MEETING

THE

PRIORITY RADIONAVIGATION NEEDS

OF THE

UNITED STATES

Budget figures not those presently in use.

SEPTEMBER 1973

FINAL REPORT

Office of the Secretary
Department of Transportation
Washington, D.C. 20590

Preface

The preparation of this study was assigned to the Department of Transportation group responsible for the preparation of the National Plan for Navigation. This group consists of representatives of the Office of the Secretary, the Coast Guard, and the Federal Aviation Administration. The principal author of this report was Dr. Arthur Goldsmith, Chief, Technical Division, Office of Systems Engineering in the Office of the Secretary. Assisting were Mr. David T. Haislip and Cdr. William J. Glass, both in the Aids to Navigation Division of the U.S. Coast Guard. Special assistance was provided by Mr. James H. Mollenauer, Deputy Associate Administrator for Engineering and Development, Federal Aviation Administration and Mr. Richard L. Beam, Assistant Director for Telecommunications, Office of Systems Engineering in the Office of the Secretary.

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EXECUTIVE SUMMARY

This study was prepared in response to the Director, Office of Management and Budget letter to the Secretary of Transportation of April 17, 1973, to determine navigational requirements and, if possible, select a single, National Navigation System which is capable of meeting the requirements of military and civilian users. The terms of reference for the study were to:

a. Determine the civilian navigation requirements for which the Department of Transportation is responsible,

b. Investigate to what extent these requirements are not satisfied,

c. Determine the best system for satisfying the requirements, taking into account avoiding of duplication of systems,and

d. Present a program for implementation of the new system, including phase-out of any replaced systems.

The providing of such navigation systems is in accord with the statutory responsibilities of the Department of Transportation, particularly that of the Coast Guard under Title 14 and the Federal Aviation Administration under the Federal Aviation Act of 1958, as amended. Although the law does not limit the geographic extent of electronic navigation aids, the interpretation has been that domestic areas are given priority. Any aids in international waters or airspace were provided in response to DOD requirements or through the voluntary assumption of the responsibility through the International Civil Aviation Organization.

A navigation aid enables the user to determine his location with respect to some fixed point. The usual purposes are to avoid a navigation hazard, reach a desired destination, or to remain in some particular designated path so as to minimize the danger of collision. The degree of accuracy required generally depends upon the amount of room for maneuvering and the amount of traffic. For example, much lower accuracy is needed upon the high seas as compared to a harbor. The Department of Transportation National Plan for Navigation has therefore sub-divided requirements both as to user and area.

The aeronautical requirements have been divided into long distance, short distance, and terminal operations. Long distance flights are transoceanic and generally use inertial or doppler radar systems. The doppler radar system requires periodic updating with Loran-A. Some preliminary flight tests have shown promise that Loran-A may be replaced by Omega or Loran-C. Work is continuing in this area and progress to date appears satisfactory. The short distance air navigation aids and terminal air navigation aids are part of the Air Traffic Control System and under continuous study by the FAA and have not been considered in detail herein.

The maritime area has been divided into high seas, the coastal/confluence area (off-shore to about 50 miles), and the harbor/harbor entrance zone. The Omega navigation system originally established in response to a DOD requirement and now in the process of being expanded on a worldwide basis through cooperation with six other nations, will probably meet the high seas requirements when fully implemented. The harbor/harbor entrance requirements are in the process of being satisfied through the work of the Coast Guard in connection with the Vessel Traffic System implementation and R&D projects under the heading of Rivers and Harbors Navigation Systems. The major unsatisfied navigation requirement is in the coastal/confluence zone. The number of users, amount of traffic and required frequency of navigation fixes far exceeds that on the high seas. The danger of collision due to straying from established sea lanes and/or grounding is much greater than on the high seas. The requirement for much greater accuracy than is now available in a large portion of the area is rapidly becoming much more critical, particularly with the advent of deep draft vessels such as super-tankers or liquefied natural gas carriers and their possible increased adverse environmental effects in case of marine disaster.

In view of this the DOT has recommended that the U.S. coastal/confluence zone be given priority consideration for providing it with an adequate navigation system. Three candidate systems were considered: Loran-C, differential Omega and Decca. Taking into account accuracy, coverage, operating experience, availability of equipment, and cost it was recommended that Loran-C be the designated system. A portion of the required system is already in existence and will remain so for considerable time in response to a DOD requirement. The installation cost of the improved system is modest compared to the possible loss of a single large ship. Installation of this system will enable U.S. Government funding of the existing Loran-A system to be phased out in a reasonable length of time and the operating costs of the improved system to cover the entire United States coastal/confluence zone and the Great Lakes will not exceed the present system operating costs.

Section 1

INTRODUCTION

This study was prepared in response to a request by the Office of Management and Budget (OMB) to determine U.S. navigation requirements and, if possible, select a single national radionavigation system which is capable of meeting the requirements of military and civilian users.(Ref. 1) This request resulted in part from the submission of the Department of Transportation (DOT) budget for FY 1974. Included therein was an item for expansion and improvement of the U.S. operated portion of the Loran-C navigation system. The proposed action was the first step in a detailed program developed by the United States Coast Guard (Coast Guard) for phaseout of U.S. Government funding of the Loran-A navigation system as the necessary Loran-C coverage was installed and become operational.(Ref. 2)

The U.S. Government primarily through the Department of Defense (DOD) and DOT supplies numerous navigation aids for both aeronautical and maritime users. Although most of these systems may have originally been provided for unique purposes, they later were found, in some cases, to have overlapping properties and uses. However, the national navigation policy as set forth in the DOT National Plan for Navigation (NPN) is to promote as an essential goal national and international standardization of a minimum number of systems to meet the needs of various users.(Ref. 3) Each system has its partisans, particularly among those who have an equipment investment that would be lost if a particular system was discontinued. There has been growing awareness throughout the U.S. government of the problem of radionavigation systems and in particular the apparent duplication among systems. The Director of the Office of Telecommunications Policy (OTP) expressed his concern in this regard and requested consideration of the possibility of decreasing the number of apparently duplicative systems.(Ref. 4)

OTP also indicated that it appeared in their view to be feasible and desirable to select a single general-purpose navigation system from among Loran-A, Loran-C, Omega, and Transit. The one chosen would be designated as the approved U.S. system. Originally all of these "candidate" systems were established by DOD to meet a military requirement. The Coast Guard now operates the U.S. portion of the Loran and Omega systems. As a navigational system itself is basically passive, a certain amount and varying degrees of civilian use began to be made of these systems as user equipment (some from the surplus market) became available. This was especially true of Loran-A.

In addition one Loran-A chain in the Gulf of Mexico was later established primarily in response to the needs of commercial maritime users.

DOT in responding to the OTP proposal stated that for any navigation system to be designated as the single general purpose U.S. system it would have to be suitable for aeronautical, maritime, and possibly land vehicle users; and provide the needed coverage and accuracy in all localities where it might be required. DOT further stated that the Department believed that Omega augmented by differential Omega (the system suggested by OTP as their choice for the selected U.S. system) had not been proven to meet all requirements nor was there any indication that it could meet them in the foreseeable future.(Ref. 5) DOD concurred that any attempt at the present time to designate a single system was premature.(Ref. 6) This position has been reiterated in the DOD response to the OMB letter initiating this study.(Ref. 15)

There is no question that the ideal solution would be to find a single system that would fulfill the requirements, including particularly accuracy, in all required coverage areas for all users at the lowest possible cost. Unfortunately, such a system does not exist nor is there any likelihood of one being developed and implemented in the near future. The crux of the matter is not to designate a single system to meet all requirements, but to satisfy to the greatest extent possible the greatest range of user requirements. Duplication of system coverage is impossible to avoid without interruption of service because of the necessary transition period inherent in any such undertaking. Therefore the goal is to meet the requirements of a major portion of the user community by providing an optimum mix of navigation systems with maximum capability and minimum duplication. The purpose of this study is to provide an overview of the U.S. navigation capabilities and requirements, to identify any major unfulfilled requirements, and where these are found to exist to select a program best suited to meet the most urgent or highest priority requirement.

In order to accomplish the foregoing objective, the following study outline has been utilized:

1. To lay the ground-work, the statutory and other responsibilities of the U.S. government for navigation systems was investigated.

2. The current navigational requirements for the civil maritime and aeronautical users were identified. Military requirements were also taken into account to assure they were fulfilled and to minimize possible system duplication.

3. The major requirements not adequately satisfied at present were identified and the priority for fulfilling them

determined.

4. Systems with the potential to meet the highest priority requirement were evaluated in all respects and the most cost-effective system with the best proven capability of meeting the priority requirement was chosen.

5. A system implementation plan based on this selection was developed.

Section 2

RESPONSIBILITIES FOR NAVIGATIONAL SYSTEMS

It has long been public policy to provide navigational aids to reduce maritime strandings and collisions. With the development of air commerce, this policy has been extended to cover the airways. However, in practically all cases this coverage has been local or contiguous to the country operating the aid. In most cases these aids are government operated for all to use. However, there have been a number of specialized systems, mostly for military use. Also, there are some privately-owned systems where the owner of the system also provides the receiving equipment to the users through sale or lease.

The procedures through which civil navigational aids are provided vary from jurisdiction to jurisdiction. In the U.S. there is a basic statute assigning responsibility for aids to navigation to the United States Coast Guard. 14 USC 81 states:

"In order to aid navigation and to prevent disasters, collisions and wrecks of vessels and aircraft, the

Coast Guard may establish, maintain, and operate:

(1) aids to maritime navigation required to serve the needs of the armed forces or of the commerce of the United States;

(2) aids to air navigation required to serve the needs of the armed forces of the United States peculiar to warfare primarily of military concern as determined by the Secretary of Defense or the Secretary of any department within the Department of Defense and as requested by any of those officials; and

(3) electronic aids to navigation systems (a) required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or any department within the Department of Defense; or (b) required to serve the needs of the maritime commerce of the United States; or (c) required to serve the needs of the air commerce of the United States as requested by the Administrator of the Federal Aviation Agency.

These aids to navigation other than electronic aids to navigation systems shall be established and operated only within the United States, the waters above the Continental Shelf, the territories and possessions of the United States, the Trust Territory of the Pacific Islands, and beyond the territorial jurisdiction of the United States at places where naval or military bases of the United States are or may be located."(Ref. 7)

In addition under 49 USC 1348(b), the Federal Aviation Administration (FAA), a unit of DOT, has been assigned responsibility for certain navigational aids primarily in the area of Air Traffic Control.(Ref. 8) With the establishment of DOT, on April 1, 1967, a natural focal point for civil navigation planning and coordination came into being. In Sections 2(b)(1) and 4(a), P.L. 89-670, this function received statutory recognition in the legislation creating the new Department. (Ref. 9) The coordination, supervision and monitoring function is vested in the Secretary of Transportation and delegated by him to certain members of his staff.

As noted in the statute quoted above, navigational aids other than electronic are limited to the U.S. owned or controlled territories and adjacent areas. There is no similar statutory limit on electronic aids. However, in practice a similar limitation has been in existence for civil radionavigation aids. The U.S. has no formal treaty obligations to provide commercial navigation aids internationally. The implication of Congressional decisions as well as precedence indicates that our basic obligation is in areas adjacent to the U.S. By subscribing to certain conventions such as those of the International

Maritime Consultative Organization (IMCO) and the International Civil Aviation Organization (ICAO) and accepting their assignment of responsibility for specific non-contiguous geographic areas, the U.S. has assumed an obligation to provide certain navigation aids for civil use.

The majority of electronic navigational aids are for use in the U.S. or contiguous areas. However, there are two systems (one operational, Transit, and one being established, Omega) which are intended to provide essentially worldwide coverage and two long-range systems giving coverage out to 1200-1500 NM (Loran-A and Loran-C). All of these were originally established to fulfill military rather than civil requirements. After a period of time information on these systems became available to potential civilian users; system charts and other data were made available, and commercial or surplus military receivers appeared on the market. The result has been an increasing use of these systems by the civilian community in areas where coverage was available. Transit, at present, is wholly U.S. owned and operated. The other three systems now have some stations owned and/or operated by other countries.

Loran-A at the present time is the primary station reference for long-distance transoceanic aircraft traffic. The system is recognized as an authorized aid for this purpose by the FAA and

ICAO. There are also many thousands of civil maritime users, particularly fishermen. Both Loran-A and Loran-C primarily exist only in the Northern Hemisphere. Coverage is marginal in some areas and non-existent in others. In the North Atlantic and North Pacific Loran-C has potentially useful coverage for aircraft navigation.(Ref. 3)

Omega, when it becomes fully operational, has the potential for meeting certain requirements for both civil air and marine navigation on transoceanic and other routes. Further evaluation will be required before extensive civil air applications can be defined. Civil maritime applications are expected to increase as coverage is expanded.(Ref. 3)

Transit is limited in its usage, and the cost of user equipment is high. While the system is suitable for maritime use on the high seas, the times between passage (approximately 90 minutes) of the satellites precludes its use where frequent position updatings (i.e., aeronautical navigation) are required.(Ref. 3)

Section 3

REQUIREMENTS

Navigation systems should be established to fulfill specific requirements; satisfying needs of groups of users. In establishing any system the requirement should come first rather than someone developing a particular system and then looking for a need which it can fulfill. DOT in carrying out its responsibilities discussed in the previous chapter, should provide navigational aids that fill at least the minimal needs for the largest number of users.

Basically a navigation aid enables a mobile user to determine his location with respect to some fixed point. The fixed point may be a navigation hazard, a desired destination or a point on a chart. The user may wish to fix his position for a variety of reasons: avoidance of hazards, reaching his destination with least expenditure of time and/or fuel, collision avoidance, locating prior found fishing grounds or mineral resources, or any combination of these. When the government establishes a navigation aid the first concern is to satisfy those requirements pertaining to safety of movement. For safe navigation the principal consideration is position accuracy, reliability, and availability of service. As the amount of traffic increases, collision avoidance becomes increasingly important. An important consideration is the total economic cost of the system to the user, vis-a-vis the risk of possible loss by not being properly equipped. Another requirement may be established by economic need such as the navigational requirements of the fishing industry. Here in addition to the factors cited above, repeatability of location as well as simplicity of operation of user equipment are important factors.

The initial source for navigational requirements are the needs of the users. They are generally dictated by the accuracy requirements needed to make a landfall or destination and to avoid navigational hazards both fixed and moving. The latter refers to the requirement of collision avoidance by remaining within an assigned aeronautical track or sea lane. These needs have been formalized locally through trade and government-industry groups and internationally by ICAO and IMCO. The basic requirements for U.S. air and marine commerce are given in the NPN.(Ref. 3) Included are the DOD requirements for enroute needs taken from unclassified portions of the Joint Chiefs of Staff Master Navigation Plan.(Ref. 10) These requirements particularly those for the U.S. coastal/confluence zone were further refined by a study conducted for the Coast

Guard by Polhemus Navigational Sciences, Inc.(Ref. 11)

As previously indicated, a navigational system should provide at least the minimal needs of a maximum number of users. Generally, if the most stringent requirements were applied universally, the result would be severe economic penalty to many potential users. In order to avoid this, both user groups and geographic areas have been subdivided. Consideration has been given both to their requirements and the capabilities of available systems. The two major user groups are aeronautical and maritime. The geographic areas considered will be discussed under each of the major user groups.

Civil air navigation requirements have been divided into three major categories associated with long distance, short distance, and terminal operations. Long distance navigation aids considered here are primarily station-referenced systems used for transoceanic navigation. Although many long distance air flights are conducted over land, these are not considered as a special category since the short distance air navigation aids are used for this service. Short distance air navigation aids are usually line-of-sight systems providing service to a range of 200 miles. Terminal air navigation aids provide coverage within approximately 50 miles of an airport.

For long distance air navigation the shortest distance or time of flight, taking weather into account, determines the desired track. As the number of users increase, the need for more accurate track-keeping, particularly with respect to other aircraft becomes a critical consideration. Inability to get an optimum flight path assigned can entail considerable additional cost to the primary oceanic airspace users, the commercial airlines. Generally, the vertical separation standard is 1,000 feet between aircraft operating below 29,000 feet and 2,000 feet vertical separation above the flight level of 29,000 feet. The horizontal standards are generally 120 NM laterally and 20 minutes longitudinally (plane speed becomes a factor in longitudinal separation). Under specified conditions, taking navigational aids into account, these criteria have been reduced in order not to penalize planes by making them fly a longer route. On the most heavily traveled principal North America/Europe tracks over the North Atlantic, the minima above 29,000 feet are 60 NM lateral with a composite system in the vertical and lateral directions. This concept involves staggering of flight levels by 1,000 feet between aircraft operating on adjacent routes while retaining 2,000 feet vertical separation between aircraft on the same route and 120 NM lateral spacing between aircraft operation at the same flight level. In the Pacific between the U.S. mainland and Hawaii, it is 100 NM lateral, 15 minutes longitudinal, and 2,000 feet vertical. For safety purposes it is necessary that an aircraft remain within half its lateral separation distance 99.95% of the time. As traffic increases the separation requirements will have to be decreased to effectively carry the greater number of aircraft above 29,000 feet altitute. By the year 2000 it is projected that the separation required will be 15 NM with 5 minutes longitudinally. The vertical separation will remain 2000 feet.

The short distance and terminal areas air navigation requirements are over U.S. airspace and are intimately associated with the operation by the FAA of the Air Traffic Control System. This system provides for a very large number of users and is an entity unto itself. The system navigation requirements and the means to satisfy them, as part of the total Air Traffic Control System are under constant study by DOT/FAA and will not be further detailed herein.

Requirements for civil maritime navigation are also divided into three categories: high seas, coastal/confluence zone (CCZ) and harbor/harbor entrance zones (HHE). The high seas are those areas remote from land masses where visual references to land or other fixes or floating aids are not possible and where hazards of shallow waters and of collision are minimal. The CCZ includes those waters contiguous to major land masses or island groups where transoceanic traffic patterns tend to converge towards harbors, where significant interport traffic exists in patterns essentially parallel to coastlines, and within which lesser ranged ships usually confine their operations. Included are portions of the Great Lakes.

The basic defining criteria for the CCZ include the presence of shallow water due to operating in proximity to continental or insular land masses and increased congestion with variety of vessel types operating in this environment. No generally acceptable distance off-shore can be said to bound the coastal areas. For the U.S. CCZ, the figure used by DOT is from the coast to a distance of 50 NM or to the edge of the continental shelf (100 fathom curve), whichever is greater. The third category, HHE, consists of those waters inside the mouths of rivers and bays, including those of the Great Lakes, in which terminal facilities are located.

In the high seas environment, commercial mariners would be satisfied now and for the next 20 years in the future with a position fix accuracy within 4 NM 95% of the time. A worldwide accuracy of half of this constitutes a goal by the the year 2000.

For the U.S. CCZ the radionavigation requirement stated in the NPN is the capability of fixing position to a repeatable rms accuracy of 1/4 NM to 50 NM off the coast. The preceeding is a general guide. In the more detailed CCZ study the most stringent requirements in the CCZ (1/4 NM 95% CPE) have been specified for the approaches to principal harbors and inland waterways, certain coastwise shipping channels, and the fairways in the Gulf of Mexico. The latter is probably the worst case situation because there is no buffer zone between "channels" carrying traffic in opposite directions. In the Gulf of Mexico, due to the navigation hazards presented primarily by man-made objects, such as oil wells, certain areas have been designated as shipping safety fairways. The fairways are marked on navigational charts but are not officially designated shipping lanes. They are areas within which the Department of the Army will not issue drilling or construction permits. The fairways are 2 NM wide and carry two-way traffic. Each vessel is expected to stay in its own 1 NM half-fairway. Coastwise lanes consist of two 1 NM one-way traffic lanes with a 2 NM separating zone. The harbor approach from seaward arrangement consists of 2 one-way traffic lanes separated by a buffer zone. The traffic lanes vary in width from 1 NM at 7 NM from the harbor entrance to 5 NM at a distance 30 to 50 NM out, and then may continue as far as an additional 200 NM at the same width. The corresponding buffer zone varies from 1 NM to 3 NM. System accuracies have been predicated on meeting the safety requirement for enroute navigation. Taking those factors into account, the Polhemus study made the requirement more stringent for some closer in areas and relaxed them slightly in some of the outer areas. The requirement varies from 1/4 to 2 NM (95% CPE) and corresponds to about 1/8 to 1 NM rms. For example in the shipping channels, it was established so that the navigation system would provide 99% assurance that a vessel would be in its own lane.

The accuracy requirement of fishermen in order to properly conduct their trade can vary from 50 yards to one mile. This accuracy may be easier to meet than the apparently less stringent safety requirements since in many cases this is a repeatability requirement rather than an absolute location. Repeatability refers to the accuracy with which the navigation system can return the user to a point where a navigational fix (reading) has already been taken, while absolute accuracy refers to fixing the users position with respect to a chart. System accuracy is usually much higher in the repeatability mode.

The harbor/harbor entrance zone demands the highest degree of maneuvering precision and vessel control to avoid the dangers of collision or stranding. A good many of the aids in this area are audio/visual. This is an area similar to terminal navigation under Air Traffic Control and requires separate consideration beyond the purview of this study.

Section 4

UNRESOLVED REQUIREMENT PRIORITIES

As noted in the previous chapter, the requirements for users vary both with the nature of the user and the area covered. The specific requirements considered previously were accuracy and coverage; however, other requirements can also be of importance. For example, in the oceanic areas, different users have different availability requirements. The maritime user would normally not have to update his position more often than about every two hours. The aeronautical user, on the other hand, needs position information at considerably shorter intervals. To meet the differing requirements, the ideal solution would be to find a single, cost effective system that would meet all performance criteria. Particularly, it must meet the most stringent accuracy, dependability, and availability requirements. Unfortunately, this is not possible within the current state-of-the-art system technology and financial constraints.

Due to limitations of resources, all presently unmet requirements cannot be fulfilled at once. The problem, therefore, is to identify the most important, i.e., highest priority, requirement that is presently unsatisfied; then identify or design the optimum navigation system to meet this requirement. The maritime coastal/confluence zone has been identified as the area requiring priority attention. This was determined through careful analysis as detailed below.

As stated in the previous chapter, the aeronautical short distance and terminal areas are contained within the Air Traffic Control System. The FAA has a continuous program for engineering and implementing an upgraded system. This includes both enroute (short distance) and landing systems (terminal area).

For long distance (transoceanic) flights both self-contained and ground-referenced aids are used. Most of the newer commercial planes, both U.S. and foreign, use inertial navigation systems. The other self-contained aid used by many of the older planes is doppler radar. The latter requires periodic updating by some ground-referenced system with Loran-A being the commonly authorized method. In addition, the airlines are currently investigating the possibility of using Omega or Loran-C for total navigation and/or updating purposes. Both of these have shown promise in preliminary tests. One of the systems (Omega) is still in the process of being implemented on a worldwide basis. Loran-A and Loran-C are available for most of the heavily traveled overseas routes in the Northern Hemisphere.(Ref. 3).

The primary user (DOD) for whom the Loran-A system was established will no longer have a requirement for Loran-A after 1974. This has been known for some time and taken into consideration insofar as station improvement and maintenance is concerned. As a result, most U.S. operated transmitting equipment is approaching obsolescence and would require considerable refurbishing if it is to be continued in use for a long period of time. Therefore, a plan has been developed for early phaseout of U.S. Government funding of the system. In contrast, DOD has a continuing long-term need for Loran-C. Thus current long distance aeronautical requirements are receiving active consideration and there appear to be a number of viable alternative solutions.(Refs. 15 and 17)

In the maritime area, the harbor/harbor entrance zone is under active consideration by the Coast Guard. They have several experimental Vessel Traffic Systems using different techniques currently in operation or planned. An R&D project for a Rivers and Harbors Navigation System is also underway. The system proposed for the CCZ may also have application for meeting the requirements of the HHE.

A number of factors, including need for navigational information, number of users, and inadequately satisfied requirements were considered in comparing the high seas and coastal/confluence zone. In considering the relative importance of the two areas, care must be taken not to confuse geographical size with priority. The oceanic area exceeds the CCZ by several orders of magnitude, yet the number of ships in the latter is much greater.

In a study made for DOT/USCG (Ref. 12), data was obtained on the average number of ships at sea at one time. The North Atlantic from the east coast about half way to Europe was taken as an example. The area covered essentially is from 22 to 60 degrees North Latitude and from the east coast of North America to 45 degrees West Longitude. The following was found:

Commercial Ships on the High Seas	712
Commercial Ships in the CCZ	1003
Fishing Vessels at Sea	4000

Most of the fishing vessels would be found in the CCZ rather than on the high seas. The exception is the comparatively small number engaged in tuna fishing. In addition, there are large numbers of recreational vessels. An estimate of the number "at sea" at one time would be in the order of 30,000. Most of them would be operating on inland waters. A goodly number, however, would be in the CCZ with practically none on the high seas. Even ignoring the recreational category, the vessels in the CCZ outnumber those on the high seas by a figure on the order of 7 to 1.

Taking the frequency of position fix requirement into account, makes the difference even greater. Consider only the commercial vessels for example. The relative difference in number is fairly small on the order of 7 on the high seas to 10 in the CCZ. On the high seas even the most conscientious of navigators seldom takes a fix more often than every two hours. In the CCZ the number of readings will vary from one every two hours at the time the ship enters from the high seas, to almost continuous fixes at harbor approaches. Ships engaged in coastal passage will also require frequent position location. Thus on the average a navigator on the high seas would be taking about 10 per day compared to about 40 per day in the CCZ. Taking both numbers of ships and number of position fixes into account, it can be seen that for commercial vessels alone the number of ship-fixes in the U.S. CCZ exceeds those on the contiguous high seas by a factor of about 6.

There are additional adverse effects that the lack of a suitable navigation system can have in the CCZ as opposed to the high seas. Maritime disasters in the form of collisions and groundings, especially the latter are in many cases due to poor position information. Exact data for the various geographic areas are difficult to determine because the boundaries for statistical purposes do not coincide with the geographical areas as defined in the NPN. However, based on an evaluation of the best information available, there is no question that the CCZ is much more dangerous than the high seas. In the North Atlantic for the four fiscal years 1969-1972 there were an estimated total of 14-20 collisions and groundings on the high seas. In the offshore area the number was 104 for the same period. A much larger number occured in harbor and harbor entrance areas subject to the Inland Rules of the Road. Some of the latter actually were in the CCZ. However, even taking the more conservative figure of 104, it can be seen that there is five times the chance of an accident in the CCZ. In addition, the environmental pollution effects of closer in disasters can be much greater, both in regard to killing of fish, marine mammals and birds and fouling of beaches.

The lack of a sufficiently accurate navigation system in the CCZ will become much more evident as additional deep draft vessels ply the offshore waters of the U.S. Many of these ships will have drafts in excess of 90 feet. Bottom chart contours of the waters contiguous to the U.S., in general, are accurate only to the 10 fathom (60 foot curve). Besides natural obstructions there are still numerous wrecks, mostly wartime ones, off the Atlantic coast. These have been cleared off to the 60 foot level beyond the 10 fathom curve. Within this line most have been cleared to a depth of 40 feet except where the depth is less than 40 feet. Thus, most present vessels can pass safely over these wrecks. Their locations, however, are not charted with sufficient accuracy to enable deep draft ships to navigate safely in their vicinity. A more accurate navigation system for general purpose users in the U.S. CCZ would enable the required charts to be made within a reasonable time and at reasonable cost as the present higher accuracy survey systems are much slower and usually most costly to use. Since the deep draft ships will be primarily oil tankers, the increased public interest in marine environmental protection adds urgency to meeting the CCZ navigation requirement.

The Omega system which requires eight stations for worldwide coverage is currently in the process of being upgraded and, in cooperation with six other countries, implemented. It is expected ultimately to provide the required accuracy for navigation on the high seas. Loran-C, which is being maintained to meet primarily military requirements, provides sufficient accuracy for most of the high seas area in the Northern Hemisphere. The notable exception is off the west coast of the U.S. and Canada. A major deterrent to worldwide expansion except for the CCZ is the large number of transmitting stations that would be required as compared to Omega although the individual station cost is lower. Most candidate systems for the CCZ would also be usable for some distance out to sea.

Thus, it can be seen that additional long range systems are not required at present. However, the accuracy needs are at present unmet for a large portion of the U.S. CCZ. From the foregoing, it is evident that the priority need is for a more accurate navigation system in this area.

Section 5

NAVIGATION SYSTEMS FOR THE U.S. COASTAL/CONFLUENCE ZONE

In the preceding chapter the coastal/confluence zone has been identified as the area most urgently needing an improved radionavigation system capability. This requirement was recognized at the time the original edition of the NPN was issued in May 1970 and development of a navigation system for this area was indicated as a priority R&D project.(Ref. 13) This need was high-lighted in the second edition of April 1972 by the Secretary of Transportation when he indicated in its letter of promulgation that DOT expected to make a decision by the end of 1972 on the selection of a navigation system for the CCZ.(Ref. 3)

The Coast Guard has undertaken a number of studies regarding the system choice. It appeared that the leading contenders were Loran-C, differential Omega and Decca. In addition to system capabilities, proven and projected, and costs; the studies also considered system operating experience and current problems.

In response to DOD requirements, the Coast Guard had installed and is operating a number of Loran-C chains both in the

U.S. and overseas. In addition, there are several non-U.S. operated chains. There has been about fifteen years of operating experience with Loran-C. The major system weaknesses were a need for an upgrading of the transmission system and providing lower cost user equipment (receivers). The status of differential Omega which depends for its operation on the Omega system was much further behind operationally and technically. The Omega system has not yet been implemented on a worldwide basis and none of the high-powered stations were then in operation. Therefore, system operating data was meager and more comprehensive tests could not be conducted. Decca has been in use, particularly in Europe, and there is considerable operational data available.

A three-pronged effort was initiated by the Coast Guard. The first was to determine the optimum navigational system for the U.S. CCZ. For this a contract was awarded to Polhemus Navigation Sciences, Inc. It had already been determined that it was not feasible to improve the Loran-A system so as to provide the required accuracy. The study therefore centered on the choice among Loran-C, differential Omega, and Decca. To insure objectivity in evaluation, Polhemus chose three manufacturers each representing one of the systems under consideration. They were asked to present the strongest possible advocacy of their respective system in the context required to meet the previously established and agreed upon operational requirements. (Ref. 11)

The second was to do some additional work on differential Omega since adequate experimental data was not available. There had been an earlier contract awarded to Tracor Inc. and another was given to Beukers Laboratories, Inc. to complement the analytical work in the Polhemus study.(Ref. 16) The third effort involved equipment improvement. Since the use of the Loran-C system at least to meet military requirements was expected to continue for a long period, work had already been done on improving the transmission system. A new station with the resulting up-graded equipment is being constructed at Presque Isle, Maine and should be on line in September of 1974. With the possibility of increased commercial usage of the system, contracts were awarded to Teledyne Inc. and Litton Industries to develop a low-cost Loran-C receiver suitable for commercial use.

All of these studies and equipment developments have now been completed. In the Polhemus study the portion of the accuracy requirements that were relaxed from those in the NPN were met to some degree by all three systems. However, a 17 station (5 chain) U.S. Loran-C System met the higher accuracy requirements to a greater degree than any of the other systems. A 140 station (38 chain) Decca system came in slightly behind and a 67 station differential Omega system ran a poor third. When the implementation cost, plus operation and maintenance costs for ten years were considered, Loran-C was considerably less costly than

Decca and somewhat higher than the monitor station cost of differential Omega.(Ref. 14) However, costs for the latter did not include the extensive communications system that would be required to transmit correction information to the users and the difficulty (if not impossibility) of obtaining the assignment of radio frequency spectrum needed.(Ref. 18) Also user equipment costs are lower for Loran-C than the other two systems. Loran-C was determined to be the most cost-effective of the three systems; particularly when the long term DOD requirement for the existing stations was taken into account. Only upgrading of some of the existing stations and several new ones would be required rather than a complete new system to cover the U.S. CCZ. An additional fallout is that only four to five additional stations would be needed to provide coverage for the entire land area of the contiguous 48 states. Thus a system possibly suitable for automatic vehicle monitoring and/or other uses would also be available. Insofar as user equipment is concerned, the Coast Guard low-cost receivers are currently under evaluation. There are several commercial marine receivers being marketed at a cost of about $3,000.

One additional important factor to be considered is the attitude of the user community to a new system. This was sampled in a survey by Polhemus Navigational Sciences, Inc. (Ref. 18) as well as informally by DOT. It should be noted that users were advised that, at least for the present, Loran-C is not intended to be a compulsory system but a selected system which will provide the required accuracy for the specified area (U.S. CCZ).

The oceanic shippers are generally divided between Loran-C and Decca. The tanker operators as represented by the American Petroleum Institute are in favor of Loran-C. The American Institute of Merchant Shipping could not reach a consensus. The group favoring Decca points out its widespread use in Europe and elsewhere. However, discussions with European shippers at international meetings indicates a growing disenchantment with Decca. Incidentially the Decca Navigator Company is also a leading manufacturer of Loran-C receivers. Coastal shipping operators generally favor Loran-C because of its higher accuracy. The fishing community generally favor Loran-A since they are currently equipped with same and it provides sufficient accuracy for their use in the repeatability mode. However, they realize that the system and equipment are obsolete and will have to be replaced. They would generally go along with a phase out period of about ten years. All of the above led to the determination by DOT that Loran-C was the best currently available system to provide for the navigation requirements of the U.S. CCZ.

Although it was not a factor in system choice, possible aeronautical use of Loran-C was considered a plus factor. It has been demonstrated that there is a possibility the Loran-C system can be used for long-range air navigation using the existing stations. The Royal Air Force has made an around-the-world flight using Loran-C. Several of the U.S. overseas airlines are testing Loran-C as a navigation aid. The concern of the airlines is not directly with the navigation system for the CCZ since they transfer to the domestic Air Traffic Control system around the outer boundary of the CCZ. They are, however, concerned about the possible phase down of Loran-A. A test program to determine if Loran-C is suitable to update the doppler radar is currently underway. This is being funded by FAA and conducted by the airlines.

Section 6

IMPLEMENTATION OF THE SELECTED SYSTEM

The studies by the Coast Guard substantiated the preliminary analysis that Loran-C should be the selected system for the coastal confluence zone. The Coast Guard has formulated a Loran-C Implementation Plan (new stations for the CCZ) and a Loran-C Improvement Plan (upgrading of Loran-C for DOD use worldwide). Funding for the start of this combined program was requested by the Department Of Transportation for Fiscal Year 1974. This item was not included in the OMB approved budget submitted to Congress nor did it appear in the DOT appropriation act for FY-74. However, this combined Loran-C program is in the current Coast Guard authorization act (PL 93-65).

At the present time covering the area containing the U.S. CCZ, there are three (3) Loran-C chains in operation. One includes the east coast, part of the Gulf of Mexico, and most of the Great Lakes within its ground wave coverage area. This chain has five ground stations including one operated by the Canadian government, The second covers the western part of the Gulf of Alaska, the Aleutians, and the Bering Sea, using four ground stations. The third, with three ground stations, covers the area roughly encompassed by the Hawaiian Islands, Midway, and Johnston Islands. One new station incorporating the improved transmission equipment is already under construction at Presque Isle, Maine. This will operate initially as a test facility and eventually as a regular part of the east coast chain. Ten additional stations are being proposed with one existing station to be decommissioned. The system would be implemented in four annual phases starting in Fiscal Year 1975. Phase I would provide coverage for the west coast of the U.S. Phase II would fill out the east coast and the Gulf of Mexico. Phase III would give coverage to the Gulf of Alaska. The balance of the Great Lakes would be covered by Phase IV. The resulting Loran-C system coverage area could replace 25 U.S. operated Loran-A stations now covering the U.S. CCZ and the Hawaiian Islands area.(Ref. 2)

The cost of implementing the Loran-C improvement and implementation program for U.S. waters would be on the order of $82 millions. Manpower requirements for the proposed system (After completion of Loran-C implementation and improvement and Loran-A phasedown) will be reduced because the new equipment will permit a reduction in the number of personnel required per station. The present authorized complements for the U.S. Loran systems are 632 (271 for "A" and 361 for "C"). The proposed Loran-C system will have a total personnel requirement of only

348. Therefore the projected personnel savings of 271 from Loran-A and 13 from Loran-C will provide an overall reduction of 284. Translating the total manpower difference (284) to cost at an average man-year figure of $10,000 results in an annual savings of about $2.8-millions. The annual operating and maintenance cost (not including personnel) for the U.S. Loran-A system is approximately $1.3 million. When fully implemented the comparable Loran-C system cost is expected to be $3.5 millions. This is an increase of $2.2 millions. (All costs have been reduced to 1975 dollars.) Adding the personnel and other operating costs together show that the proposed improved capability and coverage Loran-C system can be operated with no cost increase. In addition all the other possible cost benefits from a more accurate system capability would accrue.

Another approach would be to compare the system cost with a single large vessel which might be lost due to the lack of an accurate navigation system. The total operating cost during the period both U.S. systems (Loran-A and Loran-C) are in operation (until 1979) is estimated to be about $50 millions. To this is added the system implementation cost for a total of about $130 millions. This is comparable to just the replacement cost of a liquified natural gas carrier or supertanker of about $100 millions. In addition, there is the possible savings of lives as well as the probability of substantial environmental pollution costs.

No major engineering development equipment improvement programs are planned at the present time, and the current ones have been completed. A number of the existing Loran-C transmitter stations will be updated to incorporate the new equipment developed as a result of the past programs. The low cost Loran-C receiver was developed to provide guidance to industry with no plan to carry the unit into production under DOT sponsorship. Several additional manufacturers already have low cost ($3,000) Loran-C receivers on the market.

The Coast Guard program also includes phase out of the Loran-A system. This equipment is obsolete and becoming more difficult to maintain. In many places coverage is duplicated by the two Loran systems. DOD has indicated that they no longer require Loran-A beyond Calendar Year 1974. They do, however, have a continuing need for Loran-C. Where duplicate coverage exists, Loran-A will be phased-out as rapidly as possible. This depends upon how soon Loran-C or Omega are approved as aviation aids, and the equipment replacement time allowed aviation and marine users of the Loran-A system. In the areas receiving the new Loran-C installations, the U.S. Government funding of Loran-A will be phased-out following a reasonable changeover time. In any case, all Loran-A stations should be decommissioned between

1977, at the earliest, and 1984, at the latest depending upon the schedule chosen.(Ref.17)

Section 7

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this study:

1. The Department of Transportation has the responsibility for providing navigational aids for aeronautical and maritime commerce, with priority being given to U.S. territory and adjacent areas.

2. The position fixing requirements for radio-navigation aids both as regards accuracy and other factors vary between users, both aeronautical and maritime, depending upon whether they are needed for long range, shorter range, or terminal area operations.

3. Using present technology, there is no single system which can meet all requirements in a cost effective manner and it is therefore necessary to determine which unmet need has the highest priority.

4. The navigation requirements for most areas are either being currently met or have an adequate system planned. However, providing for the navigation requirements of the coastal/confluence zone has the highest priority since a large part of the zone does not have the required accuracy or coverage

to meet the present and future user needs, the number of users is great, the frequency of use is high, and the lack of an accurate system can have serious adverse environmental effects.

5. The optimum system to implement for the U.S. CCZ at the present time is Loran-C since it will meet or exceed the accuracy and coverage requirements, part of the system is already in being, its cost will be as low or lower than any other systems, and low cost equipment for the user is available. In addition, DOD also has a continuing requirement for the existing Loran-C capability.

6. Phaseout after 1974 of government funding of the Loran-A system or of the system itself in areas where Loran-C coverage is also provided depends on several factors. For the maritime community, it is reaching agreement on an acceptable phaseout schedule with the users, particularly the fishing industry. For the aeronautical users the major factor is proving technical capability and then obtaining approval of Loran-C and/or Omega as an authorized navigational aid by the FAA and ICAO.

It is, therefore, recommended that:

a. Loran-C be chosen as the radionavigation system to be provided for the U.S. coastal/confluence zone.

b. The DOT/USCG Loran-C CCZ improvement and installation program be approved for implementation.

c. U.S. Government funding of Loran-A be phased out in an orderly manner.

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