Federal Radionavigation Plan

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16. Abstract

The Federal Radionavigation Plan (FRP) has been jointly developed by the U.S. Departments of Defense and Transportation to ensure efficient use of resources and full protection of National interests. The plan sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

Volume IV is a summary of the Federal radionavigation R,E&D plan together with individual R,E&D plans for military and civil air, land, and marine applications. Open issues, and means for their resolution, are addressed. A key feature is a discussion on how the indiviual agency R,E&D plans will be coordinated to help assure that all aspects of each system are thoroughly evaluated while avoiding duplication of activities.

Volume IV describes the Federal government research, engineering and development (R,E&D) activities relating to the Government-provided radionavigation systems and their world-wide use by the U.S. Armed Forces and the civilian community. The document is organized in two parts: (1) Civil R,E&D efforts to be conducted mainly by DOT, and to a lesser extent by NASA and the U.S. Department of Commerce (DOC); and (2) DOD R,E&D for military uses.

Volume I, Radionavigation Plans and Policy, has 90 pages; Volume II, Requirements, has 50 pages; and Volume III, Radionavigation System Characterisitcs, has 46 pages.

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PREFACE

The Departments of Defense and Transportation developed this Federal Radionavigation Plan (FRP) to ensure efficient use of resources and full protection of national interests. The plan sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

Various existing and planned radionavigation systems used in air, land, and marine navigation are reviewed in terms of user requirements and current status. The FRP contents reflect a response to a unique combination:

- o DOT responsibilities for public safety and transportation economy
- o DOD responsibility for national security in normal and stressed situations.

This plan will be updated annually. The established DOD/DOT interagency management approach will enable continuing control and review of U.S. radionavigation systems.

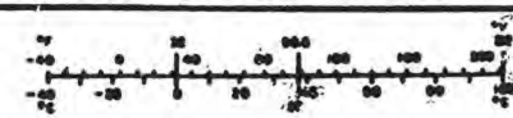
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

Approximate Conversions from Metric Measures

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



FEDERAL RADIONAVIGATION PLAN

VOLUME IV

RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT

TABLE OF CONTENTS

VOLUME IV
LIST OF ILLUSTRATIONS

VOLUME IV
LIST OF TABLES

VOLUME IV

CHAPTER 1

CIVIL RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT SUMMARY

1.0 SUMMARY AND ORGANIZATION

This document describes the Federal government research, engineering and development (R,E&D) activities relating to the U.S. Government-provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. The document is organized in two parts: (1) Civil R,E&D efforts to be conducted mainly by DOT and to a lesser extent by NASA and DOC, and (2) DOD R,E&D for military uses.

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems in order to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, marine, or land applications. The parallel efforts are described in two major sections, one covering NAVSTAR GPS and the other covering all existing systems (such as VOR, OMEGA, and LORAN-C) now in use or being considered by DOT to meet new or emerging navigational requirements.

Although the DOT R,E&D activities for NAVSTAR GPS will proceed in much the same manner as those for other systems, NAVSTAR GPS has been identified separately because of its potentially broad multimodal civil and military application and the consequent need for close cooperation between Federal agencies in its evaluation. Such cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. The cooperation should also insure DOT participation in the early stages of DOD evaluation and development of NAVSTAR GPS so that benefits can be derived from a continued assessment of DOD's advances in receiver technology and an improved government planning process.

From the point of view of DOT, the analysis of performance requirements of civil navigation systems involves a variety of complex factors before it can be concluded that a specific system satisfies the principal objective to ensure safety and economy of transportation. These factors involve an evaluation of the overall economics of the system in relation to technical and operational factors, including vehicle size and maneuverability, vehicle traffic patterns, user skills and workload, the processing and display of navigation information, and environmental restrictions (e.g., terrain hazards and man-made obstructions). For this reason, a DOT comparison of one navigation system to another requires more than just a simple evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, nine performance parameters, discussed in Volume III (System Characteristics), have been identified and are listed in Table IV-1.0.

TABLE IV-1.0

RADIONAVIGATION SYSTEM PERFORMANCE PARAMETERS

1. Signal Characteristics
2. Accuracy
    a. Predictable Accuracy
    b. Repeatable Accuracy
    c. Relative Accuracy
3. Availability
4. Coverage
5. Reliability
6. System-Imposed Fix Rate
7. Fix Dimensions
8. System Capacity
9. Ambiguity

As implied above, for DOT, the user's equipment cost is a major consideration if universal civil participation is to be achieved. DOT R,E&D activities will therefore also involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies (in conjunction with NASA) and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R,E&D activities mainly address NAVSTAR GPS evaluation by user groups in the Armed Forces which are identified by military mission requirements and national security considerations. For this reason, DOD R,E&D is defined to include all activities before the final acquisition of a navigation system in accordance with detailed system specifications. Except for a low-level effort to launch TRANSIT satellites with the space shuttle (Space Transportation System), the DOD view of TRANSIT, LORAN, TACAN, VOR, and OMEGA is that these systems are already developed and, therefore, do not require R,E&D. This leaves NAVSTAR GPS as the only military radionavigation system which must be evaluated in order to make a DOD decision on the best mix of Federal radionavigation services.

Although there are some similarities between the DOD and DOT analyses of the nine system performance parameters, DOD military missions place much greater emphasis on security and anti-jam than those for civil systems. Such factors as anti-jam, updating of inertial navigation systems, portability, and reliable operation under extreme environmental or combat conditions become very important in establishing the costs of the navigation equipment.

Concurrent with the Federal R,E&D programs, the major cost and benefit issues will be evaluated with the aid of a Federal Navigation Economic Model. This model is being constructed in two parts, one for DOT and one for DOD. Outputs of these models and R,E&D programs will be used to form joint positions related to system mix, phase in-phase out and transition strategies for "common user" (Joint military/civilian) systems and individual agency positions on non-common user systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information to allow preliminary recommendation of the best future mix of radionavigation systems in 1983. DOD R,E&D will be coordinated with DOT R,E&D under the following guidelines:

A. DOT will evaluate the costs and benefits of all radionavigation systems, including NAVSTAR GPS, which meet identified sets of civil user requirements.

B. DOD will provide an annual specification update of NAVSTAR GPS capabilities, e.g., accuracy, which are to be made available for civil uses.

C. DOT will provide DOD with the most current information on user requirements which may have a significant impact on the selection or performance specification of DOD-operated radionavigation systems.

D. DOD will provide information to DOT on possible low-cost NAVSTAR GPS receiver designs that may be applicable to low-cost civil receiver development consistent with existing DOD policy.

E. DOT will conduct studies of NAVSTAR GPS performance capabilities using low-cost receiver designs in order to provide an assessment of its applicability to the civil sector.

Prior to 1983, the current DOD NAVSTAR GPS program and the DOD provision of receivers for civil field testing will allow DOT to perform its NAVSTAR GPS R,E&D at all postulated accuracies, including the most accurate P-signal. DOT can obtain data on the cost-effectiveness of the entire spectrum of NAVSTAR GPS performance in time for a comprehensive reporting of NAVSTAR GPS user requirements to DOD. This includes the important effects of denial of the full NAVSTAR GPS signal accuracy to the civil community. Moreover, if DOT selects NAVSTAR GPS for civil applications, the results of the DOT NAVSTAR GPS R,E&D will allow a full four years for private industry to develop receivers for the civil sector by 1987, when DOD plans to have NAVSTAR GPS fully operational.

After 1983, the DOT R,E&D will consist of programs which are based on the results of prior R,E&D, the identification of the NAVSTAR GPS accuracy available for civil use, and a continuing evaluation of alternative system configurations which satisfy institutional constraints, e.g., degrees of user cost sharing, international acceptance by ICAO and IMCO, safety requirements, and equipment standards.

VOLUME IV

CHAPTER 2

CIVIL RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT ACTIVITIES

2.0 CIVIL R,E&D ACTIVITIES

The specific Civil R,E&D activities and their relationships to the Federal Radionavigation Plan and the major Federal decisions on system implementations described in Volume I (Plans) are outlined below in two parts; (l) NAVSTAR GPS: R,E&D, and (2) R,E&D for all existing civil navigation systems which include VOR, TACAN, DME, OMEGA, LORAN-C, and MLS. These two parts have been coordinated to achieve efficient use of the limited funds available for R,E&D and to avoid duplication of effort. R,E&D tasks for the individual DOT agencies (FAA, USCG, etc.) and related tasks by the DOC/MARAD and NASA are addressed and schedules have been specified so that the results of the efforts will be of maximum usefulness to all participants in the program. R,E&D schedules and activities for the FAA, the U.S. Coast Guard, and the Research and Special Programs Administration (RSPA) have been identified respectively under the aviation, marine, and land appendices of this document.

2.1 DOT NAVSTAR GPS R,E&D

2.1.1 General

The major DOT marine, air, and land R,E&D activities for NAVSTAR GPS are indicated in block diagram form in Figure IV-2.1 and are described as follows:

A. Coast Guard activities focus on establishing the performance of NAVSTAR GPS for maritime navigation. There is a particular focus upon the Harbor Approach and Harbor phases of marine navigation, where augmentation of visual piloting using radio aids to navigation is needed. Three major efforts are involved:

1. An evaluation of the ultimate accuracy potential of vessel navigation in the Harbor and Harbor Approach phases will be conducted. The evaluation will establish the technical capability of NAVSTAR GPS in its C/A mode to meet the stringent requirements of these phases.

2. A comparative evaluation of NAVSTAR GPS and existing aids to navigation will be performed. This evaluation will assess the relative cost and performance trade-offs of NAVSTAR GPS and all existing systems (LORAN-C, TRANSIT, OMEGA) for all phases of marine navigation as an input to Federal decisions on the mix of future radionavigation systems.

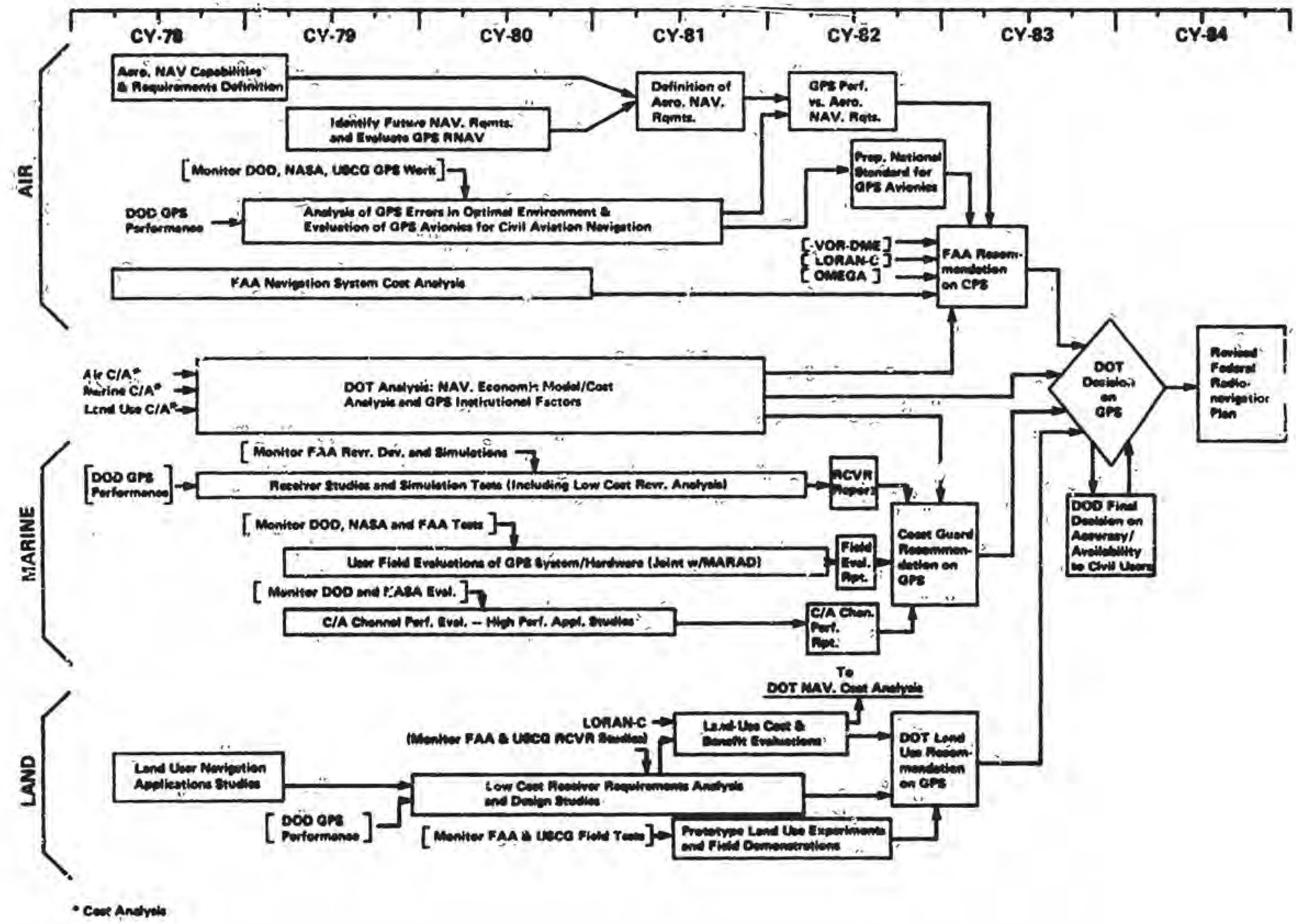


FIGURE IV-2.1 DOT R&D Activities for GPS

3. An evaluation of marine receiver designs under the guiding principle that marine users choose navigational aids for their vessels based on cost and performance assessments will be conducted. There are few governmental regulations that influence their decision. Consequently, development of low-cost receiver designs must precede the use of NAVSTAR GPS by the civil user population. Further, evaluation of receiver designs will ultimately permit the development of minimum performance standards for NAVSTAR GPS receivers.

B. The R,E&D activities of the FAA are equally varied and are larger in scope because of the many different aspects of air operations. They include substantial efforts to evaluate the technical, operational and economic characteristics of future aeronautical navigation systems, including NAVSTAR GPS. The FAA also has underway a comprehensive effort in the development of a low-cost NAVSTAR GPS receiver of minimum acceptable performance. These activities will include an extensive flight test program using single and dual channel receivers to obtain flight data aboard general aviation (GA) aircraft. Electromagnetic noise and interference in the NAVSTAR GPS L_1 frequency band (1575 MHZ) and its impact on receiver operation will be determined during this test program.

C. RSPA land R,E&D activities in connection with NAVSTAR GPS are also shown in Figure IV-2.1 and are structured in two successive stages. The first stage involves review of the results of earlier work in the design of low-cost NAVSTAR GPS receivers and field tests by the FAA, USCG, and DOD. Preliminary requirements will also be assessed at this time for potential users. This will be followed by a second phase which addresses measurements of satellite signal margins in the presence of urban and rural radio frequency interference, and measurements of signal attenuation due to terrain blockage and foliage. These measurements will then become a part of the comprehensive definition of user requirements, costs, and benefits. The definition will be developed in cooperation with other DOT modal agencies; e.g., UMTA, NHTSA, and FHWA and other Federal, State, and local administrations. Where possible, the definition will include an evaluation of operational demonstrations of NAVSTAR GPS performance and associated comparisons with alternative navigation systems.

D. Figure IV-2.1 also indicates the use of the DOT Navigation Economic Model and the types of FAA, USCG, and other DOT agency analyses and systems which will be compared at various stages of the R,E&D program. Other factors which influence each individual agency's R,E&D on NAVSTAR GPS have also been outlined. These include FAA evaluations of the ability of NAVSTAR GPS to meet user performance requirements, the preparation of national standards for avionics, and USCG receiver studies and field evaluations.

2.1.2 Civil Aviation

The possibility of using NAVSTAR GPS as the primary navigation aid for the civil aeronautical community is dependent on an investigation and analysis by the FAA of the following major topics:

- o NAVSTAR GPS technical and operational performance capability for the various classes of civil users.
- o The feasibility of low-cost NAVSTAR GPS avionics that is both affordable by the general aviation user and meets all current navigation requirements of two-dimensional area navigation (2D RNAV).
- o Overall cost-effectiveness of NAVSTAR GPS versus alternative systems; e.g., VOR/DME, LORAN-C, in satisfying the post-1990 aeronautical navigation requirements.
- o International acceptance by ICAO.

A. NAVSTAR GPS Performance Capability for Civil Aviation

Analyses of the basic NAVSTAR GPS performance available to the civil user have been underway by the FAA for over two years and are planned to continue. The objective of these studies is to determine the NAVSTAR GPS navigation performance realizable by the civilian fleet, ranging from air carrier to single-pilot, low-cost general aviation aircraft. These studies include a determination of basic accuracy and repeatability and an analysis of errors due to signal variations (such as those caused by antenna patterns), acquisition and reacquisition times, multipath, radio frequency interference, satellite geometry, and flight technical errors. Computer simulations of NAVSTAR GPS navigation performance will be performed to assess the suitability of NAVSTAR GPS for en route and terminal navigation and non-precision approach guidance, using DOD error models and test data along with FAA developed information.

The human factors area must also be considered since the NAVSTAR GPS system, by definition, is an area navigation system of a type that has not been evaluated. In such a system, the pilot must enter waypoints into the navigation system at various points along the flight path, whereas in the current VOR navigation system no such activity is required. The NAVSTAR GPS system potentially represents a change in procedures and an increase in pilot workload (with an increased possibility for blunders) over the VOR system, particularly for single-pilot IFR operations. Beginning in 1980, flight tests are planned for evaluating the performance of existing NAVSTAR GPS user equipment and software, and also for assessing the noise and radio frequency environment at airports where non-precision approaches are used. The objective of these tests is to determine if the accuracy achievable with NAVSTAR GPS will be adequate to support non-precision approaches to these airports. As a supplement to these flight tests, a laboratory simulator will be developed for testing NAVSTAR GPS receiving equipment in order to provide additional performance data in a shorter time and at lower cost than by flight testing.

B. Low-Cost NAVSTAR GPS Avionics

A major goal of the DOT NAVSTAR GPS R,E&D program is to assess the feasibility of low-cost NAVSTAR GPS avionics with performance and cost acceptable to the general aviation user. Current industry projections of NAVSTAR GPS avionics cost for units which might be suitable to general aviation are between $3600 and $4000. This must be compared with the cost of the current VOR equipment which is widely used by general aviation and is generally available at unit cost in the vicinity of $1,000. The DOT cost analysis indicates that NAVSTAR GPS should not be considered as a replacement for VORTAC until avionics are available in the $2500 or lower price range, and until it is certain that such avionics can provide an adequately high level of reliability and failure detection.

An additional factor to be addressed in this area is the current commonality between low-cost communication and low-cost navigation equipment. Because communication and navigation currently share the same VHF frequency band, combined communication/navigation units can be purchased for a small increment over separate equipment.

Design studies are currently underway addressing low-cost receivers and antennas. Candidate low-cost antennas have been built and are available for aircraft tests. While it is believed that cost-effective avionics can be built for large air carrier aircraft, there is still a question of the feasibility of developing low-cost NAVSTAR GPS user equipment of adequate performance for general aviation. The ability to achieve the necessary accuracy for non-precision approaches using low-cost equipment when the aircraft is in a maneuvering configuration at low altitudes in the terminal area is of particular concern.

Studies, analyses, and computer simulations involved in answering the above issues will continue. In addition to the studies the FAA plans to initiate development of a low-cost engineering model receiver for general aviation and to perform evaluation tests on this receiver in the field and in the laboratory during 1980 and 1981. If this engineering model is successful, prototype work will be initiated in 1981.

C. FAA Recommendation

As indicated in Figure IV-2.1 the FAA plans to have completed all studies and tests of GPS by the end of 1982. This includes comparisons with other alternative navigational systems; e.g., VOR/DME and LORAN-C, which are discussed in detail in Appendix A. Before the DOT recommendation is made on NAVSTAR GPS, the FAA will formulate a recommendation to the Secretary of Transportation on the best future mix of air radionavigation systems. The recommendation will be based on two major factors:

1. Acceptable NAVSTAR GPS performance in the approach/landing and en route terminal phases of air navigation and in accordance with the user requirements specified in Volume II.

2. The cost effectiveness of NAVSTAR GPS as an alternative to other existing or proposed navigation systems. Cost effectiveness will be assessed for the entire aviation community over all phases of operation. The assessment will utilize the results of an FAA economic model which addresses both costs and benefits to individual user categories and to the FAA.

If the recommendation is favorable for use of NAVSTAR GPS to provide one or more navigation services, work on a national performance standard for NAVSTAR GPS civil avionics will be initiated in 1982. If not, studies will be initiated to investigate new navigation systems or to continue the improvement of existing systems. In either case, the economic factors relating to the international acceptance of alternative systems will be studied in terms of their affect on the FAA and aviation community comparing the overall costs with the Government and with the air, marine, and land users.

2.1.3 Civil Marine

The major R,E&D activities of the U.S. Coast Guard related to marine uses of NAVSTAR GPS are low-cost receiver technology studies, user field tests for comparative assessment of NAVSTAR GPS versus alternative aids to navigation, and assessment of coarse/acquisition (C/A) channel performance potential.

The objective of the marine program is to acquire a sufficient data base to determine those missions of the marine fleet for which the NAVSTAR GPS system can satisfy the navigation performance requirements. Issues important to the use of NAVSTAR GPS for marine navigation include:

A. Accuracy - Can it serve only as a one-quarter nautical mile (NM) navigator suitable for en route navigation through the U.S. coastal area, or can it provide the higher accuracies needed by commercial fishing and offshore industry, and can it give the accuracy required for Harbor Approach and Harbor navigation?

B. What are the technical and economic issues that dominate a NAVSTAR GPS receiver designed for civil marine use? What is a realistic estimate of receiver cost, and what technological factors might significantly alter this estimate? What receiver performance and cost trade-offs are feasible to develop NAVSTAR GPS equipment acceptable for (1) commercial ships over 1600 gross tons, and (2) smaller ships or tugs with barges?

C. Comparison of NAVSTAR GPS with current marine radionavigation systems is required. This comparison must be made with regard to navigation accuracy and repeatability, operational features and human factors considerations. Various missions must be considered, as well as a range of vessels from supertankers to Coast Guard cutters. This work must consider also the effect on electronics design and installation of the peculiarities of operations in protected waters and on the open ocean.

D. What are the practical results of testing NAVSTAR GPS receivers in the marine environment, such as: installation criticalities, marine and harbor environment peculiarities (RFI/multipath), and the suitability of performance and display for typical operations (e.g., fishing)?

The Coast Guard plans to have compl .ed its initial studies and tests for the Harbor and Harbor Approach phases of navigation by 1982. If NAVSTAR GPS is found to have potential use in these phases, the extent to which that potential may be realized will depend upon the eventual decision concerning the accuracy of NAVSTAR GPS service that will be made available for civil use. If feasible, within constraints imposed upon NAVSTAR GPS accuracy, additional Coast Guard R,E&D may be indicated, as follows:

1. Develop low-cost NAVSTAR GPS receivers for marine use, specifying modifications to basic FAA low-cost receiver designs, to meet requirements for precise navigation in Harbor Approach and Harbor Navigation.

2. Evaluate Vessel Traffic Service systems and procedures which are based on the performance and operation of NAVSTAR GPS in the Harbor and Harbor Approach phases. These include the assessment of traffic monitoring and control procedures, ship-board display requirements, and the human factors of vessel guidance and collision avoidance.

3. Evaluate the potential of NAVSTAR GPS for navigation on inland waterways.

4. Define the role of harbor surveillance systems and alternative navigation systems as a back-up for NAVSTAR GPS where requirements exist for additional reliability, special vessel activities, or during emergencies.

If NAVSTAR GPS does not satisfy the performance and cost-effectiveness requirements for the Harbor and Harbor Approach phases, studies will be initiated in 1983 to evaluate the increased use of alternative systems in these phases. Among these are harbor surveillance systems, improved aids to navigation, and differential LORAN-C with retransmissions from shore-based monitor stations.

Regardless of the results of the initial NAVSTAR GPS R,E&D, costs and benefit information for the Coast Guard and maritime users will be provided in 1982 to the DOT Navigation Economic Model. After 1982, future NAVSTAR GPS performance and cost improvements will be included in the model to provide an annual assessment of alternative systems.

The near-term U.S. Coast Guard R,E&D program has the following elements:

A. Receiver Technology Studies

The initial effort in the study of NAVSTAR GPS receiver technology is directed toward:

- A thorough understanding of the receiver design characteristics required for NAVSTAR GPS system operation in the marine environment.
- An analysis of the NAVSTAR GPS system identifying all performance factors and error sources, and developing a software simulator model for assessing the effect of alternative receiver designs on system performance.
- An in-depth survey of current and projected technology for all components of the NAVSTAR GPS receiver system.

Other USCG studies and developments included in this part of the program are not finalized beyond the initial phase identified above. As shown in Figure IV-2.1, tentative plans call for the development of a laboratory simulator in 1981 to test receivers in the NAVSTAR GPS environment. Hardware developments of critical receiver subsystems and components may also be pursued. However, the specific efforts of the future will depend on the results of the present research and the adequacy of the resultant information in predicting the performance of NAVSTAR GPS receivers in an operational marine environment. A receiver study report will be completed in 1982 and become an input for the formulation of a Coast Guard recommendation on NAVSTAR GPS for marine applications.

B. Marine User Field Tests

These tests will be a cooperative program involving the Coast Guard and MARAD in which MARAD provides the NAVSTAR GPS receiver system (a DOD procured "low-cost" receiver) and the Coast Guard provides the data collection system and acquires the data for use by both agencies. The objectives of these tests are (1) to assess the performance characteristics of a NAVSTAR GPS receiver operating in typical marine environments, and (2) to compare the accuracy of NAVSTAR GPS relative to other aids to navigation such as LORAN-C and OMEGA/TRANSIT in a series of field tests.

In May 1979, the Coast Guard began static tests and familiarization training using a single channel sequential receiver. In late 1979, ship-board evaluation testing will be initiated on the Texas A&M University oceanographic vessel which will travel throughout the Caribbean. The results of these tests will be presented in a preliminary report on this phase of the Coast Guard program.

Beginning in 1980 and continuing for approximately two years, one or more receivers will be used for testing on commercial vessels. Software and hardware modifications may be made to the receiver to optimize it for marine use.

A final report on NAVSTAR GPS receiver field evaluation will be issued at the conclusion of this part of the program with these results being an input into the Coast Guard recommendation on future navigation systems.

C. Assessment of C/A Channel Performance Potential

The objective of this effort is to determine the maximum accuracy obtainable with the NAVSTAR GPS coarse acquisition (C/A) channel. A dual-channel receiver modified to process only the C/A signals will be used in these tests to measure those errors that are irreducible, e.g., propagation variations, RFI, and multipath. This study includes the development of analysis software in 1979 and tests to run from late 1979 through 1980. Concurrent with this study, data will be acquired from the DOD and FAA tests and reviewed for additional C/A channel performance and error information.

The information gained from this study is expected to indicate if the NAVSTAR GPS C/A channel is potentially accurate enough for Harbor Approach and Harbor navigation or if it is useful only for less accurate navigation in the open sea. This important finding will be a significant factor in the direction of the follow-on Coast Guard NAVSTAR GPS R,E&D activities and also, in the Coast Guard recommendation to DOT on the marine applications for NAVSTAR GPS.

D. Coast Guard Recommendation

Figure IV-2.1 shows the schedule of the Coast Guard NAVSTAR GPS R,E&D activities planned during the next four years which leads to a 1982 Coast Guard recommendation to the Secretary of Transportation on the best future mix of radionavigation systems for marine users. The recommendation will be based on a comparison of the performance of NAVSTAR GPS to LORAN-C, TRANSIT, and OMEGA, and the results of studies of NAVSTAR GPS receiver costs and C/A channel performance. As indicated in Figure IV-2.1, the Coast Guard will also monitor the results of NASA low-cost receiver studies, FAA NAVSTAR GPS R,E&D, and DOD progress before making its recommendation.

2.1.4 Civil Land

Within the next five years, R,E&D in land applications of NAVSTAR GPS will become increasingly important to a large number of potential public and private users. In the public sector alone, applications of a precision radionavigation capability are now being explored by four DOT agencies (UMTA, NHTSA, FRA, and FHWA), other Federal departments (DOI, DOE, and USDA) and by state and municipal governments. These potential land users will depend on DOT, because of its statutory role in civil navigation, to provide continued and comprehensive information in three areas:

A. Firm definitions of NAVSTAR GPS availability for civil use at an accuracy which has been verified for a wide variety of land environments; e.g., cities, rural areas, rugged terrain, and types of vehicles.

B. Estimates of the range of NAVSTAR GPS receiver costs as a function of annual production quantities and an initial set of performance requirements.

C. Comparisons of the performance and costs of NAVSTAR GPS with those of alternative systems such as LORAN-C, short-range multilateration systems, and proximity systems, e.g., signposts.

In contrast to the case with the air and marine communities, most land applications of NAVSTAR GPS are relatively new and do not fall under the jurisdiction of a single agency (such as the FAA or the U.S. Coast Guard). For this reason, coordination and identification of user requirements and applications is being performed by the Research and Special Programs Administration (RSPA). The DOT NAVSTAR GPS land R,E&D plan in 1979 and the early part of 1980 will rely heavily on the results of air and marine R,E&D efforts. This approach is based on two factors: (1) many land vehicle dynamic performance characteristics can be obtained by interpolation between the performance results of faster aircraft and slower marine vessels, and (2) each DOT modal agency, outside of the Coast Guard and the FAA, will have time to specify the requirements, costs, and benefits of emerging applications of land navigation.

In late 1980 and 1981, a second stage of RSPA land R,E&D activities will address measurements of satellite signal margins in the presence of urban and rural radio frequency interference and signal attenuation factors such as terrain blockage and foliage. This phase is intended to establish initial guidelines for field experiments with engineering models of low-cost receivers. The results of these experiments and analytical comparisons of user costs and benefits for alternative systems will provide comprehensive data for the DOT Navigation Economic Model.

A. <u>NAVSTAR GPS Land R,E&D</u>

The specific task areas and schedules indicating the main year-by-year efforts of the NAVSTAR GPS Land R,E&D plan are summarized in Figure IV-2.1 and are described as follows:

1. User Applications Studies: Initial estimates of the required accuracy, tolerable costs, and benefits will be made from current and planned demonstrations of precision navigation applications. These demonstrations include AVM tests of public transit vehicles in Los Angeles, Emergency Medical Services (EMS) and highway accident and road inventory applications in New York State and Tennessee.

2. User Cost and Benefit Evaluations: This activity involves a review of the FAA and Coast Guard NAVSTAR GPS low-cost receiver design studies, and an evaluation of the costs and benefits of technically feasible, low-cost receiver applications.

3. Low-Cost Receiver Designs: An identification of the NAVSTAR GPS receiver performance requirements which are unique to land vehicles and their environments. The identification will include design modifications which may be required for land demonstrations with a limited number of C/A channel NAVSTAR GPS receivers.

B. RSPA Recommendation

After 1982, the RSPA R,E&D efforts will focus on a coordinated recommendation to the Secretary of Transportation on the applicability of NAVSTAR GPS with land use. Recommendations will be made annually and will rely on evaluations of the results of demonstrations of NAVSTAR GPS capabilities by the DOT modal agencies and other land users and expanded economic analysis of cost and benefit data for existing and emerging user groups. The evaluations will also include the results of field tests comparing NAVSTAR GPS performance to LORAN-C and proximity systems.

2.2 DOT R,E&D FOR EXISTING CIVIL NAVIGATIONAL SYSTEMS

2.2.1 General

The main purposes of DOT R,E&D on existing civil navigation systems are to improve reliability and service, decrease costs, and satisfy new requirements. The major DOT R,E&D for existing systems is outlined in the context of air, marine, and land areas of operation as follows:

A. Air

The FAA will continue its ongoing modernization and maintenance/ sustaining engineering of VOR and DME/TACAN in order to reduce the O&M costs and improve the performance of ground-based air navigation aids in the Continental United States (CONUS) and U.S. territories.

The FAA will continue to asesss the suitability of OMEGA as the primary means of navigation on oceanic air routes and evaluate the use of OMEGA and Differential OMEGA for helicopter IFR operations and for general aviation in remote areas. Except for oceanic areas, similar assessments will be made for LORAN-C.

The FAA will evaluate LORAN-C and NAVSTAR GPS as VOR/DME replacement candidates for the future air navigation system within CONUS, and NAVSTAR GPS as an alternative to OMEGA and self-contained units in oceanic air routes. The evaluations are described in detail in Appendix A and will involve field tests, low-cost receiver design studies for LORAN-C and NAVSTAR GPS, the separate development of minimum performance standards for area navigation (RNAV), an assessment of the impacts on pilot workload, blunder errors and flight inspection, and institutional issues, e.g., ICAO acceptance and signal availability.

Development activities for MLS and ILS will also be continued.

B. Marine

The DOT marine R,E&D for existing systems is composed of eight U.S. Coast Guard programs (which are described in detail in Appendix B) and one program being conducted by the St. Lawrence Seaway Development Corporation (SLSDC). These programs can be grouped by agency:

1. Eight Coast Guard advanced R,E&D projects which focus on system enhancements and improved techniques for the Harbor Approach and Harbor phases of operation. These include six LORAN-C projects on chain enhancements, propagation research, signal analysis, survey techniques, grid stability measurements, one project on ship-board display systems, and one on NAVSTAR GPS applications.

2. The SLSDC has an ongoing program to evaluate the feasibility of precision navigation systems for all-weather year-round applications in the St. Lawrence Seaway and Great Lakes regions. The program will provide demonstrations of LORAN-C, RAYDIST, and trisponder ranging systems uses during poor visibility conditions and during winter periods when the standard floating navigation aids must be removed.

C. Land

In its lead role in civil navigation, DOT is conducting R,E&D in cooperation with other Federal departments (the Departments of Energy, Agriculture, Interior, Commerce, and Health and Human Services) and State and municipal governments in order to explore land applications of navigation systems. These activities are identified in five areas:

1. The DOT Research and Special Programs Administration (RSPA), the National Highway Traffic Safety Administration (NHTSA), and the Federal Highway Administration (FHWA) are jointly conducting demonstrations of LORAN-C applications in New York State. The demonstrations will evaluate uses of LORAN-C for highway site registration, emergency medical services, and police car monitoring.

2. The DOT Urban Mass Transportation Administration (UMTA) is conducting an evaluation of the application of LORAN-C and proximity systems to fixed and random-route transit vehicles in the City of Los Angeles.

3. RSPA, FHWA, and NHTSA have developed LORAN-C mobile demonstration laboratories to assess LORAN-C signal characteristics and receiver performance in a number of State and local areas, e.g., Philadelphia, Boston, and Washington, D.C.

4. The Federal Railroad Administration (FRA) is evaluating the use of LORAN-C for monitoring train location in rail freight transportation.

5. RSPA has initiated a five-year program to assess LORAN-C land uses by the DOT modal agencies, other Federal departments, and State and municipal governments. This program is described in detail in Appendix C and is intended to specify the lead-in work required for a coordinated multiagency evaluation of a wide variety of potential land applications. These include fire suppression, cargo security, automatic vehicle monitoring of buses and police cars, aerial spraying, and many land inventory uses. The activities will cover measurements of LORAN-C signals and noise, technical assessments of the results of present and planned demonstration, government and statewide technology sharing, and comparisons of LORAN-C performance and costs with alternative navigation systems.

2.2.2 Specific Civil R,E&D Activities

The specific DOT activities for existing civil navigation systems and the relationships of these activities to the Federal Radionavigation Plan and the major decisions on system implementations are described in their associated air, marine, and land phases as follows:

A. Civil Aviation

The activities of the FAA, associated with improving navigation systems serving civil and military air users are scheduled as shown in Figure IV-2.2 The systems described are part of the existing National Airspace System and are presented in the categories of short-distance systems, off-shore and remote areas, oceanic, landing, area navigation, and helicopter IFR operations. In many of these areas, the FAA is developing requirements for accuracy and additional coverage to meet the projected growth in air traffic. These requirements will be used in technical and cost analyses to assist in determining the navigation system mix best suited for aviation.

1. Oceanic En Route

The FAA has approved the use of OMEGA for the purpose of updating self-contained systems including Doppler and inertial navigation systems. The FAA has recently approved dual OMEGA as a stand-alone oceanic air navigation system. The FAA OMEGA program includes activities to determine the continuing suitability of OMEGA as a sole means of oceanic navigation and the use of OMEGA as a remote area supplement to VOR/DME. The program approach is similar to that for the LORAN-C program and includes the establishment of a worldwide OMEGA data bank by collecting data on board domestic, foreign and government aircraft.

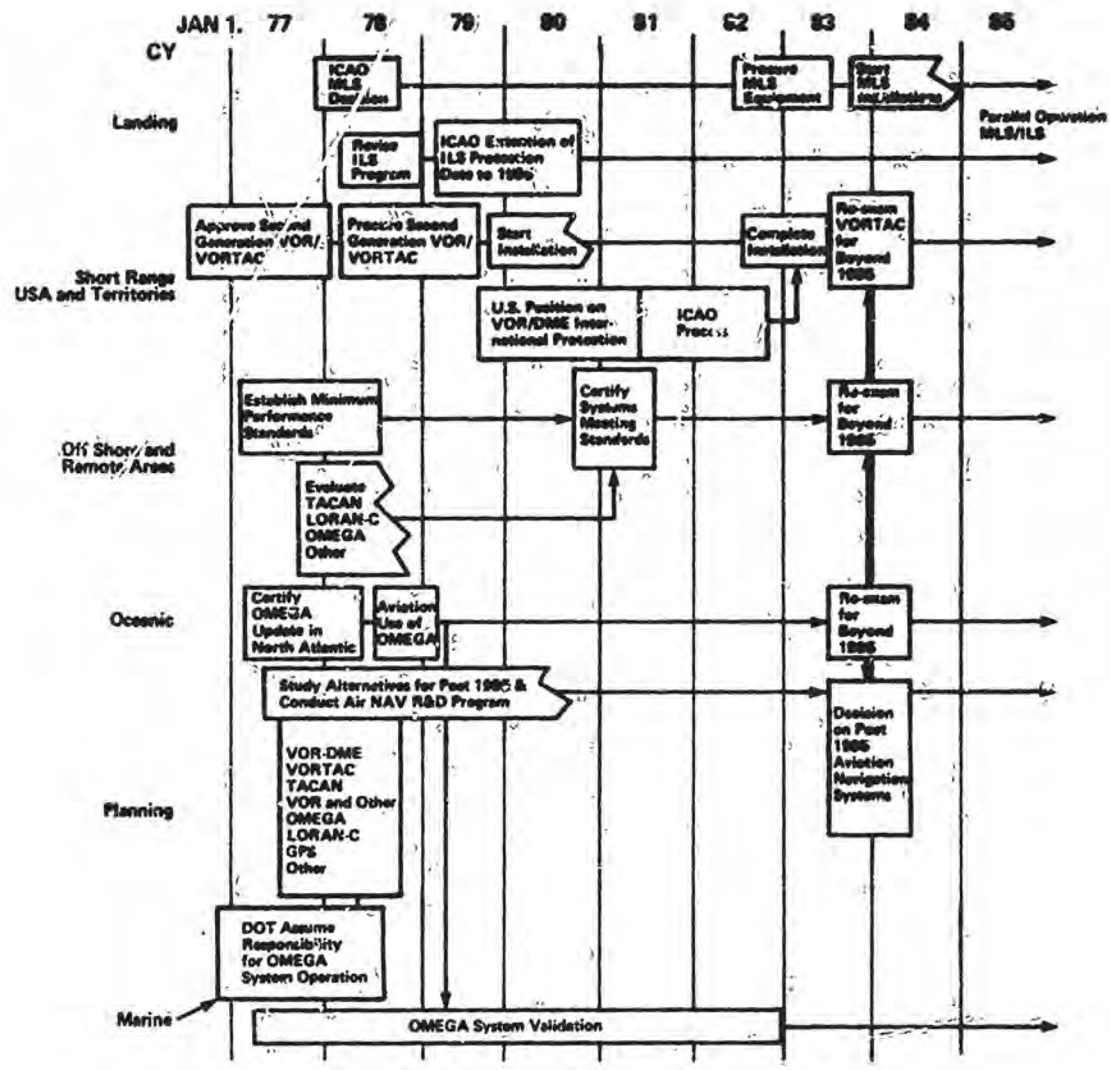


FIGURE IV-2.2 Air Navigation Actions/Decisions

Another activity in the FAA oceanic OMEGA program is the development and evaluation of an OMEGA-VLF monitor system. This system provides warnings on OMEGA and VLF signal outages and marginal signals and identifies the best stations for use in each geographical area. This information is to be provided to Flight Service Station (FSS) centers, and will be passed on to the pilots through Notice of Airmen (NOTAM).

Since the OMEGA system is required to operate at very low signal-to-noise ratios, another program activity is to develop a low-noise antenna. This antenna is now undergoing testing and evaluation. Future activities under the noise reduction program include studies of alternative methods of noise reduction, further antenna research, and determination of improved methods of discharging and bonding aircraft.

An OMEGA simulator is also being developed to permit rapid evaluation and certification of new OMEGA receiver designs. It will simulate a variety of signal-to-noise conditions of the OMEGA signal as well as station failure conditions and aircraft movement.

2. Domestic En Route (CONUS, Alaska and Hawaii)

The FAA is conducting a program to modernize the VOR/DME/TACAN system with solid-state equipment which will include remote maintenance monitoring provisions. This modernization program is expected to be completed in the mid-1980's. It is expected that this equipment will be in use at least until 1995.

A LORAN-C Monitor system is also being developed which will provide a real-time input to FAA Flight Service Stations (FSS) on the status of LORAN-C stations, identifying stations that are unstable or off the air for maintenance and providing data relating to planned outages. This information will be disseminated through the NOTAM.

The FAA LORAN-C program addresses the issue of LORAN-C signal availability and reliability; the performance of the LORAN-C system for en route, terminal, and non-precision approach operations; and the feasibility of developing low-cost avionics, particularly for general aviation. This is part of a joint effort between the FAA and the United States Coast Guard which includes establishing a LORAN-C data base, developing a LORAN-C monitoring system, evaluating various avionics equipments, developing low-cost avionics equipment, developing geographical grid corrections, and determining the impact of using LORAN-C navigation in the air traffic control (ATC) system and flight inspection procedures.

DOT (FAA and RSPA) and NASA are also conducting tests to assess the operational feasibility of using LORAN-C for en route, terminal and non-precision approaches for a number of airports in the State of Vermont. In addition, measurements will be made by the DOT of short-term variations in LORAN-C signal stability. NASA and RSPA will be examining long-term seasonal variations. FAA tests of LORAN-C aided non-precision approaches are also planned at other airports along the East Coast, the West Coast, and in Alaska.

3. Remote Areas (Including Off-shore)

While the present VOR/DME coverage meets most civilian user requirements, there are areas, such as some mountainous regions and low altitude airspace areas, where there is a requirement for air navigation service that VOR/DME does not presently provide. Alternatives being investigated to provide the required coverage include additional VOR/DME facilities, and supplementing the existing VOR/DME system with LORAN-C, OMEGA, and OMEGA/VLF. Currently, OMEGA/VLF is approved as a supplement to VOR/DME with LORAN-C approval expected to be completed within a year.

As part of a remote area air navigation R,E&D effort, the FAA plans to start an evaluation program with Transport Canada on a Differential OMEGA system in the Fall of 1979. Three nondirectional beacons will be equipped to transmit the ferential OMEGA corrections to aircraft. The evaluation will be conducted over the next year in the Alaskan Region, and will involve the FAA flight inspection Convair, a Canadian Twin Otter and some cooperating commercial aircraft operations. It is anticipated that four sets of avionics will be used for the program.

4. Helicopter IFR Operations

The FAA is examining special navigation requirements of helicopters for operation within the air traffic control system, both within the CONUS and in offshore areas. The portion of this program relating to navigational requirements covers the operational evaluation of LORAN-C and OMEGA as well as VOR/DME and DME/DME for operations on area navigation routes within the CONUS and on specially defined routes suitable for supporting offshore oil exploration. The program will also examine the use of airborne weather radar in conjunction with supplementary equipment to assist in locating and making approaches to offshore platforms. This latter activity will examine the effectiveness of several techniques including active beacon systems, passive reflectors, corner reflectors and a variety of RF lenses for this purpose. Data collection will be conducted using a NASA CH-53H helicopter operating along the area navigation routes between Boston and Washington. Another FAA effort will be data collection by the FAA/NASA helicopter operating in the offshore area in the vicinity of Atlantic City. The data collection system will simultaneously be taking data from the VOR/DME (where available), LORAN-C, and OMEGA stems on board the helicopter.

In addition to the FAA helicopter activity, the Coast Guard will be operating a helicopter with LORAN-C avionics equipment along a route between Otis Air Force Base in Massachusetts and Washington National Airport. The helicopter will take position data from the Automated Radar Terminal System (ARTS) III facilities located along the route and from an FAA precision radar at National Aviation Facilities Experimental Center (NAFEC) in order to assess the performance of the LORAN-C system in helicopter operations.

5. Area Navigation

The FAA has implemented Area Navigation (RNAV) routes. The objective of the RNAV program is to support integration of RNAV, in an evolutionary manner, into the National Airspace System. At present the main objective is associated with development of avionics standards. This FAA activity will be closely coordinated with the aeronautical industry. The end products of the RNAV program are the development of minimum performance standards for avionics prepared with the coordination of industry.

The advent of latitude/longitude grid navigation systems such as LORAN-C and NAVSTAR GPS has increased awareness of the pilot workload, pilot blunder and system integration problems involved in using latitude/longitude RNAV equipments. RNAV procedures with such systems may differ from RNAV based on the VOR/DME system. Typical LORAN-C equipment will be installed in a simulation facility to study problems related to pilot/controller workload, real time coordination, and minimization of flight technical error for various civil air user groups, e.g., VFR through high density IFR. R,E&D will also be devoted to development of RNAV charting concepts and waypoint definition.

6. Non-Precision Approach

As indicated in paragraph 3 above, a number of activities are underway related to LORAN-C use for non-precision approaches.

The joint U.S./Canadian Differential OMEGA work (paragraph 3 above) will address the feasibility of Differential OMEGA use for non-precision approach in Alaska.

Some of the RNAV work (paragraph 3 above) is also applicable to the non-precision approach area.

7. Precision Approach and Landing

At the ICAO meeting in April 1978, the member states agreed that the instrument landing system (ILS) would be operated at international airports until at least 1995. ICAO also decided on a specific microwave landing system (MLS) technique to be used as the international standard. While the ILS system currently in use has an excellent safety record, the MLS is being proposed as a replacement because the siting and installation problems are much less pronounced, which makes the MLS usable at more locations and with lower installation costs than ILS. Also, there is a limit on the number of ILS facilities that can be installed in a small geographical area because of radio spectrum crowding problems. The cost impacts of MLS dictate careful and continued consultation and cooperation with both domestic and international interests.

B. Civil Marine

The plans of the USCG for improving marine navigation systems, which serve the civil maritime user, are described below and scheduled as shown in Figure IV-2.3 The Figure also indicates the DOT Navigation Economic Model and the inputs required from the air and land phase prior to a DOT decision on post-1995 navigation systems. The discussions are presented in terms of the phases of marine navigation as follows: Oceanic, Coastal, Harbor Approach, Harbor and Inland Waterways.

1. Oceanic

The USCG is in the process of validating the coverage and accuracy of the OMEGA system as an oceanic aid to navigation for marine and aviation users. The OMEGA navigation system provides general purpose en-route navigation service worldwide for marine and air users from a network of eight stations.

There remain some questions about the actual worldwide performance of OMEGA. The Coast Guard will promulgate progressively, on a regional basis, the results of a worldwide general assessment of the coverage and accuracy of the OMEGA system.

As each given geographic area is thus validated, the OMEGA system users will be advised concerning operational limitations as appropriate. The OMEGA system cannot be declared fully operational, worldwide, until the eighth station is in operation, and the accuracy and coverage is measured and validated. This is expected to take place sometime in 1982. Operation and validation of the OMEGA navigation system, and the progressive improvement of corrections for OMEGA propagation errors, are the major Coast Guard activities associated with oceanic navigation.

2. Coastal

The primary system in use for U.S. coastal marine navigation is the LORAN-C system. LORAN-C is replacing LORAN-A in this phase of marine navigation, the latter being terminated in December 1980. OMEGA is the designated LORAN-A replacement for ocean navigation. A national implementation plan was initiated to provide LORAN-C coverage in the Coastal area of the contiguous 48 states, Southern Alaska, and in the Great Lakes. New station implementation and reconfiguration of one existing chain are essentially complete, except for one new station which will complete the coverage of the Wes rn Great Lakes in 1980. This plan adds 12 U.S. stations and 2 Canadian stations to the network of stations built originally for the DOD throughout much of the Northern Hemisphere.

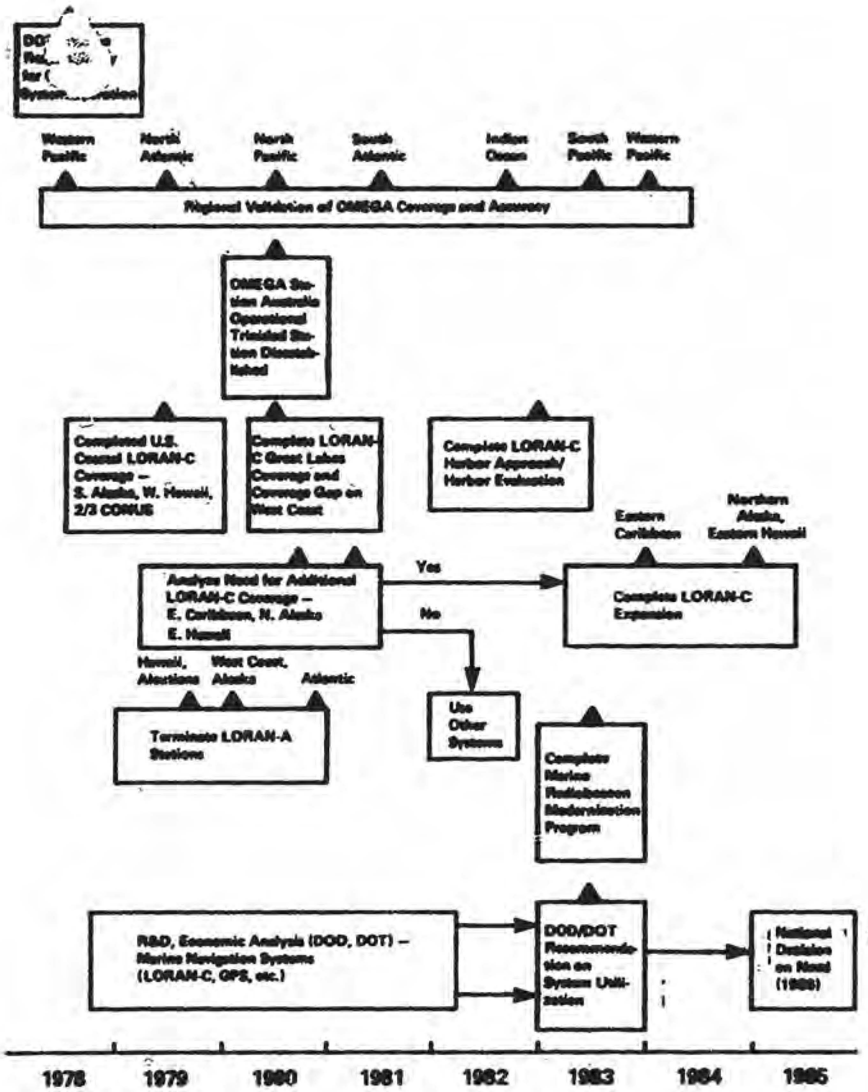


FIGURE IV-2.3 Marine Navigation Actions/Decisions

Extensions of LORAN-C coverage to the Eastern part of Hawaii, the Alaskan north slope, and Puerto Rico and the Virgin Islands are now being considered by the Coast Guard. Decisions will be made by 1982 and will involve an assessment of Federal and user costs and benefits, user requirements, and the extent of geographical coverage to be provided by various LORAN-C configurations and transmitter power levels. The decision to provide additional coverage for the Alaskan North Slope depends on both air and marine navigation requirements. A review of the maritime requirements is scheduled for 1980. In the meantime, the FAA is evaluating LORAN-C, OMEGA/Differential OMEGA, and VOR/DME for air navigation in this region.

The USCG operates a network of marine radio-beacons to provide the primary radio aid to navigation for many smaller vessels and boats. The radiobeacons are also used by many large ships for homing and harbor approach. In the U.S., there are 196 existing radio beacons today, and 30 more are being established to meet the increasing use by small vessels. The current improvement program will replace 48 different types of obsolete, unreliable radiobeacon equipment with a standardized design of solid-state transmitting equipment which will reduce annual operations and maintenance costs.

Radar beacons (RACONS) are short-range radio devices used to provide radar reference points in areas of flat coastal terrain and other places where it is important to identify a special fixed or floating aid. The Coast Guard is planning to add a modest number of swept-frequency RACONS in the 1980's to meet critical requirements.

3. Harbor Approach, Harbor, and Inland Waterways

There are a number of projects to investigate the use of LORAN-C for other than offshore marine navigation in the coastal area. The retransmission of LORAN-C coordinates is being examined for use in surveillance and tracking of marine vessels. The Coast Guard is developing LORAN-C for use as a precision navigation system in Harbor Approach and Harbor areas. For example, a mini-LORAN-C chain installed in the St. Marys River is being evaluated to establish the capabilities of a short baseline LORAN-C chain configured specifically for precision navigation in a localized harbor area.

The St. Lawrence Seaway Development Corporation (SLSDC) has undertaken a program to improve all-weather navigation in the St. Lawrence Seaway. The program is expected to result in a three to fourfold increase in system capacity during those periods at the beginning and end of the shipping season when conventional lighted, floating aids to navigation have been removed because of ice.

Under the Congressionally mandated and funded Great Lakes-St. Lawrence Seaway Navigation Season Extension Demonstration Program, the SLSDC, in its capacity as U.S. lead agency for operations in the St. Lawrence River, is pursuing a demonstration project comprised of:

a. A definition of system requirements -- system capacity as a function of accuracy and specification of guidance parameters and reliability.

b. The development of a test plan -- selection of a test bed for the Saint Lawrence River and definition of test procedures.

c. A survey of available electronic positioning systems, including shipboard hardware.

d. A full evaluation and validation of the system requirements utilizing one or more selected systems.

From the test results, the SLSDC, in consultation with its Canadian counterpart, will assess the costs and benefits of the various types of all-weather navigation systems. The decision to go ahead with an installation in the Saint Lawrence Seaway will depend on the results of the cost and benefit study.

C. Land Navigation

As navigation benefits to land users become apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve multimodal civil users may prove cost-effective. DOT R,E&D activities are planned, therefore, to investigate the potential benefits of LORAN-C to both public and private land users, e.g., truck fleets, rail vehicles, buses, and police and emergency vehicles.

The LORAN-C stations which serve maritime navigation in the U.S. CCZ and the Great Lakes also provide coverage over two-thirds of the land area of the contiguous 48 states, and 92 percent of its population. This service has many potential applications which can be expanded on a more economical nationwide basis by the addition of three to five LORAN-C stations in the mid-continent. The Coast Guard is prepared to build these stations and incorporate them into the existing LORAN-C network if the Secretary of Transportation directs this expansion of LORAN-C coverage for the benefit of land users.

There appears to be a great number of potential uses for radio-location service on land which may provide substantial benefits to transportation. Federal, State, and private organizations are becoming increasingly aware of this potential. Organizations within DOT such as FHWA, FRA, NHTSA, and UMTA are conducting or planning projects to investigate land use of LORAN-C. An application of LORAN-C in urban areas for automatic vehicle monitoring is currently being sponsored by UMTA.

The Departments of Energy, Agriculture, Interior, Commerce, and Health, and Human Services, as well as a number of States, are conducting or planning projects involving land applications of a radionavigation capability. To date, the projects are generally investigations to develop techniques to use LORAN-C for specific purposes where its accuracy, availability, and low user costs may be adequately demonstrated. It appears highly probable that in future years, "land navigation" will develop as a growth industry providing maj- benefits for government, industry, and the general public.

The major DOT land navigation actions are described in detail in Appendix C. An analysis of the mid-continent cost/benefits of LORAN-C for land user applications has been completed and a report was published in January 1979. Concurrent with this analysis are land application demonstrations of LORAN-C being carried out by DOT and several State governments. A LORAN-C R,E&D program is in progress to obtain data on propagation effects of LORAN-C coverage, signal margins, and radio frequency interference. The critical issue for land users pertains to the DOT decision to extend LORAN-C coverage to the mid-continent region of the contiguous U.S. Assuming such a decision is made, major efforts will be devoted to expanding the implementation of land applications of LORAN-C for the increased number of users who will require the nationwide navigation capability. The efforts will emphasize the transfer of technology to both the public and private sectors.

D. NAVSTAR GPS R,E&D Planned by the NASA Office of Aeronautics and Space Technology (OAST)

The currently planned OAST activities are largely associated with the civil application to NAVSTAR GPS and involves both Space and Aeronautics R,E&D. The space activities are focussed on providing accurate onboard time and position which either NAVSTAR GPS or TDRSS might provide. The aeronautics tasks involve antenna-siting investigations and low-cost receiver design concepts for civil aircraft navigation.

While OAST has no requirements per se, survey of potential space users indicate that most scientific and applications missions require position accuracy no greater than 50 meters. However, to perform onboard image registration, position accuracies of 5 to 10 meters will be required. On the aeronautical side, research has been conducted on automatic landings for commercial transports using the FAA NAFEC facilities and the NASA terminal configured vehicle (TCV) research aircraft. Our findings indicate that to handle high traffic capacity at major terminals, the following accuracies (2 sigma) might be necessary:

Cross Track	±30 meters (100 ft.)
Along Track	±1.5 to 3 M (5-10 ft.)
Vertical	±0.3 to 0.6 M (1-2 ft.)

Requirements for general aviation aircraft would be less stringent. OAST will be working with the FAA to develop future navigational requirements for other phases of flight.

A detailed outline of space and aeronautics activities is as follows:

1. Space R,E&D

As part of the NASA end-to-end data system (NEEDS) program, OAST is developing techniques and procedures to provide accurate onboard orbit, altitude, and time; and defining components necessary for onboard imaging registration capability for earth-pointing imaging spacecraft such as LANDSAT-D. This effort includes the establishment of a simulation laboratory where applicable onboard orbit and attitude determination and control algorithms can be developed and rigorously tested using minicomputers and a group of microprocessors that generate the appropriate sensor data in parallel. This ground breadboard system will be supplied actual C/A and P code NAVSTAR GPS data.

2. Aeronautics R,E&D

OAST is in the process of discussions with the FAA on a joint program which could lead to an augmentation of our current plan over the next several years. These added tasks might entail cooperative experimentation and system demonstrations using NAFEC facilities, for example, and, if and when they materialize, the current plan will be updated and the information forwarded.

Efforts involve antenna-siting investigations and low-cost receiver design concepts. The antenna task will establish siting requirements for various types of civil aircraft and will involve laboratory experiments with about two aircraft models per year.

At the request of the FAA, NASA has been involved in studies of low-cost approaches to the development of NAVSTAR GPS receivers for general aviation navigation. The principal driver is achieving a unit cost for a 10-20 meter system which would be attractive to commercial and private aviation users.

The conceptual design of a low-cost receiver has both study elements and laboratory analysis/experimentation. The studies involve investigating innovative design options which may be suitable for a civil but not a military application and establishing civil navigational accuracy requirements. A satellite simulator and breadboard receiver will be procured to provide a laboratory research tool for concept analysis and experimentation.

In FY 1981 studies will be made on advanced architecture concepts. The breadboard receiver will be modified in FY 1981 and FY 1982 with experimental sub-systems and circuits to evaluate the potential for a low-cost, practical design. Further modifications will be made during FY 1982-84, based on selected technology development such as Charge Coupled Devices (CCD), microwave integrated circuits, low-cost clock concepts, etc., to assess their potential so that in FY 1984 OAST will be in a position to study receiver design options and trade-offs based on our laboratory experimental findings.

VOLUME IV

CHAPTER 3

DOD RADIONAVIGATION RESEARCH, ENGINEERING & DEVELOPMENT

3.0 DOD R,E&D ACTIVITIES

DOD R,E&D activities described in this volume concentrate only on those radionavigation systems that have clearly defined common-user (civil/military) characteristics. Common user systems include those which emit signals in space which are available to anyone using properly designed equipment obtainable without restrictions. Further, these systems are available on a full time basis, and are not dependent on tactical military operations. At this point in time, common-user systems having active R,E&D programs are NAVSTAR GPS, TRANSIT, and MLS.

3.1 OBJECTIVES

The DOD R,E&D plan for radionavigation systems describes only engineering development activities affecting common-user radionavigation systems. These activities are primarily driven by the mission requirements of the commanders of the Unified and Specified Commands and the Military Departments/Services. These mission requirements normally include accurate navigation within the Continental United States, in oceanic areas, and in overseas theaters. Other requirements include security, resistance to meaconing, interference, jamming and intrusion and saturation limit and worldwide coverage. These radionavigation requirements form the basis for the overall DOD R,E&D program which impacts a wide range of equipments, some of which have common-user characteristics.

3.2 RESPONSIBILITIES

DOD and its component elements are responsible for developing, testing, evaluating, operating, and maintaining aids to navigation and user equipment for miliary missions. DOD is also responsible for assuring that military vehicles, operating in consonance with civilian vehicles have the required navigation capabilities to operate in a safe and expeditious manner.

3.3 R,E&D EFFORT

3.3.1 NAVSTAR GPS

The major R,E&D effort addressed to common-user systems is being applied to the NAVSTAR Global Positioning System (GPS). This system, currently in the engineering development phase, will have a significant effect on the use by the Armed Services of LORAN-C, OMEGA, TACAN, TRANSIT and VOR/DME. Current efforts in Phase II (Full Scale Engineering Development) include initiation of development of prototype user equipment, initiation of prototype satellite and control station production, and initial operational test and evaluation of user equipment. Details concerning NAVSTAR GPS program goals, schedules, and test planning are contained in Appendix D, DOD Research, Engineering and Development for Selected Radionavigation Systems.

3.3.2 TRANSIT

TRANSIT development is essentially complete except that two additional TRANSIT satellites are planned for launch in CY 1980. The only exception is a low-level effort to modify the TRANSIT satellites to be compatible with the attach points in the space shuttle orbiter bay for easier integration.

3.3.3. Microwave Landing System (MLS)

MLS R,E&D activities are currently limited to participation, within the scope of responsibility and the funding authorized to the Federal Aviation Administration, to ensure that maximum progress is made toward providing the DOD with an operationally effective tactical microwave landing system design. Objectives for the DOD participation are interoperability between avionics and ground installation, civil or military; performance accuracy in compliance with MLS standards and military requirements; reliability, maintainability, producibility and life-cycle-cost goals attainment; achievement of size, weight and human factor goals; and demonstration of approach flight capabilities and Short Take-off and Landing (STOL) and Vertical Take-off and Landing (VTOL) projections.

FEDERAL RADIONAVIGATION PLAN

APPENDIX A

FAA RADIONAVIGATION RESEARCH, ENGINEERING & DEVELOPMENT

TABLE OF CONTENTS

APPENDIX A
LIST OF ILLUSTRATIONS

APPENDIX A

FAA RADIONAVIGATION RESEARCH, ENGINEERING, AND DEVELOPMENT

This appendix discusses and summarizes the current civil air navigation system alternatives, and the complete FAA radionavigation R,E&D plan. The plan contains the framework for providing the operational and technical data base needed for the selection of the future civil air navigational system.

The FAA under the Federal Aviation Act of 1958 (PL85-726) has responsibility for development and implementation of radionavigation systems to meet the needs for safe and efficient navigation and control of all civil and military aviation, except for those which are peculiar to air warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

1.0 ALTERNATIVE RADIONAVIGATION SYSTEMS AND ISSUES

1.1 IDENTIFICATION OF ALTERNATIVE NAVIGATION SYSTEMS

The alternative navigational systems discussed below are VOR/DME, NAVSTAR GPS, LORAN-C, and OMEGA. They are discussed with respect to domestic, oceanic, and offshore airspaces. LORAN-C and OMEGA are also discussed as supplements to the present VOR/DME system.

1.1.1 Oceanic En Route Phase

Oceanic coverage can be achieved by using a long-range, ground-based system, a self contained system or a satellite-based system. The three systems discussed below for this function are OMEGA, NAVSTAR GPS, and LORAN C.

A. OMEGA

The OMEGA system is currently used in the oceanic airspace as a stand alone navigational system and as a LORAN-A replacement. It provides worldwide coverage such that those aircraft engaged in international operations can use their OMEGA equipment anywhere.

B. NAVSTAR GPS

NAVSTAR GPS, when implemented, could serve as the successor to OMEGA for oceanic use. It should enjoy the coverage advantages of OMEGA, should provide a much higher accuracy and, in addition, possess the potential to provide a domestic en route as well as an oceanic system.

1.1.2 Domestic En Route & Terminal Phase

A. VOR/DME

VOR/DME* is the worldwide civil short range air navigational system. It has been adopted and standardized by the International Civil Aviation Organization (ICAO). The air routes of the National Airspace System (NAS) are based upon VOR/DME. The standard route structure is a network of fixed point-to-point segments. The route guidance is provided by fixed radial courselines emitted from the VOR ground stations. Hence, general aviation aircraft are able to fly in the NAS, under Instrument Flight Rules (IFR), with only VOR navigation. In addition, the VOR provides navigational information to the pilots of thousands of aircraft who are flying under Visual Flight Rules (VFR). The DME, collocated at the VOR ground station, provides distance from the ground station. It is carried by about 25 percent of the general aviation fleet and is required for air carriers. The DME simplifies and forms the basis of some ATC procedures, especially in the terminal area. VOR/DME angle and distance information is readily transformable to provide navigational information along any desired flight path, if the aircraft is within ground station coverage. Navigational capability, allowing flight along any desired path, is called area radionavigation (RNAV). More than 10,000 RNAV sets are in use today by civil aviation, and continued growth is expected.

The majority of the VOR ground facilities in the U.S. is collocated with the military TACAN** system. TACAN provides DME to both the civil and military users and azimuth informations to the military users. Thus, both civil and military users can navigate in the NAS in a compatible manner. The VOR/DME is affordable to the general aviation users, who constitute the largest number of users, and is well thought of by the air carriers. The user can opt for various levels of capability (radial navigation to area navigation) to suit his needs. Therefore, the modernized VOR/DME, presently under procurement being attractive to both the government and the users, is of the candidates for the future civil air navigation standard.

B. NAVSTAR GPS

NAVSTAR GPS is a satellite-based navigational system which is being developed by DOD primarily for high accuracy weapons delivery and other military missions. It will use orbiting satellites to provide L-band,*** worldwide, continuous, all-weather, information to users operating in a passive mode.

As compared with VOR/DME, NAVSTAR GPS could provide low-altitude coverage over all of the continental United States and it is inherently an RNAV system. It has the potential to become a multimodal and common civil/military system.

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* VOR - Very High Frequency (VHF) Omni Range, 108-118 MHz band, DME - Distance Measuring Equipment, 960 - 1215 MHz band.

** TACAN - Tactical Air Navigation gives both radial and DME, 960-1215 MHz band.

*** L-Band - 1227 MHz and 1575.42 MHz.

However, the civil aviation user could be required to purchase a level of navigational equipment which is significantly more costly than VOR/DME. That is, a user, whose primary need is radial navigation, may not be willing or able to pay a higher price for increased capability.

C. LORAN-C

LORAN-C is a low-frequency, pulsed ground-based navigational system. In its most common mode of use (hyperbolic) it requires navigational signals to be received from three ground stations. LORAN-C has been implemented as the Government-provided marine navigational system for the U.S. Coastal Confluence Zone. (CCZ) This implementation has resulted in coverage over most of the continental United States, with the exceptions of the mid-continental region. DOT studies indicate that complete coverage for land position determination can be obtained by the addition of three more ground stations. This coverage will not be adequate for aviation since the outage of a ground station would have a significant impact on air traffic operations. An FAA study indicated that 13 or more additional ground stations would be required to assure sufficient coverage in the event of a ground station outage. The performance of the aviation user's equipment is more critical than other users because of the time dynamics of air traffic operations.

LORAN-C, like NAVSTAR GPS, is an RNAV system which can provide low altitude coverage. LORAN-C is being flight tested as an RNAV system supplement to VOR/DME and in areas without VOR/DME coverage.

D. OMEGA/Differential OMEGA

OMEGA is a very low frequency (VLF) radionavigation system which supplies almost worldwide coverage with only eight ground stations. OMEGA has been approved as an en route RNAV system supplement to VOR/DME under certain conditions.

Differential OMEGA is not currently considered as a primary candidate for domestic air navigation, primarily because it does not appear to provide adequate signal coverage over all of the continental United States. However, the FAA is conducting flight test evaluations of Differential OMEGA as a supplementary system for remote areas such as Alaska, where adequate signals do exist.

1.1.3 Remote Areas

Remote areas are defined as regions which either do not meet the requirements for installation of VOR/DME service or where it is impractical to install this system. These include offshore areas, mountainous areas, and a large portion of the State of Alaska. The systems being investigated to provide aviation navigational service in these areas are OMEGA/Differential OMEGA, LORAN-C, and NAVSTAR GPS.

A. OMEGA/Differential OMEGA

The OMEGA system, used in conjunction with the Navy VLF communication network, has been providing navigational service for operations in the offshore environment- outside coverage of the VOR. It enjoys limited certification as a supplement to VOR for IFR operations and it is expected to be used for the foreseeable future. This system (in the Basic and Differential Mode) is also being evaluated for the remote areas such as the Alaskan regions.

B. LORAN-C

LORAN-C is being considered and is expected to be certified as a supplement to VOR/DME in the near future.

C. NAVSTAR GPS

NAVSTAR GPS, when implemented, will be a candidate for providing aviation navigational service in remote, as well as worldwide, areas.

1.1.4 Helicopter Operations

Helicopter operations occur in offshore domestic low-altitude airspace. Since VOR/DME is limited to line-of-sight coverage, it generally cannot provide the required navigational service. The systems of interest are the same as those for Remote Areas (OMEGA/Differential OMEGA, LORAN-C and NAVSTAR GPS).

A. OMEGA

The OMEGA system, used in conjunction with the Navy VLF communication network, has been providing navigational service for operations in the offshore environment; outside coverage of the VOR. It enjoys limited certification as a supplement for IFR operations and it is expected to be used for the foreseeable future. This system (in the Basic and Differential Mode) is also being evaluated for the remote areas such as the Alaskan regions.

B. LORAN-C

The LORAN-C is being considered for providing the navigational service for helicopter operations as a supplement to VOR/DME. Both the U.S. Coast Guard and civil helicopter operators are pursuing programs with the FAA to obtain LORAN-C certification for instrument flight operations.

C. NAVSTAR GPS

NAVSTAR GPS, when implemented, will become a candidate for providing navigational services for helicopter operations.

1.1.5 Approach and Landing Phase

A. Precision Approach and Landing

NAVSTAR GPS (for non-DOD users) and LORAN-C are not sufficiently accurate for this phase of operations and it is not being considered. Specialized precision approach and landing systems, e.g., Instrument Landing System and Microwave Landing System, are the only systems capable of meeting requirements in this phase.

B. Non-Precision Approaches

1. VOR is currently in use for non-precision approaches.

2. NAVSTAR GPS

NAVSTAR GPS is being considered for non-precision approach phase of navigation. The effects of NAVSTAR GPS pilot workload on Flight Technical Error and Blunder Rate, NAVSTAR GPS unique system errors, and NAVSTAR GPS available civil-user accuracies, are being investigated.

Flight Technical Error (FTE) refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the indicated aircraft position to match the indicated command of desired position. It does not include procedural blunders. A blunder error is defined as a significant unintended and undetected deviation from the desired flight path.

3. LORAN-C

Evaluations are currently in process to determine the effects of LORAN-C pilot workload and signal characteristics.

4. Differential OMEGA

Evaluations similar to LORAN-C are currently underway.

1.1.6 Summary of Identified Systems

The identified systems to be considered by the FAA are:

A. Oceanic En Route Phase

- OMEGA*
- NAVSTAR GPS

B. Domestic Terminal and En Route Phase

- VOR/DME supplemented by OMEGA and LORAN-C
- NAVSTAR GPS
- LORAN-C

C. Special En Route Phase (Remote & Helicopter)

- OMEGA/Differential OMEGA*
- LORAN-C*
- NAVSTAR GPS

* Self-contained aids including inertial navigation and Doppler radar systems with update from one of these aids are also being considered.

D. Non-Precision Approach and Landing Phase

- o VOR/DME
- o NAVSTAR GPS
- o LORAN-C
- o Differential OMEGA
- o Non-Directional beacons

E. Precision Approach and Landing

- o Instrument Landing System (ILS)
- o Microwave Landing System (MLS)

As can be seen, NAVSTAR GPS is the only system which has the potential to provide a single-air navigational aid for all phases except Precision Landing.

1.2 CRITICAL ISSUES

There are certain issues that are common to the implementation of any candidate system other than the present VOR/DME system. These are:

A. Concurrent operations of multiple navigational systems and standards during the transition period.

B. Reliability of the signal in space and signal status information dissemination to pilots and controllers.

C. Flight inspection method to be carried out for the alternative system.

Specific systems issues are discussed below.

1.2.1 NAVSTAR GPS Issues

Some of the key factors that will impact the decision on civil use of NAVSTAR GPS are operational feasibility in the ATC environment; ability to enable general aviation and air carriers to perform critical navigational functions now being provided by VOR/DME; costs to these users and the government; and the importance of improving navigational capabilities to meet potential future needs. The critical issues related to three broad categories are technical, economic, and institutional.

A. Technical Issues

1. NAVSTAR GPS signal level and accuracy (degraded mode);

2. Operational suitability of low-cost, single frequency user equipment;

3. Suitability for non-precision approach;

4. RF interference susceptibility;

5. Multipath problems during approach;

6. Aircraft antenna coverage;

7. Initial acquisition time and acquisition time during flight;

8. Human factors of the man/machine interface such as, pilot workload, flight technical error, blunder rate, cockpit automation and pilot confidence when performing approaches;

9. Satellite constellation failure modes detection and restoration time; and

10. System integrity.

B. Economic Issues

1. Overall user costs and cost recovery;

2. Operational feasibility of low-cost avionics suitable for non-precision approaches in single pilot aircraft;

3. Civil/military cost sharing; and

4. Implementation plan impacts.

C. Institutional Issues

1. Availability to the civil/international community;

2. System operational responsibility (U.S. civil, U.S. military, or an international body); and

3. ICAO acceptance of a new U.S. military weapons delivery system for navigation.

1.2.2 LORAN-C Issues

Although LORAN-C is an operational maritime radionavigation system, the FAA's experience with the LORAN-C for air navigation is still limited. The technical issues applicable to NAVSTAR GPS are, to some lesser extent, applicable to LORAN-C. Other areas of concern are its signal error characteristics, suitability of low-cost receivers, feasibility of adding the additional stations required for redundancy, potential power line switching interference problems, and potential cross chain interference problems. Institutional and economic issues applicable to NAVSTAR GPS are generally applicable to LORAN-C.

1.2.3 VOR/DME Issues

VOR/DME meets the short-range needs of today and the near future at a minimum. Until a definitive (post-1995) air navigation requirements analysis becomes available, the capability of VOR/DME to meet such future requirements cannot be fully assessed. Previous R,E&D performed by the FAA has demonstrated that the accuracy of the VOR can be improved and the capacity of the DME can be increased sufficiently to meet forecasted aviation growth. Thus, the only remaining major requirement that cannot be met is remote area and low-altitude coverage (due to its line-of-sight radio propagation limitation).

2.0 FAA RADIONAVIGATION R,E&D PLAN

This section presents detailed discussions of the more important R,E&D task efforts supporting a 1983 recommendation on the choice of the future radionavigation system structure.

In order to facilitate meaningful evaluation and assessment of alternative future navigational systems, it is necessary to establish a reference document that outlines the present navigational capabilities and the requirements for the future. This is by no means an easy task because many features of the present system are not documented as explicit requirements. (Examples are degree of signal processing, system integrity, pilot workload, and blunder protection.)

The FAA has prepared and is revising a draft document entitled, "Civil Aviation Navigation Requirements." This document presents issues which require further quantitative analysis and which form the basis for current FAA R,E&D activities. Future navigational requirements will be developed so that candidate navigational systems can be evaluated within a standard framework. Figure A-1 presents the plan for detailing present navigational capabilities, determining future navigational requirements, and evaluating alternative system structures.

2.1 EXAMINATION OF NAVSTAR GPS AS A CANDIDATE SYSTEM

The overall objective of the tasks detailed below is to determine the potential of NAVSTAR GPS to satisfy the requirements of the civil air navigation. The primary considerations are system performance within the National Airspace System and costs to general aviation, air carriers and the government. This section concentrates on the coupled issues, performance and receiver costs. The tasks related to the impact of NAVSTAR GPS operating in the ATC environment are addressed in Section 2.6.

In the analysis of NAVSTAR GPS performance and receiver costs, four tasks have been identified: Analysis and Simulations (Section A-2.1.1); Assessment of Signal and Noise Characteristics (Section A-2.1.2); Evaluation of DOD NAVSTAR GPS Receivers (Section A-2.1.3); and Develop and Test Low Cost NAVSTAR GPS General Aviation Receiver (Section A-2.1.4). A detailed flow diagram showing the four tasks and the related subtasks are shown in Figure A-2.

2.1.1 Analysis And Simulations

The objective of this task is to determine the NAVSTAR GPS navigation performance through the use of mathematical analyses, computer simulations, cockpit simulators and flight tests. The work includes the development of error models for signal anomalies and variations, acquisition and reacquisition times, multipath, differing satellite geometries, tracking filters, processing delays, and flight technical errors. These models, coupled with DOD's error model of the intentionally

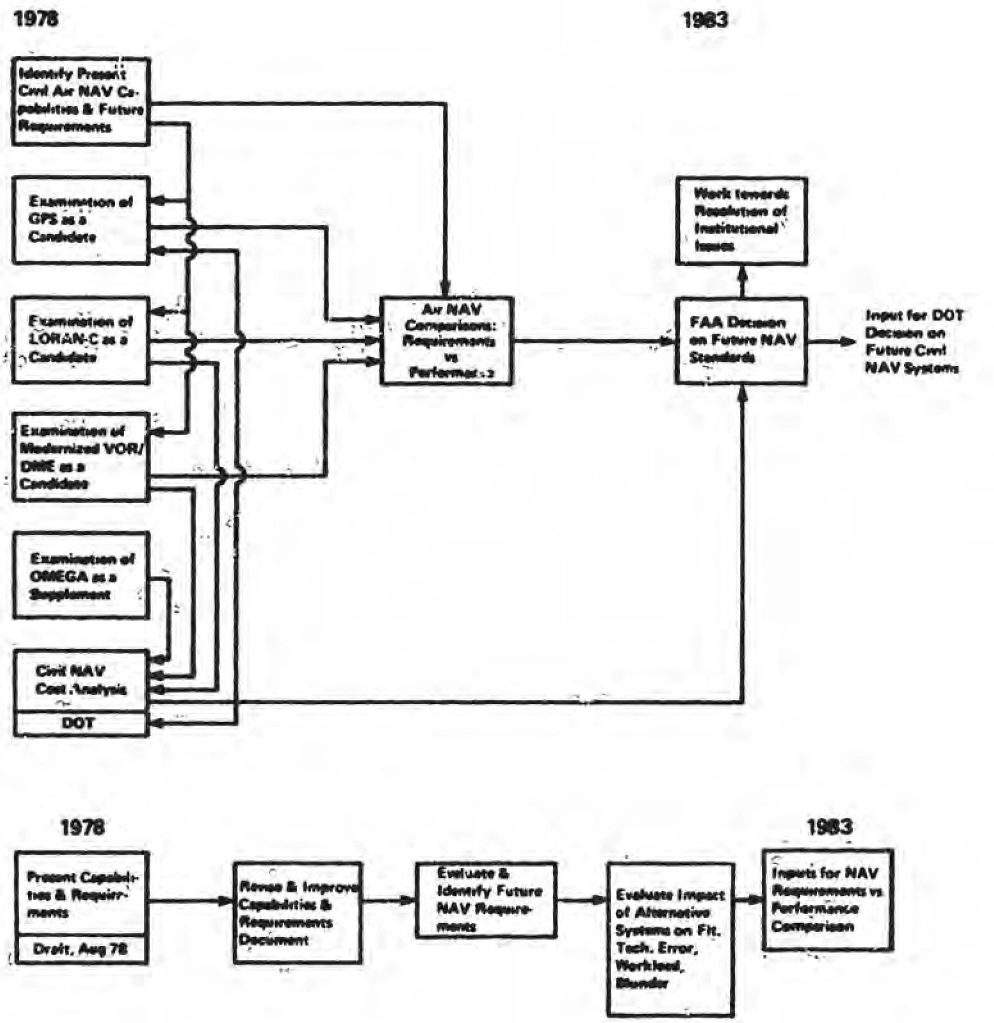

FIGURE A-1 Future Civil Aviation Navigation Standard Decision Plan and Present Aviation Navigation Capabilities and Future Requirements

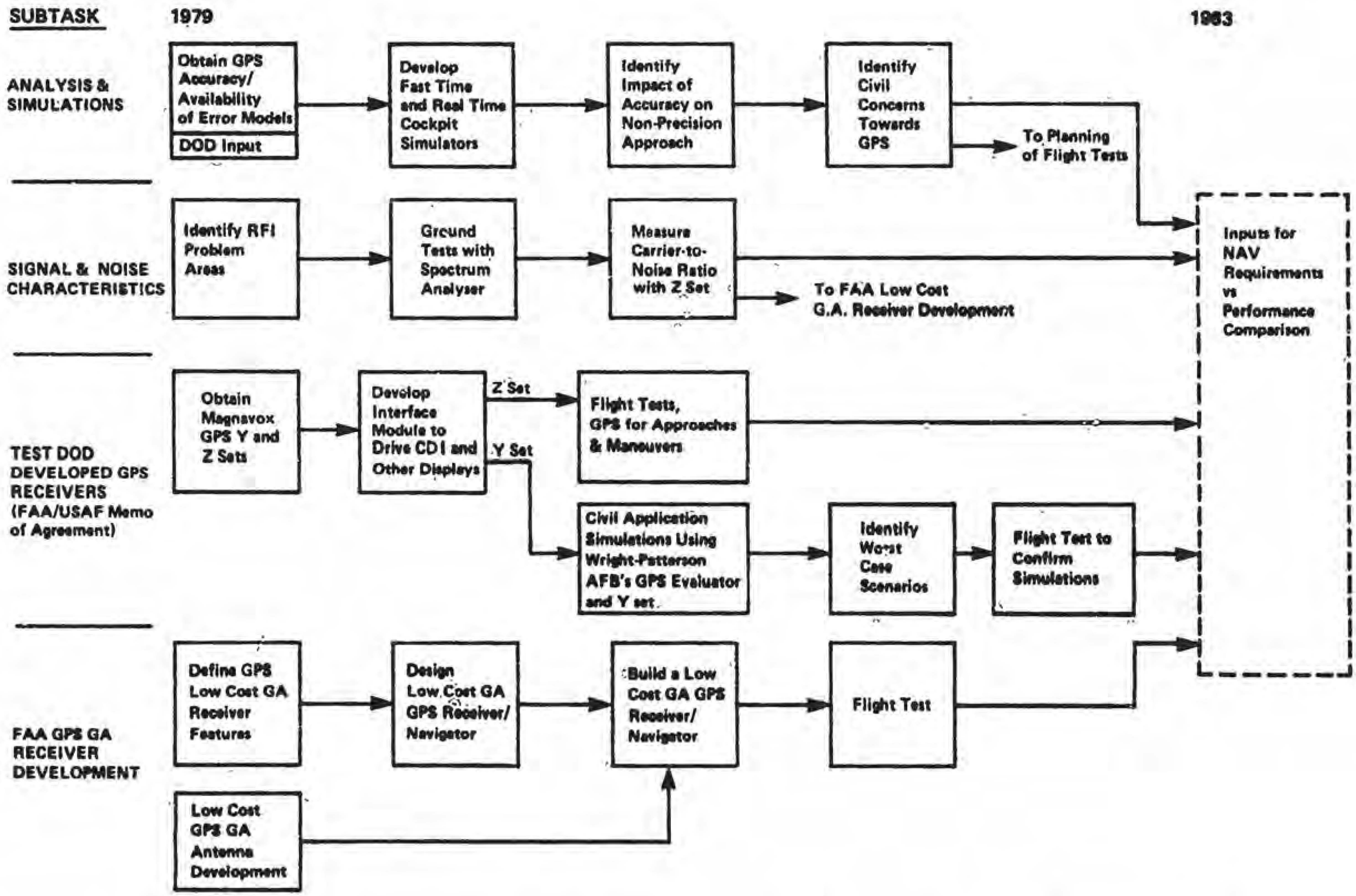

FIGURE A-2 Examination of GPS as a Candidate for Future Civil Air NAV Systems degraded NAVSTAR GPS signal, in conjunction with cockpit simulations, will be used to estimate the suitability of NAVSTAR GPS to satisfy the basic accuracy and reliability requirements for en route/terminal and approach phases of navigation. The results will also be used in designing flight test experiments. In particular, the adequacy of NAVSTAR GPS to support non-precision approaches to airports and maintenance of holding patterns will be addressed. Pilots' reactions to its use as a primary navigation aid will be assessed during the cockpit simulations. An analysis to identify any NAVSTAR GPS coverage gaps and to evaluate system failure modes will also be performed.

2.1.2 Assessment of Signal and Noise Characteristics

The adequacy of NAVSTAR GPS to support non-precision approaches is a critical issue since the aircraft will be maneuvering at low altitudes where there is the greatest amount of radio frequency interference, multipath, and satellite shielding problems. Therefore, a prime concern is the signal-to-noise ratios that can be obtained at low altitudes, especially with the low-cost general aviation type of NAVSTAR GPS antenna & receiver. Initial analysis indicates that the performance may be marginal. The initial task is to identify the potential problems associated with high local interference levels, determine their levels, assess their impact, and finally measure the actual interference levels with specific receiver designs. If the measurements indicate that the obtainable signal-to-noise ratios is inadequate, then a secondary task may be initiated to define and assess methods to insure adequate signal.

2.1.3 Evaluation of DOD NAVSTAR GPS Receivers

The objective of this task is to determine the adequacy of the DOD developed NAVSTAR GPS receivers: Yset (dual frequency, single channel, C/A and P code) and Z set (single frequency, single channel, C/A code only) in the typical ATC environments, especially in the critical non-precision approach and terminal maneuver area. In addition, the worst interference environments (identified in Section A-2.3.2) will be flight tested using those receivers.

The U.S. Air Force's NAVSTAR GPS Evaluator (a simulator and test equipment at Wright-Patterson Air Force Base) or an FAA laboratory simulator may be used to reduce the amount of flight time required, and minimize satellite availability problems.

2.1.4 Development and Test of Low Cost NAVSTAR GPS General Aviation Receiver

Another critical issue of NAVSTAR GPS as a primary navigation aid is the cost of general aviation NAVSTAR GPS navigation sets. At present, the FAA estimated price for the low-cost NAVSTAR GPS set is about three times that for equivalent VOR sets. Therefore, the FAA is pursuing development of a low-cost NAVSTAR GPS navigation set that will be suitable for low budget general aviation users. In addition, a related antenna development is also underway.

The final output of this task will be a NAVSTAR GPS navigation set that can satisfy the performance requirements of the majority of general aviation users at the lowest possible cost.

2.2 EXAMINATION OF LORAN-C AS A CANDIDATE AND/OR SUPPLEMENTARY SYSTEM

LORAN-C is the U.S. Government-provided marine radionavigation system for coastal and confluence areas. Currently, LORAN-C is being evaluated for land navigation and position determining. The FAA expects increasing use of LORAN-C by aviation and is determining the suitability of LORAN-C both as a replacement for and supplement to VOR/DME. Specifically, the FAA plans in coordination with the U.S. Coast Guard to analyze the signal and noise characteristic of LORAN-C and to develop a low-cost LORAN-C receiver for general aviation. These two tasks and the associated subtasks are shown in Figure A-3.

A third task, to examine the ATC related issues (e.g., monitoring concepts), will be addresed in Section A-2.4.

2.2.1 Assessment of Signal and Noise Characteristics

The FAA plans to analyze the suitability of LORAN-C signals for air navigation using special test equipment and commercially available LORAN-C receivers. Both static ground tests and flight tests will be made to assess land/sea transition errors, cross chain interference errors, short- and long-term signal stabilities, signal-to-noise requirements, and conductivity problems. In addition, tests will be made in areas where VOR/DME coverage is non-existent or unacceptable, i.e., in remote mountainous areas and in offshore areas.

2.2.2 Development and Test of General Aviation Avionics

As with NAVSTAR GPS, a key question in using LORAN-C as a replacement for the present VOR and VOR/DME system involves user cost, especially for the general aviation user. The present cost of a commercially available LORAN-C receiver is considerably more than that of VOR or VOR/DME equipment. It should be emphasized that the LORAN-C receiver design features, such as master dependency or independency, have a significant impact on the number of LORAN-C ground stations required for redundant coverage. For example, an FAA study estimated that 13 additional ground stations would be required for master independent receiver features whereas 16 additional ground stations would be required for master dependent receivers. Hence, it is important to define LORAN-C receiver features that would minimize joint user and government costs. In two related tasks, the FAA will develop a LORAN-C signal simulator to aid in equipment design evaluation and a low-cost, low-noise antenna.

2.3 EXAMINATION OF MODERNIZED VOR/DME AS A CANDIDATE SYSTEM

The modernized VOR/DME system is a strong candidate for the future navigation system because of the large user investment. It is the current international standard air navigation system, and the basic general aviation (GA) VOR receiver is low-cost. There is a need to determine whether the VOR/DME system can satisfy the air navigation requirements into 1995 and beyond, in conjunction with NAVSTAR GPS, LORAN-C and/or OMEGA.

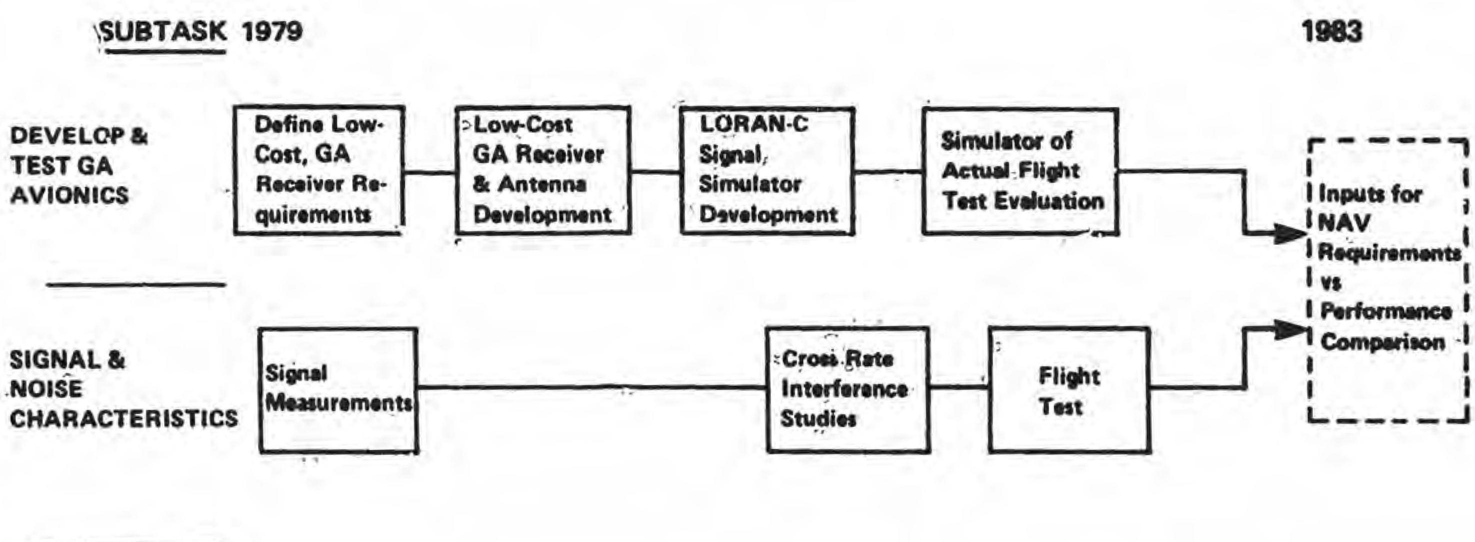

FIGURE A-3 Examination of LORAN-C as a Candidate for Future Civil Air NAV Systems

2.3.1 Impact of Modernization on Operation and Maintenance Costs

The goal of the modernized VOR/DME system is to increase maintenance technician productivity by using high reliability equipment, remote maintenance monitoring, and facility certification. Economic analysis indicates that modernization will lead to at least a 50 percent decrease in O&M costs. The tasks include supporting the operation services to implement the new modernized VOR/DME.

2.3.2 Future Growth Potential

A significant percentage of the present VOR's are currently restricted by poor signal quality due to multipath efforts. There is a need to determine the signal coverage and propagation anomaly problems if a greater portion of the VOR service volume is to be utilized in support of increased traffic and RNAV requirements. Part of the activity will include a VOR propagation model, which will be verified and calibrated by flight tests. This model will be used to assist in the siting analysis and development of optimum siting criteria. A related task is the study of future DME capacity requirements, false lock-on problems, and accuracy enhancements.

2.4 IMPACT ON ATC OF NEW NAVIGATION SYSTEMS

This section emphasizes the point that the navigation system is a part of the overall Air Traffic Control (ATC) system and every alternative system has to be evaluated with respect to what impact it will have on the ATC system.

2.4.1 Area Navigation

Current alternatives to VOR/DME operate only as RNAV systems. Present experience has shown that RNAV systems tend to cause increased pilot workload and blunder errors. In addition, there is no standard for specifying system integrity.

A. Pilot Workload

The key human factor consideration for general aviation is the workload for single pilot operations. Today, many users nominally have a single VOR set and operation of the equipment is simple and essentially blunder free; station and course selection are the two actions required. This simplicity of operation minimizes the pilot's workload and helps prevent blunders. The workload for single pilot operations would be evaluated for the low-cost NAVSTAR GPS and LORAN-C receivers and would be compared with VOR and VOR/DME-RNAV operations.

B. Blunder Errors

Navigation information that is directly tied to the desired flight path frame of reference is available when flying VOR radial routes. This point source of information includes a transmitted station identification which informs the pilot that he is tuned to the desired ground station and is flying the desired route. In RNAV, the pilot has to be able to enter waypoints. In this case, a suitable method for detecting erroneous entries needs to be incorporated. NAVSTAR GPS and LORAN-C are inherently RNAV systems, candidate avionics will be thoroughly evaluated for blunder rate and blunder detection.

C. Integrity

Every candidate system must have automatic fail-safe modes like those which are inherent to VOR/DME.

2.4.2 Dual Navigation System Operation During Transition

If the FAA selects LORAN-C or NAVSTAR GPS rather than VOR/DME as the system of the future, two systems would be operating together during the transition period of 10 to 15 years. The issue to be resolved concerns how to insure that the user of either or both systems will navigate safely in the NAS.

2.4.3 Notices to Airmen (NOTAM) System Development

Today's VOR/DME system has an on-line, near-field monitor to ensure signal reliability. If the signal goes out of tolerance the system is shut down automatically or manually from the Flight Service Stations. The FAA issues NOTAM's when a facility is shut down. With LORAN-C or NAVSTAR GPS, the systems would most likely be operated by agencies other than the FAA. These systems cannot be shut off when the signals are not acceptable for aviation but are for marine users. A NOTAM system (the monitors) will have to be developed to encompass this situation.

2.4.4 Flight Inspection System Development

The FAA periodically carries out flight inspections of the VOR/DME system to insure that errors stay within specified bounds. An analysis set of procedures and standards will have to be developed and assessed for candidate navigation systems.

2.5 CIVIL AIR NAVIGATION SYSTEM ECONOMIC ANALYSIS

The overall economic analysis of alternative systems and system mixes is a critical part of the system selection process. For example, the civil user community is extremely concerned with overall cost and benefit trade-offs. Many factors enter into the economic equation and need evaluation. To this end, the FAA will use an economic model capable of evaluating costs and benefits.

2.5.1 Model Development

A computer model for evaluating costs to the FAA and the civil aviation user has been developed. Costs estimates have been obtained as a function of duration of transition period (to new systems), types of systems used and user capabilities. Cost breakdowns were obtained for the various users by aircraft type, geographic region and sophistication of avionics. The model is currently being expanded to include benefits.

2.5.2 Model Inputs

Model inputs are constantly being refined based upon the outputs of related FAA tasks, avionics cost estimation, relationship between production quality and price, and impacts of future technology on costs.

2.6 FAA DECISIONS AND RECOMMENDATIONS TO DOT

The tasks described in this document have to be completed by mid-1982 so that the FAA can forward its recommendations on the future navigation system mix to DOT by 1983. The FAA recommendations will be based upon a thorough evaluation of performance, cost, and safety.

3.0 FAA RADIONAVIGATION R,E&D PROGRAM SCHEDULE

The FAA R,E&D program schedule is presented in Figure A-4. The proposed plans are dependent upon resource decisions.

4.0 RELATED CRITICAL ISSUES

In addition to the technical and economic issues that are being resolved by the FAA R,E&D program, there exists other critical issues which must be addressed and resolved. These so-called institutional issues will arise if the U.S. recommends that VOR/DME be replaced. The issues are:

1. Would the system be controlled by one ICAO member state (the U.S. in the case of NAVSTAR GPS) or an international body?

2. What guarantees would there be of signal availability in times of stress?

3. To what extent would international bodies, and bodies related to different transportation modes, participate in the development of Standards and Recommended Practices (SARPS) related to signal formats, procedures and documentation?

4. How, and to what extent, would initial costs be recovered and ongoing costs be shared?

5. Should the U.S. unilaterally adopt a new navigation system if it is cost-effective for domestic use but not supported by ICAO? In this case the U.S. would also still have to support the ICAO standard system to the extent necessary to meet its international commitments. The U.S. is required by ICAO agreement to operate VOR/DME for International Air Operations until 1985. It is expected that the agreement will be extended until 1995.

REFERENCES:

(1) Evaluation of LORAN-C for Domestic Air Navigation (MTR-7180), October 1976, by the MITRE Corporation.

(2) Economic and Performance Analyses of the Second Generation VORTAC (MTR-7140), March 1976, by the MITRE Corporation.

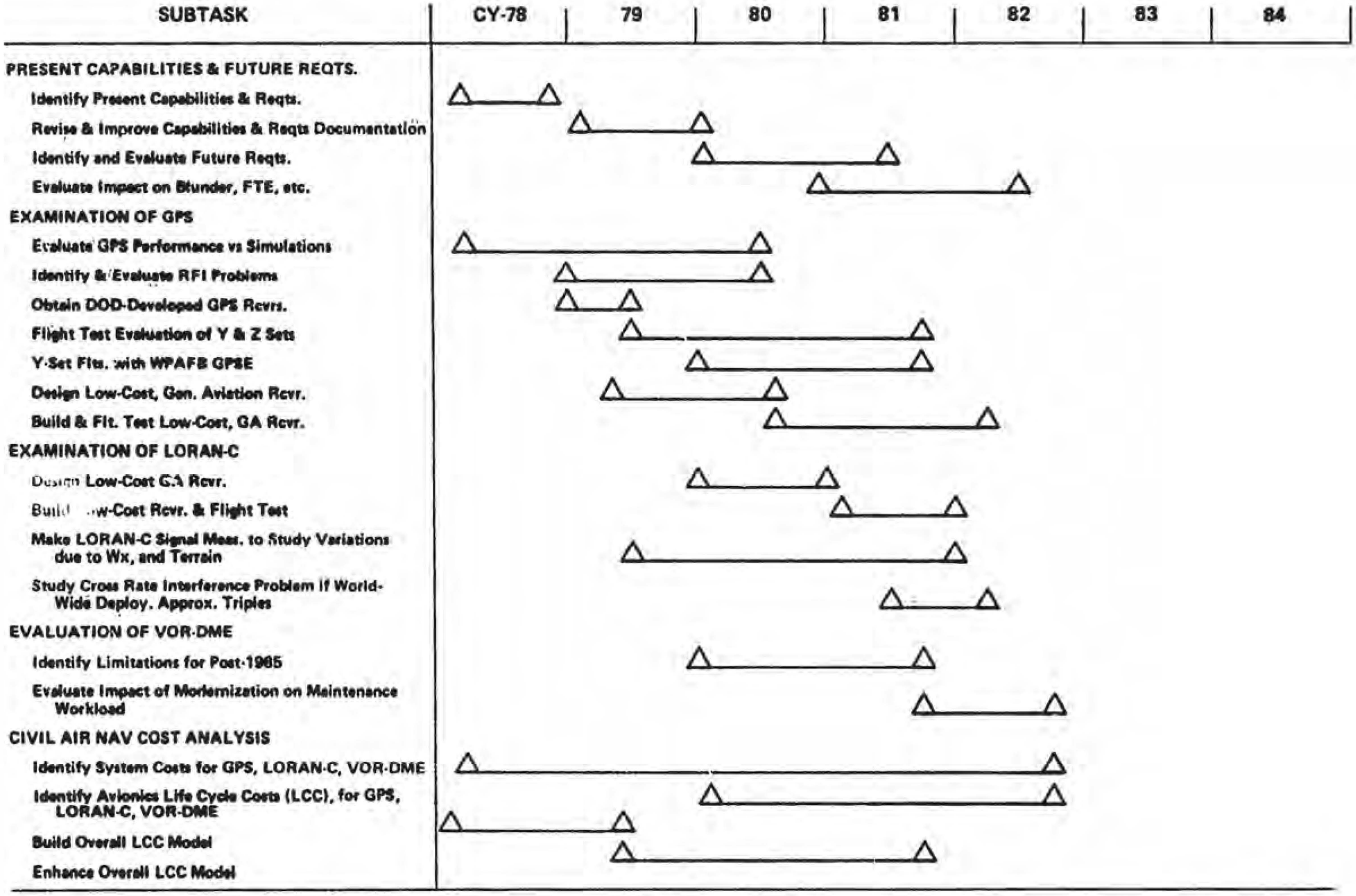

FIGURE A-4 Civil Air Navigation R&D Program Milestones

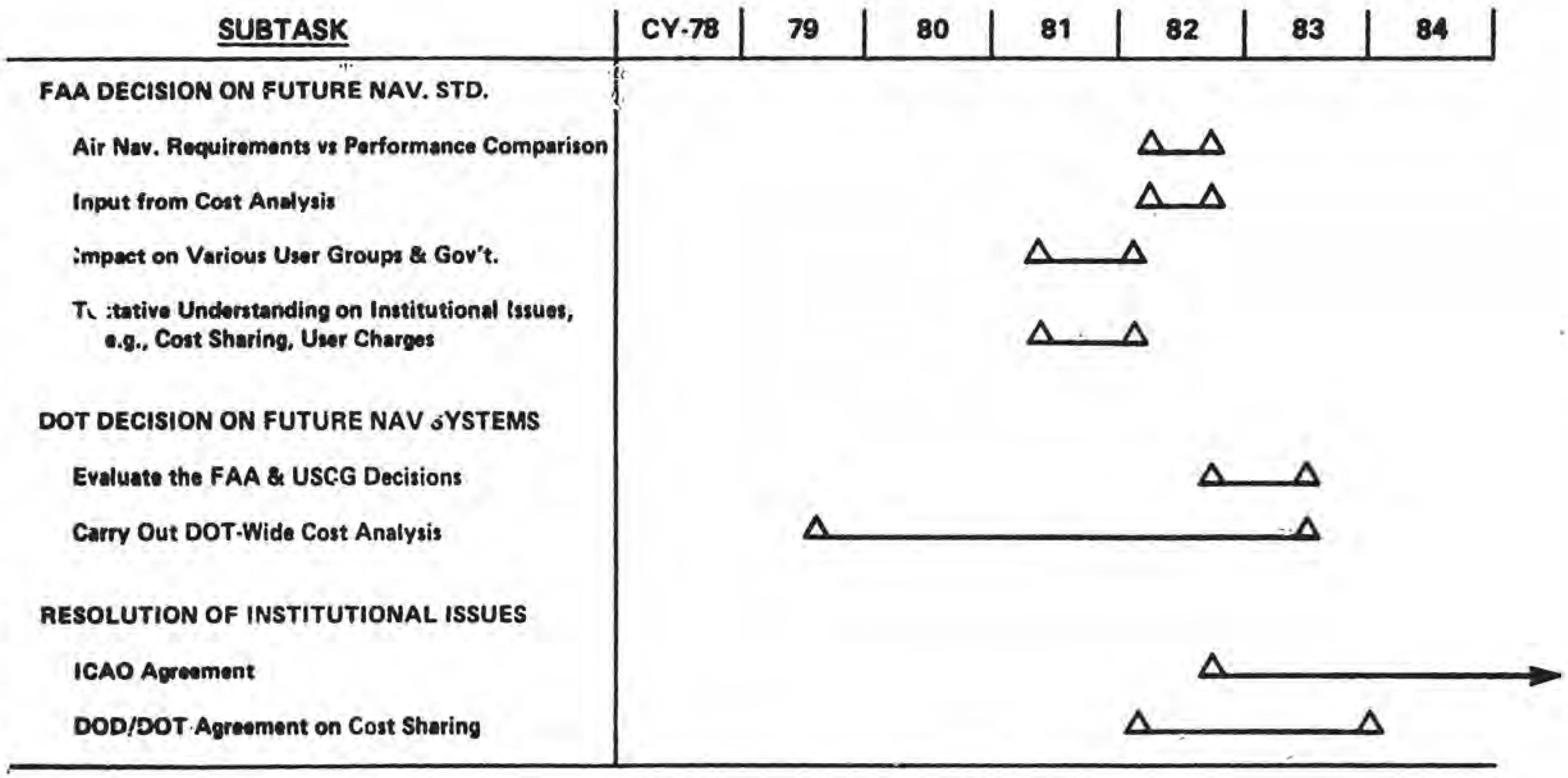

FIGURE A-4 Civil Air Navigation R&D Program Milestones (Continued)

FEDERAL RADIONAVIGATION PLAN
APPENDIX B
USCG MARINE NAVIGATION R,E&D PROGRAMS

TABLE OF CONTENTS

APPENDIX B
LIST OF ILLUSTRATIONS

APPENDIX B

USCG MARINE NAVIGATION R,E&D PROGRAMS

1.0 INTRODUCTION

This appendix describes the R,E&D activities of the U.S. Coast Guard for radionavigation systems. For the purpose of identification and to delineate program information which will accompany budget requests, the activities are divided into two groups:

A. Harbor and Harbor Approach R,E&D

These activities involve six programs to assess future use of the LORAN-C system for Harbor Approach and Harbor navigation and one program to evaluate the ship-board display of navigation information. The LORAN-C programs involve propagation research, signal analysis, the evaluation of survey techniques, the development of survey methods and procedures, and an overall project to demonstrate precision LORAN-C navigation.

B. NAVSTAR GPS Applications R,E&D

This program will assess NAVSTAR GPS applications to marine navigation. It involves extensive signal simulations and field tests to compare the performance of NAVSTAR GPS with LORAN-C, OMEGA, and TRANSIT.

1.1 R,E&D PROGRAM OVERVIEW

This document sets forth Coast Guard R,E&D program plans over the near term (5years) in the marine radionavigation area. The programs represent an integrated attempt to address existing shortfalls in marine radionavigation, to capitalize on new technology as it becomes available, and to foster an economical and effective provision of general-purpose navigation services to the multimodal U.S. military and civil community. Particular emphasis is being given to satisfaction of the only major, currently identified, unfulfilled requirement, that of an all-weather, continuous, precise navigation capability for the Harbor Approach and Harbor regions of the United States to supplement the primary short-range aids to navigation system. New technologies may allow unmet requirements to be satisfied, or may reduce costs for both the Government and the user community. NAVSTAR GPS is an example of a promising application of new technology that is being evaluated, although its usefulness will depend ultilmately upon both the user costs and policy restrictions on the availability of its full capabilities, as well as its technical performance. When coupled with study of various operational, economic and institutional questions, the results of the R,E&D should furnish an essential data base needed to sustain informed national judgments on the optimal mix of radionavigation systems needed to satisfy future multimodal navigation requirements in the most economical manner.

Just as marine navigation systems are component elements of a larger marine safety system, these activities are a derivative of a broader Coast Guard effort in support of the general goal of enhancement of marine safety.

2.0 RELATIONSHIP TO PHASES OF MARINE NAVIGATION

This section describes the relationship of the U.S. Coast Guard R,E&D activities to the five phases of marine navigation defined in Volume III. The activities are built mainly around response to the shortfall in the Harbor Approach and Harbor phases of navigation within the United States. Additionally, where new technology is available (such as NAVSTAR GPS) that may offer improved performance in other phases, it is being evaluated. In this respect, NAVSTAR GPS offers potential for all five phases of marine navigation, and is being examined from that perspective. Considering each phase individually, the R,E&D activities are summarized as follows:

2.1 OCEAN NAVIGATION

The OMEGA navigation system is expected to satisfy, or nearly satisfy, minimum requirements for safe navigation and reasonable economic efficiency in the ocean region. An ongoing validation program will provide information on any coverage or accuracy shortfalls. TRANSIT provides some benefits not available from OMEGA. Although the interval between TRANSIT fixes is sometimes longer than the specified two-hour requirement, its much greater inherent accuracy makes the cumulative error in navigation between fixes lower, generally, than that obtainable with OMEGA. Given the satisfaction of minimum requirements by these two systems, no R,E&D is planned specifically for the ocean phase of marine navigation. NAVSTAR GPS, if implemented, could be expected to replace OMEGA and TRANSIT in virtually all oceanic uses.

2.2 COASTAL NAVIGATION

The LORAN-C and radio-beacon systems meet all minimum safety requirements and maximize special user benefits. Radio beacons provide the primary navigation service to many smaller craft in the coastal area, and essential medium-accuracy position fixing and homing services to all users. No R,E&D is planned specifically for coastal navigation. Some improvements to the stability and accuracy of LORAN-C service in the coastal area may flow from R,E&D in the Harbor Approach and Harbor navigation phases. NAVSTAR GPS, if implemented, should satisfy minimum safety of navigation requirements for coastal navigation, and the Coast Guard's evaluation of NAVSTAR GPS will provide the basis for receiver performance standards needed to support prospective regulatory requirements.

2.3 HARBOR APPROACH AND HARBOR NAVIGATION

The existing system of short-range audiovisual aids to navigation, supplemented by the use of radar, is now and will remain the primary system for these phases of navigation. However, the safety and expeditious movement of marine traffic is impaired at times by low visibility, which interferes with the use of visual aids, and by ice cover, which requires the removal or reduction in number of floating aids to navigation in some areas in winter. While the use of ship-borne radar to supplement visual piloting provides some compensation for the impairment of the services of visual aids, it alone is not accurate enough over many wide coverage areas to reduce the risk to an acceptable level. An all-weather, precise navigation capability is needed as a supplement to short-range aids to navigation in these areas. No existing radionavigation system meets the specified accuracy requirements, which themselves cannot be stated as uniform standards throughout the United States. A combination of an area navigation system (like LORAN-C or NAVSTAR GPS) plus shoreside transponders working with ship-borne radars is likely to offer the best potential for the future. However, assuming that precision accuracy can be obtained, there is a further need to develop a means for processing and displaying the navigation information so that it is most useful for real-time guidance of the ship's conning officer.

2.4 INLAND WATERWAY NAVIGATION

Vast amounts of commerce move on the United States Inland Waterway system, much of it in slow-moving, low-powered tug and barge combinations. Tows on the inland waterways, although comparatively shallow in draft, may be longer and wider than large seagoing ships which call at U.S. ports. Navigable channels used by this inland traffic often are narrower than the harbor-access channels used by large ships. Restricted visibility and ice cover present problems in inland waterway navigation, as they do in Harbor Approach and Harbor navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective use of land-based area systems for precise navigation. The continual movement of the navigable channels in some unstable waterways creates additional problems in the use of any radionavigation system which provides position measurements in a fixed coordinate system. The probable consequences of a grounding in inland waterway navigation, and thus the overall level of risk, are somewhat lower than for large, seagoing ships in restricted waters.

The requirement for extensive R,E&D combined with less apparent risk, at least in the short term, has left inland waterway navigation lowest in priority for the development of a radionavigation capability (other than ship-board radar). Requirements, which would be derived from the consideration of practically achievable performance and expected benefits, have not yet been defined. However, R,E&D in Harbor and Harbor Approach navigation with LORAN-C and NAVSTAR GPS is expected to produce results which will support future programs to assess their application to inland waterway navigation.

3.0 LORAN-C R,E&D

Modern radionavigation technology offers a potential for supplementing visual piloting in restricted waters, and for replacing it as the primary method of navigation in poor visibility and in ice-covered waters. To be of general usefulness for the navigation of large ships in restricted waters, a radionavigation system must provide very accurate positions at very short intervals. To be sufficient as a primary or sole method of navigation for large ships, the complete navigation system must automatically process radionavigation signals and other supplementary information obtained, as necessary and practicable, from on-board instruments. It must calculate and display the present position and directional guidance information sufficient in quantity, quality, and form to permit the navigator to direct the movement of the ship safely through straight and winding channels and around sharp turns, as necessary to conform to the configuration of the waterway.

All of the project activities described in this section relate to the development of LORAN-C to satisfy the above goals. This phase of navigation is the leading area of operational concern because no existing or planned radionavigation system appears capable of meeting the stringent accuracy requirements without further development. However, LORAN-C provides the opportunity to achieve this goal, at least in part, through its basic accuracy and relatively good stability, combined with precise surveying of harbor areas. No new basic research or technological breakthrough is required, but rather the development of more detailed knowledge of the stability and the maximum obtainable accuracy of LORAN-C. NAVSTAR GPS may provide superior inherent accuracy in general. National security considerations, however, are expected to result in some restriction on the accuracy of NAVSTAR GPS service that will be available for general use by civil navigators. Nevertheless, a full appraisal of the inherent capability of NAVSTAR GPS to serve civil navigation is a necessary input to an informed national decision on the specific limitation which may be imposed on NAVSTAR GPS accuracy.

To be useful in the harbor area, LORAN-C must be accurate, precise, and stable. The inherent accuracy of the existing wide-area LORAN-C system may be sufficient in some areas. Where it is not, local area augmentation (e.g., mini-chaining or low-powered secondary stations) may be necessary to overcome range and geometric limits. If LORAN-C wide area grid stability is insufficient, local area monitoring at fixed sites may be necessary, coupled with dissemination to local users of corrections to apply to the time difference readings they measure on their vessels (Differential LORAN-C). Application of these techniques is being investigated through the R,E&D program. Actual operational implementation of any differential service or local augmentation of the wide-area signals in a given geographic area would be based on cost-benefit analysis, accounting for factors such as types and volumes of marine traffic, risk to commerce, the environment, and the public.

Assuming suitable stability and accuracy is achieved, it would then be necessary to survey the local area LORAN-C coverage. This consists of establishing the true geographic coordinates of all channel boundaries, shoreline, waypoints, fixed and floating aids to navigation, and other vital navigational parameters in terms of the "electronic coordinates" (i.e., precise LORAN-C time difference readings) that a vessel's equipment will use. This coordinate conversion defines a common frame of reference (electronic and geographic) between the user's equipment-derived position and the true position of the ship in the water, effectively removing charting errors that limit the ultimate potential of radionavigation and visual navigation today.

Lastly, the interface between the human pilot and the navigation system must be considered to allow optimum use of the available navigation information for vessel conning. In ocean and coastal navigation, manual plotting of fix information followed by adjustment to vessel course is satisfactory. This process may be automated for convenience or efficiency, but automation is not essential to safety. In the Harbor Approach and Harbor phases, real-time guidance is needed. The quantity, quality, and format of that guidance information is being investigated. A separate project seeks to develop the relationship between the quantity and quality of guidance information and pilot's consequent ability to navigate safely. This will provide the foundation for designing or specifying ship-board guidance systems. R,E&D efforts are directed to the development of a graphics/digital display that might be useful with any navigation sensor or navigation processor. The display will enable the navigator to make the most effective use of all sources of navigation information and help him follow a safe track within the narrow margin of safety that is available to him in a restricted waterway. Because it has potential application to the use of any navigation system, this work is described separately from LORAN-C in section B.3.2. Figure B-1 summarizes the radionavigation R,E&D activities of the Coast Guard, except for those related solely to the NAVSTAR GPS application studies.

The following sections describe the objectives, background, and technical approaches for the eight R,E&D programs being conducted by the U.S. Coast Guard. Event flow diagrams showing the tasks and schedules for each of these programs are included.

3.1 LORAN-C PROPAGATION RESEARCH

The objectives of this program are two-fold: (1) To perform research of the properties of LORAN-C propagation; and (2) to develop a propagation model for the evaluation of methods to improve LORAN-C grid stabilities and reduce the costs of taking signal surveys. This program will draw heavily on the results of LORAN-C signal analysis, survey evaluations, and techniques for enhancing services. (See Sections B.3.2 through 3.4.)

3.1.1 Background

LORAN-C operation can be extended to uses in the much more stringent Harbor Approach and Harbor regions if the coverage can be predicted or surveyed with high precision and the quality of coverage ascertained. Presently, coverage must be determined by surveying. While it may never be possible to determine coverage entirely by prediction, it can be used to assist in making more efficient and hence, less costly surveys. Use of LORAN-C in the Harbor Approach and Harbor areas also requires knowledge of temporal instabilities in the coverage grid. This project plan delineates the U.S. Coast Guard effort in propagation research and builds upon the information base provided by chart verification surveys, the LORAN-C Signal Analysis project, and the studies of the St. Marys River mini-chain.

3.1.2 Technical Approach

To extract the inherent accuracy of the LORAN-C system through an improved understanding of the bounding physical elements as determined through improved analysis, model development, testing and verification. This program is summarized in Figure B-2 and involves the following six project elements:

A. <u>LORAN-C Calibration</u>

An empirical force-fit grid distortion method was devised in an attempt to calibrate the St. Marys River mini-chain using prediction. This method did not prove to be accurate enough for precision navigation in the severe St. Marys River situation, but does appear to have promise in improving the quality of prediction

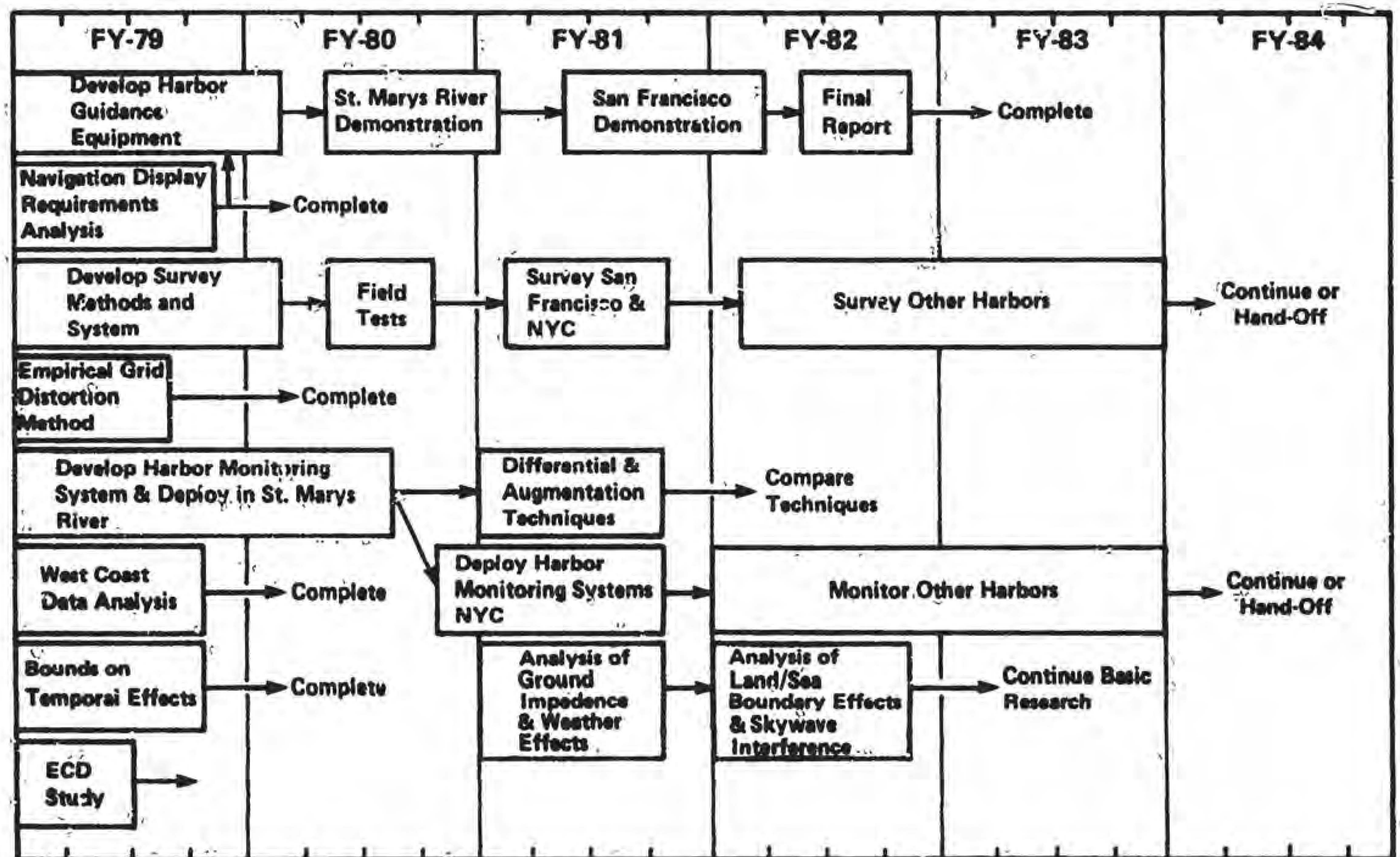

FIGURE B-1 Radionavigation (Event Flow Diagram)

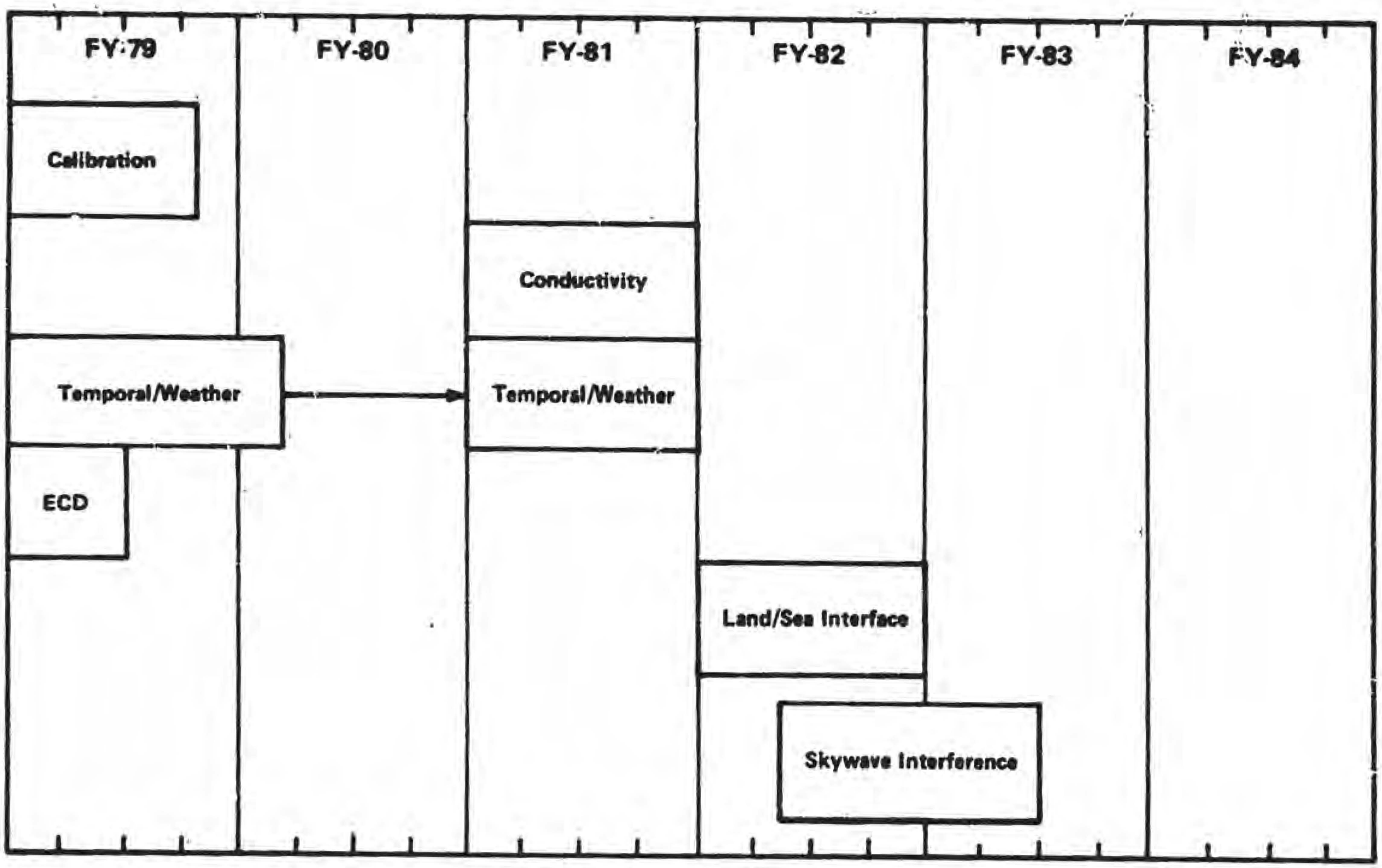

FIGURE B-2 LORAN-C Propag.tion Research (Event Flow Diagram) for the coastal region. This project will attempt to use the force-fit method with actual time difference data collected on the southern U.S. West Coast. This project, which is presently being negotiated with the contractor who developed the technique, is being managed by the Coast Guard R&D Center.

B. LORAN-C Propagation Analysis and Conductivity Measurement

Since LORAN-C propagation depends upon ground conductivity (or surface impedance), accurate LORAN-C prediction requires knowledge of this parameter. This project element investigates various techniques for directly measuring ground impedance.

C. LORAN-C Study Of Temporal/Weather Effects

Use of LORAN-C as a precision radio aid to navigation in restricted waters depends upon the stability of the time difference grid. One factor affecting strongly the stability of this grid is the weather. LORAN-C propagation is affected by the ground impedance and the atmospheric refractive index, and weather can affect both of these parameters. At the present there is little knowledge of the magnitudes and durations of these weather-induced temporal variations. A project will provide the theoretical bounds upon these variations for typical propagation paths. Knowledge of the durations, extent, and magnitude of time shifts due to weather changes is important for determining the practicality, need, and information rate for Differential LORAN-C. A project will verify the theory and provide a means of predicting or anticipating temporal effects due to weather.

D. Study of ECD

Use of LORAN-C as a precision radionavigation system is dependent upon knowledge that the Envelope-to-Cycle Difference (ECD) is within reasonable bounds. This is part of the chain control problem. The ECD study will attempt to predict the behavior of the far-field ECD from near-field ECD measurements using the transient solution to the integral equation propagation model.

E. New Propagation Model for Land-Sea Boundary (Including Terrain Variation) Effect

The integral equation propagation model, which is considered to be the best available method for LORAN-C propagation prediction, is not adequate for predicting Time Difference (TD) or Time of Arrival (TOA) in the vicinity of a land-sea boundary or in places where the conductivity along a propagation path changes rapidly. It is therfore desirable to develop another model for this purpose. Since this propagation problem is mathematically difficult, as a first step a simple model which does not account for weather effects will be considered. This model will then be validated using collected data during FY-82. If this effort is successful, the model will be modified to include weather parameters and then will be validated against field test data.

F. Skywave Interference Effect in Northern Latitudes

The LORAN-C system is stable over long ranges because it uses only the groundwave portion of the signal. Since the skywaves travel a longer propagation path, they are sufficiently delayed to permit use of the beginning of the groundwave pulse leading edge. In the northern latitudes during solar disturbances, the ionosphere is depressed significantly with an attendant shortening of the skywave delay. This causes contamination of the usually skywave-free measurements. While the effects of skywave contamination are significant in the coastal region, they can be catastrophic in the Harbor Approach and Harbor region. This project, to commence in FY-82, will attempt to determine quantitative relationships between the solar events and the reduction of the skywave delay. This will help to provide a strategy for overcoming these effects.

3.2 LORAN-C SIGNAL ANALYSIS

The objective of this program is to analyze practical methods for improving LORAN-C grid stabilities for the Harbor and Harbor Approach phases of marine navigation. The analysis will examine methods for augmenting LORAN-C with local mini-chains, low-powered secondary stations, or differential monitors in order to realize a precision capability in specific operating areas. The program event flow is summarized in Figure B-3.

It is noted that the propagation medium is the great uncontrolled variable in the LORAN-C system, and is the main source of error in calibration and surveying and the main cause of instability with time. An improved understanding of propagation prediction techniques will reduce the amount of data needed to perform survey, thereby permitting more economical, timely, and accurate surveys and calibrations. Knowledge of the temporal weather variations is essential if the need for Differential LORAN-C is to be established rationally. This knowledge is also essential for providing cost-effective processes for LORAN-C chain control.

3.2.1 Background

Several sets of Data Collection System (DCS) equipment have been developed previously for collecting LORAN-C information from both the West Coast Chain and the St. Marys River Mini-Chain. The Coast Guard R&D Center is developing a monitor system consisting of a DCS plus additional hardware and software to allow remote dial-up telephone access to the LORAN-C information. Eight of these systems with the additional hardware and software capabilities will be deployed during FY-79 and FY-80 for collecting St. Marys River mini-chain data. These systems are identified as Harbor Monitoring Systems (HMS).

3.2.2 Technical Approach

The technical approach to this project involves two tasks. These are indicated in Figure B-3 and are described as follows:

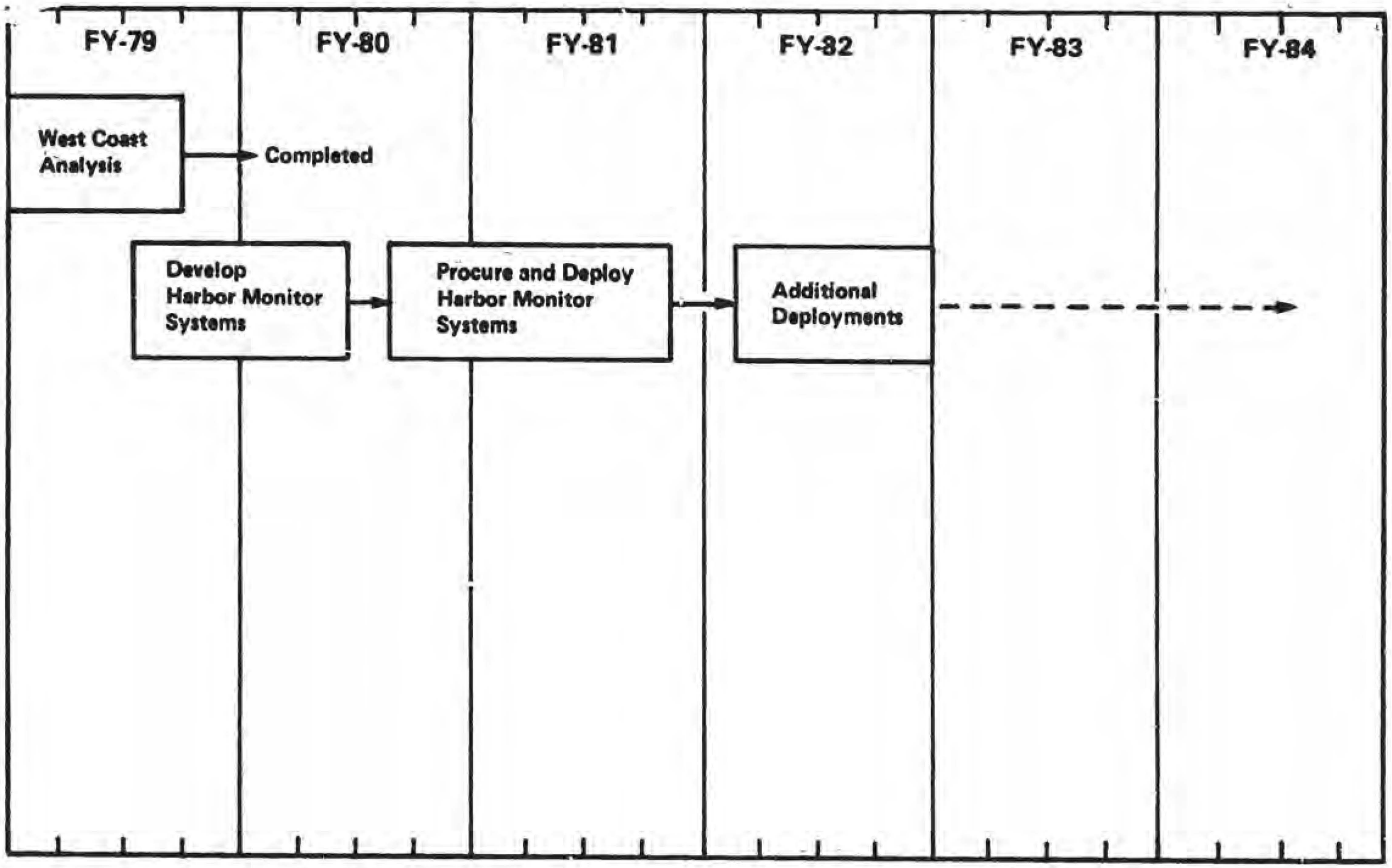

FIGURE B-3 LORAN-C Signal Analysis (Event Flow Diagram)

A. LORAN-C Signal Analysis

A large amount of data on the West Coast LORAN-C chain was collected under the signal analysis project. The work remaining on this project is to provide plots of the remaining essential data and publish a final report.

B. Harbor Monitoring Program

This project calls for development, fabrication and deployment of the eight Harbor Monitor Systems (HMS) in FY-80 to collect LORAN-C stability data in the Harbor Approach and Harbor environment. The HMS data, consisting of one-hour average TD's collected twice daily, will be gathered periodically by phone line access from a central location. These data will be analyzed to determine the temporal stability of the TD grid in each area studied. Two monitoring sites should be sufficient to characterize the stability in most harbor regions. New York and San Francisco Bay are two of the early demonstration harbors. Data collection should begin in the summer of 1980.

It is noted that although this project is based upon existing technology, more elaborate data collection techniques may be required in FY-81. The program will characterize the quality of Harbor Approach and Harbor positioning available from LORAN-C throughout the U.S. This characterization is essential to the decision to recommend LORAN-C as an all-weather aid to navigation. Where enhancement of existing LORAN-C coverage may be necessary to realize a precise navigation capability in some harbor areas, this program provides a methodology to determine which areas require enhancement.

3.3 TRACKLINE SURVEY TECHNIQUES

The objective of this project is to develop a cost-effective methodology to describe accurately tracklines within harbor areas in terms of repeatable LORAN-C coordinates and to measure the degree of grid warpage near a trackline.

3.3.1 Background

In the Harbor Approach and Harbor regions, operators of vessels do not have time to interpret LORAN time difference numbers, but require a pictorial display of their navigation situation. User equipment is being developed under another project (see Section 3.1) to provide this display based on LORAN-C signals. Some means of relating the LORAN readings to an actual position is essential. Tests on the St. Marys River have demonstrated that prediction techniques are presently inadequate for the accuracy required in the Harbor Approach and Harbor region. This means that the relationship between actual position and LORAN readings will have to be measured (at least at key points). The trackline survey methodology and system being developed under this project are the means of establishing this relationship.

3.3.2 Technical Approach

The approach in this program is summarized in Figure B-4 and involves the difficult problem of identifying survey information as was learned in the St. Marys River program. Marine TD survey involves determining the exact position of a survey vessel with simultaneous observations of TDs. One technique, applicable to many harbors, is to site a precision short-range survey system at known terrestrial markers and then observe TDs at the measured vessel location. The practical problems involved using this technique are solvable. The vessel is unavoidably moving and the LORAN-C receiver introduces dynamic errors into the TDs. The near-term program will develop an integrated system to deal with this using Kalman filters to remove such TD dynamics, assist the operator in locating the vessel using the precision positioning system, and compute measurement errors. This automatic Time Difference Survey System (TDSS) can be moved through any region and provide optimum estimates of TDs versus Lat/Long with known estimates of the errors.

The St. Marys River proved to be intractable with this approach to TD survey because it was usually not possible to site the precision transponders with line-of-sight view of the vessel, or to determine the location of the sites that could be used. The river current and continual traffic made actual stopping and visual positioning impossible, except for a brief period during the spring breakup when the survey vessel was wedged in the ice and accurate survey points determined. The user equipment did succeed ultimately in presenting precise information to the navigator, but the conversion data was determined in a largely adhoc manner by repeated running of the channel and adjustment of the conversion table until reality and display agreed. While this approach is inefficient and technically unsophisticated, it does work and can be used in difficult situations. A possible solution to the St. Marys dilemma lies in airborne use of survey-grade inertial systems. Working from a known marker, a helicopter can navigate to one-or-two meter accuracy for short periods from the inertial system alone, thus providing exact Lat/Long location input to be matched with the receiver's TD observations. Again, dynamic combination of both systems can be made for improved TD accuracy with error estimation techniques.

Both of the above approaches relate LORAN-C data to a geodetic coordinate system. Unfortunately there are a large number of visual aids to navigation in channels and shorelines which have not been surveyed accurately in common geodetic coordinate system. A third technique, which uses the same survey LORAN-C and calculating equipment, can be used to relate LORAN-C time differences to a point at the intersection of two visual navigation ranges. This technique takes advantage of the fact that all points in a visual range lie in a straight line and LORAN-C time differences taken at same points will also lie in a straight line in LORAN-C coordinates if the region of interest is small enough. Statistical techniques can be used to describe the LORAN-C coordinates of two such range lines and determine the time difference at their intersection to the desired degree of accuracy. These techniques greatly expand the possibilities for LORAN-C harbor approach and inland waterways use and are the basis for possible future use of equipment calibrated by its own user. The near-term program will explore this concept further with the goal of establishing three possible TD survey methods within the next two years which are:

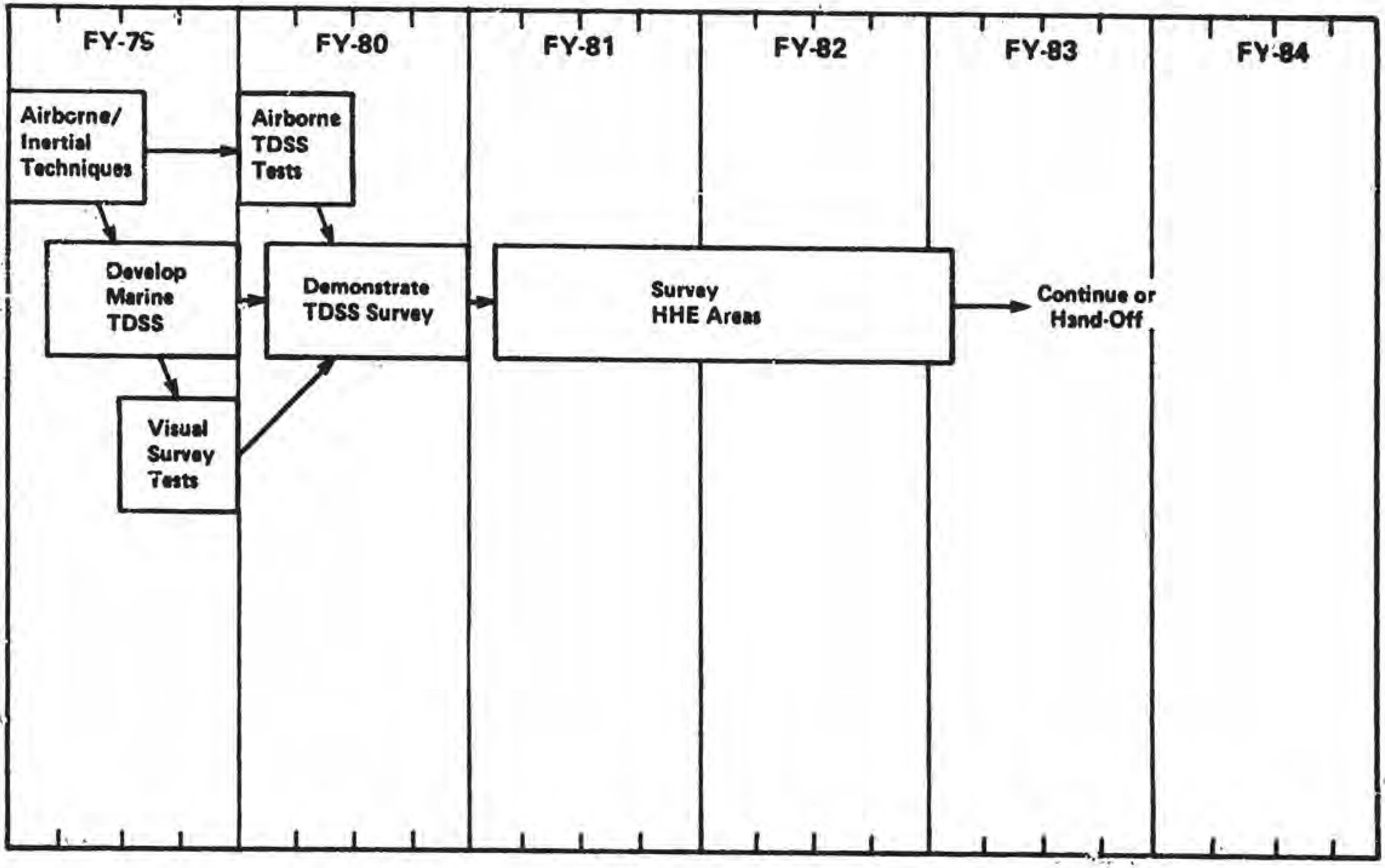

FIGURE B-4 Trackline Survey (Event Flow Diagram)

A. Ad hoc or visual, used in areas of difficult terrain with narrow channels which have a high density of visual fixed markers.

B. Standard marine, used in relatively open areas with a microwave precision system as reference, integrated processing aboard the vessel, and the ability to move continuously over the desired trackline.

C. Airborne, used in any area by determining present position as a precise directional range (DR) from a known start point. With integrated processing, the method can be used to move continuously over a trackline, or to hover at any fixed waypoint prescribed in the DR coordinate frame.

Specific tasks for each Fiscal Year from FY-79 to FY-82 are outlined as follows:

a. FY-79

(1) Evaluate airborne/inertial system.
(2) Design and fabricate a marine data collection system.
(3) Evaluate visual survey techniques.

b. FY-80

(1) Perform/test airborne surveys.
(2) Perform/test marine data collection system.

c. FY-81-82

Define Harbor Approach and Harbor trackline survey methodology

It is noted that this program will require filter refinements, statistical algorithms, an improved knowledge of positions of navigation features in geographic coordinate system, and the use of visual survey techniques. The project provides a cost-effective methodology to define waypoints and trackpoints for marine navigator user tapes and expands the possible number of LORAN-C Harbor Approach and Harbor use areas.

3.4 TECHNIQUES FOR ENHANCING LORAN-C SERVICE

The objective of this program is to develop and evaluate operating procedures, techniques, and equipment to enhance LORAN-C chain coverage for precision navigation in the Harbor Approach and Harbor areas of the U.S. Coastal areas. This program will use the results of the LORAN-C signal analysis and track-line survey projects (described previously in Sections B.3.2 and B.3.3).

3.4.1 Background

Several techniques have been advanced to enhance LORAN-C chain coverage and to provide the signals necessary for precision navigation in restricted and heavily congested waterways. Among those techniques are mini-chains, differential techniques, and supplemental low-powered secondary stations.

3.4.2 Technical Approach

This program is illustrated in Figure B-5 and involves four tasks:

A. Mini-Chain Support

The Coast Guard has installed a four-station "Mini-Chain" to provide LORAN-C coverage of the St. Marys River. The chain has been operated by Coast Guard personnel during FY-76, FY-77, and FY-78 to permit evaluation of user equipment. However, in the course of data collection over the entire service area during FY-78, large temporal instabilities were recorded that would, if true, render LORAN-C unusable for precision navigation on the St. Marys River. It is believed these instabilities are the result of the equipment and procedures used to collect the data, and are not endemic to the mini-chain. The Coast Guard is presently instrumenting a detailed program to verify and quantify the stability of the mini-chain grid. It is also recognized that both the electronic equipment used by the mini-chain and the operating staff are inadequate for an operational system. Before starting the grid stability study, the Coast Guard will make modest improvements to the monitor and control equipment, and will augment the manning structure at the mini-chain.

B. Mini-Chain Evaluation

Three monitoring sites, in addition to the System Area Monitor (SAM), have been established along the St. Marys River to evaluate the stability of the mini-chain. Twice daily samples from the monitor and transmitter sites will be evaluated in an on-going process to characterize the quality of chain coverage and to help determine the causes of temporal instabilities as soon as they occur. Detailed data analysis will be made for those times when the samples indicate that it may be fruitful.

C. Differential LORAN-C Evaluation

While the mini-chain approach looks promising, several other techniques are being considered to augment the coverage available from existing large-scale LORAN-C chains. Differential LORAN-C was first explored in the Delaware Bay study of 1973 as a means of removing the effect of temporal instability. It showed that improved accuracy can be achieved at distances of at least 100 kilometers by the use of differential techniques.

D. Supplemental LOP Techniques

A technique to deal with a weak LORAN-C coverage due to low signal level, poor crossing angle, or temporal instability is to add one or more low-power stations in a local area. Adding only one station to the basic long-baseline chain is always preferable to a more involved approach, but its improvement is totally controlled by geometry; i.e., the location of the geographical area with respect to the master LORAN-C station. A more complex approach, but of the greatest impact and flexibility, is to add both a master and secondary mini-station and hence provide a new grid line whose orientation can be chosen for any desired advantage. As the user equipment is adaptable to this approach, a candidate region will be selected

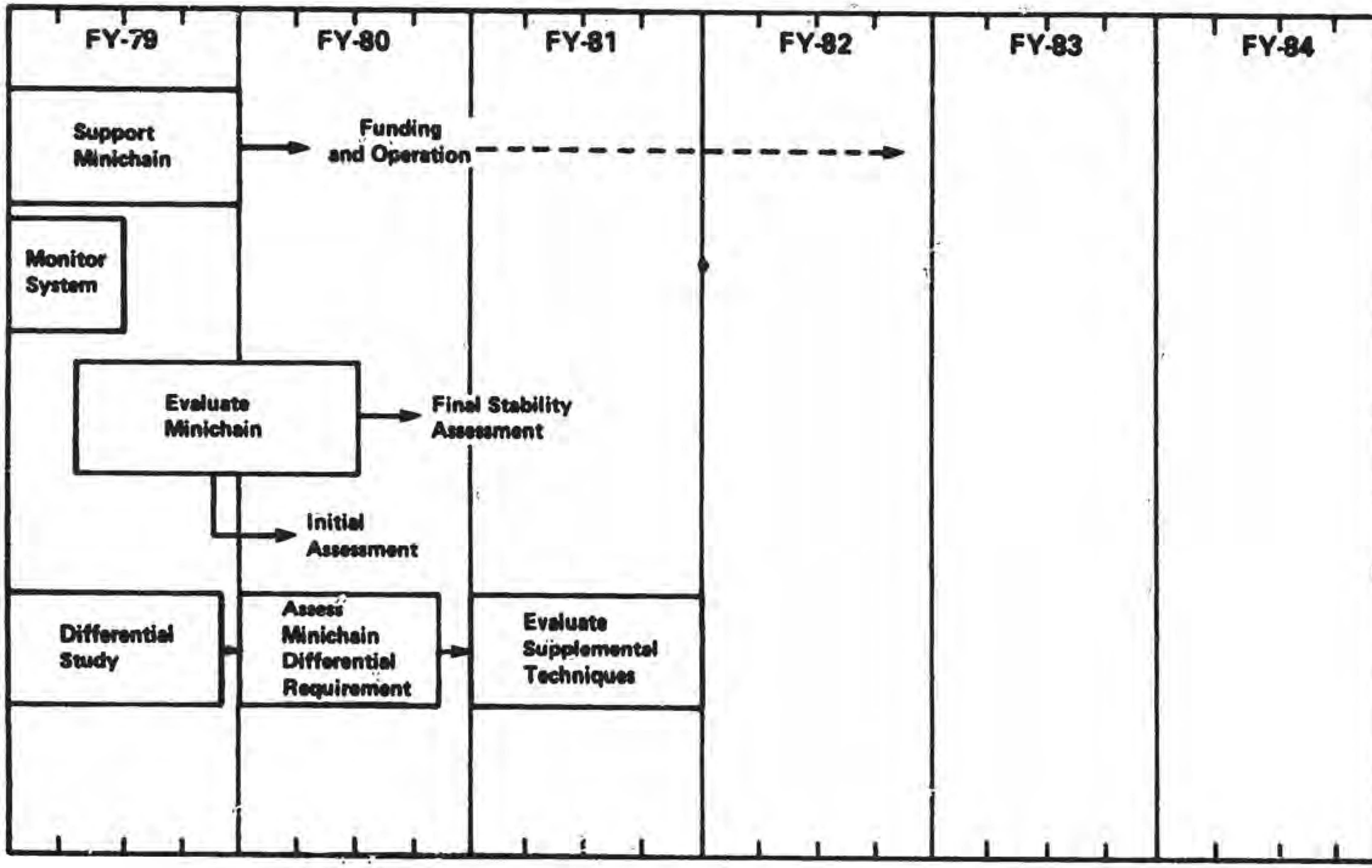

FIGURE B-5 LORAN-C Chain Enhancement (Event Flow Diagram) and the technique explored. This should occur later in the five-year program and only if it appears that the technique offers benefits which justify the cost. Portions of the St. Marys River mini-chain could be operated in coordination with the Great Lakes wide-area coverage to evaluate these techniques. The Coast Guard embarked on the St. Marys River project with the understanding that it involves one of the most severe navigational situations in the marine environment. Failure to provide adequate all-weather navigation on the St. Marys River may create the erroneous opinion that LORAN-C cannot meet the requirements for other less-demanding environments. If the project succeeds, it may be prohibitively expensive to install and operate mini-chains in other areas requiring a precision radionavigation aid. Also, excessive proliferation of mini-chains could create unacceptable cross-rate interference situations between mini-chains themselves, and with the large-scale LORAN-C chains. These factors will be included in an analysis of the performance and the costs and benefits of LORAN-C service enhancement techniques.

It is noted that the differential LORAN-C and the low-powered secondary technique may provide the accuracy of a mini-chain without the expense of a dedicated chain and without the cross-rate interference problems that could result from a proliferation of mini-chains.

The main additional tasks to be addressed in FY-79 are related to hardware and communications reliability. Techniques and procedures will be developed to disseminate timely differential correction information to the user, and to fit low-powered secondary stations into the existing rate structure for some LORAN-C chains.

The St. Marys River Project has provided a prototype LORAN-C mini-chain and prototype user equipment which can be evaluated for other applications in the harbor approaches and harbor areas of the United States. The St. Marys River mini-chain could minimize shipping delays now experienced when ice conditions or low visibility make the use of conventional visual aids to navigation impractical. The user equipment project has three major segments: (1) development of user equipment and tape cassettes; (2) assembly of a number of demonstrator user equipments; and (3) deployment of these equipments for quantitative performance measurements. The harbor guidance equipment will be supported by an analysis of navigation display requirements for the St. Marys River and San Francisco harbor. The display requirements will then be expanded to cover other harbor areas prior to each operational demonstration.

E. Survey Techniques

For the present, the only practical method of providing the necessary conversion from LORAN-C time difference readings to geographical position in the restricted waterway regime is by detailed survey. This contrasts with the coastal regime where quite satisfactory results are obtained using prediction, supported by selective surveying of limited extent. The experience with the practical difficulties in surveying the St. Marys River (described in Section 3.4) reveals the need to develop methods for applying several survey techniques to LORAN-C grid calibration. These include use of visual, microwave, and inertial reference systems aboard airborne and marine survey platforms and the development of a survey receiver and reference-derived positioning aids.

F. Grid Stability

Data collected during the St. Marys River project in FY-78 is inconclusive for establishing mini-chain stability. Data taken in the San Francisco harbor indicate excellent stability there. The question of the St. Marys River stability will be resolved in 1979 and the stability of other regimes will be investigated in the following years so that the potential performance of LORAN-C in precision navigation can be characterized accurately.

G. Supportive Research

There are two methods of providing precision LORAN-C coverage in regions when the coastal coverage is inadequate: Differential LORAN-C and augmentation through the addition of one or more low-power stations. Supportive research is included for both of these methods. In addition, this project relies on survey information (see Sections 3.3 and 3.4) to convert precise time differences to geographical positions. It is desirable to replace or augment existing surveying techniques with more precise or less-expensive methods. Finally, it is noted that all of the potential problems in precision LORAN-C are related to propagation. Any R,E&D program in precision LORAN-C should include a moderate effort in fundamental propagation research.

3.5 HARBOR APPROACH AND HARBOR GUIDANCE EQUIPMENT

The objective of this program is to develop and demonstrate a practical, low-cost LORAN-C Harbor Approach, and Harbor navigator. This program is illustrated in Figure B-6 and represents the culmination of the LORAN-C R,E&D activities described in the previous sections.

3.5.1 Background

Two sets of guidance equipment have been developed and evaluated on the St. Marys River. The first, User I, provided the user with off-track speed and cross-track speed. This system performed quite well, but was somewhat awkward to operate. The second system, User II, provided a CRT true-motion display which showed the vessel, the desired trackline, surrounding shoreline, channel boundary, and buoys. The present User II system is too complicated and expensive to represent a practical ship-board precision navigational aid. This project will attempt to demonstrate a practical and low-cost Harbor Approach and Harbor navigator that will incorporate the essential features of User II. This project provides the means for demonstrating that the LORAN-C grid, whose stability has been characterized, is, in fact, usable by the navigator in the Harbor Approach and Harbor environment.

3.5.2 Technical Approach

This project is summarized in Figure B-6 and involves the following three functional components in the evaluation of the harbor navigation equipment:

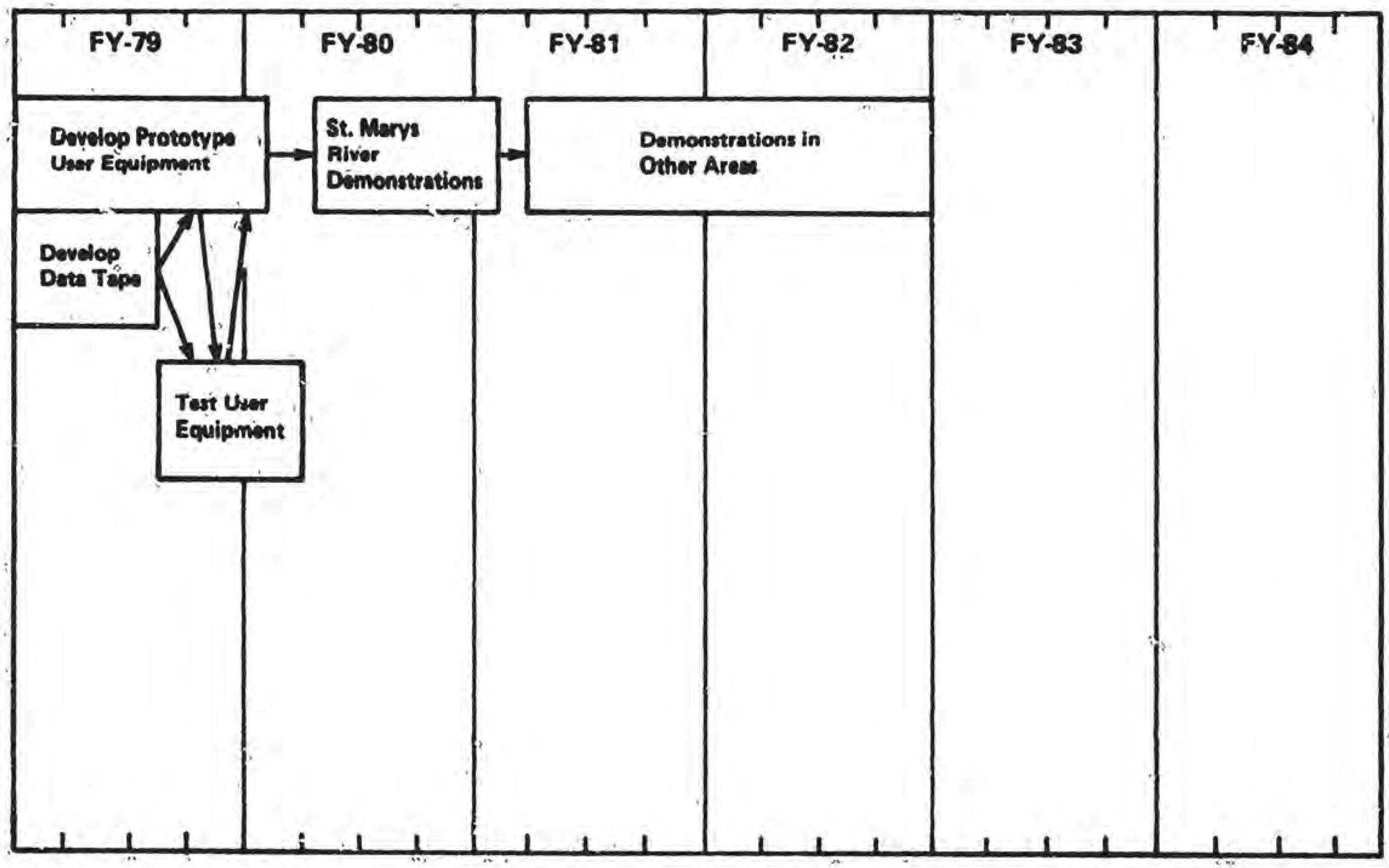

FIGURE B-6 Guidance Equipment (Event Flow Diagram)

A. The surveyed conversion information, as well as other details such as TD gradients, channel boundaries, shorelines, etc., will be carried on a magnetic tape cassette. The mariner will insert this cassette prior to entering a given region, and select an intended trackline which corresponds to a file on the tape. Significant deviations from the trackline, where possible in a broad harbor, will not result in serious errors because the grid is similarly "regular" in such a harbor.

B. The navigator will connect to any receiver providing up to three TDs, or to two receivers delivering a total of three TDs. Selection of receiver is a user economic decision depending upon required accuracy.

C. The navigator display will be a CRT showing true-motion of the vessel as well as all of the background information carried by the tape. Possible performance options in the display (e.g., update time, zoom, pan, tracks-up/north-up) can dominate both the economics and complexity of the total system. Microprocessor technology and prepackaged CRT graphics will hold the maufacturing cost of the navigator below $10,000.

The above components will be incorporated in a self-contained developmental system which will include the software and "dummy" input to perform Differential LORAN-C. Only the data link need be added in the future to realize operational Differential LORAN-C. Similarly, three TDs will provide optimum three line fixes and continued navigation in the event of one line dropout, and will permit direct augmented operation.

As stated in the objective of the program, to determine the feasibility of the practical user equipment in many Harbor Approach and Harbor regions, the entire navigator system, including both equipment and tape, must be reproducible at low cost so that a truly CONUS-wide evaluation can be made. Further development of the navigator may include the provision for self-calibration by the user. In this mode, the user will develop a user tape through repeated runs in the normal operating area.

The specific activities in this project for each Fiscal Year are identified as follows:

A. FY-79

- o Develop a two and three line-of-position grid matrix algorithm.
- o Develop user tape software.
- o Develop prototype navigator.
- o Test navigator on simulator at the Coast Guard's Electrical Engineering Center.
- o Test self-contained navigator in the St. Marys River.

B. FY-80

- o Fabricate six to eight demonstration harbor approach/harbor navigators.
- o Deploy three units on ore carriers in Great Lakes.
- o Deploy remaining units in San Francisco or another suitable harbor.

C. FY-81

- o Additional operational test and evaluation experiments in CONUS.
- o Development of self-calibrate capability.

Although the guidance equipment may demonstrate the precision operation of LORAN-C, the marine navigators may not accept the content and format of the information presented. This risk is minimized by experience in St. Marys River with User II. Moreover, the grid may be unstable in some areas of CONUS. This may be solved by Differential LORAN-C with a corresponding increase in cost and complexity. The system errors may also preclude using the navigator in some restricted waterways. This problem can be minimized by augmentation techniques such as Differential LORAN-C or supplemental Lines-of-Position (LOPs).

4.0 DISPLAY REQUIREMENTS

The objective of this project is to determine what format and detail are optimum for the display of precise navigation information for Harbor Approach and Harbor use. The project will provide guidelines on the trade-off between guidance system display complexity and a navigator's ability to direct the movement of his vessel along a desired track utilizing the guidance system. The primary end results of this project will be the development of specifications and standards for user display equipment, and the determination of how the performance of mariners is affected by radionavigation system errors.

4.1 BACKGROUND

Demonstrations of the two marine guidance system (discussed in Section 3.6) on the St. Marys River involved two widely divergent types of display of navigation information. One system used digital and bar graph formats, while the second system presented a detailed pictorial representation of the vessel, channel boundaries and shoreline. With both of these methods, it is unknown how the mariners ability to direct the motion of the vessel is affected by the format and detail of the navigation display. Results of experiments conducted at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) using a digital display to augment visual aids showed significant improvement in a pilot's performance in navigating in a difficult channel configuration, but also showed that a pictorial display is needed to pilot a ship in any restricted waterway except a straight channel. From the experience on the St. Marys River and at CAORF, it is evident that a guidance system will provide a useful navigational aid to a mariner. What needs to be assessed is the impact the format and detail of the display have on the performance of the mariner.

4.2 TECHNICAL APPROACH

Work in this project area is summarized in Figure B-7 and will be accomplished as a separate project, distinct from the development of LORAN-C itself. The project will seek answers to the questions "How do I best present electronic navigation information to the mariner?" and "What information do I present?". Man-in-loop experiments at a contractor's facility with simulated display fromats and detail will be utilized to determine performance trade-offs and mariners' preferences. These answers will provide valuable input to the development of user equipment. Additional project work may be required in the future to assure that the simulations represent the "real world" in sufficient detail to obtain representative performance measures. "Optimum" display formats may be difficult to define due to the range of navigation situations and individual mariner preferences. This may result in "class optimizations" for groups of vessel type and navigation situation.

4.2.1 Contribution of Errors to Navigational Performance

Utilizing the optimum class of display (low, moderate or unlimited cost), the project then will analyze the contribution of radionavigation system errors to the performance of the mariner. The mariner will navigate a simulated channel using only the electronic display, with system errors introduced in the form of position "noise."

4.2.2 Summary

In summary, the project will provide definitive information about the ability of a mariner to navigate a restricted waterway in limited visibility conditions with electronic display systems.

5.0 NAVSTAR GPS APPLICATION STUDIES

The objective of this program is to determine the capability of, or the development necessary for NAVSTAR GPS, to satisfy the requirements of civil maritime transportation in the oceanic, coastal, Harbor Approach and Harbor phases of navigation.

5.1 BACKGROUND

Coincident with the DOD evaluation of NAVSTAR GPS the Coast Guard plans to contribute to the body of knowledge needed to make informed national judgments on the best use of NAVSTAR GPS for civil applications. From the marine viewpoint, NAVSTAR GPS appears capable technically of satisfying most navigation requirements and thus is a prime candidate to supplement and/or replace all existing radionavigation systems.

However, many specific questions must be answered before it would be possible to predict the optimal use of NAVSTAR GPS. These could be characterized along operational, technical, institutional, and economic lines. Foremost among these are the issues of accuracy that will be made available to the civil marine user and

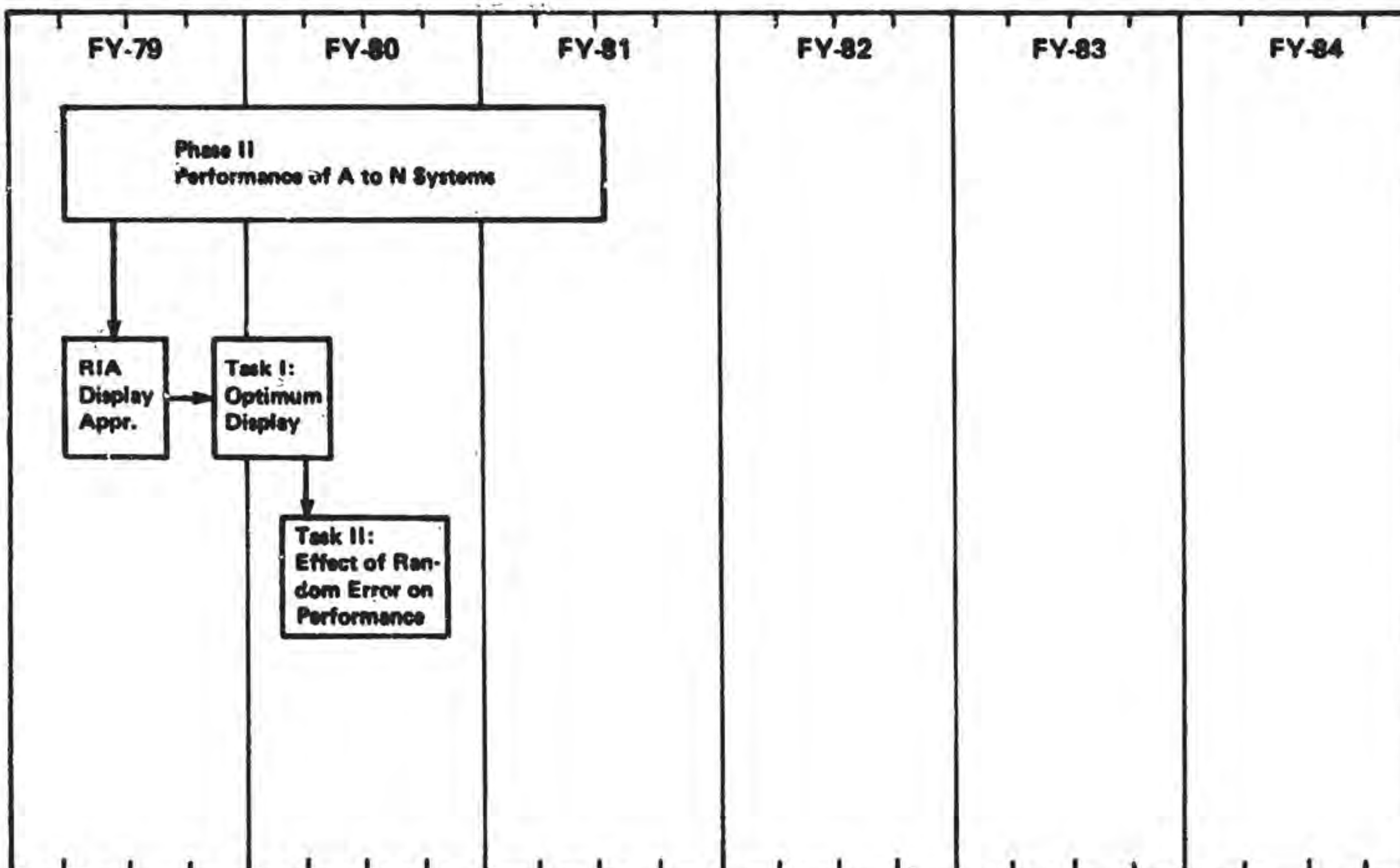

FIGURE B-7 Display Requirement (Event Flow Diagram) of cost/performance trade-offs that are possible with the final navigation system. A full appreciation of the potential usefulness of NAVSTAR GPS to civil maritime navigation, in terms of cost and performance, is one essential consideration in the formulation of national policy concerning the level of accuracy to be made available for general, civil use. Assuming that NAVSTAR GPS will be implemented and that some service of reasonable quality will be available for general use, it will be especially attractive as a system which will allow large ships to operate safely and with optimum efficiency almost anywhere in the world, at least in coastal and ocean waters, seaward of the immediate approaches to ports. For smaller maritime operators, commercial and recreational, the cost/performance trade-offs will be critical. In the absence of a Government regulatory requirement, these vessels are unlikely to accept NAVSTAR GPS willingly unless it provides comparable or better performance at an equal or lower cost than the navigation systems which are existing today.

5.2 TECHNICAL APPROACH

The NAVSTAR GPS program is one that involves a large effort within the DOD, its contractors, and other agencies. The Coast Guard program must be supplementary and reactive to this broad program, confining itself to exploring issues of concern to civil marine users, and flexible enough to adjust quickly to changes in the overall effort beyond Coast Guard control. The present program approach is as follows:

A. Study all available information on C/A channel receivers and performance.

B. Cooperate with MARAD in the testing of one of the few such receivers presently in existence.

C. Monitor all Government programs related to NAVSTAR GPS, particularly those of the FAA, NASA, and MARAD.

D. Sponsor "add-on" Coast Guard peculiar research in NAVSTAR GPS whenever possible as part of existing efforts. Attempt to determine the ultimate C/A (civil) channel performance from such studies.

E. Develop in-house simulation capability, first in software, and later hardware, for analyzing and testing receivers.

F. Conduct user tests of NAVS[illegible] GPS side-by-side with other aids to navigation.

G. Sponsor R,E&D into methods of reducing cost or improving performance of potential NAVSTAR GPS marine receiver technologies.

The above objectives are reflected in three project categories which are indicated in Figure B-8. These categories are receiver technology, user field tests, and C/A channel ultimate performance potential. All three of these categories combine in a major system decision block sometime in the FY-82 or FY-83 time frame.

5.2.1 Five Specific Major Project Areas of the Program:

A general category of receiver studies to be performed [illegible] the Transportation

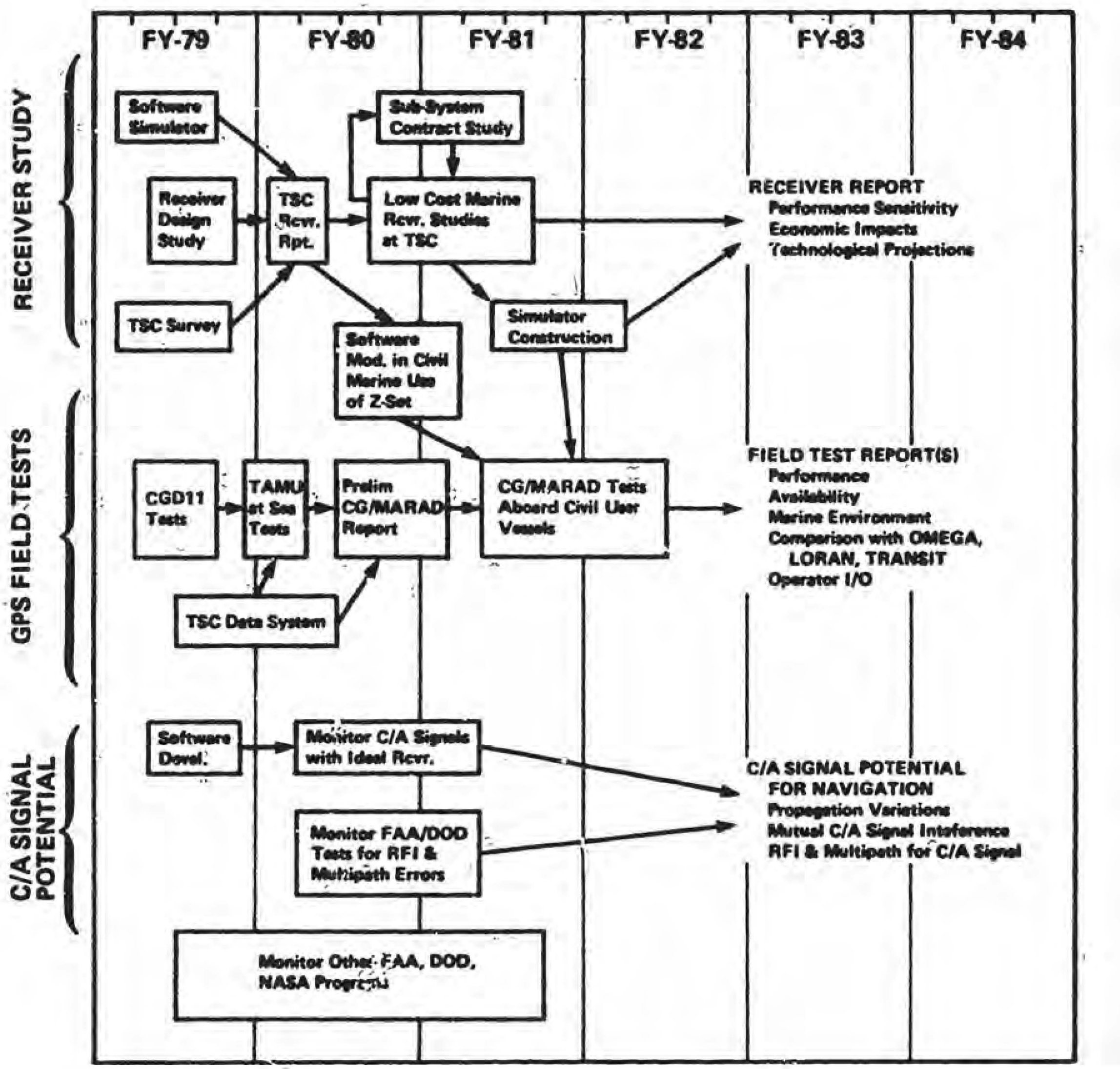

FIGURE B-8 GPS Application Studies (Event Flow Diagram)

Systems Center (TSC) and by contract. This program may or may not include a simulator development, and may include other hardware developments, such as receiver subsystems R,E&D. This task is a dynamic one in which the future, like all R,E&D, depends very much upon present research and cannot be identified clearly. The Coast Guard does not envision contracting for a receiver during the next several years. Studies and subsystem testing will be adequate to predict performance.

The bulk of the DOD monitor effort will be borne by Coast Guard personnel located near the Joint Program Office in California and by the new DOT NAVSTAR GPS Deputy Program Manager. Periodic visits with their engineering personnel, plus their reports and submissions, will maintain very close contact with these programs of interest to the Coast Guard. A resident DOT Deputy Program Manager, who is a Coast Guard Officer, has been appointed to facilitate liaison and coordination. Liaison has been established with both the FAA and NASA in Washington, D.C., to stay abreast of their efforts.

Simulation facilities are necessary to study civil marine-peculiar receiver options, and eventually to test competing receiver designs or subsystems objectively. This program will proceed with necessary low-cost items, but will defer signal hardware construction until receiver production patterns are established.

The Joint USCG/MARAD program is expected to last two years, with an output to consist of a first-cut analysis of civil NAVSTAR GPS and a portable data recorder for comparative analysis of NAVSTAR GPS and other aids to navigation. One or more Z-sets (single-frequency, single channel, course acquisition code only) receivers will be available for a field test program on user vessels beginning in late FY-80 and continuing indefinitely, or until other receivers are available. Possible software or firmware modifications might well be made to the Z-set during this program to optimize it for marine use, as opposed to the aircraft mode for which it was designed.

The C/A channel-potential study is planned for execution at the Johns Hopkins Applied Physics Laboratory (APL) using available receiver equipment there. This receiving equipment, an X-set (high dynamics, high anti-jam resistance) which has been reconfigured for multimission use under computer control, will be configured to process C/A signals only during these tests. The tests will show accuracy histories and statistics for a perfect civil receiver navigating only on C/A signals.

Follow-on programs, beyond the initial R,E&D described, will depend entirely on the outcome of this program and the disposition of operational, economic and institutional questions. For example, if NAVSTAR GPS seems to offer a significant potential for Harbor Approach and Harbor navigation, in the light of both cost/performance and national policy on the quality of service to be made available to the public, then major in depth R,E&D must be mounted to study low probability, but debilitating phenomena such as multipath, ionospheric delay aberrations not covered by the model, and so on. On the other hand, if NAVSTAR GPS shows little practical hope for this use, the Coast Guard's efforts in the field will be reduced to a lower level of fostering receiver development and the development of national and international performance standards for maritime receivers. The bottom line is really the impact of NAVSTAR GPS on the marine aids to navigation system, and this impact will be defined by the combined total influences of performance, economics, and institutional questions. That is, the R,E&D program is oriented towards performance potential first, and secondarily, towards the factors of economics and policy.

5.3 NAVSTAR GPS APPLICATIONS STUDIES DURING EACH FISCAL YEAR

A. FY-79 - Understanding the issues and questions: This key event is basically one of education, learning in detail how the system works and how receivers interact with system capability to result in ultimate accuracy. From this will come a specific set of questions related to the system (e.g., ionospheric propagation error budget) that impact civil use, followed by similar set of questions/trade-offs in receiver design that determine price or performance. This year's output is essential both for future R,E&D programming, and as input for use in Government policy decisions.

B. FY-80 - Preliminary Tests of Issues and Questions: This year will provide the opportunity to participate with MARAD in NAVSTAR GPS "low-cost" receiver tests. At the same time every effort will be made to collect and analyze system performance information from any source (e.g., DOD monitor stations, FAA measures of RFI). Thus FY-80 will provide the first field answers to the FY-79 questions, and inevitably suggest further questions.

C. FY-81 - This year is expected to provide refinement and amplification to the FY-80 field results, and see starts in Coast Guard hardware projects.

D. FY-82 - Simulator Construction and Delivery: A hardware signal simulator for testing receivers under controlled in-house conditions will be delivered this year. Major reports on receiver technology and field performance will be published.

E. FY-83 - All major tools will be in place for decisions concerning the potential for civil maritime use of NAVSTAR GPS.

FEDERAL RADIONAVIGATION PLAN
APPENDIX C
LORAN-C LAND R,E&D PROGRAM
TABLE OF CONTENTS

APPENDIX C
LIST OF ILLUSTRATIONS

APPENDIX C
LORAN-C LAND R,E&D PROGRAM

1.0 INTRODUCTION

This appendix describes a five-year DOT Research, Engineering and Development (R,E&D) program to assess land applications of existing radionavigation systems. The program mainly addresses LORAN-C and does not cover the NAVSTAR GPS R,E &D activities described previously in II.2.4. However, over the long-term, land R,E&D for GPS, LORAN-C, and other alternative navigation systems will be coordinated within this appendix and will cover the following Federal, State, and local municipal agencies and potential civil users:

- o DOT Modal Administrations: RSPA, UMTA, NHTSA, FHWA, and the FRA
- o Other Federal Departments: DOE, DOC, DOI, USDA, and HRS
- o State Governments
- o Municipal Agencies (e.g., Police, Fire, and Highway Departments and Emergency Medical Services)
- o Industry
- o Private Users (e.g., trucks and taxis).

The appendix is intended to outline the long-term tasks required to evaluate potential land applications in the public domain and is organized as follows:

1.1 Background
2.0 DOT LORAN-C Land R,E&D Issues
3.0 Objectives
4.0 Approach
5.0 Tasks and Schedules.

The R&D activities defined in this plan are the responsibility of the DOT Research and Special Programs Administration (RSPA). Task and schedule information covering each Fiscal Year from FY-79 through FY-83 will be identified under the title "Land R&D for Navigation Systems" when prepared to accompany the budget submissions.

1.1 BACKGROUND

There has been an increasing need for DOT to provide leadership in the implementation of technical and operational evaluations of LORAN-C and NAVSTAR GPS in land navigation applications within the United States. The need was formally recognized in 1977 when the DOT National Plan for Navigation (NPN) established an intent to assure services to major segments of the population, which include those who could derive significant benefits from a precise determination of position on land. In providing a radionavigation capability for the civil maritime community in U.S. Coastal and Great Lakes Waters, the Coast Guard's operation of LORAN-C transmitters will offer [illegible]itaneou[illegible] [illegible]tional advantage of coverage for over two-thirds of the area of the contiguous United States and 92 percent of its population. The existence of this coverage, and possibility of its expansion to a nationwide system, has prompted considerable interest in land surveillance and location identification uses of LORAN-C by a number of Federal and State agencies and industry. Within DOT alone these interests range from active demonstration of automatic vehicle monitoring of transit vehicles and dangerous cargoes to police car dispatching, emergency medical services, and highway safety programs.

By most standards, the inherent accuracy and receiver prices of LORAN-C satisfy the preliminary cost-effectiveness criteria of a potentially large number of land users. Future market sizes for radio-location services may approach one million for trucks and taxis and over one-hundred thousand for police cars, ambulances, fire engines, and other public service vehicles. However, the ability of radionavigation systems to meet the needs of these users depends on their successful operation in vehicle and urban environments, both of which are more severe than those encountered by the maritime community. Land vehicle speeds and internal electromagnetic interferences are more difficult to treat and the receivers are subject to intense local radio-frequency interference from a wide variety of industrial and private sources (power distribution lines, stoplights, burglar alarm systems, etc.).

2.0 DOT LORAN-C LAND R,E&D ISSUES

In its central role in civil navigation, DOT will need to address five major issues relating to land use of radio-location systems before the current investments by its own agencies (UMTA, FHWA, NHTSA, and FRA) and other public agencies become substantial. These are:

A. Are the LORAN-C and NAVSTAR GPS signal strengths high enough or visible enough to enable operation in at least 90 percent of the urban areas where the radio-frequency (RF) noise is most prevalent? Are inexpensive alternative systems available to augment these systems in local regions where the RF noise is dominant or the signal strength has been reduced due to low satellite elevation angles or external shielding (e.g., structures, powerlines) of the receiver antenna?

B. How should DOT respond to an emerging user community requirement to limit the RF noise produced by existing sources (e.g., powerlines, stoplights, telephone line test signals).

C. Is it possible to overcome the effects of signal reflection noise through a low-cost redesign of the receiver or with dead-reckoning procedures which minimize the effects of short-range noise sources?

D. Will the early uses of LORAN-C be restricted to the low RF noise suburban and rural areas where higher benefits can be achieved at lower risk?

E. What guidelines should DOT provide to potential users so that they can easily evaluate their costs, benefits, and technical developments in a step-by-step manner?

F. What practical uses can State and local governments make of LORAN-C?

G. To what extent are State and local governments interested in using LORAN-C?

H. Can State and local governments afford LORAN-C - first cost of purchasing equipment, systems, etc.?

3.0 OBJECTIVES

The main objective of this R,E&D plan is to establish a long-term program which supports DOT decisions on land uses of radio-location systems and specifies the requirements to evaluate potential land application in the public domain. The plan concentrates on near-term activities for the LORAN-C system and can be used to structure similar activities for future systems such as NAVSTAR GPS. The DOT support will provide comprehensive performance and cost-effectiveness information consistent with the special functional, geographic, and operational needs of each user group at Federal, State, and local levels. Procedures will be developed which prescribe the early steps which should be taken in the evaluation of LORAN-C applications prior to a decision to proceed with large-scale demonstrations or major system implementations. These include preliminary measurements of RF signal and noise, determining enforceable actions on radio-frequency illegal or unregulated radiations, providing technical evaluations of the results of present and planned user demonstrations, and comparing LORAN-C performance and costs with those of alternative navigation systems. The specific short-term objectives within the next two years are:

A. Develop equipment rapidly to assess receiver-independent signal strengths and noise sources from measurements taken in areas identified by potential users.

B. Establish a data base for LORAN-C program planning and the analysis of LORAN-C performance and costs. This includes system designs, equipment costs, computer programming requirements, and system calibration.

C. Identify the quantifiable and other indirect benefits which can be employed in comparing LORAN-C with current operations.

4.0 APPROACH

The LORAN-C Land Action approach consists of two successive efforts: (1) near-term work entitled "LORAN-C Land R-E&D," and (2) a long-range activity called "Operations Management and Technology Sharing." The earlier phase is intended to establish the necessary expertise, data bases, and equipment designs for the second phase where operational evaluations and technology sharing will be developed more actively with potential users. The five-year relationship of these two phases to the major DOT critical decisions and the separate LORAN-C programs of the modal administrations is illustrated in Figure C-1. The most important factor in the planning of work after 1980 will be the DOT decision on whether or not to fund the

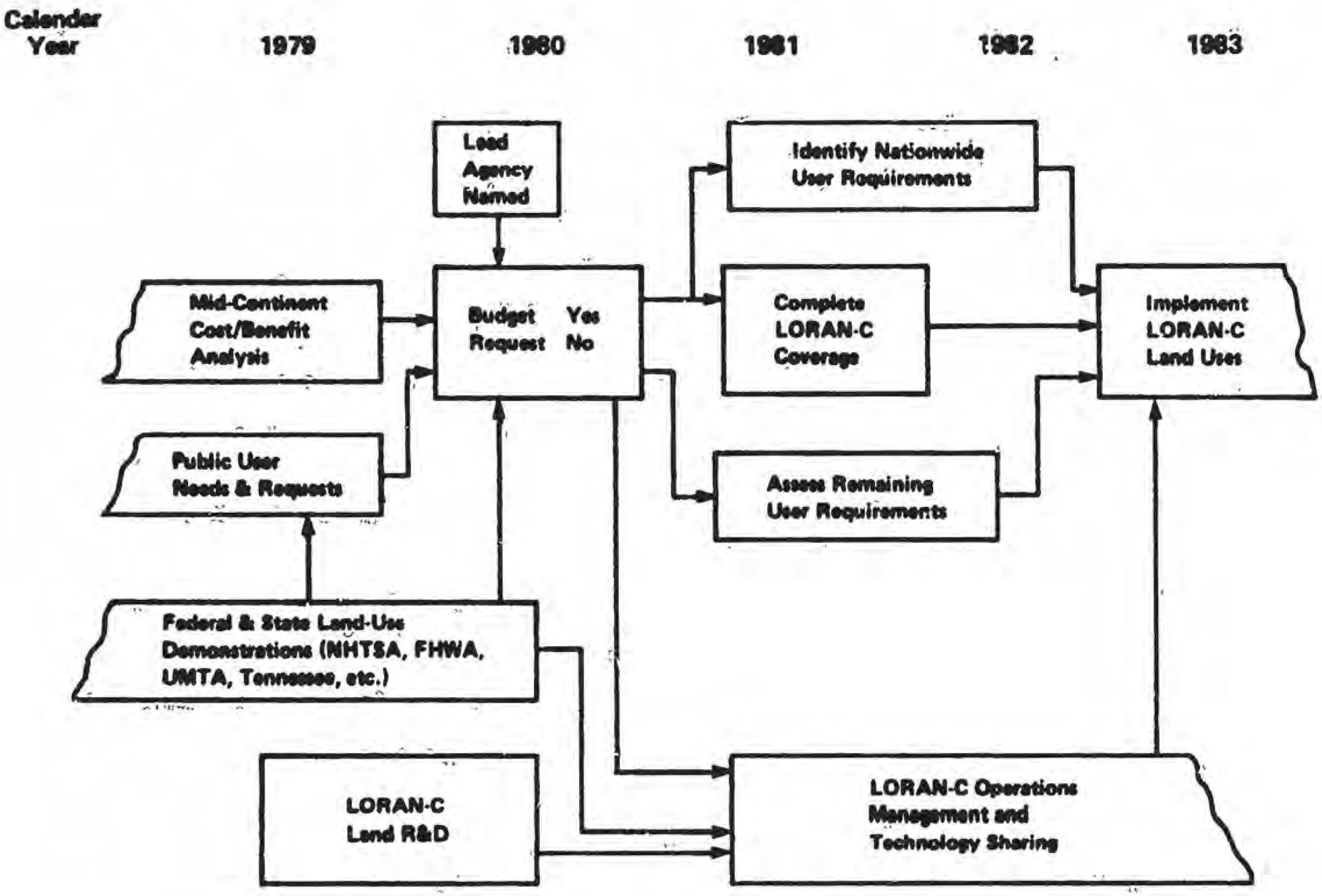

FIGURE C-1 DOT LORAN-C Land Actions

expansion of LORAN-C to the mid-continent region of the United States. During 1979 and 1980, the LORAN-C Land R,E&D activity will refine the cost/benefit data and provide expanded information on the user requirements and the results of LORAN-C demonstrations for a mid-continent budget request. Once the budget decision has been made, the Operations Management and Technology Sharing phase of the program will be restructured to cover either the requirements of the users on a nationwide basis or in the areas which do not depend on the mid-continent coverage. Regardless of the restructuring, the second phase will continue to provide comprehensive data on the remaining user requirements, costs, and benefits and will focus on the annual report to supply detailed guidelines on LORAN-C implementations to the user community.

The LORAN-C Land Action Program is a part of a larger DOT project entitled Navigation System Studies. The larger project will utilize a Navigation Economic Model to compare the costs and benefits of future civil navigation system alternatives involving land, sea, and air users on a nationwide basis. In addition to providing data for this model, the Land Action Program will provide comparisons of LORAN-C receiver costs with alternative systems (e.g., NAVSTAR GPS, OMEGA, signposts) now being studied by the FAA, U.S. Coast Guard, and other DOT agencies. By mid-1980, these comparisons and the results of field tests (particularly for the NAVSTAR GPS, low-cost receiver studies and the UMTA automatic vehicle monitoring with LORAN-C and signposts in Los Angeles) will be evaluated and submitted as information to accompany the budget requests.

5.0 TASKS AND SCHEDULES

The tasks and schedules indicating the main year-by-year efforts of the LORAN-C Land Action Program are summarized in Figure C-2. The figure identifies seven major tasks which are defined as the Land R,E&D phase up to 1981 and thereafter support the main end product of Operations Management and Technology Sharing. The figure also shows five major related activities which will be evaluated as additional information sources for the budget request and for the preparation of guidelines for the potential LORAN-C applications. The specific objectives and descriptions of each task are as follows:

5.1 USER APPLICATION STUDIES

The objective of this task is to collect and organize information relating to land applications of LORAN-C in a form which will identify both the special and common requirements of the various user groups. Although this task will be performed on a continuing basis throughout the program, the major work will occur in 1979 and 1980 and consist of:

A. Establishing a library and a bibliography of LORAN-C reference material, project reports, and information sources (e.g., list of contacts, areas of expertise, and equipment capabilities) which focus on land uses.

B. Developing and updating a computerized data base of LORAN-C activities which can be accessed to printout cross-correlated information on user functions, applications, organizations, project sizes, and schedules.

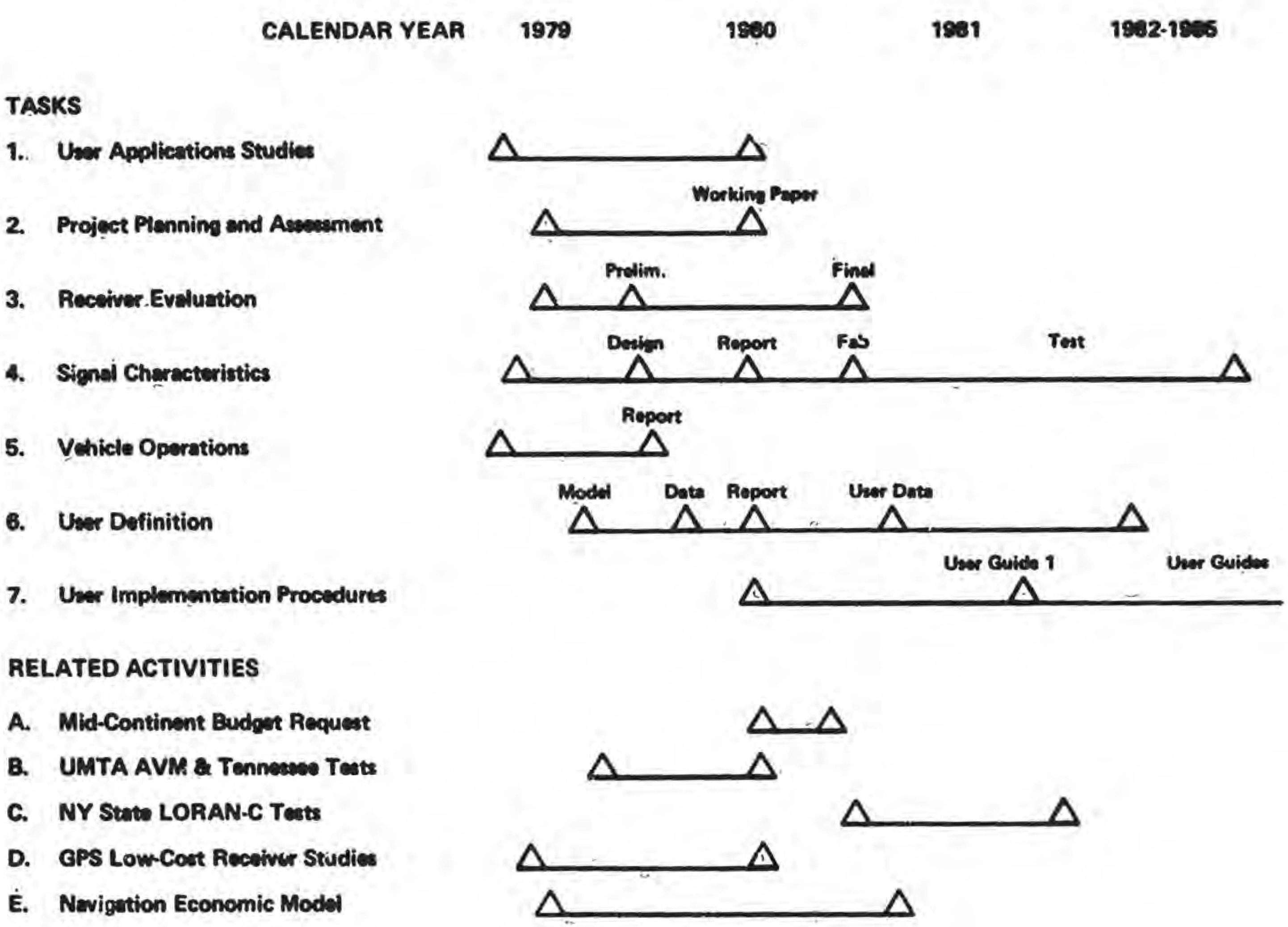

FIGURE C-2 LORAN-C Land Action Tasks and Schedules

C. Providing updated histories of LORAN-C receiver prices, manufacturers, modifications, and new designs (e.g., light-weight compact units, special packaging, new operational features, and communications and control interfaces).

D. Collecting ancillary information and summaries of past work which is considered to be a secondary importance to the project. This includes general information on grid prediction techniques, communications procedures, human factors, LORAN-C time referencing, mini-chain operation, and combined OMEGA and LORAN-C receiver designs.

5.2 PROJECT PLANNING AND ASSESSMENT

The goals of this task are three-fold: (1) to objectively assess demonstrations of LORAN-C land uses; (2) to define future demonstrations which should be performed; and (3) to incorporate useful information obtained from studies of air and marine applications of LORAN-C. This work will include an analysis of data obtained from three major related activities listed in Figure C-2. These are: (1) UMTA LORAN-C automatic vehicle monitoring experiments now being conducted in Los Angeles; (2) prototype testing of emergency medical service (EMS), highway safety, and various other applications now underway in Tennessee, Kentucky, and Pennsylvania; and (3) preliminary designs of rural police, EMS, and highway department applications being planned by the State of New York. The results of these and other activities will be summarized in a working paper for the budget decision in mid-1980 and will involve:

A. An evaluation of past and present LORAN-C land demonstrations being conducted by DOT (e.g., RSPA, UMTA, NHTSA, FHWA, and FRA), other Federal organizations (U.S. Forest Service, BLM, ERDA, etc.) and State and local agencies.

B. Recommendations for additional testing in areas where firm conclusions cannot be made or where problems occur.

C. A test plan for future LORAN-C experiments which emphasizes demonstrations that should be performed by DOT agencies (UMTA, NHTSA, etc.) and other interested Federal and State agencies which have similar guideway and navigation accuracy requirements.

D. An assessment of the degree to which information on land applications of LORAN-C can be extrapolated from the results of air and marine experiments and activities conducted by the FAA and the U.S. Coast Guard.

5.3 RECEIVER EVALUATION

The objectives of this task are three-fold: (1) to identify those areas where the current marine receivers can be modified to operate more effectively in the land environment; (2) to verify with the manufacturers and from field tests that the modifications can be made at low cost and with a minimum of technical risk and complexity; and (3) to define central processing techniques which can be used to improve the overall accuracy of a multi-vehicle LORAN-C system, e.g., Differential LORAN-C. This task will focus on in-vehicle operation of LORAN-C receivers at representative turn rates and velocities during periods when the signal-to-noise ratios are marginal. Design options now being considered by the manufacturers and by LORAN-C land demonstration programs in Los Angeles, New York, and Tennessee include the following:

A. Improved velocity aiding and coasting and blanking strategies either within the receiver or at a remote central processor in order to reduce errors over short distances where the noise is high.

B. Vehicle position error corrections and calibrations from a local monitor or a remote tracking facility which relate the vehicle velocity and direction to the LORAN-C position error ellipse, and reasonability checks on predicted positions or actual location readings obtained from an augmenting system.

C. Lost-lock or cycle-slip warning indicators which inform the operators that their receivers are not working and generate requests to the remote tracking facility for course reasonability checks which are based on predicted position or area-wide signal and noise profiles.

D. Receiver design modifications such as faster relocking, narrower bandwidths, improved notch filtering, faster time constants and tracking logic, and optimal weightings of time differences derived from more than one LORAN-C chain.

The initial analysis of the most promising design options in this task will be perfromed by Purdue University in an existing contract with RSPA. The analysis will derive information from earlier studies of signal and noise characteristics and vehicle electromagnetic interference in Tasks 4 and 5 in order to provide a preliminary report in October 1979. The report will specify a hierarchy of design approaches which should be taken to minimize the effect of defined types and magnitudes of urban noise (e.g., short and medium-range continuous wave and discrete radio-frequency interferences) at processing rates suited to stationary vehicles and vehicles moving at transit vehicle speeds. The report will also include an assessment of system architectures and processing algorithms which optimize the wide-area error correction techniques in both the receivers and from the central monitoring facilities.

In 1980, guidelines will be developed for a LORAN-C receiver performance specification for land use vehicles. The guidelines will be evaluated against the current and projected states of technology (e.g., new integrated circuits) and the receiver manufacturer's ability to implement specified designs at reasonable cost. The evaluation will include an assessment of prior receiver modifications tested in the field (e.g., Los Angeles, New York and Tennessee) and the cost and performance trade-offs between in-vehicle and central facility processing. The assessment will also contain an analysis of vehicle operations in rugged rural terrain and at the position reporting rates and velocities encountered in the majority of land applications.

5.4 SIGNAL CHARACTERISTICS

The long-term goal of this task is to develop a mobile LORAN-C laboratory which can be used to assess rapidly the temporal and spatial quality of LORAN-C signals in a variety of areas within the United States. On-site measurements taken by the laboratory are intended to serve as the starting point from which requesting States of local users can make early decisions on the ability of LORAN-C to meet their performance criteria. The laboratory is intended to provide signal and noise profiles which can be used to make an initial assessment of signal strengths and local position monitoring requirements before major R,E&D investments are incurred. Emphasis will be placed on making a rapid report to prospective users on the results of the measurements as the first step to a more complete definition of total system requirements in Tasks 6 and 7 (sections C.5.6 and C.5.7).

During 1979 and 1980, the Land Action Program will be devoted to the design and fabrication of the LORAN-C mobile laboratory and to the measurement of temporal changes in LORAN-C accuracies at selected rural locations. Both of these efforts will draw heavily on the present Coast Guard experience and procedures for measuring LORAN-C transmitter signals in the field. The laboratory design will proceed from a review of urban RF noise characteristics which are now being diagnosed as a part of the AVM experiments in Los Angeles. These and other noise measurements (e.g., power-line carrier noise assessments in Tennessee) will be used to determine data storage rates and sizes for RF noise analysis routines which will be developed in 1980. The routines will be developed from a test plan which specifies the methods for obtaining a representative noise profile as a function of geography, local structure and anomalies, and over predetermined estimates of signal correlation distances and times. The profile will be expressed in terms of fixed percentages of the spatial and temporal availabilities of usable LORAN-C signals.

The purposes of the early measurement of temporal changes in the LORAN-C grids are to determine the requirements for differential operation of LORAN-C and to establish a land signal monitoring capability which is coordinated with existing and new Coast Guard monitor stations throughout the United States. Early efforts in this area will consist of an examination of Coast Guard monitoring equipment and procedures in order to assess their ability to provide unified monitor data to regional State and local agencies. The assessment will focus on optimal weightings of position corrections obtained from multiple monitor stations and will include the requirements for providing local information on chain reliabilities. In 1979, preliminary estimates of these data requirements will be obtained from measurements of repeatability by an existing RSPA LORAN-C van at selected rural locations in Vermont, Tennessee, and New York State.

In mid-1980, a report summarizing the progress and findings of all signal characteristics activities will be prepared. The report will provide the following:

A. A description of the mobile test laboratory and the plan for its use in a comprehensive technology sharing program between the Federal Government and public users at State and local levels.

B. A preliminary identification of the types and degrees of radio frequency interferences (RFI) which have been determined from measurements in the field.

C. The DOT procedures and documentation needed to initiate possible FCC administrative actions to both limit RFI and determine the impact of the limitations on established operations.

D. A preliminary assessment of the adequacy of LORAN-C signal-to noise ratios for land uses in urban and rural areas.

E. A description of the methods and investments needed for improving the signal-to-noise ratios through the use of local mini-transmitters, multi-chain operation, or position updating transmissions from local monitoring facilities.

F. A description of the steps required to achieve coordinated monitor station operation and data dissemination between U.S. Coast Guard and local monitor stations.

The fabrication, assembly, and acceptance testing of the LORAN-C mobile laboratory will be completed by 1981. Extensive field testing in response to user requests will begin in 1982 and is expected to provide the critical data for decisions to go ahead with large-scale LORAN-C implementations. The data are intended to establish the initial guidelines for a more extensive definition of user requirements, costs, and benefits in Task 6.

5.5 VEHICLE OPERATION

The purpose of this task is to develop techniques for improving the installation and operation of LORAN-C receivers in land vehicles. This task will be performed by Purdue University in an existing contract with RSPA and mainly addresses LORAN-C antenna designs and guidelines for minimizing the effects of the vehicle environments on the received signals. This activity will result in a final report by the end of 1979. The report will consider bus, ambulance, police car, and highway inventory vehicle types and will involve the following:

A. An analysis of present and new antenna design (e.g., loop, stub, phased-array) and antenna locations which minimize receiver errors caused by low signal strength, signal polarization, and shielding by the vehicle or its structure.

B. Installation guidelines which assure proper grounding of the receivers and minimize antenna shielding by the vehicle metallic structures or other antennas.

C. A specification of the temperature ranges and electromagnetic interference (EMI) environments in the dashboard, trunk, or equipment storage areas of land vehicles. The specification will cover all-weather operations for a wide variety of vehicle types and EMI sources (e.g., alternators, citizens-band radios, police radios).

D. An assessment of the suitability of the present LORAN-C receivers to operate within the land vehicle temperature ranges and when fastened to mounting fixtures specifically designed to minimize the effects of shock and vibration.

E. The specification of a standard electrical interface and signal description for LORAN-C receivers in land vehicles. The description will include: position location data words, receiver status (e.g., lost-lock, acquisition, vehicle identification, ECD, noise values), LORAN-C status (e.g., blink, chain identification), and data request and control functions.

5.6 USER DEFINITION

The objective of this task is to provide a continuing and comprehensive description of the user requirements, costs, and benefits in land applications of LORAN-C. The description will be developed from the data base and prior work in Tasks 1 through 5 (sections C.5.1 through C.5.2) and provide specific definitions of the special and common needs of user groups in three areas:

A. Requirements:
This subtask will compare the overall system requirements of user groups to specific system designs which insure an integrated and technically acceptable operation of LORAN-C in land applications. The system designs will consider augmenting systems, vehicle accuracies and responsibilities, coasting times, central facility monitoring and position update rates, receiver characteristics, and other pertinent factors. These designs will then be analyzed to determine viable modes of multi-vehicle and multi-modal operation which involve optimal local monitor strategies, minimization of mutual interference, interagency coordination, and specific geographic, terrain, and temporal and spatial coverage methods.

B. Costs:
This subtask will specify the total system costs to implement fully the systems defined by the user requirements. The cost estimates will reflect current LORAN-C receiver prices and market sizes and will include the following:

1. Receiver initial purchase and yearly operation and maintenance costs as a function of their price-versus-demand histories, present volumes of production, and equipment life-times.

2. Initial installation costs, retrofit expenses, and equipment amortizations expressed as a function of vehicle operating environments and life-cycles.

3. Initial training and annual retraining expenditures.

4. Costs for LORAN-C grid calibrations, local monitor facilities, low-powered local transmitter stations, and map preparation and dissemination.

5. Central processing costs for the acquisition, sorting, storage retrieval, and retransmission of LORAN-C data.

6. Central facility (e.g., displays, keyboards) and operations costs associated with automatic vehicle monitoring and control.

C. Benefits:
This subtask will provide estimates of the tangible and intangible benefits which may be derived from specific system implementations of LORAN-C. The estimates will reflect the ranges of benefits derived from similar past and future applications of LORAN-C and will specifically reference the sources and rationale employed to quantify monetary values. The benefits will include:

1. Annual savings in operating personnel and vehicle moving costs (fuel, tire wear, etc.).

2. Savings from the elimination or supplementation of existing location systems (e.g., highway mileposts, ground flagmen, precision odometers, etc.).

3. Revenues derivable from other local agencies who benefit from an established Management Information System with local position reference data.

4. Safety-related benefits resulting from improved highway accident aid and selective enforcements, faster general emergency services (e.g., medical, fire suppression), and faster aid during criminal emergencies (e.g., policemen, bus drivers, taxis).

5. Savings from more efficient search and rescue operations and coordinated position monitoring and control in forest fire suppression or natural disaster relief.

6. Intangible benefits from the improved tracking and routing of dangerous cargoes.

In 1979, prior to establishing the more complete information on land user requirements and benefits, preliminary estimates of the cost data for existing and potential users will be provided for the DOT Navigation Economic Model. Aggregate user costs for LORAN-C user population projections obtained from the model will then be summarized along with the preliminary benefit estimates in a report for the budget request. In April 1981, a final user definition document and a mechanism for incorporating additional future user requirements will be prepared in a form suitable for continued in-house use of the model by DOT.

5.7 USER IMPLEMENTATION PROCEDURES

This task covers the generation of a continuing set of procedures and guidelines which will inform existing and potential users of the progress and problems encountered in all land applications of LORAN-C. Its main purpose is to generate yearly user guides and short reaponse newsletters to potential users. Three types of documents will be published in order to stimulate a multi-user exchange of information and elicit inquiries into coordinated and cost-effective applications of LORAN-C by groups of users in their local operating regions. The description of these publications is as follows:

A. Short-response newsletters in the form of introductory primers and state-of-art overviews will be issued at least once a year in order to introduce the users to LORAN-C and its applications and to inform them of recent advances in receivers and navigation system techniques.

B. User guides will be published once each year and will specify the progressive steps required in the consideration of groups of LORAN-C applications and the orderly implementation of their operation within the users' existing systems.

C. User directories will be prepared which summarize the major results of on-going research, development and demonstration projects. The directories will also provide information on user conferences and DOT meetings and decisions affecting land uses of LORAN-C.

As shown in Figure C-2, the publication of user guides will begin in 1981 and continue through 1985 as the major reporting mechanism of the LORAN-C Land Action Program. It is hoped that the combined use of these guides and the newsletters and directories will generate a long-term technology sharing process where DOT acts as the focal point for detailed information and guidance in its leadership role for civil navigation.

FEDERAL RADIONAVIGATION PLAN
APPENDIX D
DOD RESEARCH, ENGINEERING AND DEVELOPMENT FOR SELECTED RADIONAVIGATION SYSTEMS

TABLE OF CONTENTS

APPENDIX D
DOD R,E&D FOR SELECTED RADIONAVIGATION SYSTEMS

1.0 OBJECTIVES

This R,E&D plan for radionavigation systems has as its objective, a description of the development of selected, common-used radionavigation capabilities required by the Commanders of the Unified and Specified Commands, and Military Departments/Services to fulfill the tasks specified in the Joint Strategic Planning System (JSPS). The JSPS outlines the military strategy and force levels for attaining the national security objectives of the United States. Tactical navigation requirements are established by the Unified and Specified Commands and coordinated by the Office of the Joint Chiefs of Staff (OJCS). The requirements are consolidated and used as a basis for the Five-Year Defense Program (FYDP) which forms part of the President's budget submitted for approval and funding by the Congress.

1.1 SYSTEMS ACQUISTION PROCESS

The system acquisition process of the DOD is a sequence of specified phases of program activity and decision events directed toward achievement of established program objectives. The process is initiated with the approval of a mission need and extends through successful completion of development, production and deployment of the Defense system or termination of the program. DOD Components (the Military Departments and the Defense Agencies; the term "Services" refers to the Army, the Navy, and the Air Force) are responsible for a continuing analysis of mission areas to identify mission needs and to define, develop, produce and deploy systems to satisfy those needs. Mission needs are stated in terms of the operational task to be accomplished and not in terms of performance or characteristics of systems to accomplish the mission.

The Secretary of Defense shall make the decisions to initiate, increase, decrease, redirect or terminate program commitments. DOD Component Heads are accountable to the Secretary of Defense to execute approved system acquisition programs in accordance with the Secretary's decisions and to keep the Secretary informed on the current status. The four key Secretary of Defense decision points identified with separate phases of program activity are structured as follows:

1.1.1 Milestone 0 - Program Initiation

At such time as the Secretary of Defense requests or a DOD Component Head determines that a new capability is to be acquired to meet a perceived need, the DOD Component Head shall submit a statement of the mission need to the Secretary of Defense and request approval to proceed to identify and explore alternative solutions to the mission need. The consideration to support the determination of the mission need shall be documented in the Mission Element Need Statement (MENS).

When a mission need is determined to be essential and reconciled with other DOD capabilities, resources and priorities, the Secretary of Defense will approve the mission need and direct one or more of the DOD Components systematically and progressively to explore and develop alternative system concepts to satisfy the approved need.

1.1.2 Milestone 1 - Demonstration and Validation

When the DOD Component completes the competitive exploration of alternative system concepts to the point where the selected alternative warrants system demonstration, the DOD Component Head shall request approval to proceed with the demonstration and validation effort. The recommendations shall be documented in a Decision Coordination Paper (DCP), and reviewed by the Defense System Acquisition Review Council (DSARC) and the (Service) System Acquisition Review Council ((S) SARC) prior to the Secretary of Defense's decision.

The Secretary of Defense's action will reaffirm the mission need and approve one or more selected alternatives for competitive demonstration and validation.

1.1.3 Milestone 2 - Full-Scale Engineering Development

When the demonstration and validation activity has been completed and the Component Head is prepared to recommend the preferred systems for full-scale engineering development, the recommendations shall be documented in an updated DCP and reviewed by the DSARC and (S)SARC prior to the Secretary of Defense's decision.

The Secretary of Defense will reaffirm the mission need and approve the selection of a system for full-scale engineering development, including procurement of long-lead production items and limited production for operational test and evaluation.

1.1.4 Milestone 3 - Production and Deployment

When the Component Head is prepared to recommend production of the system, the recommendations shall be documented in an updated DCP and reviewed by the DSARC and (S)SARC prior to the Secretary of Defense's decision. The Secretary of Defense will reaffirm the mission need, confirm the system ready for production, approve the system for production and authorize the Component to deploy the system to the using activity.

Following a Milestone 3 decision, the DOD Component Head shall make quarterly reports to the Secretary of Defense on key program issues. The DOD Component shall keep the Defense Acquisition Executive and the OSD staff informed on key program actions as the program progresses.

The DOD Component Head shall decide when the system is ready to be deployed to the using activities and shall advise the Secretary of Defense.

The following DOD documents define the DOD policy in specific functional areas dealing with system acquisitions:

Document	Number	Subject
DOD Instruction	4005.3	Industrial Preparedness Production Planning
DOD Manual	4005.3M	Industrial Preparedness Planning Manual
DOD Directive	4100.35	Logistic Support
DOD Directive	4105.62	Proposal Evaluation and Source Selection

Document	Number	Subject
DOD Directive	4120.3	Standardization
DOD Directive	4155.3	Quality Assurance
DOD Instruction	4200.15	Manufacturing Technology
DOD Instruction	4400.1	Priorities and Allocations
DOD Directive	C4600.3	Electronic Counter-Countermeasures (ECCM)
DOD Directive	5000.1	Major System Acquisitions
DOD Directive	5000.2	Major System Acquisition Process
DOD Directive	5000.3	Test and Evaluation
DOD Directive	5000.4	Cost Analysis Improvement Group
DOD Directive	5000.23	Management Careers, System Acquisition
DOD Directive	5000.28	Design to Cost
DOD Directive	5000.30	Defense Acquisition Executive
DOD Instruction	5010.8	Value Engineering
DOD Instruction	5010.12	Data, Acquisition of
DOD Instruction	5010.19	Data, Acquisition of
DOD Directive	5100.40	Responsibility for the Administration of the DOD Automatic Data Processing Program
DOD Directive	6015.1	Environmental Considerations in DOD Actions
DOD Directive	7000.1	Resource Management Systems of the DOD
DOD Instruction	7000.2	Cost/Schedule Control System
DOD Instruction	7000.3	Selected Acquisition Report (SAR)
DOD Instruction	7000.6	Management System Control
DOD Instruction	7045.7	The Planning, Programming and Budgeting System
DOD Manual	7110-1-M	DOD Budget Guidance Manual Armed Services

2.0 NAVSTAR GPS

2.1 OVERVIEW

NAVSTAR GPS is currently in Phase II (Full-Scale Engineering Development (FSED)) which includes initiating the development of prototype user equipment, initiating the prototype satellite and control station production, and initial operational test and evaluation (IOT&E) of user equipment. In keeping with the desire to support the broadest possible civil use of NAVSTAR GPS consistent with national security, activities will be undertaken by DOD to assure the proposed selective availability policy (DOD Supplement) is fully implemented with the development and acquisition process. DOD will continue to work with civil agencies in support of planning and activities required to define future civil use of NAVSTAR GPS. The DOD/DOT Interagency agreement provides for DOT representation at the Systems Program Office (SPO) and coordination/information transfer of the finding of the NAVSTAR GPS development program.

2.2 PHASE II: FULL-SCALE ENGINEERING DEVELOPMENT (FSED)

2.2.1 Space Vehicle

To insure that a minimum of five satellites are available for Phase II Development Test and Evaluation (DT&E) and Initial Operational Test and Evaluation (IOT&E) a number of replenishment satellites will be acquired from the Phase I (Demonstration and Validation) supplier in FY-79 after Milestone II (DSARC II - June 1979). This satellite constellation will provide apporximately four hours per day of test time over the Western United States. Atlas E/F and the stage vehicles required to launch the replenishment satellites will also be acquired.

The Joint Program Office (JPO) will contract with the Phase I developer to upgrade the Phase I satellite to a shuttle compatible, survivable configuration. Provisions to qualify a second production source are also contemplated for this contract. The upgraded satellite will be the prototype of the production NAVSTAR GPS satellites to be acquired in Phase III (Production and Deployment).

2.2.2 Operational Control Segment (OCS)

The OCS will consist of a NAVSTAR Control Center (NCC), monitor stations, and an Alternate Control Center. In order to maintain competition during the design phase, Phase II was divided into two stages. In Stage 1, three contractors were selected (in December 1978) to complete NCC/monitor station designs through Preliminary Design Review (PDR). After PDR (1980) and Milestone 2, the single Stage 1 contractor with the best overall preliminary design, including design-to-life-cycle-cost (DTLCC) considerations, will be selected to continue as the Stage 2 contractor for NCC development and deployment. An Alternate Control Center will be acquired after Milestone 3 (DSARC III - July 1981) to augment the NCC; however, it will be either the Phase I Master Control Station or a new site. The location of the Alternate Control Center and the acquisition approach depend on life-cycle-cost trade-offs to be made during Stage 2. Modifications to the OCS designed to increase automation and reduce life-cycle cost are also to be undertaken after Milestone 3.

2.2.3 User Equipment

Phase II includes the paralleled full-scale engineering development of a family of user equipment. Emphasis will be on required performance capabilities and ease of integration with host vehicles at the lowest life-cycle cost. Commonality of modules across all configurations is the goal. In order to provide maximum competition for this development, Phase II was broken into Phases IIA and IIB for User Equipment. In Phase IIA, four contractors were competitively awarded firm fixed-price contracts for preliminary design of User Equipment. Following the parallel design effort, two of the Phase IIA contractors will be competitively chosen (after Milestone II) to complete development of prototype user equipment. A sufficient number of user equipment sets will be developed for testing by independent service test agencies. Test results will be used in evaluating proposals for selection of the Phase III user equipment production contractor(s).

2.3 PROGRAM GOALS

2.3.1 Technical

Key operational and technical goals for the GPS program are as follows:

	Goals	Threshold
A. Operational		
1. 3-D Position Accuracy of User Equipment	16m Spherical Error Probable (SEP)	+5m (SEP)
2. Prototype Phase II Satellite Mean Mission Duration	6yrs	-18 mo
3. Systems Availability*	95%	-10%
B. Technical		
1. Expected Ground Power (End of Life) @ 5° EL		
L1 (P CODE)	160 dbW	-3dB
L2 (P CODE)	163 dbW	-3dB
2. Clock Stability (T=1 day)	$2x10^{-13}$	$+2 \times 10^{-13}$
3. User Equipment Reliability MTBM (AFR 80-5)		
Airborne	550 hr	275 hr
Ground	850 hr	425 hr
Sea	900 hr	450 hr
4. User Equipment Maintainability Mean Man Hours to Repair		
Airborne	1.3 hr	2.4 hr
Ground	1.2 hr	2.25 hr
Sea	1.3 hr	2.7 hr

* Availability of signal source needed to provide 16 meter SEP to users uniformly distributed on or near the earth.

2.3.2 Schedule

Major schedule dates in each of the program segments are as follows:

		Planned Date	Threshold
A.	Space Segment		
	- Replenishment Satellites		
	o Contract Award	Nov '79	N/A
	- Operational Prototype		
	o Block Change	July '80	N/A
	o OPS/QTV* Launch (1st STS Launch)	Nov '84	N/A
B.	Control Segment		
	o Development Contract Award	Sep '80	N/A
	o Launch Support for OPS/QTV	Nov '84	N/A
	o GPS/CSOC Capability	Nov '85	N/A
C.	User Segment		
	o Phase IIB FSED Contract Awards	July '79	
	o IOT&E (START)	Jan '83	+9 mo
	o First Production Contract Award	Oct '83	+9 mo

* Qualification Test Vehicle.

D. Program

o DSARC IIIA (Space)	Oct '81	+9 mo
o DSARC IIIB (User Equipment)	Sep '83	+9 mo
o Initial Two Dimensional Worldwide (12 satellite) Capability	3rd Qtr CY '86	+9 mo
o Three Dimensional Capability (Satellite constellation increased to 18 satellites)	4th Qtr CY '87	+9 mo

2.4 TEST PLANNING

By the end of Phase II, there are certain questions and areas of risk which must be resolved. Concerning development, it must be determined whether NAVSTAR GPS user equipment can (1) be designed and built to integrate efficiently into a wide range of user equipment vehicles; (2) achieve the level of immunity to jamming required by the military mission at an affordable cost; and (3) demonstrate the minimum acceptable values fo. the reliability and maintainability characteristics prior to Milestone 3. The accomplishment of these objectives will determine whether NAVSTAR GPS user equipment can provide adequate positioning, navigation, and timing information to accomplish typical missions and operations in a more effective manner for each of the individual services' specific requirements.

2.5 TEST OBJECTIVES

2.5.1 General

Since Phase II navigation equipment will be prototype of operational equipment, the primary emphasis will be the combined Development Test & Evaluation/Initial Operational Test and Evaluation (DT&E/IOT&E) of the user equipment integrated into the IOT&E host vehicles. The DT&E and IOT&E test objectives listed below will be used in planning the actual test events and scenarios to be accomplished in the combined test programs. The Air Force has the lead responsibility for the development of the NAVSTAR GPS system. This includes the DT&E and IOT&E to satisfy all service objectives.

2.5.2 Phase II DT&E Objectives

A. Quantitatively measure the performance of the navigation equipment and compare with the development specifications.

B. Verify that the installed NAVSTAR GPS user equipment is ready for IOT&E.

C. Identify any engineering design deficiencies which can be eliminated to reduce Life-Cycle Costs (LCC).

D. Provide estimates of system reliability and maintainability to be expected when the operational system is deployed.

E. Determine by analysis the ability of Control Segment satellite commands to overcome a jamming environment.

F. Determine by analysis the capability of the satellite command system to reject non-authorized communications.

G. Identify and track deficiencies and improvements during the entire Phase II test effort.

2.5.3 Phase II IOT&E Objectives

A. Air Force Objectives

1. Evaluate NAVSTAR GPS operational effectiveness to include:

   a. General navigation capability.

   b. Ordnance delivery capability.

   c. Aiding Radar Bomb Scoring (RBS) missions.

   d. Ability to be used as a landing approach aid.

   e. Aerial survey and reconnaissance navigation capability.

   f. Capability to provide navigation data (in common coordinate reference) for air-to-surface operations and air-to-air operations rendezvous.

   g. Estimation of integration effectiveness with host vehicle component and systems.

   h. Software operational effectiveness.

   i. Identify and track deficiencies and improvements for the user, space and control segments during IOT&E.

   j. Adequacy of flexibility of satellite constellation replenishment plans.

2. Measure the impact on system operational effectiveness, in terms of navigation accuracies, as a result of:

   a. Normal control and space segment operations such as satellite upload, satellite orbit adjustment and satellite momentum dumps.

   b. Extended time periods between satellite uploads.

   c. Loss of data from one or more monitor stations.

   d. Jamming of uplink to or downlink from satellites.

   e. Navigation with fewer than four satellites in the various modes of user set operation (such as inertial aiding and altitude hold).

f. Control segment sabotage (for several hypothetical levels of severity).

3. Evaluate user, space and control segment operational suitability to include:

   a. Reliability
   b. Availability
   c. Maintainability
   d. Supportability
   e. Training
   f. Human Engineering
   g. Operations Maintenance Procedures
   h. Software

4. Provide information for developing and refining tactics and doctrine.

B. Army Objectives

1. Obtain data to assess the mission performance of the user equipment in a representative operational environment.

2. Obtain data for assessment of the operational reliability, availability, and maintainability (RAM) of the user equipment in a realistic operational environment.

3. Provide data for the assessment of the logistical support concept.

4. Provide information to assess the vulnerability of the user equipment.

5. Provide information to assess the adequacy of proposed doctrine, tactics, organization and training.

6. Provide data to assess operational human factors.

C. Navy Objectives

1. Generate sufficient data to support firm recommendation on approval for service use.

2. Determine NAVSTAR GPS user segment operational suitability and military utility.

3. Identify any operational deficiencies or requirements for modification.

In addition, IOT&E testing must yield data on:

1. The probability of fast acquisition and reception aboard a submarine at periscope depth at sea with a representative range of sea states, antenna heights, and satellite elevations.

2. The probabilities of fast acquisition and erroneous data in the severe RFI environment of an aircraft carrier during flight operations.

3. The mission reliability and the ratio of maintain-to-operate hours in a carrier-based aircraft environment including catapult launch, arresting landing, fast warmup and erratic power.

4. The operational availability including the mean time between failure (MTBF), time to repair, and probability of needed parts being available under a full range of maintenance environments that prevail for carrier aircraft, submarines, shore-based aircraft, and surface ships (consistent with the DTLCC goals).

5. The resistance of the system to jamming or deception by a sophisticated enemy possessing full knowledge or signal structure but not knowing the cryptographic key.

6. The capability of navigation suites in ships and aircraft NAVSTAR GPS receivers integrated to meet the accuracy, timeliness, and reliability requirements established for each particular ship or aircraft type, as outlined in the U.S. Navy Navigation Policy (OPNAVINST S3350.1).

7. The effects on speed of re-acquisition and subsequent navigation error resulting from the maneuvering of an attack or fighter aircraft.

D. Marine Corps Objectives

Marine Corps objectives are included in other Services' objectives. No unique objectives have been identified.

3.0 TRANSIT

Under the aegis of DDR&E (now the Under Secretary of Defense for Research and Engineering), the Navy initiated a TRANSIT Improvement Program (TIP) in 1969. The TRANSIT satellites were to use the most recent technology but were to be fully compatible with existing user equipment. Three developmental TIP satellites have been launched, and all R,E&D objectives have been met. The TIP program is now into production. The only remaining development is a low-level effort to provide Space Shuttle compatible satellites.

4.0 MICROWAVE LANDING SYSTEMS (MLS)

4.1 OVERVIEW

As the DOD lead service for the Joint Tactical Microwave Landing System (JTMLS) program, the U.S. Army is responsible for developing and testing a militarized man-transportable MLS ground subsystem and associated avionics for potential tactical application by the services. Current plans are to award a contract for the design and development of advanced development (AD) models of the JTMLS ground and avionics subsystems during FY-80. This activity is part of the National Plan for Microwave Landing System that was authorized by Congress in 1972 and is administered through the Federal Aviation Administration (FAA). The objective of this program is to ensure that, within the scope of responsibility and the funding authorized to the FAA, maximum progress is made toward providing the DOD with an operationally effective tactical MLS design. The DOD's criteria for operational effectiveness in this case are:

- Interoperability between any MLS avionics and any MLS ground installation, civil or military.
- Performance accuracy in compliance with MLS standards and the stated military requirements.
- DOD's reliability, maintainability, productivity and life-cycle cost goals.
- Demonstrated achievement of size, weight and human factor goals.
- Steep approach flight capabilities, STOL and VTOL projections.

4.2 SERVICE OBJECTIVES

4.2.1 Army

At the present time there exists a serious void in the approach subsystem necessary to satisfy the Army's Air Traffic Management System Material Need (ATMS MN). Therefore, to comply with the Army's ATMS MN requirement for a tactical approach subsystem, it is planned to develop and field a tactical MLS for the family of present and future Army aircraft systems. The principal tactical approach and landing system currently used by the Army is the ground-controlled approach (GCA) radar system. The GCA equipment is heavy, cumbersome, limited to 200-foot decision height operation and requires a highly skilled ground controller. Early development and fielding of a new, modern state-of-the-art tactical landing system, such as the JTMLS, will meet the majority of Army aviation instrumented tactical and non-tactical landing needs until at least the Year 2000.

4.2.2 Navy

To accomplish its assigned mission, the Navy has identified the requirement to employ naval carrier-based aircraft capable of executing around-the-clock (night and all-weather) air defense and attack missions. In order to provide for the safe return of these aircraft to the carrier, the Navy developed the all-weather carrier landing system (AN/SPN-42) which is currently employed aboard 13 aircraft carriers and installed at 6 air stations for aircrew training. The prototype ship-board MLS must meet or exceed the same requirements currently being met by the SPN-42. To accomplish the landing requirements, the carrier landing system must be capable of automatically controlling aircraft to touchdown within specified landing dispersions under ship motion and turbulence. It must sense deck motion, stabilize the antenna or the signal in space, and generate and transmit coordinate translation data to compensate for siting offsets and deck motion.

4.2.3 Air Force

The USAF operates worldwide to accomplish its mission of defense of the United States. The nature of the mission requires that USAF aircraft use not only U.S. military and civil air traffic control and navigation facilities, but also those civil and military facilities of allies and facilities that may be available from nonaligned nations. The USAF has traditionally depended upon Precision Approach Radar (PAR) and ILS/TACAN to provide guidance during the approach and landing phase. PAR is not universally available, therefore, it is increasingly necessary for the USAF to make use of the standard navigation and landing aids as defined by the International Civil Aviation Organization (ICAO). This interoperability is currently manifested in the additional implementation of ground and airborne ILS. The USAF will continue to implement those approach and landing aids that are interoperable with standard national and international civilian aviation systems. Air Force requirements range from those desiring a limited capability at minimum cost to those requiring sophisticated equipment capable of providing fully automatic approaches and landings.

4.2.4 Marine Corps

Marine Corps operational requirements are documented in CNO SOR 34-26, "Marine Remote Area Approach and Landing System (MRAALS),", and CNO SOR 34-22, "Marine Air Traffic Control and Landing System (MATCALS)." Since MLS is designed as the replacement for ILS/GCA/CCA, to satisfy Marine Corps requirements it must be suitably adaptable to provide precision approach and navigational guidance to fixed-wing, rotary-wing and other V/STOL aircraft in remote areas, expeditionary airfields and fixed bases. The Marine Corps has defined those requirements which will be met with MRAALS and MATCALS and must be met with the military MLS, as a minimum, to satisfy Marine Corps needs. Marine Corps requirements for approach and landing navigational systems are directed at a capability to conduct flight operations in all-weather conditions thereby achieving a DOD goal of increased aircraft sortie rates.

4.3 TEST AND EVALUATION

A Coordinated Test Program (CTP) for the JTMLS will be developed to define the comprehensive test and evaluation program that will be pursued during the development of the JTMLS. The CTP will be developed by a Test Integration Working Group (TIWG) which will include representatives from all the military services. Emphasis will be placed on elimination of duplicate testing in order to minimize test cost.

The prime objective of the JTMLS test program will be to evaluate the overall system performance in several tactical and civil environments and to evaluate critical parameters such as the DME, multipath effects, conical coordinates and split site/collocated requirements.

During advanced development, the equipment will be subjected to Army DT-I/OT-I level of testing. These tests will be coordinated with the overview by the Test Integration Working Group (TIWG).

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