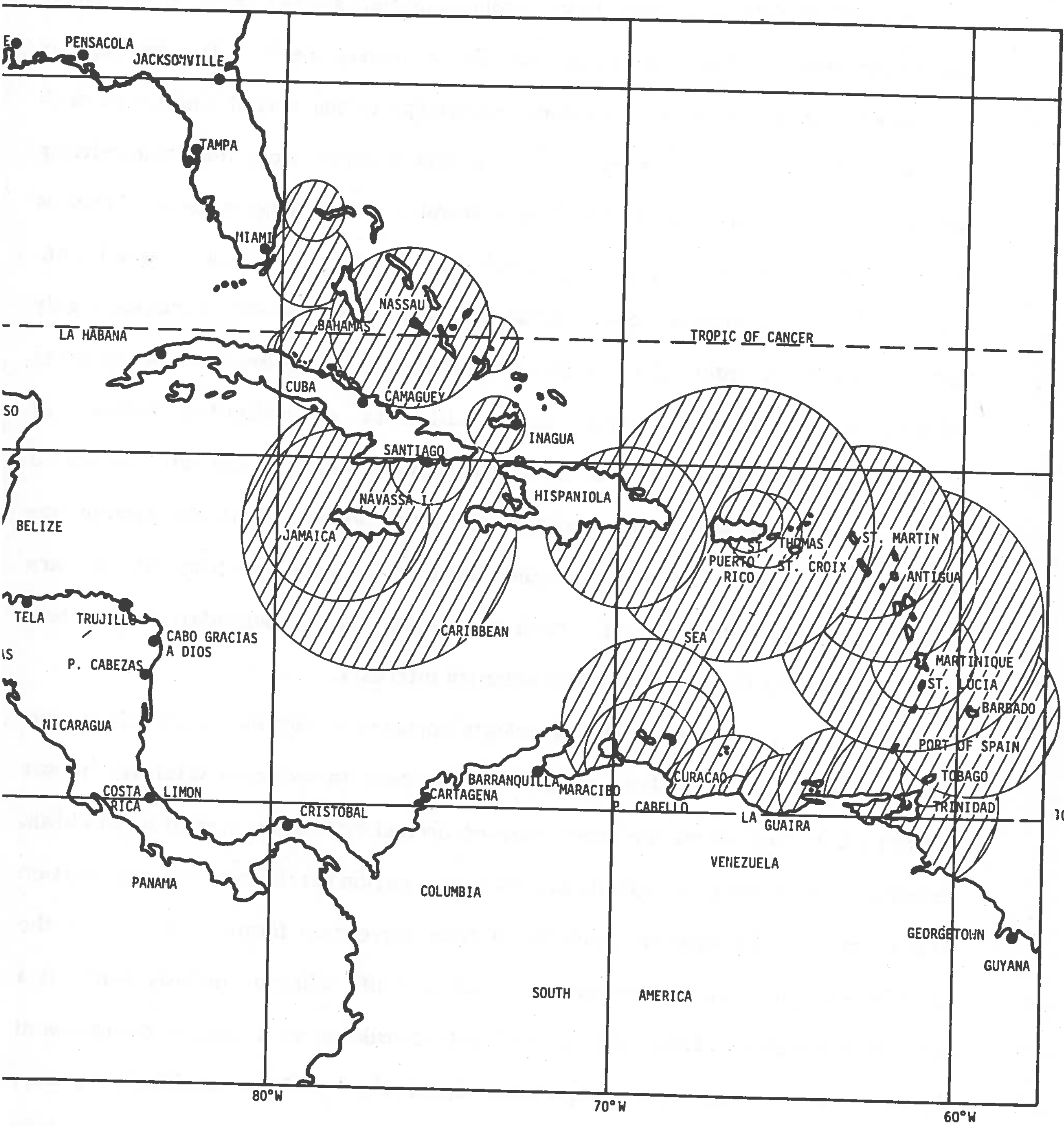

FIGURE A-11 EASTERN CARIBBEAN RADIOBEACON COVERAGE equipment measures four independent pseudoranges and range-rates and translates these to three-dimensional position, velocity and system time. Worldwide full operational capability is expected by 1987. The characterisics of NAVSTAR GPS are summarized 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

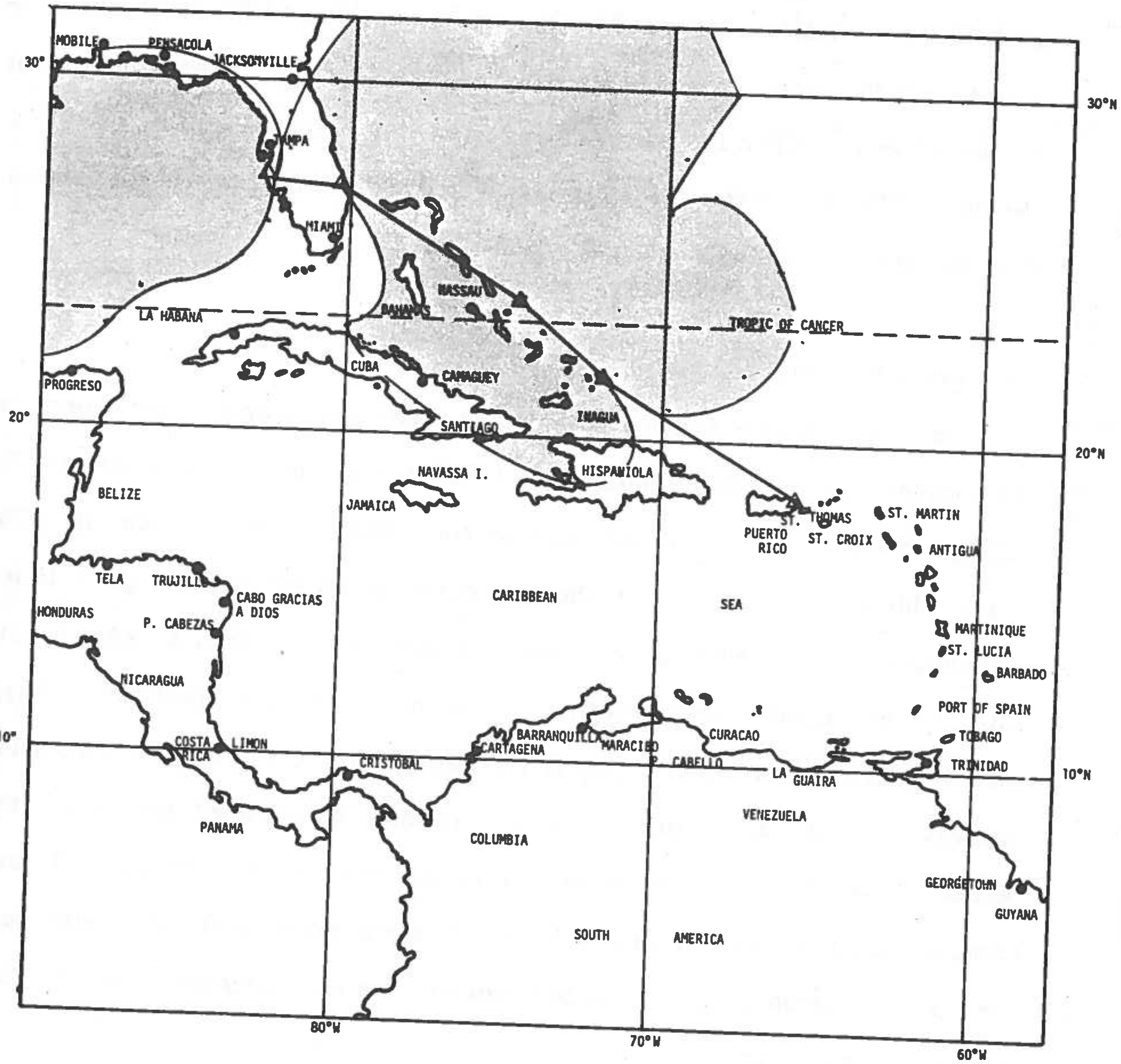

FIGURE A-12 CARIBBEAN LORAN-A COVERAGE

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

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)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Rate	Fix Dimension	Capacity	Ambiguity
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

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)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Rate	Fix Dimension	Capacity	Ambiguity
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 Commerical 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

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

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

- o Grounding and Strandings

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

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

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

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

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

- o Non tankers greater than 5,000 GT.

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 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.

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 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 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

- o Sailing Vessel "Dogstar" (US) grounded Buck Island Reef, St. Croix, Virgin Islands, October 4, 1978.
- o 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

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:

- o U.S. flag vessels transiting through the Eastern Caribbean, i.e., vessels which do not call at Caribbean ports
- o Foreign flag vessels transiting through the Eastern Caribbean
- o 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.

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.

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.)

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.

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.

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

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.

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

4.2 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.

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

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

U.S. VIRGIN ISLANDS PORTS	INTRA-CARIBBEAN		NORTH COAST OF SOUTH AMERICA		BAHAMAS		AFRICA		EUROPE		OTHER		TOTAL	
	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

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).

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-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

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,

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-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. (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

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-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-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

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

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:

- o Caribbean Fishery Management Council (Appendix F)
- o Southeast National Fishery Center (Appendix F)
- o 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

- 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

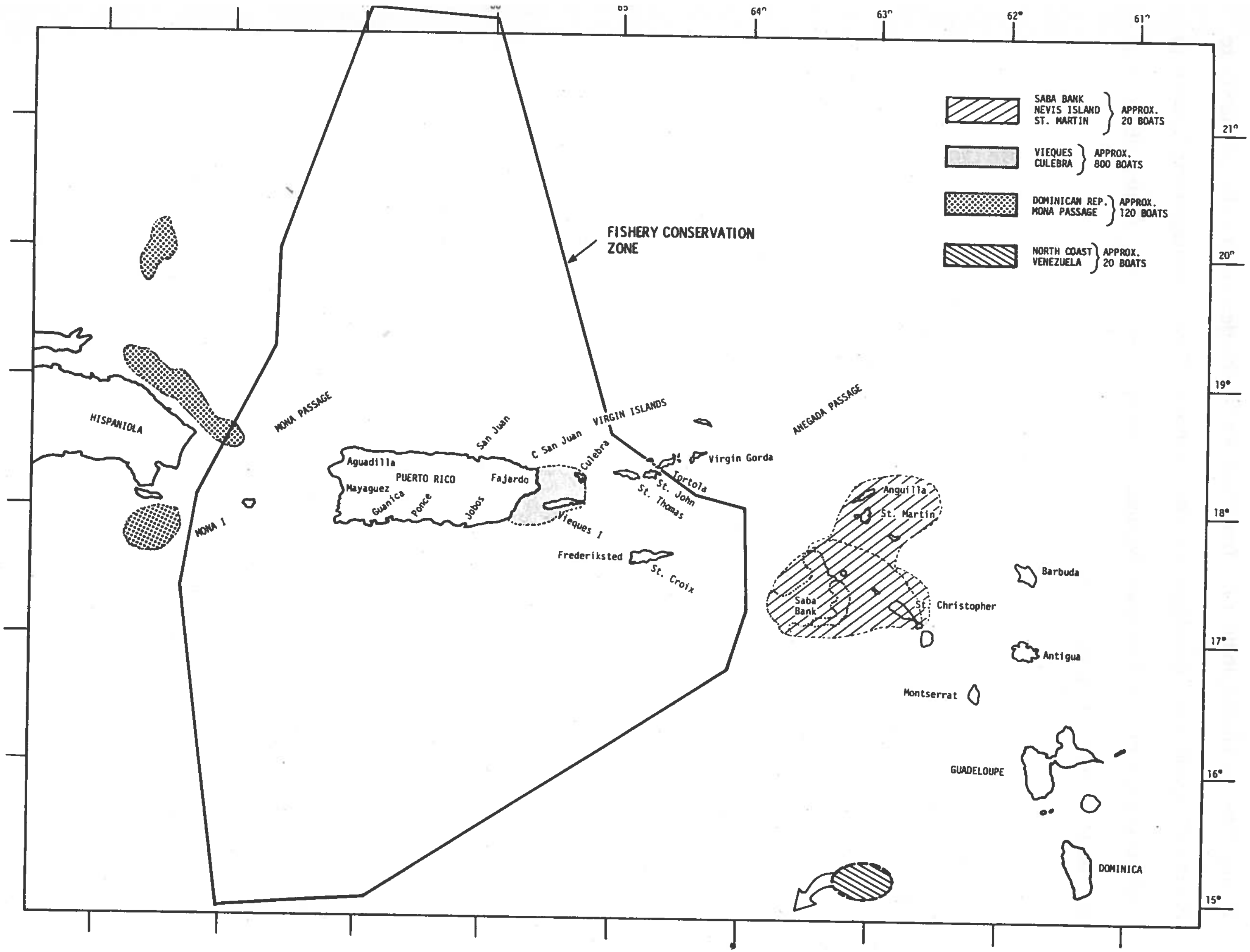

FIGURE D-1 FISHING LOCATIONS IN THE CARIBBEAN

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.

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

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.

- 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.

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.

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 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.

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)

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.

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:

- 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

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	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	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

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.

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):

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

where:

$PLCU_{\text{year } n}$ = 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.

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-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:

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

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 fact that all craft which sailed to Puerto Rico also cruised to the U.S. Virgin Islands.

- 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.

APPENDIX F LIST OF CONTACTS

1. U.S. GOVERNMENT

- o 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

- o 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

- o Coast Guard - Marine Safety Office, San Juan, PR
  - Executive Officer, LCDR James R. Townley

- o Coast Guard Air Station, Borinquen, PR
  - Executive Officer, CDR. William J. Wallace
  - Operations Officer, LCDR. Jerald H. Heinz

- o Coast Guard R&D Center, Groton, CT.
  - Lt. S.R. Osmer

- o Coast Guard Headquarters, Washington, D.C.
  - Office of Operations, Aviation Branch, LT. J.A. Brokenik
  - Office of Boating Safety, Mr. G. Steykes

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

. 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

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.

- 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

• 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