Radiation first appeared in the United States as radio direction finding experiments carried out by the U.S. Bureau of Standards in 1912 and 1913. These experiments resulted in a practical demonstration of radio direction finding using signals from a spark gap transmitter located at the Navesink Lighthouse in New Jersey. This demonstration was conducted jointly by the U.S. Lighthouse Service and the Bureau of Standards in January 1917. Development of radio-navigation was suspended during World War I and further testing was not conducted until 1919. The first operational radio-navigation system was available for public use on May 1, 1921. It was a Radio Fog signal (also known as a Wireless Fog signal) transmitted from spark gap transmitters installed at the Sea Girt Lighthouse in New Jersey and on the Ambrose and Fire Island Light ships at the entrance to New York Harbor.

This radio direction finding system, now known as the Marine Radio Beacon System, has become the cornerstone of maritime navigation. There are now 201 Marine Radio BeacoH Transmission Sites in the United States and there are more users of the Marine Radio Beacon System than of any other radionavigation system.

The durability of the Marine Radio Beacon System is a characteristic not inherent in the multitude of other radionavigation systems that are now or have been used. As excellent example of how technology has made a radionavigation system obsolete is the short history of the LORAN-A system.

The concept for LORAN-A was first proposed by the U.S. Army Signal Corps in 1940 as a precision navigational equipment for guiding airplanes. LORAN-A was developed at the Massachusetts Institute of Technology Radiation Laboratory with the first tests of the system carried out on the East Coast of the United States in mid-1941. These tests were quite successful and the first operational LORAN-A chain was in place in June 1942. The original stations were located at Montauk Point, NY and Penwick Island, DL. In October 1942 two Canadian stations were added and LORAN-A became an operational reality. By 1945 more than 30,000 aircraft and 3,000 surface ships were equipped with LORAN-A.

LORAN-A was, however, doomed by the advances of technology. Extensive tests of a much improved system, LORAN-C, were carried out between 1952 and 1955. The first LORAN-C chain consisted of stations at Cape Fear, NC; Carabelle, FL; and Forestport, NY. The LORAN-C tests indicated great promise for the system. In 1956 and 1957, the original LORAN-C chain was re-oriented to provide its best coverage to sea. The advantages of LORAN-C were immediately obvious; thus began the downfall of LORAN-A.

Today, there are 44 LORAN-C stations providing coverage for the United States, Canada, North Atlantic Ocean, Norwegian Sea, Mediterranean Sea and portions of the Pacific Ocean. The LORAN-C system became the designated radionavigation system for the Coastal Confluence Zone of the United States in 1974. The phase out of LORAN-A began shortly aftei LORAN-C became the primary Maritime radionavigation system. The last U.S. operated LORAN-A chain was shut down on December 31, 1980. The last Canadian LORAN-A chain, also the last LORAN-A chain in North America, will be shut down on December 31, 1983.

The shut down of one radionavigation system in favor of a more advanced one should not be considered an unusual phenomenon. The United States operates four major radionavigation systems that benefit the civil maritime community. They are LORAN-C, OMEGA, Marine Radio Beacons and the Navy Navigation Satellite System (TRANSIT). The NAVSTAR Global Positioning System (GPS) is being readied by the Department of Defense for full operation in 1988. GPS offers an alternative radionavigation system that could replace some or all of the systems now in use.

The redundancy of capability available due to the proliferation of radionavigation systems and the cost savings realized by reducing this redundancy have long been recognized. The termination of LORAN-A is an example of a cost savings without reducing the overall radionavigation availability. The need to control the proliferation of federally operated radionavigation systems was highlighted in a Comptroller General's report that, late in 1978, prompted Congress to legislate a degree of control over the proliferation of federally operated radionavigation systems. Section 507 of the International Maritime Satellite Telecommunication Act (Public Law 95-564 November 1978) directed that:

"(a) The President, in conjunction with government agencies which will or may be affected by the development of a government-wide radio navigation plan, shall conduct a study of all government radio navigation systems to determine the most effective manner of reducing the proliferation and overlap of such systems. The objective of such study shall be the development of such a plan."

"(b) The President shall transmit a report to the Congress no later than 12 months after the date of the enactment of this title relating to the study conducted under subsection (a) of this section. Such report shall contain a detailed statement of the findings and conclusions of such study, any action taken by the President related to such findings and conclusions, and any recommendations of the President for such legislation or other action as the President considers necessary or appropriate for implementation of a government-wide radio navigation plan."

This legislation resulted in the formation of a joint Department of Transportation (DOT) and Department of Defense (DOD) Navigation Council to formulate the Plan. The Plan enacted as a result of the Navigation Council's work is known as the "Federal Radionavigation Plan." This plan outlined all federal efforts in the area of radionavigation and specified a procedure to set policy to reduce the proliferation of radionavigation systems. The procedure calls for the Secretaries of Defense and Transportation to make a joint Policy statement establishing a preliminary selection of the post 1995 mix of radionavigation systems in 1983. This procedure requires the policy to be finalized in 1986. Figure 1 illustrates the steps in this planning process.

The preliminary selection of the post 1995 mix of federally operated radionavigation systems takes into
Consideration current efforts to develop the GPS system. The selection concentrates on domestic civil user oriented systems. The need for overseas systems, operated by the United States for national defense, is decided solely on DOD requirements.

The need for the overseas LORAN-C system, for example, has been determined on the basis of DOD requirements. Assuming that GPS becomes operational in 1987, the United States plans to withdraw support for overseas LORAN-C on the following schedule:

- North Atlantic: 1992
- Norwegian Sea: 1992
- Mediterranean Sea: 1992
- Northwest Pacific: 1992
- Korea: 1996

The need for and the possible overlap of domestic radionavigation is a much more complex problem. The domestic issue requires consideration of a much more complicated set of factors.

The preliminary selection considers air and land radionavigation systems as well as marine radionavigation systems. In the remainder of this paper, I will discuss the rationale for a selection of the post-1995 mix of civil maritime radionavigation systems. I will discuss the requirements and issues, the identification of system alternatives and the comparison of system alternatives. I will then indicate how the Departments of Transportation and Defense will use this data to develop the selection.

The radionavigation requirements of the marine user can be categorized under the ocean, coastal and harbor/harbor approach (HHA) phases of navigation. Although the requirements for each of the phases of navigation are different, it is possible that the requirements for two or more phases may be met by one radionavigation system. The requirements for safety of navigation for each phase can be summarized as follows:

- Oceanic requirements can generally be satisfied with predictable 2 to 4 nm (2 drms) accuracy from a radionavigation system, although 1 to 2 nm (2 drms) is desirable. The maximum interval between fixes must be 2 hours or less, but 15 minutes or less is desirable, and the signal should be available at least 95% of the time.

- In the coastal phase of radionavigation, the requirements for safety of navigation are .25 to 2 nm (2 drms) for ships and .25 to 20 meters (2 drms) for recreational boats and smaller vessels. Additionally, a vessel must be able to obtain a fix at least every 15 minutes. The repeatability of a system also becomes much more important in the coastal phase. This requirement for repeatability, however, stems more from a need to achieve economic benefits than from navigation safety. Additionally, U.S. regulations (33 CFR Part 164) currently require vessels of 1600 gross tons or more to have a LORAN-C or satellite navigation receiver installed, before entering U.S. ports.

- The requirements for safety of navigation in the harbor/harbor approach phase vary from 8 to 20 meters (2 drms) with a fix available at least every 15 minutes. These requirements stem from the need to navigate very large vessels through congested harbors and channels with a precision measured in tens of feet.
The 20 meter figure could be met in some harbors by LORAN-C, but in most cases would not be met by existing systems except in a differential mode. It is doubtful that the 8 meter (2 drms) requirements could be achieved even in a differential mode. These extreme accuracy requirements must be satisfied by some type of specialized system, rather than a general purpose radionavigation system.

The economic requirements of the marine user tend to relegate certain systems to particular types of users. While the large ocean-going vessel may derive economic benefit from long-range radionavigation systems, in spite of moderate accuracy or infrequent fix characteristics, the commercial fisherman or coastal trade vessels may be unable to tolerate those same characteristics. Conversely, good repeatability, which is essential to the economic well being of the commercial fisherman and other groups, may be of limited or no economic benefit to the large ocean-going vessel. Apart from these operationally oriented economic requirements are the system costs and user equipment life-cycle costs. Large ocean-going vessels may have thousands of dollars budgeted for navigation equipment, so that fifteen thousand dollars for a navigation receiver is of little concern. In contrast, some small commercial vessels such as fishing boats cannot afford a third of that amount for their complete electronics package and must keep their navigation receiver cost down to a few thousand dollars at most.

The economic requirements can be roughly broken into the phases of navigation. To provide benefits in the ocean phase, requirements vary from 10 to 400 meters (2 drms) with maximum fix intervals varying from 1 to 5 minutes. Coastal phase requirements to provide benefits vary from 1 meter (2 drms) for hydrography, science and resource exploitation, to 460 meters (2 drms) for most other users. Certain fishing operations require high-repeatable accuracy from a system which enables them to return to the same location without knowing its precise geographic coordinates. Harbor/harbor approach requirements to provide benefits are difficult to assess because of the variance from one harbor to the next.

The following systems are being considered for the future mix of federally operated radionavigation systems for marine users:

Marine Radio Beacons are used for coastal navigation at short ranges and for marking the harbor entrances. There are 201 of these operated by the Coast Guard, and limited growth is expected in their numbers due to radio frequency congestion.

LORAN-C is the federally provided system for the Coastal Confluence Zone (CCZ); its use or that of a satellite navigation system is required by vessels over 1600 gross tons entering U.S. ports. It is used extensively by the fishing industry due to its high-repeatable accuracy of 18 to 90 meters (2 drms). The use of differential LORAN-C can provide even greater accuracy for use in harbors and inland waters.

OMEGA provides 2 to 4 nm (2 drms) accuracy and worldwide coverage for use as a general purpose en route navigation system. Use in the differential mode may provide accuracy in the order of 0.25 nm (2 drms) at a range of 50 nm, \(^8\) degrading to 1 nm (2 drms) at 500 nm from the reference monitor. Differential OMEGA may be used to meet specific requirements in portions of the Coastal Confluence Zone. These areas include the Caribbean Sea and Alaska.

TRANSIT provides 200 to 500 meter (2 drms) to users worldwide. It is a military system that is available for civilian users. The fix rate for TRANSIT users can vary up to several hours depending upon the user's location.

NAVSTAR GPS will provide worldwide coverage when operational. If full accuracy from the Standard Positioning Service is provided, it is capable of meeting oceanic requirements and most coastal requirements. Differential NAVSTAR GPS appears capable of providing the accuracies required to meet some additional requirements, but its applicability will be limited to the coverage area served by the reference monitor.

In making a technical comparison of marine radionavigation systems, it appears beneficial to make the comparison in terms of the three phases of marine radionavigation. Such a comparison is as follows:

Ocean—In the ocean phase of navigation, the mariner typically uses OMEGA, TRANSIT, or LORAN-C. The 2 to 4 nm (2 drms) accuracy and nearly worldwide coverage of OMEGA make it suitable for oceanic radionavigation, although its use by the maritime community is limited. The TRANSIT system's accuracy of 200 to 500 meters (2 drms) is its most attractive feature. It also features worldwide coverage but due to low satellite orbits and orbital precession, the coverage is not continuous. Due to those factors, fix rate varies from under an hour to several hours, depending on the user's location. LORAN-C, with its .25 nm (2 drms) accuracy and continuous fix rate, is highly attractive. It cannot be considered a true oceanic system, however, since its coverage normally extends only a few hundred miles offshore. NAVSTAR GPS, although not operationally tested at this time, appears to have the capability of meeting all requirements for ocean phase radionavigation.

Coastal—In the coastal navigation phase, the marine user is generally afforded the choice of LORAN-C, TRANSIT or Radio Beacons. Although OMEGA can be used, its accuracy is not adequate for the more congested inner coastal areas. Differential OMEGA does provide sufficient accuracy for coastal navigation. The U.S. provides Differential OMEGA service in Puerto Rico. U.S. operated Differential OMEGA is not expected to expand where it would duplicate LORAN-C coverage. Because of its coverage and accuracy, LORAN-C is used extensively for coastal area navigation. TRANSIT can provide sufficient accuracy for coastal navigation, but the long periods between fixes in some areas limit its usefulness. Radio Beacons generally provide two-line fix coverage within 50 nm of the coast. Again, NAVSTAR GPS, although not operationally tested, appears to have the capability of meeting most coastal phase radionavigation requirements. If, however, the SPs portion of NAVSTAR GPS is degraded to the currently proposed 100 meters (2 drms) level, the system may not meet all of the coastal repeatability requirements.

Harbor/Harbor Approach—The requirements for the HHA phase of navigation, although generally undefined, are considered to be more stringent than can be met by current radionavigation systems. While Loran-C can provide adequate accuracy in some harbors, this is not generally the case. Differential LORAN-C, or possible differential NAVSTAR GPS, could provide adequate service for some HHA applications, but they would require additional operator equipment, and impose additional costs on both the system operator and user.

There are also institutional issues that have to be considered in comparing any group of radionavigation systems. The major institutional issues are:
User Charges--Currently, NAVSTAR GPS is the only radionavigation system used or proposed for use by the mariner with any scheme developed or partially developed to implement a user charge. This proposed DOD schedule of user charges for NAVSTAR GPS has created apprehension among certain marine users. While DOD proposed user charges for NAVSTAR GPS appear high when compared to the currently limited or non-existent charges for other marine radionavigation systems, it must be considered that user charges may eventually be instituted for other systems as well. Many potential users, however, cannot accept a user charge.

Availability--Signal availability and accuracy in times of national emergency is the most difficult of the institutional issues to address. The classification of most material relating to the subject prevents developing any user dialog. This in turn leads to innumerable concepts in the users' minds regarding the availability of different systems. DOD operated systems are undoubtedly seen as being less available in times of national emergency than the DOT operated systems. This does not, however, appear to have deterred users from investigating in the TRANSIT system.

Accepcence--International acceptance of radionavigation systems is probably quite closely related to the issue of signal availability and accuracy in times of national emergency. In this respect, the international character of the OMEGA system undoubtedly increases its acceptability with the navigation communities of the world. Conversely, the U.S. defense-oriented systems are less acceptable. NAVSTAR GPS, being DOD controlled, probably suffers most in the eyes of the world users in terms of international acceptance and perceived questionable availability in times of national emergency. It is possible, however, if sufficient accuracy is made available from NAVSTAR GPS, that its acceptability could increase to the level now seen in the TRANSIT system. LORAN-C falls somewhere between OMEGA and NAVSTAR GPS in terms of how the international user perceives its availability in terms of a U.S. national emergency. TRANSIT, although initially a system for military use only, has found considerable acceptance in the international civil community.

In preparing the recommendation for the future mix of federally operated radionavigation systems, the user requirements, the alternative systems and a comparison of the requirements and systems must be looked at. The Departments of Transportation and Defense are now making this analysis and expect to issue a joint policy statement in November 1983. The policy statement will be a preliminary recommendation for the post 1995 mix of federally funded radionavigation systems. The policy statement, as it will be incorporated into a 1984 revision of the Federal Radionavigation Plan, will be open to public comment. A National decision regarding the post 1995 mix of federally funded radionavigation systems will be made in 1986.

Some general conclusions regarding the post 1995 mix of federally operated radionavigation systems can be made prior to the official policy statement by examining the available data. The first and most obvious conclusion is that NAVSTAR GPS, with its 100 meter 2 dmas accuracy, worldwide positioning service, will duplicate and in many cases exceed the capability of existing radionavigation systems. The government's stated policy to reduce the proliferation and overlap of radionavigation systems and the national support for NAVSTAR GPS will mandate that some of the existing radionavigation systems be phased out. The government has already announced a phase out schedule for overseas LORAN-C and has announced that TRANSIT will be phased out in 1992. This leaves the future status of Radio Beacons, OMEGA and LORAN-C open.

The Marine Radio Beacons serve a different economic segment of the marine user community than other systems. For this reason it is unlikely that other radionavigation systems will be phased out. For LORAN-C, phase out could be expected at any time after NAVSTAR GPS phase in. For OMEGA, since it is a multi-national system the United States cannot unilaterally shut it off. OMEGA shut off, if it occurs, would occur after all operating nations agree that it is no longer needed.

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