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NAVSTAR GPS
CIVIL APPLICATIONS STUDY

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NAVSTAR GPS CIVIL APPLICATION STUDY

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This report has been reviewed by the Information Office (OIS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations. This technical report has been reviewed and is approved for publication.

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Navstar Global Positioning System

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This report examines the impact on the civil navigation community and on military operations of introducing the Navstar GPS for civil applications.

Institutional, operational; technical and cost factors are considered and assessed. A low cost GPS user set for civil applications is employed to develop comparative costs for current vice GPS oriented civil navigation environments.

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1.0 INTRODUCTION

The single most important National objective of any independent country is the establishment and maintenance of National Security. In the United States, a substantial portion of the annual budget is dedicated to achievement of National Security. The Department of Defense, through the activities of the Joint Program Office (JPO) in the Air Force Space and Missiles System Organization (SAMSO), has initiated a development program for an advanced satellite radionavigation system; the Navstar Global Positioning System (GPS).

For some time, the aggregate of navigation and position location requirements, as developed through military mission analyses, has exceeded the available technology. In order to objectively respond to the potential for the deployment and operation of military forces on a global scale, it is essential to provide navigation services that exhibit the following characteristics:

(1) World-Wide Coverage

(2) Precision Accuracy

(3) Continuous Service

The single system, current or planned, that responds to all the above required characteristics is the Navstar GPS.

Since the GPS is a satellite-based radionavigation system, the emitted signals are detectable over extensive areas and, therefore, subject to potential use by non-DOD elements. In order to guard against hostile actions which may include use of

the system, the GPS was designed to include several additional characteristics:

(4) AJ Margin

(5) System Access Deniability

The addition of the protective features required the application of spread sprectrum waveform technology which provides relative immunity to intentional interference and a suitable format for providing signal deniability.

Because of the extraordinary performance promised by this new development, there has been generated a substantial interest in examining the possibility of extending its application to the civil sector.

The outstanding features of the system, particularly its global coverage and precision accuracy, encourage its use as a National and International asset satisfying a multitude of navigational and position location requirements.

Its potential applicability is widespread, but a number of issues arise that may impact the ultimate direction of a program conceived and developed, by the DOD, for use in support of a wide range of military operations.

The major issues occupy several diverse areas that include:

(1) Policy

(2) Technology

(3) Economics

The policy issue is complex and involves, as a basic prerequisite, the question of even seriously considering the military/

civil sharing of Navstar GPS. For a global system, access cannot be practically granted to some and denied to others.

The DOD has offered to provide the capability for limited access (i.e., to a less accurate signal structure), but cannot consider making available a world-wide, precision system designed for strategic and tactical operations by any force equipped with suitable equipment.

The formulation and implementation of a suitable policy to provide joint civil/military utilization and, at the same time, protect vital military interests requires careful consideration. Civil operations for air and sea involve international organizations with numerous member states.

The formulation and implementation of a suitable policy raises further obstacles. The military anticipates and protects against system losses through contingency planning and redundancy. As a military system, the Navstar GPS is a potential enemy target. Its interruption or loss through hostile action is a factor that must be considered for civil applications. The development of procedures and responsibilities for management, operation, restoral of service, emergency actions, conflicts of interest, preservation of National Security pose formidable problems.

The technology issue is no less complex and contributes to the policy issues. The technology employed for the provision of GPS navigation services is sophisticated, but available to any industrialized country.

The signaling system was not optimized for both military and civil use since military requirements dictate the use of spread spectrum techniques for antijamming protection. The detection and processing gains of spread spectrum signals call for coherent carrier detection and code correlation or matched filtering techniques. These processes are incrementally more costly than conventional signaling that would satisfy civil applications. There are several alternatives that are evident.

First, the GPS can provide its presently designed coarse/acqusition (C/A) signal at an accuracy considerably less than that available on the precision (P) signal designed principally for military use.

Second, the GPS may provide a secondary payload containing a navigation signaling system designed specifically for civil use—with an accuracy equivalent to that provided by the C/A signal, but with some potential for reducing the user segment cost.

Third, the U.S. civil sector may consider plans for an independent satellite navigation system providing accuracies equivalent to that provided by the military P signal. (This option poses a policy issue at a National level).

Finally, an international consortium may elect to implement

a satellite navigation system with U.S. participation and P signal accuracy.

The economic issue involves cost considerations that are difficult to assign among the various participants. It is simplistic to assume that the total National cost should be minimized. The civil user apportionment stands out with maximum visibility. What size investment or subsidy, if any, should the government expend to assure the potential civil user segment a "low cost" GPS navigation receiver? Low cost is meaningful only when compared with other alternatives.

Presumably, if the GPS user segment achieves a relatively low cost, the currently available alternatives may be phased out of service. Otherwise, the government suffers a net loss by fielding yet another system.

This report is intended to achieve two objectives: First, determine the impact of the civil community of users on military applications of the Navstar GPS. Second, determine the impact on military applications of GPS were it to be civil operated.

Section 2.0 examines civil user populations and requirements.

Section 3.0 examines the military/civil missions and the degree of commonality among missions and requirements.

Section 4.0 examines the constraints and impact on the GPS program as a consequence of civil user participation.

Section 5.0 examines the categories of impact upon the GPS system as a result of several approaches to modification of the

system to serve civil users, and develops an estimated cost for a GPS Civil User Segment.

Section 6.0 presents a relative cost comparison between the continued use of current radionavigation systems and the introduction of GPS for civil use.

Section 7.0 presents the principal conclusions and recommendations.

2.0 CIVIL SYSTEMS REQUIREMENTS ANALYSIS

2.1 Introduction

The scope of the examination of civil navigation requirements considers vehicular operations in three major environments.

1. Civil Aviation
   - Transoceanic En Route
   - U.S. Domestic En Route
   - U.S. Domestic Terminal Area
   - U.S. Domestic Approach and Landing
   - U.S. Domestic Offshore Operations
2. Civil Maritime Transportation

   Marine Navigation
   - High Seas
   - Coastal and Confluence (CCZ)
   - Harbor and Harbor Entrance (HHE) and Inland Waters
3. Land Mobile Radiolocation
   - Rural
   - Urban
   - Central Business District

The application of radionavigation and radiolocation systems, in these three environments, focuses on providing services primarily to mobile elements; however, the use of such systems to support the accurate location of stationary elements (e.g., site registration on land) is not excluded.

It is useful to note here that the following analysis of the civil navigation requirements considers a set of informal statement of needs obtained from various sources within the

civilian agencies covering the environments mentioned. Formal requirements for civil radionavigation, with the exception of those obtained from the Department of Transportation's (DOT) National Plan for Navigation (NPN), dated November, 1977, are not currently available.

2.2 U.S. Government Role Relative to Civil Navigation

2.2.1 General

The Department of Transportation is the primary Government provider of civil aids to navigation. The responsibility for navigation matters within the DOT, and the promulgation of the National Plan for Navigation is assigned to the Secretary of Transportation, as part of his authority under the DOT Act (Public Law 89-670). The U.S. Coast Guard and the Federal Aviation Administration (FAA), two agencies within DOT, have assigned statutory responsibilities relative to providing aids to navigation.

2.2.2 U.S. Coast Guard

The Coast Guard has the statutory responsibility to define the need for and to provide aids to navigation and facilities needed for safe and efficient navigation. Section 81 of Title 14, United States Code, provides:

"In order to aid navigation and to prevent disasters, collisions, and wrecks of vessels and aircraft, the Coast Guard may establish, maintain and operate:

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

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

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

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

2.2.3 Federal Aviation Administration

The Federal Aviation Administration, under the Federal

Aviation Act of 1958 (Public Law 85-726), 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 needs of military agencies which are peculiar to air warfare and primarily of military concern. The FAA also has the responsibility to operate aids for air navigation required by international treaties.

2.2.4 Other DOT Agencies

The Federal Highway Administration, the National Highway Traffic Safety Administration, and the Urban Mass Transportation Administration, under their respective statutory authorities, have the responsibility to sponsor research, development, and demonstration projects on land uses of radiolocation systems. Also, through their various grant authorities, they provide performance standards and assist state and local governments in planning and implementing such systems.

The St. Lawrence Seaway Development Corp. (SLSDC) has responsibility for assuring safe navigation along the seaway. Jointly with the St. Lawrence Seaway Authority of Canada, the SLSDC operates a Vessel Traffic Control System.

2.3 Definition of Radionavigation Requirements

2.3.1 General

The development of requirements for radionavigation for the civil sector differs considerably from that generally associated with the military. Since the military both provides

and uses systems designed to achieve well defined mission objectives that support the goal of National Security, the formulation and structure of requirements usually exists within a well ordered format. Additionally, the military organization is formalized, with specific relationships established among the military services and the Department of Defense, resulting in a more disciplined approach to planning procedures. The relationship between the Government and the diverse public communities of radionavigation users must always maintain a balance between freedom and regulation of user interest. As described, the Government, through the DOT, exercises the role of radionavigation service provider and, consequently, regulates, to varying degrees, the many civil applications of radionavigation. As a result, a continuing diversity of interests between public interest groups and the Government, concerning the amount of regulation necessary to assure safety and yet maintain freedom of activity among users, exists.

It will be evident that the Government-Public relationship impacts the formulation and promulgation of requirements since such requirements define performance parameters to be satisfied to gain access to regulated air, marine, and land operational environments. The degree of regulation is most advanced in the area of air operations wherein the FAA's Air Traffic Control System is assigned the responsibility for providing safe and efficient air travel. The nation's airspace is utilized by air carriers, the military and general aviation. The air traffic

control system must accommodate all classes of users; this results in a mixed airspace with varying levels of requirements for access.

In contrast, marine operations currently have no centralized control system that is equivalent to the FAA's Air Traffic Control System. The Coast Guard has the statutory responsibility for maritime aids to navigation. The Maritime Administration of the Department of Commerce (DOC-MARAD) represents the interests of the American Merchant Marine. The maritime operating environment is normally divided into three categories: (1) High Seas (2) Coastal/Confluence Zone, (3) Harbor/Harbor Entrance Zones, and Inland Waterways. The Government, through the Coast Guard, provides radio aids to navigation for marine users, but has not generally instituted a closed loop marine traffic control system. However, for the HHE environment, the Coast Guard has implemented several Vessel Traffic (Control) Systems for supporting harbor entrance operations. Land-based operations are further removed from formalized control system configurations, and the application of radionavigation is directed toward providing radiolocation services as part of surveillance activities for various classes of users.

There is, then, a substantial range of civil activities that require some form of radionavigation service. In addition, the degree of required response from any specific navigation system also varies widely.

The provision of a single system or family of systems that

responds to all user requirements represents an attractive concept due to the potential operational cost savings that would result. However, since a single system would have to meet all user requirements, including the most stringent, the resulting cost of user borne equipment provides the principal arguments against this single system concept.

2.3.2 Levels of Requirements

The process of formulating requirements that define the parameters of expected system performance proceed through several levels of definition. Figure 2-1 shows a representative sequence of system life-cycle activities beginning with a stated goal and ending with an operational system. The mission or operational requirements shown in Box 4B define the level of system performance required to meet objectives. The requirements at this level are non-specific relative to potential system characteristics, so that normally, a number of alternative approaches may be evaluated. The expected performance requirements are generally fixed so that the evaluation of alternative system candidates is based upon minimization of life-cycle-cost. Feedback paths are shown to indicate that concepts and/or requirements may have to be modified because of lack of technology or excessive cost. The system design requirements that finally evolve are descriptive of the specific system configuration in terms of technical performance characteristics. The level of detail employed will limit the degrees of freedom a potential supplier may utilize in developing a responsive configuration.

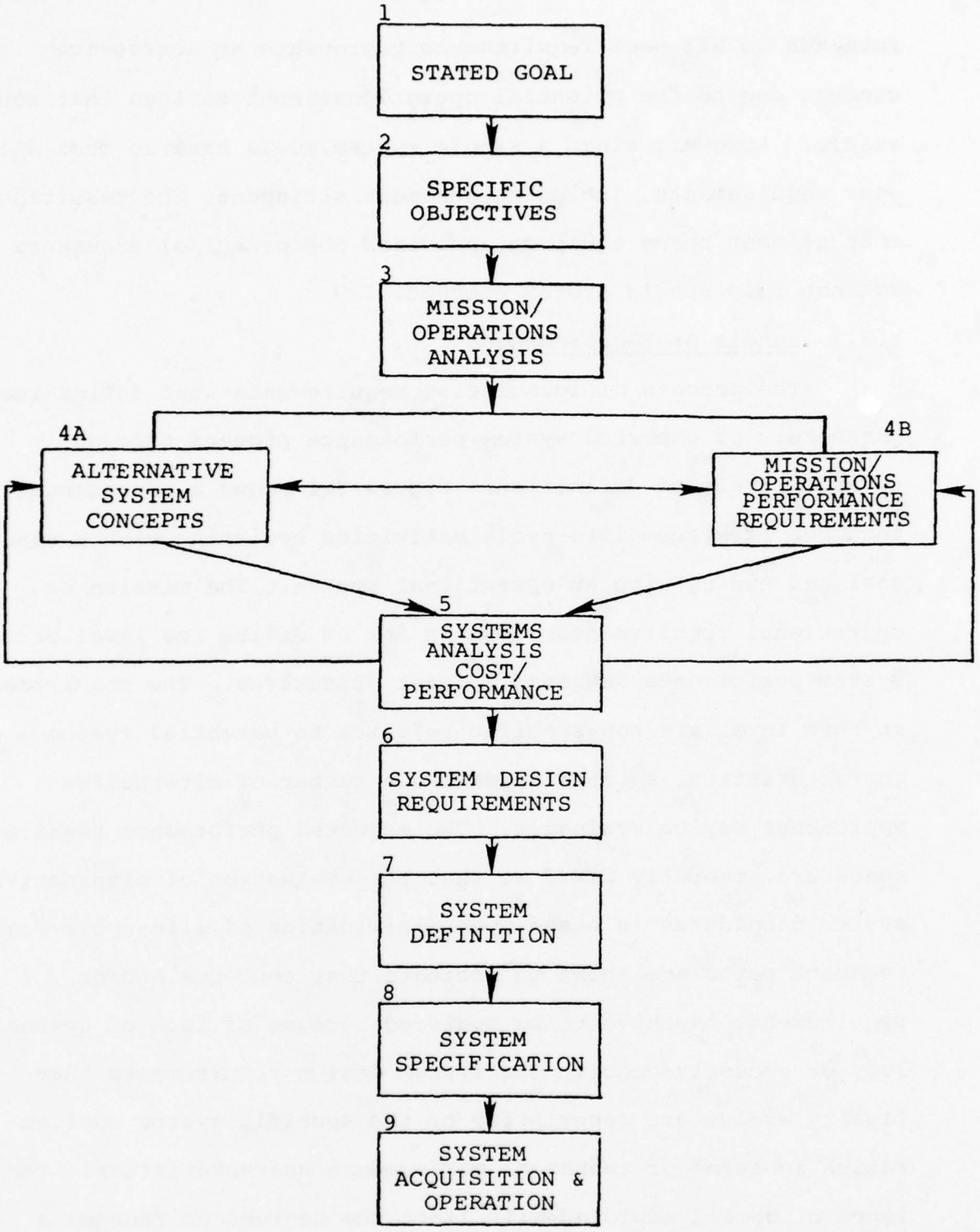


Figure 2-1 System Life-Cycle Activities

For the purpose of considering the Navstar GPS as an alternative radionavigation system, the mission/operations performance requirements (Box 4B) are of primary interest.

The expression of mission/operation performance requirements for civil radionavigation covers a wide range of format and content depending upon the specific application and upon the specific radionavigation system in current use. As an example, the FAA states the required airspace radionavigation accuracy capability in a two-dimensional form related to the accuracy provided by the currently used VOR/DME navigation system. The vertical dimension requirement is not expressed since a different system (aircraft altimeter) provides the information to pilots.

It will be evident, as the various radionavigation requirements are examined, that the parameters expressed almost invariably describe the currently available system characteristics. Thus, the process shown in Figure 2-1 is not an accurate representation for the evolution of civil system requirements. There is no quantitative linkage between Boxes 2, 3 and 4. For example, civil applications normally cite safety and efficiency as objectives, but do not translate these objectives into expressions for operational requirements.

2.3.3 Requirement Parameters

For purposes of relative assessment of requirements for civil radionavigation applications, it is necessary to define a common basis. The following parameters will be used to serve as a framework for examining the air, marine and land-based environments:

1. Position Accuracy
2. Service Availability
3. Position Fix Interval
4. Service Coverage
5. Equipment Size
6. Fix Acquisition Time
7. Service Capacity
8. Mobile Element Speed

2.3.3.1 Position Accuracy

Position Accuracy defines the difference between an estimated and actual position. The error in position is assumed to exhibit a normal or Gaussian distribution. In practice, several forms of expressing position accuracy are employed that depend upon the mission requirements. Since radionavigation systems are generally affected by random and bias categories of error, the bias errors can be calibrated or cancelled for some applications. This consideration leads to several expressions for position accuracy:

Predictable accuracy is the accuracy of predicting position with respect to precise space and surface coordinates (also denoted absolute accuracy).

Relative accuracy is the accuracy with which a user can measure his position relative to that of another user of the same navigation system at the same time.

Repeatable accuracy is the accuracy with which a user can

return to a position whose coordinates have been measured at a previous time with the same navigation system.

Accuracy requirements are stated in several forms. Common expressions used are:

CEP - circular error probability - defines the circular area within which there exists a 0.5 probability of a position determination error less than the circle radius.

dRMS - the 1σ value equivalent to a 0.667 probability that the position determination error is less than d.

2dRMS - a 2σ value equivalent to a 0.954 probability that the position determination error is less than 2d.

This study will express accuracy in terms of 2dRMS, unless otherwise noted.

2.3.3.2 Service Availability

Service Availability is defined as the minimum percentage of time that the radionavigation signal is available at the specified level over the coverage area/volume.

The specification of an availability as a probability relates to both reliability and maintainability for repairable systems. The radionavigation user equipment that processes the radio signal is considered non-repairable (during a mission time) and its availability is therefore expressed as a reliability.

2.3.3.3 Position Fix Interval

Position Fix Interval defines the elapsed time allowable between position determinations. This requirement may also be stated in its inverse form as the update rate, i.e., the

frequency of position determinations.

2.3.3.4 Service Coverage

Service Coverage defines the area or volume that bounds the operational activity of the system elements requiring navigational service.

2.3.3.5 Equipment Size

Equipment size defines the weight and volume constraints of the user equipment. In addition to the volume constraint, there may be specific dimension constraints.

2.3.3.6 Acquisition Time

Acquisition Time defines the time to first position fix, to a degree of accuracy, for any given set of fixes. This parameter may also be used to specify the time to first fix after successful recovery from system signal loss.

2.3.3.7 Service Capacity

Service Capacity is defined as the maximum number of independent position determinations required within one fixed interval.

2.3.3.8 Mobile Element Speed

This parameter defines one measure of the dynamic conditions under which the system is expected to perform.

2.3.4 The Civil Requirements Dilemma

A system requirement may be defined as: "A statement describing the level of performance necessary to achieve a specified system objective."

Implicit in this definition is a penalty that is associated with failure to achieve the required level of performance. The penalty can normally be expressed in terms of cost, e.g.,

(1) The cost of missing an assigned target (for military operations).

(2) The cost of a mid-air collision (for civil air operations).

(3) The cost of running aground (for marine operations).

(4) The cost of delay (for land mobile operations).

In the practical environment of requirements analysis and system design, there ensues an interactive process wherein the bounds of available technology must modulate the requirement statement. This process usually results in a more modest specification of the system objective so that a balance is attained. The important consideration is that the system objective must be expressed in terms that allow an objective trade-off analysis among: (1) objective; (2) requirements; (3) system design; and (4) cost.

For the civil radionavigation environment, a dilemma currently exists since (1), (2) and (4) above are not well defined. Objectives are stated in terms of safety, efficiency, and/or economy with no further definition. For the most part, civil radionavigation systems form the basis for expressing procedures for user operations.

In reviewing the section on "civil requirements", it must

be noted that the expressions listed are those that could be gathered from various documented presentations of civil operations. Since the formulation of requirements is invariably the responsibility of the authorized government agencies, there has been no attempt to modify the expressions utilized.

This uncertain status deserves serious consideration when attempting to assess the impact of "civil requirements" for radionavigation on the Navstar GPS Program.

Costly decisions made on the basis of the material presented could well prove inaccurate if the basis subsequently is shifted or altered.

2.4 Air Navigation Requirements

2.4.1 General

The national and international airspace are environments shared by a heterogenous mix of users comprised of air carrier, military and general aviation fleets of aircraft. It is not practical for safety reasons to allow aircraft to independently navigate through the airspace so that U.S. air traffic is regulated utilizing the DOT-FAA Air Traffic Control System. Under the regulatory procedures, aircraft must navigate within specified segments of airspace. The National Airspace is divided into a number of areas for various types of flight operations. As specified by Federal Aviation Regulations, an aircraft must be equipped to perform minimum standards of operation in order to gain access to the various portions of airspace.

Figure 2-2 shows the division of airspace. Table 2-1 shows the airborne equipment requirements for operations within the various segments. Figure 2-2 and Table 2-1 show that the navigation performance requirements are less stringent for operations in the uncontrolled and non-positive controlled portions of the airspace. Airspace categories 1, 2 and 4 require a compass and altimeter for access. Categories 3 and 5 require a navigation system and altimeter. Category 6 requires the addition of DME and Beacon Transponder.

Because of safety concerns relative to midair collision potential, there exists pressure for increased regulation of the airspace. The general aviation community is generally in opposition to any further restrictions that require the addition of instrumentation to the aircraft, primarily for cost reasons.

2.4.2 Air Navigation Characteristics

Table 2-2 summarizes the civil aviation characteristics for radionavigation in terms of the mission/operational parameters defined earlier. These expressions are stated for the major operational environments of civil aviation. The characteristics are stated in summary form with footnotes to provide supplementary information. In addition to the characteristics shown, there are additional descriptions that do not fall within those listed, that are appropriate to this level of assessment (i.e., the mission/operational analysis phase). The following statements express qualitative system performance

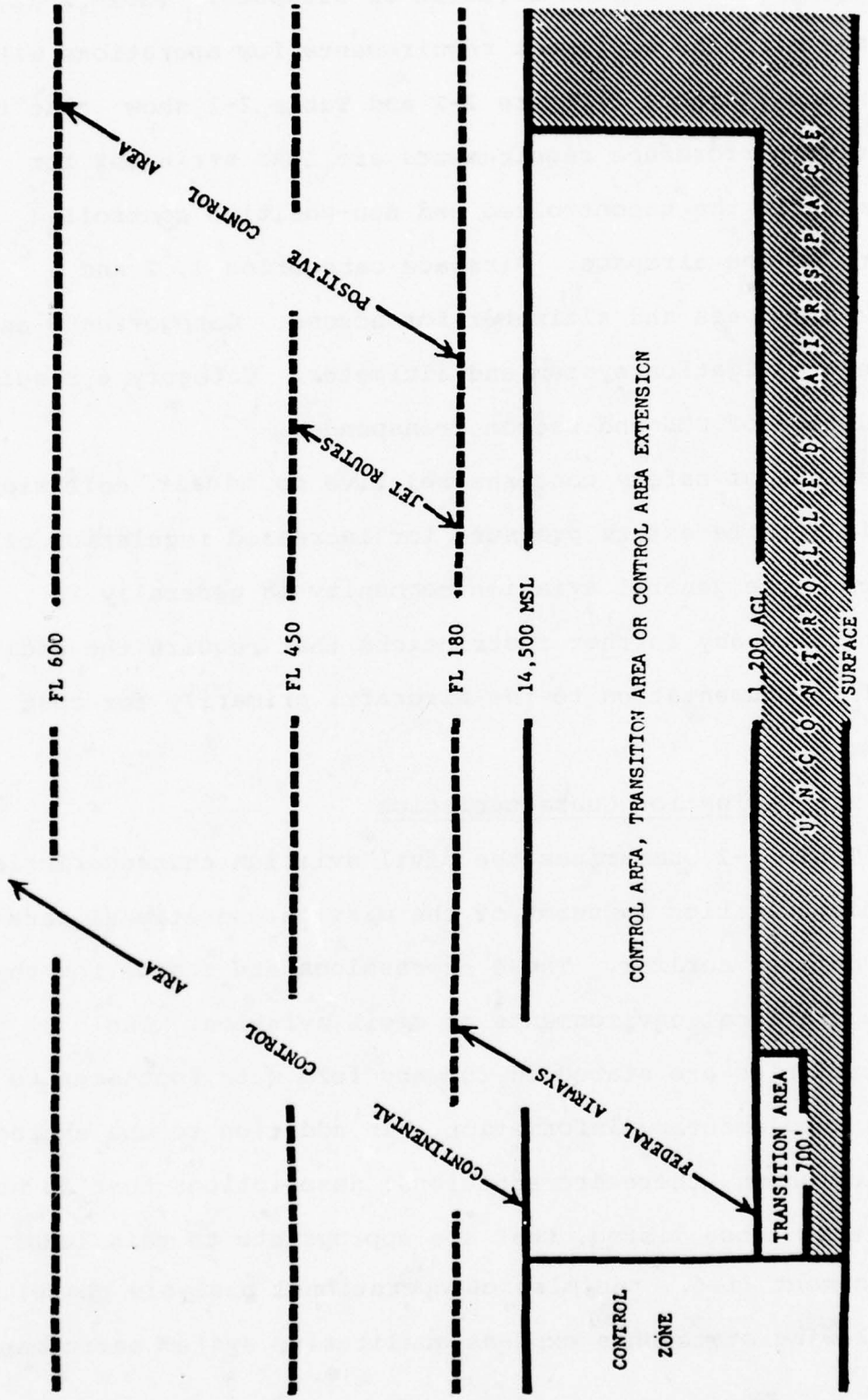


Figure 2-2. Vertical Extent of Airspace Segments

TABLE 2-1 AIRBORNE EQUIPMENT REQUIREMENTS

Types of Airspace	Flight Condition	Airborne Equipment Requirements	
		1972	198X
1. Uncontrolled	VFR (day)	1. Airspeed 2. Altimeter 3. Compass 4. Tachometer 5. Oil Temp. 6. Man. Press. 7. Fuel Gauge 8. Ldg. Gear 9. Belts (FAR 91.33)	Same as 1972
2. Uncontrolled	VFR (night)	All above plus: 1. Position Lights 2. Anti-Collision Lights 3. Ldg. Lights 4. Battery 5. Fuses	Same as 1972
3. Uncontrolled	VFR	Same as VFR plus: 1. Two-Way Radio 2. Nav. System 3. Gyro. Turn/Bank 4. Altimeter Adjustable for Baro. Press. 5. Clock with Sweep Second Hand 6. Artificial Horiz. 7. Directional Gyro. or Equivalent 8. Generator	Same as 1972, plus Transponder
4. Controlled (nonpositive)	VFR	Same as uncontrolled VFR	Same as 1972 plus: 1. Transponder 2. PWI/CAS and/-or IPC
5. Controlled (nonpositive)	IFR	Same as uncontrolled IFR	Same as 1972 plus: (Same as Preceding)
6. Positive Control	VFR	Not Authorized	Not Authorized
	IFR	Same as controlled IFR plus: 1. DME 2. Transponder	Same as 1972 plus: 1. Area Nav. 2. PWI/CAS and/-or IPC

(Source: FAA)

TABLE 2-2
CIVIL AVIATION NAVIGATION CHARACTERISTICS SUMMARY

	ACCURACY (2 dRMS) ABSOLUTE	UPDATE RATE	AVAILABILITY	COVERAGE	WEIGHT (kg) (MAXIMUM)	VOLUME (cm^3) (MAXIMUM)	ACQUISITION TIME	CAPACITY	SPEED (km/hr)
OCEANIC EN ROUTE	±23 km Horizontal[1] ±90 m Vertical	CONTINUOUS	∿100%[5]	OCEANIC AIR ROUTES	10	10,000	2 Min.[7]	UNLIMITED	0-MACH 3[8]
U.S. DOMESTIC EN ROUTE	±2.8 km Horizontal[2] ±67 m Vertical (Level Flight) ±110 m Vertical (Ascent/Descent Flight)	CONTINUOUS	∿100%	CONUS[6]	10	10,000	2 Min.	UNLIMITED	0-1444[8]
TERMINAL AREA	±2.0 km Horizontal[3] ±67 m Vertical (Level Flight) ±87 m Vertical (Ascent/Descent Flight)	CONTINUOUS	∿100%	CONUS[6]	10	10,000	2 Min.	UNLIMITED	0-1444[8]
APPROACH	±.55 km Horizontal ±36 m Vertical (Level Flight) ±46 m Vertical (Ascent/Descent Flight)	CONTINUOUS	∿100%	CONUS[6]	10	10,000	2 Min.	UNLIMITED	0-574[8]
PRECISION LANDING (CATEGORY III)	±4 m Lateral ±.55 m Vertical	CONTINUOUS	∿100%	DESIGNATED AIRPORTS	10	10,000	2 Min.	UNLIMITED	N/A[9]
NON-PRECISION LANDING	±23 m-2.2 km - Lateral[4]	CONTINUOUS	∿100%	DESIGNATED AIRPORTS	10	10,000	2 Min.	UNLIMITED	N/A
VFR	NONE	CONTINUOUS	∿100%	CONUS	10	10,000	2 Min.	UNLIMITED	N/A

TABLE 2-2 (Continued) CIVIL AVIATION CHARACTERISTICS SUMMARY
(Footnotes)

1. The accuracy expressions for oceanic flight also stipulates that the proportion of the total flight time spent by aircraft 55 km or more off track should be less than 5.3×10^{-4}, whereas, that same proportion spent 90-130 km off track should be less than 13×10^{-5}.
2. Allows aircraft to remain inside $\pm$4 nm (7.4 km) air route.
3. Allows aircraft to remain inside $\pm$2 nm (3.7 km) air route.
4. Depends on airport and altitude minimums.
5. This characteristic is given as follows for all categories:
   a) Availability goal is 100 percent signal availability exclusive of user hardware.
   b) In the event of non-availability, the system should provide fail safe warning with warning availability approaching 100%.
6. Should include coverage for offshore operations from shore to 555 km offshore with a minimum en route altitude of 152 m above sea level or obstructions.
7. Since update rate is continuous, this characteristic applies to power-up and recovery from power loss.
8. Also includes an expression for specified performance over an acceleration range of 0-2g.
9. Not available.

1. The navigation system must have a simplicity comparable to VOR/DME.
2. The navigation equipment should allow the operator to conveniently input required route definition parameters.
3. Navigation equipment, providing horizontal or vertical guidance should provide:
   a. Cross track guidance data and altitude above a reference surface, as a minimum.
   b. Bearing to waypoint.
   c. Distance to waypoint/fix.
   d. Present position in geographical coordinate.
4. Navigation data, which meets or exceeds minimum accuracy characteristics, should be provided to the operator during turns.
5. After completion of any maneuver which exceeds specified dynamic limits, the navigation equipment should provide specified accuracies within five (5) seconds of returning to specified flight performance.
6. As a minimum, the reliability of navigation equipment should be sufficiently high to permit specified equipment accuracy characteristics to be met.
7. The navigation system should be capable of recovery from loss of prime power as follows:

Dropout Time	Maximum Recovery Time
1 Second	2 Seconds
1 Minute	10 Seconds
>1 Minute	2 Minutes

8. The navigation system should be compatible with the existing environment into which it is introduced so that a mixed structure can be safely operated during a potential transition period.
9. The accuracy of any new system generally must be equal to or better than the presently installed system, particularly in the approach and departure area about an airport.
10. Redundancy of signals should be such that there is an extremely high confidence of obtaining a minimum of two lines of position, which will yield a position whose error is not greater than that specified for the region of operation.

Finally, a few comments may be made about the basis of the accuracy characteristics in terms of the currently used methods with VOR/DME for the different environments.

2.4.2.1 Domestic En Route and Terminal Areas

The system of airways and routes used in the United States has widths of route protection, based on a VOR system accuracy of $\pm$ 5.0° with 95% probability. The $\pm$5.0° VOR error justifies the application of $\pm$4.0 nautical mile (nm) route widths out to a distance of 51 nm from the VOR facility, and a widening of

route protection of the ±4.5° basis beyond 51 nm. Area navigation (RNAV) routes that are not radial to a VOR facility also use a protected area of ±4.0 nm on either side of a route centerline. When within 102 nm of a VOR facility, the RNAV route boundaries splay at 3.25° beginning at the point where the route centerline exists the ±4.0 nm area. When beyond 102 nm, the RNAV route protected area is increased at the rate of 0.25 nm for each 10 nm increase in distance from the VOR ground station.

RNAV terminal area protected areas are defined as 2.0 nm each side of routes in which the tangent distance of the route centerline is within 53 nm of the VOR ground station. The area becomes 4.0 nm each side of the route centerline at the point where the route centerline exits the 4.0 nm zone.

The total error contributions of the airborne equipment (including update, aircraft position, and computational errors), when combined with appropriate flight technical errors, should not exceed the following values with 95% confidence over a period of time equal to the update cycle:

	Cross Track	Along Track
En Route	2.5 nm	1.5 nm
Terminal	1.5 nm	1.1 nm

Flight technical errors are given as: (1) en route ±2.0 nm and (2) terminal ±1.0 nm. The vertical separation of aircraft is 1000 feet. Total error in vertical guidance, including 250 feet error for altimetry and 250 feet flight technical error, is 350 feet, 3σ (99.7%).

Approach and Landing:

International agreements have been made to achieve an all-weather landing capability through an evolutionary process, reducing landing weather minima step-by-step as technical capabilities and operational knowledge allow. The following table shows the operational performance objectives:

Category	Decision Height	Runway Visual Range
I	200 feet	2600 feet
II	100 feet	1200 feet
IIIA	0 feet	700 feet
IIIB	0 feet	150 feet
111C	0 feet	0 feet

Design goals for landing systems currently under development are:

Azimuth: Coverage of ±4.0° relative to runway centerline with an accuracy of 0.059° at runway threshold.

Elevation: Coverage from 0° to 20° with an accuracy of 0.092° at runway threshold on a 2° glideslope.

Flare Guidance: Coverage 0° to 15° with an accuracy of 0.04° at threshold.

Distance Measuring Equipment: ±40 feet accuracy.

2.4.2.2 Oceanic En Route

The methods of navigation and the separation standards applied in the oceanic areas vary at the present time. Generally, the vertical separation standard is 1000 feet between aircraft operating below 29,000 feet, and 2000 feet for those

above 29,000 feet. The horizontal separation is 120 nm laterally and 30 minutes, in time, longitudinally. Under specified conditions, the standards have been reduced in some areas to the following current minima:

(1) In the principal flight areas of the North Atlantic, the minima are: 60 nm lateral, 15 minutes longitudinal, and 2000 feet vertical in a composite system.

(2) In the principal flight area of the Pacific (i.e., between the U.S. mainland and Hawaii), the minimum is: 100 nm lateral, 15 minutes longitudinal, and 2000 feet vertical.

A minimum navigational performance specification has been proposed which defines limits for actual navigation performance of aircraft permitted to fly in the North Atlantic organized track system. The specification will read as follows:

"In order to maintain a lateral separation of 60 nm in the North Atlantic Organized Track Structure, the navigation performance of an aircraft flying in that track system should be such that:

(a) The standard deviation of the lateral deviations from track should be less than 12.6 nm.

(b) The proportion of the total flight time spent outside 30 nm should be less than 3×10^{-4}.

(c) The proportion of the total flight time spent at lateral deviations from track between 50 and 70 nm should be less than 8×10^{-5}."

This minimum navigational performance specification is only a proposal to ICAO and has not been accepted, but it is of interest in planning for future separation criteria in oceanic areas.

2.4.2.3 Low Altitude Offshore

This special situation is not listed on Table 2-2. It is defined for purposes of this report in terms of five components.

(1) The range of operation from shore should be 300 nm. The Department of Interior anticipates lease sales out to 200 nm in some coastal areas.

(2) The minimum altitude at which offshore en route navigation is permitted should be 1000 feet above the known obstructions of about 300 feet. The minimum en route altitude, then, would be set at 1300 feet.

(3) The accuracy of navigation must be sufficient to permit an aircraft to remain within $\pm$4.0 nm of the airway centerline with a 95% probability. The system accuracy must also permit pilot to identify a 5.0 nm radius en route descent area.

(4) The navigation system must permit a safe descent to an altitude of 300 feet above obstructions, in a designated en route descent area, for non-precision approaches to landing sites.

(5) Reliability of the navigation system must be such that failure of any part of the total system, either of a ground or airborne component, will not result in a complete loss of navigation capability.

These are proposed offshore navigation characteristics and are not yet approved for use. Helicopters are expected to provide most offshore service.

2.5 Marine Navigation Characteristics

2.5.1 General

Marine navigation is substantially less structured than air navigation. Since there is no overall marine traffic control system, the various classes of users provide the direct source for navigation characteristics. The characteristics are therefore generated by the basic need to make a landfall or to reach destination and to avoid both fixed and moving navigational hazards. Thus, the marine user classes are free to make a selection based on the trade-off between cost and the risk of potential loss due to improper equipage.

Expressions for civil maritime navigation are divided into three categories: high seas, coastal/confluence zone and harbor/harbor entrance zones, and inland waters. The high seas are those areas remote from land masses where visual references to land or other fixes or floating aids are not possible and where hazards of shallow waters and of collision are minimal. The CCZ includes those waters contiguous to major land masses or island groups where transoceanic traffic patterns

tend to converge towards harbors, where significant interport traffic exists in patterns essentially parallel to coastlines, and within which less ranged ships usually confine their operations. The basic defining criteria for the CCZ include the presence of shallow water due to operating in proximity to continental or insular land masses and increased congestion with variety of vessel types operating in this environment. The U.S. CCZ extends from the coast to a distance of 50 nm or to the edge of the continental shelf (100 fathom curve), whichever is greater. The third category, the harbor and harbor entrance area and other inland waters are defined as navigable waters inland from the harbor entrance, that is, inland from the inter boundary of the coastal and confluence zone.

2.5.2 Characteristics for Civil Maritime Radionavigation

Table 2-3 summarizes (in terms of parameters defined earlier) the expressions for radionavigation for the civil marine community. Table 2-3 represents a slightly different presentation than that for aviation. The expressions are stated in terms of the three major operational areas of maritime activity and further subdivided into different vessel classes, depending variously on size or type of activity.

For safe, general navigation under normal circumstances, the characteristics for accuracy and frequency of position-fixing on the high seas are not very strict. The ability to fix positions within a few miles, at intervals of a few hours

TABLE 2-3 CIVIL MARITIME NAVIGATION CHARACTERISTICS SUMMARY

	ACCURACY (2 dRMS) ABSOLUTE	RELATIVE	REPEATABLE (95%)	FIX INTERVAL (MAXIMUM)	AVAILABILITY (MINIMUM)	COVERAGE	WEIGHT (kg) (MAXIMUM)	VOLUME (cm^3) (MAXIMUM)	ACQUISITION TIME (MAXIMUM)	CAPACITY	SPEED RANGE (km/hr)
HIGH SEAS											
LARGE SHIPS											
- GENERAL	3700-7400m	NONE	NONE	2 hrs	99%(1)	WORLDWIDE	10(3)	14,000(3)	30 min	UNLIMITED	0-50
- MAXIMUM ECONOMIC EFFICIENCY	185-460m	NONE	NONE	15 min	99%	WORLDWIDE	10(3)	14,000(3)	30 min	UNLIMITED	0-50
SMALL VESSELS/RECREATIONAL BOATS	3700-4700m	NONE	NONE	2 hrs	95%(1)	WORLDWIDE EXCEPT POLAR REG.	9	14,000	30 min	UNLIMITED	0-50
SEARCH AND RESCUE	460m	185m	NONE	1 min	99%	NAT'L MARITIME SAR REGION	9	14,000	N/A(4)	UNLIMITED	0-100
SCIENTIFIC AND RESOURCE EXPLORATION	185-460m	90m	90m	1 min	95%	WORLDWIDE	9	14,000	N/A	UNLIMITED	0-50
COASTAL AND CONFLUENCE ZONE											
LARGE SHIPS	460m	NONE	NONE	5 min	99%	CCZ/FCZ(2)	10(3)	14,000(3)	10 min	UNLIMITED	0-50
COMMERCIAL FISHING	460m	NONE	15-180m(6)	1 min	99%	CCZ/FCZ(2)	9	14,000	10 min	UNLIMITED	0-50
SMALL VESSELS/RECREATIONAL BOATS	925-3700m	NONE	30-180m	5 min	99%	CCZ(2)	9	14,000	10 min	UNLIMITED	0-50
SCIENTIFIC AND RESOURCE EXPLORATION	150m(5)	15-180m	NONE	1 min	99%	CCZ(2)	9	14,000	10 min	UNLIMITED	0-50
SEARCH AND RESCUE	460m	90m	90m	1 min	99%	CCZ/FCZ(2)	9	14,000	10 min	UNLIMITED	0-50
HARBOR AREA AND INLAND WATERS											
LARGE SHIPS AND VESSELS	8-10m	NONE	NONE	6-10 sec	99.9%	Footnote 8	9	14,000	Footnote 10	UNLIMITED	0-50(11)
RECREATIONAL, FISHING AND OTHER SMALL VESSELS	Footnote 7	NONE	15-90 sec	15-20 sec	99%	Footnote 9	9	14,000	N/A(4)	UNLIMITED	0-50

TABLE 2-3 (Continued) CIVIL MARITIME NAVIGATION CHARACTERISTICS SUMMARY (Footnotes)

1. Additionally: A position measurement at least once every 12 hours 99% or more of the time.
2. Coastal Confluence Zone and Fisheries Conservation Zone.
3. Total size and weight of 82,000 cm^3 and 100 kg or more not unacceptable if bulky, heavy components need not be in immediate vicinity of control/display unit.
4. Not available/specified.
5. Applies to outer Coastal Confluence Zone.
6. Primary accuracy expression.
7. Expression for accuracy varies from one area to another, and from one ship to another.
8. Coastal and Great Lakes Harbor Entrances and Harbors, including waterways used by oceanic traffic.
9. Coastal and Great Lakes Harbor Entrances and Harbors.
10. Dependent upon useful range of signals seaward of Harbors and Harbor Entrances, user must be locked on at least 5 minutes before entry in Harbors and Harbor Entrances.
11. Operable at specified performance at all rates of acceleration normally experienced on ships of 1,600 gross tons and over, operating at speeds up to 27 km/hr in restricted HHE channels.

or less, would permit reasonably safe oceanic navigation—provided that the navigator understands and makes allowance for the probable error in his navigation, and provided that he has more accurate navigational service available to him as he approaches land.

Economic efficiency in transoceanic transportation, safety in emergency situations involving the location of the scene of a distress, and special maritime activities such as scientific research, hydrography, and resource exploration and development, all require, or would benefit from navigational accuracy higher than that needed for safety in routine, point-to-point oceanic voyages. There has not been sufficient analysis to establish very credible, quantitative relationships between navigational accuracy and economic efficiency. The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, however, and—more significantly—the increasing use of relatively expensive satellite navigation by merchant ships and larger, ocean-going fishing vessels is evidence of the value which is attached to highly accurate highseas navigation. The maximum value of very accurate position-fixing probably cannot be realized, however, unless position measurement is possible at intervals as short as 5 to 15 minutes.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at

most. Even more than with larger ships, this capability is particularly important in time of emergency or distress. Many, perhaps most, of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost.

Requirements have not been established for the HHE yet by quantitative analysis or experiments, and are estimated for large merchant ships. Requirements on accuracy and position fix interval for HHE will be somewhat less strict for comparatively small, highly maneuverable craft. Recreational and fishing craft whose systems are capable of the repeatable accuracies specified as desirable (for recreational boats) or required (fishing vessels) in the CCZ will find these systems useful also in many areas of the HHE.

2.6 Land Based Position Location

2.6.1 General

The civil application of radionavigation to land based position location is the most uncertain area of the three environments under discussion. The National goal, associated with the consideration of such applications, appears to be related to transit efficiency through increased mobility for the general public and to economic benefits through integrated transit management. There is no central concept, and most of the effort has concentrated on urban traffic control experimentation carried out under the sponsorship of the Urban Mass Transit Administration (UMTA). The UMTA automatic vehicle monitoring

program includes the evaluation of several techniques including sign post, pulse-trilateration and LORAN C.

Multipath and shadowing associated with built up urban areas (central business districts) pose severe additive and multiplicative noise problems. As a result, the sign post technology may well prove the most applicable of the techniques under evaluation.

With the current status, it is difficult to identify firm quantitative requirements that may be satisfied by radionavigation systems. The estimation of user interest and economic preference is speculative because of the relatively "soft" expressions for service that must be traded off against the cost-benefits to the potential users.

2.6.2 Land User Navigation Characteristics

Table 2-4 presents a summary of radionavigation/location characteristics for land users in terms of two distinct categories of operations:

1. Automatic Vehicle Monitoring and Vehicle Dispatch - This category includes locating vehicles so that they can be monitored at a remote location.
2. Site Registration - This category includes land uses of location systems in vehicles and on foot so that the location of a person, place or event can be recorded.

2.7 Civil Application Characteristics Extremes

The concept of a single system or a single family of

TABLE 2-4 LAND RADIONAVIGATION/LOCATION CHARACTERISTICS SUMMARY

	ACCURACY		UPDATE INTERVAL	AVAILABILITY (MINIMUM)	COVERAGE	WEIGHT(kg) (MAXIMUM)	VOLUME(Cm^3) (MAXIMUM)	ACQUISITION TIME (MAXIMUM)	CAPACITY	SPEED (km/hr)
	PREDICTABLE(95%)	REPEATABLE								
AUTOMATIC VEHICLE MONITORING AND VEHICLE DISPATCH	15-150m - URBAN 60-300m -SUBURBAN .25-2km -TRANSCON. CARGO MONITORING	N/A	20-60sec	95%	N/A	9	14,000	2 Min	UNLIMITED	0-160
SITE REGISTRATION	N/A(1)	3-150m	1 Min	95%	N/A	9	14,000	2 Min	UNLIMITED	0-80

(1) NOT AVAILABLE

systems, to satisfy all needs for radionavigation and radiolocation for both military and civil applications, requires that the candidate systems meet the performance characteristics for the most stringent user applications. Table 2-5 lists the most stringent (overall) expressions for the three civil radionavigation environments discussed (i.e., air, sea, land). For each environment, the application listed represents that which exhibits the most severe parameters. From another perspective, Table 2-6 shows the most stringent value for each performance parameter and the application(s) for which the value is desired.

Table 2-5 shows that the civil application with the most stringent performance characteristics is the Category III Precision Landing in civil aviation. The only parameters for which the values are not at the extreme in the table are (1) the service coverage, since this application is only limited to airports requiring precision landing capability and (2) vehicle speed, only because a value for this parameter was unavailable.

2.8 Civil User Population Estimates

2.8.1 Civil Aviation

Most of the aircraft fleet operates in the airspace with a minimum of navigation equipment. Table 2-7 shows the projection of aircraft population for different avionics complement classes through the year 2001. Tables 2-8 and 2-9 provide a definition of the classes of avionics in terms of (1) types of operations and (2) types of avionic equipment carried, respectively. It is useful to note that the classes defined in Table 2-9 assume the implementation of all planned upgraded third

TABLE 2-5
OVERALL MOST STRINGENT USER CATEGORY

	ACCURACY (2dRMS) ABSOLUTE	FIX INTERVAL	AVAILABILITY (MINIMUM)	COVERAGE	WEIGHT (kg) (MAXIMUM)	VOLUME (cm^3) (MAXIMUM)	ACQUISITION TIME	CAPACITY	SPEED (km/hr)
CIVIL AVIATION RECISION LANDING (CATEGORY III)	±4m LATERAL ±.55m VERTICAL	0[1]	∿100%[2]	DESIGNATED AIRPORTS	10	10,000	2 min[3]	UNLIMITED	N/A[4]
CIVIL MARITIME HARBOR AND HARBOR ENTRANCE, LARGE SHIPS AND VESSELS	8-10m	6-10 sec	99.9%	FOOTNOTE 5	9	14,000	FOOTNOTE 6	UNLIMITED	0-50[7]
CIVIL LAND AUTOMATIC VEHICLE MONITORING AND VEHICLE DISPATCH	15-150m	20-60 sec	95%	N/A[4]	9	14,000	2 min	UNLIMITED	0-160

TABLE 2-5 (Continued) OVERALL MOST STRINGENT USER CATEGORY
(Footnotes)

1. The expression was stated as a continuous update rate.
2. No further specifity given other than "approaching 100% availability".
3. Time-to-first-fix or recovery time since the update rate is continuous.
4. Not available.
5. Coastal and Great Lakes Harbor Entrances and Harbors, including waterways used by oceanic traffic.
6. Dependent upon useful range of signals seaward of harbors and harbor entrances; user must be locked on at least 5 minutes before entry into harbor/harbor entrance.
7. Operable at all rates of acceleration experienced by ships in this category.

TABLE 2-6
MOST STRINGENT VALUES FOR EACH PERFORMANCE PARAMETER

PARAMETER	VALUE	USER CATEGORY
ABSOLUTE ACCURACY (2dRMS)	±4m LATERAL ±.55m VERTICAL	PRECISION LANDING (CATEGORY III CIVIL AVIATION
RELATIVE ACCURACY (2dRMS)	15m	SCIENTIFIC AND RESOURCE EXPLORATION-CCZ[1]-CIVIL MARITIME
REPEATABLE ACCURACY (95%)	15m	COMMERCIAL FISHING-CCZ/FCA[2] CIVIL MARITIME
FIX INTERVAL (MAXIMUM)	0[3]	ALL CIVIL AVIATION CATEGORIES
AVAILABILITY (MINIMUM)	99.9%[4]	LARGE VESSELS-HARBOR AREAS CIVIL MARITIME
COVERAGE	WORLDWIDE	LARGE SHIPS-HIGH SEAS-CIVIL MARITIME
WEIGHT (MAXIMUM)	9kg	ALL CIVIL MARITIME CATEGORIES EXCEPT LARGE SHIPS[5]
VOLUME (MAXIMUM)	10,000 cm^3	ALL CIVIL AVIATION CATEGORIES
ACQUISITION TIME (MAXIMUM)	2 min.	ALL CIVIL AVIATION AND CIVIL LAND CATEGORIES
CAPACITY	UNLIMITED	ALL USERS
SPEED RANGE	0-MACH 3	OCEANIC EN ROUTE-CIVIL AVIATION

TABLE 2-6 (Continued) MOST STRINGENT PERFORMANCE PARAMETER VALUES
(Footnotes)

1. Coastal and Confluence Zone of U.S.
2. CCZ and Fisheries Conservation Zone of U.S.
3. Expression stated as continuous update interval.
4. The civil aviation characteristic was stated as "approaching 100%"; this may be more stringent; however, because of qualitativeness, it is not used.
5. Also all civil land users.

TABLE 2-7

AIRCRAFT AVIONIC CLASS POPULATION PROJECTIONS

Year	Class A	Class B	Class C	Class D	Class E	Class F	Total Fleet
1975	12526.	31110.	41625.	49694.	32922.	16150.	184026.
1976	12609.	32479.	42939.	51022.	33861.	16700.	189609.
1977	12687.	33821.	44117.	52174.	34687.	17200.	194667.
1978	12762.	35345.	45545.	53606.	35703.	17800.	200762.
1979	12838.	36916.	46966.	55012.	36706.	18400.	206838.
1980	12907.	38383.	48124.	56095.	37498.	18900.	211907.
1981	12975.	39849.	49555.	57564.	38532.	19500.	217975.
1982	13095.	41507.	51233.	59307.	39754.	20200.	225095.
1983	13185.	43697.	53666.	61933.	41572.	21210.	235285.
1984	13259.	46026.	56260.	64672.	43471.	22270.	245959.
1985	13333.	48500.	58948.	67521.	45451.	23380.	257133.
1986	13407.	51050.	61654.	70364.	47432.	24500.	268407.
1987	13456.	53630.	64300.	73114.	49357.	25600.	279456.
1988	13530.	56533.	67311.	76254.	51552.	26850.	292030.
1989	13654.	59632.	70485.	79552.	53861.	28170.	305354.
1990	13753.	62699.	73497.	82639.	56035.	29430.	318053.
1991	13851.	66063.	76790.	86022.	58416.	30810.	331951.
1992	13950.	69657.	80243.	89554.	62907.	32260.	346550.
1993	14024.	73426.	83855.	93233.	63506.	33780.	361824.
1994	14123.	77418.	87601.	97028.	66194.	35360.	377723.
1995	14197.	81675.	91553.	101018.	69024.	37030.	394497.
1996	14296.	85941.	95688.	105220.	71990.	38760.	411896.
1997	14395.	91487.	100058.	108647.	75119.	40590.	430295.
1998	14469.	95199.	104512.	114132.	78296.	42460.	449069.
1999	14567.	100325.	109346.	118996.	81743.	44490.	469467.
2000	14641.	105670.	114312.	123965.	85272.	46580.	490441.
2001	14715.	111322.	119508.	129143.	88956.	48770.	512415.

TABLE 2-8 AIRCRAFT AVIONICS CLASSES

Class A: ● IFR capability in all controlled (mixed, positive control, and high density) airspace regions of the National Airspace System under instrument meteorological conditions (only VFR flights may be conducted in uncontrolled airspace). ● Equips with dual, high quality avionics characteristic of air carrier and military aircraft.
Class B: ● IFR capability in all mixed and positive controlled airspace regions (requiring 3D-RNAV), except where procedures requiring 4D-RNAV equipment are in effect. ● Equips with dual, high quality avionics characteristics of expensive general aviation aircraft.
Class C: ● Typically operates IFR in mixed airspace regions. ● Has nonredundant, medium quality avionics of limited navigation (as above 2D-RNAV) and data link communication capability.
Class D: ● Generally operates VFR in all low-density terminals and mixed on-route airspace. ● Has low cost avionics without area navigation equipment.
Class E: ● Typically operates VFR in mixed or uncontrolled airspace. ● Has low cost avionics with VOR navigation equipment.
Class F: ● Operates in uncontrolled airspace with only voice communications and minimum VOR navigation capabilities.

TABLE 2-9 TYPICAL AVIONICS COMPLEMENTS BY AIRCRAFT AVIONICS CLASS ASSUMING IMPLEMENTATION OF ALL POSSIBLE UG3RD COMPONENTS

CLASS	AVIONICS
A	Dual High Quality Discrete Address Beacon (DABS) Transponders Dual High Quality Encoding Altimeters Dual High Quality IPC/ATC Data Link Logic and Displays Dual 4D-RNAV Navigation Equipment Dual High Quality Microwave Landing System Equipment Dual Voice Communications Equipment
B	Dual High Quality DABS Transponders Dual High Quality Encoding Altimeters Dual IPC/ATC Logic and Displays Dual Voice Communication Dual 3D-RNAV Navigation Equipment Dual Microwave Landing System Equipment
C	DABS Transponder Encoding Altimeter IPC/ATC Logic and Displays 2D-RNAV Navigation Equipment Microwave Landing System Equipment Dual VOR Navigation Equipment Dual Voice Communications Equipment
D	DABS Transponder Encoding Altimeter IPC Logic and Displays Dual VOR Navigation Receivers Dual Voice Communications Equipment
E	DABS Transponder Encoding Altimeter IPC Logic and Display Voice Communications Equipment VOR Navigation Receiver
F	Voice Communications Equipment VOR Navigation Receiver

generation ATC systems. For comparison purposes, Table 2-8 also shows the size of the total aircraft fleet with projections through the year 2001.

Class A and B users comprise all air carrier and air taxi aircraft, all military aircraft, all general aviation turbine aircraft and 80% of all multi-engine general aviation aircraft. For the year 1979, classes A and B total only 49,754 out of a total fleet population of 206,838 or 24%. These data indicate that over 75% of the fleet population operate with nonredundant, medium to low quality avionics with limited or minimum navigation capabilities.

In realistic terms, this means that only 24% of the aviation community provide the market for navigation systems that exhibit the high quality performance associated with Navstar GPS. It is also evident that this restricted class of users is relatively insensitive to cost of equipment as long as expected performance is achieved.

The airspace environment is very different for operations over oceanic areas. The operational fleet is comprised only of air carrier, military and small segment of the general aviation aircraft. (Approximately equivalent in capabilities to classes A and B, defined in Table 2-9.) The second major difference is the extent of the air traffic control system. Due to line of sight limitations over wide ocean areas, there is no surveillance system, and communications are limited to the use of high frequency (HF) radio. For the same reason, radionavigation

coverage is limited; so aircraft carry self contained systems such as inertial or doppler radar. Since the air traffic density is far lower than in the domestic airspace, the airspace separation criteria are less stringent. Increasing the degree of air traffic control over oceanic airspace is of limited interest to the air carriers who are the primary users. The only measurable cost benefit to the industry is a reduction of flight path deviation (through reduction of lane separations) that saves time and fuel. Air traffic activity over the North Atlantic has decreased due to increased load factors and the use of wide-bodied jets so that the airlines normally fly optimum paths which are available. Thus, as reflected in Congressional hearings, the air carriers do not consider the potential benefits to be of sufficient magnitude to trade-off against the investment of re-equipping the fleet with new navigation or communication equipment. On the other hand, inertial equipment, used by the air carriers, costs approximately ($100,000)[1], and because of reliability considerations, two or three units are normally carried.

2.8.2 Civil Marine Transportation

Figure 2-3 shows the maritime user categories and the projected growth through the year 2000.

As of 1977, the population numbers for each category were:

(1) Recreational Boaters - 1.2 million

(2) Small Commercial Operators - 20 thousand

(3) Commercial Fishing - 94 thousand

(4) Large Marine Operator - 19 thousand

[1]Delco C-IVA; Litton LTN-201 (1977 Price $110,000)
FAA-ASP-78-3, Table B.3, April 1978.

(1) - Recreational Boaters

(2) - Small Commercial Operators

(3) - Commercial Fishing and Commercial Sport Fishing

(4) - Large Marine Operator (U.S. only)

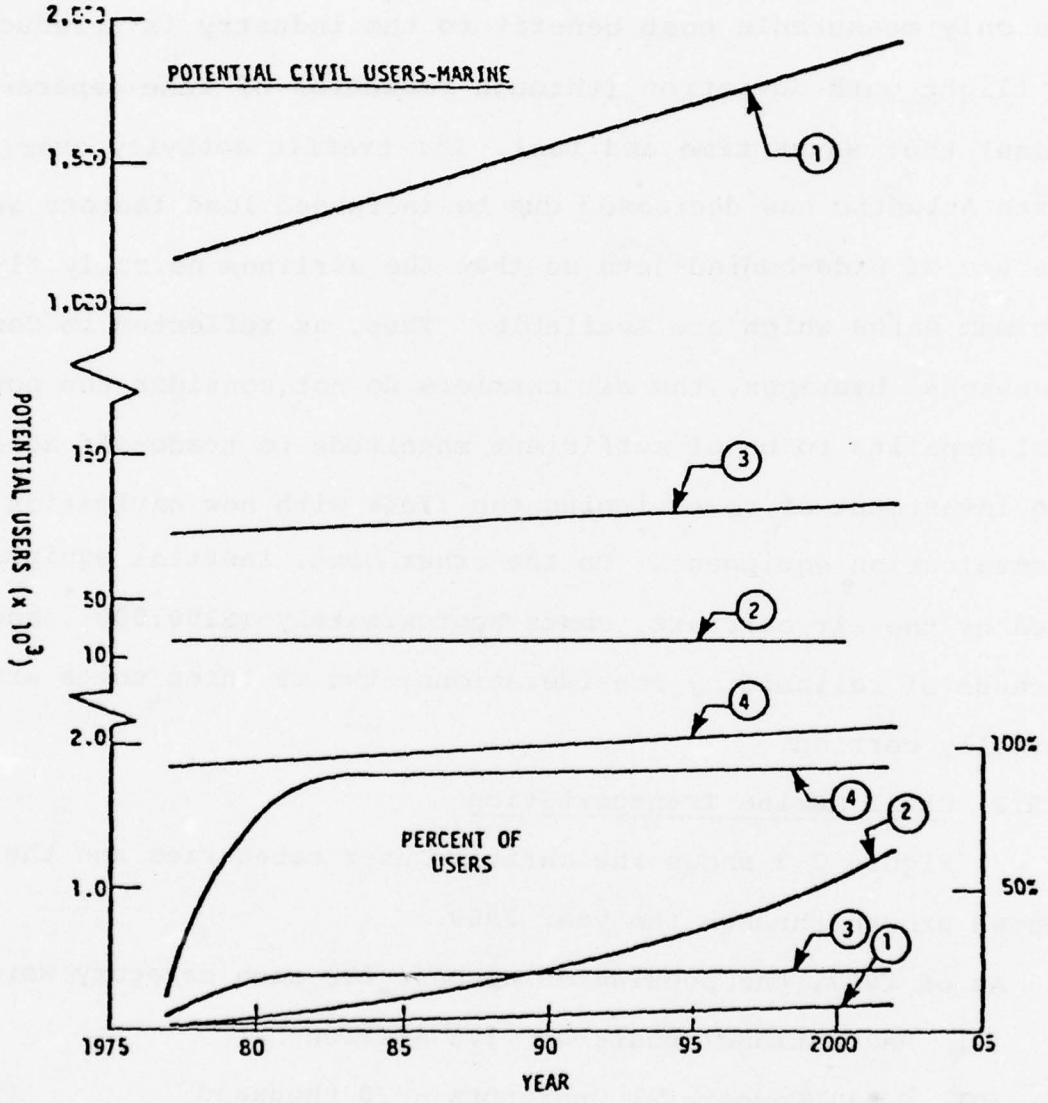


Figure 2-3 U.S. Maritime User Populations

Tables 2-10 and 2-11 show a further breakout of the world maritime fleet (Category 4). The population totals mentioned above in categories (1), (2), and (3) represent the U.S. user population for these categories. Category (4) represents the world population of large marine operators. Non-U.S. owned flagships in this category are included in the population count because of previous experience with other worldwide accessible systems such as OMEGA and TRANSIT. Figure 2-4 exclusively represents U.S. populations. Reference to Figure 2-4 shows that the user populations that actually create a market for radionavigation services varies widely. The lower part of the figure shows an estimation of the percentage of users for each category that will provide a market for radionavigation equipment. It is evident that the largest percentage (90%) is assigned to the large marine operator. Here, as in the case of civil aviation, this class of user is relatively cost insensitive assuming that the required level of performance is achieved.

At the other extreme, the extremely large population of recreational boaters provide a very limited market for radionavigation services.

2.8.3 Civil Land Transportation

Figure 2-4 shows a projection of U.S. land user population as well as an estimate of percentage of users with a need for radiolocation.

The U.S. user populations are as follows:

- Category 1: Trucks - 2.62 million
- Category 2: - Taxis - 225 thousand

TABLE 2-10 1975 WORLD FLEET COMPOSITION BY WEIGHT AND CLASS (OVER 5,000 DWT)

TYPE \ WEIGHT CLASS	DWT (000's)							
	5-9	10-19	20-29	30-49	50-69	70-99	100-	TOTAL
CARGO	223	136	42	10	2			413
FREIGHT	3700	4514						8214
BULK	743	874	1086	712	365	198	294	4272
TANKER	730	1460	623	866	562	380	870	5491
TOTAL	5396	6984	1751	1588	929	578	1164	18,390

TABLE 2-11 NEW SHIPS - 1975 BY WEIGHT AND CLASS

TYPE \ WEIGHT CLASS	DWT (000's)							
	5-9	10-19	20-29	30-49	50-69	70-99	100-	TOTAL
CARGO	5	4						9
FREIGHT	160	167						327
BULK	27	36	55	58	33	11	30	250
TANKER	39	40	59	35	9	44	161	387
TOTAL	231	247	114	93	42	55	191	973

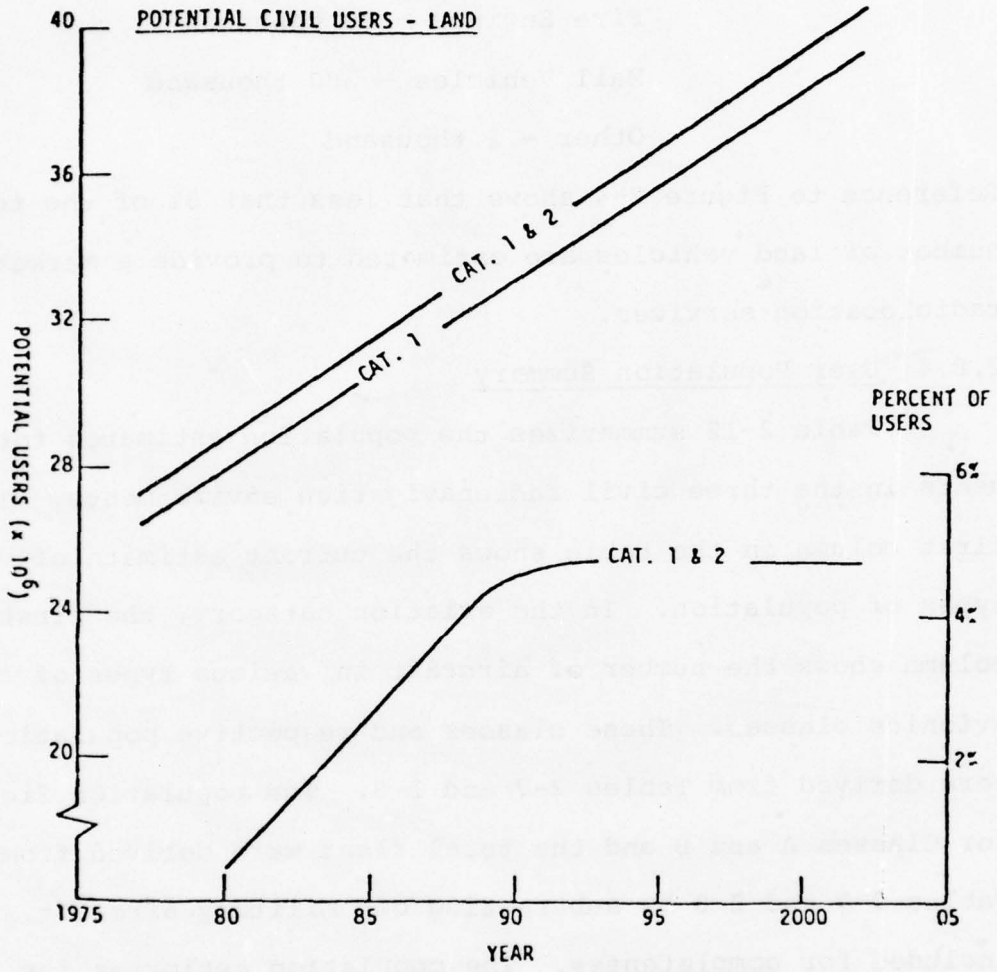


Figure 2-4 U.S. Civil Land User Population

Police Cars - 170 thousand

Urban Buses - 50 thousand

Ambulances - 44 thousand

Fire Engines - 80 thousand

Mail Vehicles - 300 thousand

Other - 2 thousand

Reference to Figure 2-4 shows that less that 5% of the total number of land vehicles are estimated to provide a market for radiolocation services.

2.8.4 User Population Summary

Table 2-12 summarizes the population estimates for the users in the three civil radionavigation environments. The first column in the table shows the current estimate of various types of population. In the aviation category, the first column shows the number of aircraft in various types of avionics classes. These classes and respective populations were derived from Tables 2-7 and 2-8. The population figures for Classes A and B and the total fleet were derived from Tables 2-7 and 2-8 by subtracting out military aircraft, included for completeness. The population estimates for the civil marine transportation represent the total population for the classes shown, regardless of the instrumentation carried or the sophistication of the vessel. Similarly, the civil land transportation category represents the total current population. The second column in Table 2-12 shows forecast estimates of the population of the various classes of users at

TABLE 2-12 USER POPULATION ESTIMATES

USER CATEGORY	CURRENT POPULATION ESTIMATE (000's) (2)	FORECAST POPULATION (000's) (2)	PROBABLE USER POPULATION (000's) (2)
CIVIL AVIATION	1979 (ESTIMATE)	2000	1985
CLASS A (See Table 2-3)	2.8	4.6	3.3
CLASS B	26.9	95.6	38.5
CLASS C	46.5	114.3	58.9
CLASS D	55.0	123.9	67.5
CLASS E	36.7	85.2	45.4
CLASS F	18.4	46.5	23.3
CIVIL MARITIME	1977 (ESTIMATE) (1)	2000	1985
LARGE MARINE OPERATORS	19	20	18.5
COMMERCIAL FISHING VESSELS	94	117	23.3
SMALL COMMERCIAL VESSELS	20	22	2.8
RECREATIONAL/PLEASURE BOATS	1200	1820	44.0
CIVIL LAND	1977 (ESTIMATE) (1)	2000	1985
TRUCKS	2600	4100	77.0
TAXIS	225	274	6.5
MAIL DELIVERY	300	369	8.7
URBAN BUSES	50	61	1.5
POLICE VEHICLES	170	209	4.9
AMBULANCES	44	54	1.2
FIRE ENGINES	80	98	2.3

(1) 1977 used because of data availability.
(2) All categories are U.S. market except Large Marine Operators as explained in text.

the turn of the century.

The last column in Table 2-12 shows estimates of the number of users who will potentially have a need for radionavigation equipment by the year 1985. These estimates were projected from forecasts of the user populations for 1985 and coupled with an approximation of those users with an indicated need for radionavigation as expressed in Figures 2-3 and 2-4 (the lower set of graphs) for civil marine and land transportation. In the case of civil aviation, because of the definition of the user classes, it is estimated that 100% of the population of the various classes depicted will have a definite need for radionavigation. The population figures shown in this last column are estimated as the most probable navigation user population for 1985. These figures may be used to support an economic analysis to determine the most probable impact of alternative GPS options on the civil sector. The results derived from the most probable figures can be compared to those obtained from optimistic (100% of all users in all categories) and pessimistic (figures less than the most probable based on unplanned situations) estimates of the user population. It is useful to note that the most probable population is shown for 1985, but can be estimated for any other year prior to the year 2000, based on current forecasts.

BIBLIOGRAPHY

1. Department of Transportation, National Plan for Navigation, November, 1977.

2. "Estimation of UG3RD Costs", Report No. FAA-AVP-7710, January, 1977.

3. R. L. Wiseman and C. N. Veronda, "The Costs and Benefits of a Mid-Continent Expansion of LORAN-C", Report No. DOT-TSC-RSPA-79-3, February, 1979.

4. Joint DOD/DOT Briefing presented to Interagency Working Group on Radionavigation System Consolidation, March 7, 1979.

5. Memorandum to Interagency Working Group on Radionavigation System Consolidation, March 13, 1979.

6. "Civil Maritime Navigation Systems Requirements",(DRAFT) U.S. Coast Guard, Department of Transportation, May 17, 1978.

7. "Civil Aviation Navigation Requirements," June 13, 1978.

8. "Recreational Boating in the Continental United States in 1973 and 1976: A Nationwide Boating Survey", U.S. Coast Guard, Department of Transportation, Report No. CG-B-003-76, March 1978.

9. "Radio Navigation Study", Computer Sciences Corporation, February 1975.

10. H. David Reed, et al, "A Study of the Costs and Benefits Associated with AVM", Report No. UMTA-MA-06-0041-77-1, February, 1977.

11. "DOT Update of CSC/OTP Radionavigation System Alternative Study - Volume I - Civil Sector" (DRAFT), Transportation Systems Center, December 13, 1978.

3.0 CIVIL/MILITARY MISSION ANALYSIS

3.1 Missions and Goals

The major difference between military and civil goals, within the context of application of radionavigation systems, is in the control of the environment.

For the military, the requirements developed to achieve the goal of National Security are driven by forces outside of their direct control. The military force structure and operation must compete successfully with those of potential enemies.

For civil applications, the goals are controllable and, therefore, flexible. For example, if the safety goal (which remains undefined) for the civil air traffic control system is not achieved (excessive midair collisions) then the procedures may be changed to provide greater separation criteria.

Since civil goals are somewhat flexible, the underlying requirements will also tend to shift values as a function of public opinion, congressional interest, availability of funds for new development, and available technology.

On the other hand, if a military mission calls for coordinate bombing of a specific target and that target is missed because of navigational errors, then the consequences to the U.S. may be immeasurable and irretrievable.

It is important in any consideration of joint civil/military utilization of a Naticnal asset, that the priorities are set in the appropriate order:

(1) Military - National Security

(2) Civil - Economics

Any civil requirement may be relaxed by a reduction in the efficiency of the system's operation.

The major missions and goals for the various activities may be expressed as follows:

ACTIVITY	MISSION	GOAL
Military	- Command and Control of US Forces	- National Security
Civil Air	- Air Traffic Control	- Safety;Efficiency
Civil Marine	- Vessel Traffic Management	- Safety;Efficiency
Civil Land	- Land Vehicle Transit Management	- Efficiency

3.2 Military Command and Control

C^3I (command, control, communications and intelligence) systems form the nucleus of all military operations—stragetic, theatre and tactical.

U.S. forces operate within a hierarchical, multi-level structure headed by the NCA (National Command Authorities)

C^3I systems functions at all levels as closed-loop, near real time activities. Intelligence and warning information serve as inputs describing the status or hostile action of enemy forces. Due to the decreased warning time available under missile threats, the information and control loop response time must approach minimal delays for effective counter force application.

The collection of intelligence information relative to

enemy forces and the subsequent U.S. force operations depend upon the three integrated functions of surveillance, navigation, and communications. Force effectiveness of global dimensions requires world-wide capability for precision navigation and supporting communications. Once a conflict is initiated, the C^3 systems must respond to terminate the conflict quickly by accurate target location and weapons delivery under all conditions. Navigation and position location are absolutely essential functions that support offensive operations in today's highly mobile environment. For nuclear conflict, precision accuracy in navigation and position location is essential.

Tables 3-1 through 3-3 list the collection of military missions categorized in terms of air, sea and land, as well as by host vehicle.

3.3 Civil Air Traffic Control

Civil air traffic control is the responsibility of the DOT-FAA. The air traffic control system is similar to military C^2 systems in that it represents a closed-loop system with centralized control of the system elements. However, the basic objective of instituting regulation of air traffic is to safely share the available airspace among all users. Navigation and position location functions, that are absolutely essential to military operations, do not carry the same priorities for civil air activity.

TABLE 3-1 MILITARY AIR MISSIONS

HOST VEHICLE CATEGORY - FIGHTER/ATTACK	
Host Vehicles	
A-4	F-18
A-6 (A-6E TRAM)	A-10
A-7	F-4G, F-4J
F-14	RF-4C
F-16	F-4E
F-15	AV-8
F-111, FB-111	OV-10
Missions	
Tactical Reconnaissance	Electronic Warfare
Target Acquisition	Defense Suppression
Coordinate Blind Bombing	Missile Launch
Air-to-Ground Interdiction	Photo Reconnaissance
Air-to-Air Warfare	Amphibious Operations
Close Air Support	

HOST VEHICLE CATEGORY - STRATEGIC AIRCRAFT
Host Vehicles
B-52 D
B-52 G/H
F-111
Missions
Coordinate Blind Bombing
Missile Launch

TABLE 3-1 MILITARY AIR MISSIONS (Continued)

HOST VEHICLE CATEGORY - TACTICAL TRANSPORT/TANKER/ASW	
Host Vehicles	
C-141	C-130
AMST	KC-135
C-5A	E-4
P-3C	O-2
S-3	E-2
C-2	E-3A
Missions	
Tactical Reconnaissance	Aerial Refueling
Anti-Ship Warfare	Close-Air-Support
Antisubmarine Warfare	Electronic Warfare
Tactical Airlift	Defense Suppression
HOST VEHICLE CATEGORY - TRAINER/TRANSPORT	
Host Vehicles	
T-38	T-39
T-43	C-135 A/B
F-5E	C-9
TA-4	
Missions	
Pilot Training	
Navigator Training	
General Airlift	

TABLE 3-1 MILITARY AIR MISSIONS (Continued)

HOST VEHICLE CATEGORY - HELICOPTER/ARMY RECONNAISSANCE	
Host Vehicles	
AAH (YH-63)	RH-53D
AH-1S	HH-53B/C
CH-47	CH-53
HXM	H-2
OH-58	CH-3
UH-1	SH-3
UH-60A	OV-1D
	U-21
	CH-46
Missions	
Air Cavalry	Close Air Support
Army Reconnaissance	Electronic Warfare
Aerial Fire Delivery	Defense Suppression
Airmobile Troop Assaults	Anti-submarine Warfare
Medical Evacuation	Tactical Airlift
General Navigation	Search and Rescue
	Mine Countermeasures
	Amphibious Operations

TABLE 3-2 MILITARY SEA MISSIONS

HOST VEHICLE CATEGORY - SURFACE SHIP	
Host Vehicles	
CV	AE
FF	AOE
FFG	ASR
MSO	CG
LPH	CGN
LHA	DD
LSD	DDG
LPD	LST
	LKA
Missions	
Anti-Ship Warfare	Logistic Support
Anti-Submarine Warfare	Naval Gunfire Support
Anti-Air Warfare	Amphibious Operations
Mine Countermeasures	Patrol/Blockage
Aviation Support	En Route Navigation
HOST VEHICLE CATEGORY - SUBMARINE	
Host Vehicles	
SSN	
SSNB	

TABLE 3-2 MILITARY SEA MISSIONS (Continued)

Missions
Anti-ship warfare
Anti-submarine warfare
Strategic Weapon Launch

TABLE 3-3 MILITARY LAND MISSIONS

HOST VEHICLE CATEGORY - MANPACK/VEHICULAR	
Host Vehicles	
Foot Soldier	Riverine
Jeep (M151)	Fighting Vehicle System (XM3)
Tank (M60A1-PI)	LVT
Tank (XM-1)	Armored Personnel Carrier (M113A1)
Truck (M956)	
Command Post Carrier (M57A1)	Missile Tank (M60A2)
Missions	
Sighting/Surveying Portable Radio Systems	Mechanized Maneuvers
Tactical Reconnaissance	Engineer Survey
Sensor Emplacement	Amphibious Operation
Artillery Forward Observer	SIGINT/EW
Close-Air-Support	Ground-based Forward Air Controller

The primary purpose of navigation aids is to support a track keeping function to allow airspace users to fly a prescribed air route without interference from other aircraft. It is evident that track keeping for aircraft may be accomplished through aircraft position fixing or through ground based surveillance. Users of the National Airspace System under positive control are under radar surveillance and also utilize radionavigation aids.

Landing operations represent the most stringent position fixing performance characteristics and are supported by air terminal Instrument Landing Systems (ILS) and the planned Microwave Landing Systems (MLS).

Table 3-4 lists the collection of civil air missions and the set of host vehicles.

3.4 Civil Marine Vessel Traffic Management

At the present time, there is no comparable closed-loop control system for marine traffic. There are a few vessel traffic systems established for harbor use in which surveillance and communications are combined with the vessel's navigation capabilities to provide for safe entrance to harbors or estuaries.

For the most part, the different categories of users will carry navigation systems that support their particular operational environment (i.e., high seas, coastal confluence or harbor-harbor entrance).

TABLE 3-4 CIVIL AIR MISSIONS

HOST VEHICLE CATEGORY - AIR CARRIER[1]

ITEM No.	Model	Manufacturer	Number of engines by power type					ITEM No.	Model	Manufacturer	Number of engines by power type				
			Turbo-fan	Turbo-jet	Turbo-prop	Turbo-shaft	Piston				Turbo-fan	Turbo-jet	Turbo-prop	Turbo-shaft	Piston
	(1)	(2)	(3)	(4)	(5)	(6)	(7)		(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	AC-680FL	Aero Commander					2	31	DC-8-50	Douglas	4				
2	AD-500B	Aero Commander					2	32	DC-8-50F	Douglas	4				
3	B-18[2] [6]	Beechcraft					2	33	DC-8-61	Douglas	4				
4	B-99[2]	Beechcraft			2			34	DC-8-62	Douglas	4				
5	B-707-100B	Boeing	4					35	DC-8-63F	Douglas	4				
6	B-707-300	Boeing		4				36	DC-9-10	Douglas	2				
7	B-707-300B	Boeing	4					37	DC-9-30	Douglas	2				
8	B-707-300C	Boeing	4					38	DC-9-50	Douglas	2				
9	B-720B	Boeing	4					39	DC-10-10	Douglas	3				
10	B-727-100	Boeing	3					40	DC-10-30	Douglas	3				
11	B-727-100C/QC	Boeing	3					41	DC-10-40	Douglas	3				
12	B-727-200	Boeing	3					42	DHC-2[3]	de Havilland					1
13	B-737-200	Boeing	2					43	DHC-3[3]	de Havilland					1
14	B-737-200C	Boeing	2					44	DHC-6/PT6[3]	de Havilland			2		
15	B-747	Boeing	4					45	F-27	Fairchild			2		
16	B-747C	Boeing	4					46	FH-227	Fairchild			2		
17	B-747F	Boeing	4					47	FW Under 300HP	[4]					1
18	B-747SP	Boeing	4					48	FW 300-450HP	[5]					1
19	BAC-111-200	British Air Corp.	2					49	G-21A[3]	Grumman					2
20	BN-2/A	Britten-Norman					2	50	G-44A[3]	Grumman					2
21	C-46	Curtiss					2	51	G-73[3]	Grumman					2
22	C-402/402A[3]	Cessna					2	52	L-188A/C	Lockheed			4		
23	C-421[3]	Cessna					2	53	L-1011	Lockheed	3				
24	CV-340/440	Convair					2	54	M-404	Martin					2
25	CV-580	Convair			2			55	Metro	Swearinger			2		
26	CV-600	Convair			2			56	Mo-298	Nord/Mohawk			2		
27	D-35	Beechcraft					1	57	S-61[3]	Sikorsky				2	
28	DC-3	Douglas					2	58	SC-7[3]	Short			2		
29	DC-6B	Douglas					4	59	YS-11	Nihon			2		
30	DC-8-10/20/30	Douglas		4				60	Unknown[7]						

Missions

Passenger Transport

Cargo Transport

[1] Airport Activity Statistics, US DOT, June 1977.

[2] 12,500 pounds or less maximum gross takeoff weight.

[3] Helicopter.

[4] Single engine fixed-wing types 299 METO HP or less

[5] Single engine fixed-wing types 300 to 450 METO HP

[6] In table 7 listed as Beech 18

[7] One and two engine piston aircraft flown by Wein Air Alaska, Inc.

TABLE 3-4 CIVIL AIR MISSIONS (Continued)

HOST VEHICLE CATEGORY - GENERAL AVIATION	
Host Vehicles	
Fixed wing single engine piston 1-3 seats	
Fixed wing single engine piston 4+ seats	
Fixed wing two engine piston 1-6 seats	
Fixed wing two engine piston 7+ seats	
Fixed wing other	
Fixed wing two engine turboprop 1-12 seats	
Fixed wing two engine turboprop 13+ seats	
Fixed wing turboprop other	
Fixed wing two engine turbojet	
Fixed wing turbojet other	
Rotorcraft piston	
Rotorcraft turbine	
Missions	
Executive	Instruction
Personal	Aerial Application
Business	Air Taxi
Industrial/Special	Rental
Civil Air Patrol (Search and Rescue)	

The systems are open-loop in that each user operates independently without centralized management or control.

Table 3-5 lists the various missions and host vehicles relating to marine operations.

3.5 Land Vehicle Transit Management

The primary interest in the land vehicle area of operations is in establishing and maintaining surveillance for the purpose of exercising closer control over vehicular traffic. Similar to the military C^2 systems, the land vehicle user would like to ascertain the position and status of distributed elements of a specific land vehicle system. Thus, the objective is a closed-loop system, utilizing a combination of surveillance and communications.

Since communications already exist for most land vehicle systems, the addition of a position fixing capability would allow each user to report position via the communications link and thereby establish a surveillance function.

Table 3-6 lists the vehicle categories and missions for land mobile activity.

3.6 Commonality of Civil/Military Radionavigation Requirements

It appears that the total aggregate of civil radionavigation requirements form a subset of military radionavigation requirements.

Military vehicles share the air and marine environments with civil vehicles and must exhibit similar performance characteristics to operate safely and efficiently. In addition,

TABLE 3-5 CIVIL MARITIME MISSIONS

HOST VEHICLE CATEGORY - LARGE MARINE OPERATORS
Host Vehicles
Tankers
Ore and Bulk Carriers
Resource Exploration Ships
General Cargo Vessels
Oceanographic and Hydrographic Vessels
Missions
Cargo Transport
Passenger Transport
Hydrographic Charting
Oceanographic Research
Bathythermographic and Metereological Exploration
Aeromagnetic Surveying
Resource Exploration
General Geophysical Research
HOST VEHICLE CATEGORY - COMMERCIAL FISHING BOATS AND SHIPS
Host Vehicles
Tuna Boats
Shrimp Boats

TABLE 3-5 CIVIL MARITIME MISSIONS (Continued)

Lobster Boats Trawlers Draggers Large Fishing Vessels Fishing Factories Other Commercial Fishing Vessels Missions Fishing Trawling Catch Processing Fisheries Research Lobster/Shrimp Catching and Processing
HOST VEHICLE TYPE - OTHER SMALL COMMERCIAL VESSELS (Excluding Fishing Vessels)
Host Vehicles General Cargo Vessels Passenger/Cruise Ships Tugs Ferries Dredges Salvage Vessels Coastal Research and Exploration Vessels

TABLE 3-5 CIVIL MARITIME MISSIONS (Continued)

Missions
Passenger Transport
Salvage
Dredging and Sweeping
Cargo Transport
Coastal Hydrographic, Oceanographic, Geophysical, and Metereological Research
Coastal Resource Exploration
HOST VEHICLE CATEGORY - RECREATIONAL AND PLEASURE BOATS
Host Vehicles
Inboard Gas Twin Engine
Inboard Gas Single Engine
Inboard Diesel Twin Engine
Inboard Diesel Single Engine
Outboard Single Engine
Outboard Twin Engine
Sailboat Gas Auxiliary
Sailboat Diesel Auxiliary
Sailboat with no Auxiliary
Rowboat
Kayak
Canoe
Skiff

TABLE 3-5 CIVIL MARITIME MISSIONS (Continued)

Dinghy Inboard/Outboard Single Engine Inboard/Outboard Twin Engine Johnboat Inflatable Missions Pleasure Cruising or Sailing, Water Skiing Recreational Fishing Hunting Racing White Water Canoeing, Rafting and Kayaking Other Canoeing, Rafting and Kayaking
HOST VEHICLE CATEGORY - U.S. COAST GUARD
Host Vehicles USCG Fleet Missions Search and Rescue Marine Navaid Operations and Maintenance U.S. Coast Patrol

TABLE 3-6 CIVIL LAND MISSIONS

HOST VEHICLE TYPE	MISSION
Commercial Trucks	Cargo Transport
Urban Buses	Passenger Transport
Taxis	Passenger Transport
Police Cars	Law Enforcement, Emergency Services
Fire Engines	Firefighting, Emergency Services, Rescue
Ambulances	Emergency Medical Services, Rescue
Mail Trucks	Mail and Cargo Transport

The military must respond to a set of uniquely defined mission requirements. As a general consideration, it may be assumed that military vehicles, whose radionavigation system performance is responsive to mission requirements, will also satisfy any civil radionavigation requirements.

The converse does not apply, i.e., civil vehicles cannot, in general, meet military radionavigation requirements.

3.7 Unique Civil Radionavigation Requirements

Although the civil sector engages in missions that are distinct from those of the military, the missions do not generate requirements that are unique relative to navigation performance. There do exist a number of civil requirements related to various law enforcement operations that combine position finding with surveillance techniques. However, if military surveillance requirements are also considered, it is highly likely that no unique civil radionavigation-surveillance requirements exist.

The consideration of surveillance, communications and navigation as a total interrelated system activity is warranted for both military and civil operations as a more realistic measure of cost-effectiveness. However, such consideration was beyond the scope of the present study.

3.8 Consideration of Navstar GPS Modifications to Meet All Civil Radionavigation Requirements

For the set of civil missions discussed in Section 3, it will be evident that the GPS will adequately respond to all civil missions.

There exist two areas of uncertainty that require further examination:

(1) GPS Accuracy - The accuracy of position determination provided by GPS for potential civil use is not as yet fully defined. The accuracy potentially available and the accuracy provided may differ considerably due to selective availability requirements as set forth by National Security Policy.

(2) Aided Operations - The unaided use of GPS for civil use eliminates the application of the system to high accuracy operations related to aircraft approach and landing and ship harbor-entrance operations. The civil sector currently employs a specialized local system (ILS/MLS), for terminal air activity. The harbor-entrance requirement is not satisfied by any of the current radionavigation systems.

It appears that a local reference aiding the GPS would provide an increment in accuracy sufficient to provide service for air and ship terminal operations.

Placement of ground based GPS receivers at fixed, known locations, such as air terminals or harbor entrance areas, would provide highly accurate relative navigation over a localized area.

Since the addition of local references would be confined to domestic application, selective availability may still be consistent with National Security objectives.

4.0 IMPACT OF JOINT CIVIL/MILITARY UTILIZATION

4.1 General

Historically, in the United States, most radionavigation systems have been developed mainly for or by the military and justified solely for military use. As the advantages of these "military systems" became known to the civil community, civil usage developed and the systems were in turn made available for civil as well as military use.

Navstar GPS has initially followed this historical pattern in that it is being developed to provide precise three dimensional positional, three dimensional velocity, and time information to DOD users for navigation enhancement of weapons delivery accuracy and to support military missions.

However, unlike past systems, such as LORAN, TRANSIT and, to a lesser extent, OMEGA, the development of GPS has gained early visibility and has resulted in numerous requests that the GPS be planned and implemented as a joint civil/military system which would eliminate the time lag or learning time formerly experienced in considering civil user of military systems.

Therefore, in the case of GPS, the impact or constraints that civil use may have on the military and/or the constraints placed on civil users of a military system has become an issue during the system planning stages. The major impact may be expected to occur in the areas of technical compatibility needed to meet civil/military requirements and in operational

or institutional procedures relating to access and control of the system.

4.2 Technical Assessment for Civil Use

If the GPS is capable of meeting DOD requirements, it should be technically capable of meeting similar civil requirements. However, technical characteristics can have a major impact on the ease of use of the system and must be examined to determine the adequacy of the military design for civil users.

Major technical factors of interest to civil use are:

(1) Signal accuracy of satellite broadcast

(2) Signal availability

(3) Signal coverage of satellite broadcast

(4) Signal reliability of satellite broadcast

(5) Signal processing by user

(6) Signal acquisition by user

4.2.1 Signal Accuracy of the Satellite Broadcast

The operational signal accuracy of the GPS has yet to be determined. However, present R&D tests are providing better than design accuracies. Tests on relative accuracy and repeatable accuracy have not been conducted, but from the system design and propagation characteristics of the signals, the relative and repeatable accuracies should be materially better than the predictable or geometric accuracies. Therefore, from a technical point of view, the accuracy to be afforded by the GPS should be inherently acceptable for most civil users.

4.2.2 Signal Availability

Signal availability is the percentage of the average time that the signals, at specified performance level, are available for use. The civil objective is as near 100% signal availability as possible, exclusive of user equipment reliability.

Signals from four GPS satellites will be needed for a complete three dimensional solution to a given navigation problem. The number of satellites from which signals are normally expected to be available ranges from six at the equator to eleven at the poles. Therefore, signals from four satellites should be available over 95%, and probably 100%, of the time due to the configuration and number of satellites in the system.

4.2.3 Signal Coverage (Service Area)

Satellite geometry and altitude; signal frequency, power, and waveform; and satellite antenna design are such that essentially world-wide coverage will be afforded to all users. With a five degree masking angle, signals should always be available from at least six satellites.

4.2.4 Signal Reliability

Reliability of a navigation system is principally related to the frequency with which failures occur within the system and, in quantitative terms, the probability that it will perform its function within defined performance limits for a specified period of time under specified operating conditions.

The GPS system design provides an extremely high degree of

system redundancy or failure protection. As few as 18 satellites are expected to provide continuous, world-wide, three-dimensional fix capability. Thus, the planned 24 satellite system will have up to six satellites for the purpose of added reliability or redundancy. Further, the basic design as a three-dimensional system provides another degree of redundancy or reliability to the two-dimensional user of the system. Thus, the large number of autonomous satellites, together with the three-dimensional capability of the GPS, is expected to provide a significant built-in redundancy, which should minimize the adverse effects of satellite and/or satellite equipment failure. Accordingly, the signal reliability is expected to be equivalent to, or better than, other existing or planned radionavigation systems.

4.2.5 Signal Processing

Signal processing is a process whereby signals from the satellites are received by the user equipment, the desired information extracted therefrom, manipulated in accordance with programmed instructions, and meaningfully displayed to the user. Signal structure significantly influences the complexity of the user equipment, signal acquisition time, and accuracy.

This signal format (waveform) of the GPS is expected to be moderately complex to the extent required to facilitate nominal ease of acquisition and simplicity in processing.

4.2.6 Conclusion

There are technical questions that have been raised by

the DOT which they feel must be resolved before the GPS is proven for general civil use such as:

(a) Signal attenuation by foliage, etc.

(b) Multipath effects

(c) Required/available signal strength (SNR)

(d) Vehicle dynamics and antenna siting

(e) Signal acquisition and tracking continuity

(f) Time to first fix and update rate

(g) EMI effects

However, results of recent tests conducted at Yuma, San Diego, and Florida, as well as at sea, addressing these factors, have been very good and indicate there should be no problem in resolving the questions raised by DOT. Therefore, there appears no technical reason which would prevent acceptance of the GPS by a significant number of civil users, national and/or international, if the signals are available and the user is willing to pay some costs. There have been suggested modifications to the space segment, which some feel may reduce the cost of civil user equipment. The impact, if any, would be on the cost of user equipment and not on the basic system capability to provide a navigation service.

4.3 Operational or Institutional Assessment

Policies and decisions by the U.S. Government (Legislative and Executive Branches), foreign governments, and international organizations, will all impact on the joint civil/military use of a system such as GPS, but the U.S. Government's policy as to

system operation and system access will probably be the deciding factor.

4.3.1 Policy Issues

Policy and decisions by the U.S. Government, that could significantly influence, if not decide, the GPS utilization as a joint civil/military system are:

(1) System availability for civil use

(2) Signal accuracy available for civil use

(3) System life

(4) Operation and maintenance standards

(5) Cost of operation and maintenance

(6) Information distribution

(7) International agreements.

4.3.1.1 System Availability for Civil Use

The manner in which the GPS is operated, i.e., whether it is operated strictly as a military system or as a civil or a joint civil/military system, could be the major constraint to general acceptance of the system by civil users.

As shown by civil use of the Navy TRANSIT system and the pre 1974 military LORAN C system, some civil users will use a "military" system if it provides a useful or unique service. On the other hand, as shown by the pre 1974 civil use of LORAN A in preference to the better performing "military" LORAN C, most civil users continued to use the civil sponsored LORAN A. Therefore, if the GPS is operated strictly to meet military requirements, without any "civil" participation in the control,

performance or life of the system, the economic risks may be considered too great to attract the majority of civil users. Thus, joint use of the GPS will likely require either civil agency participation in operation of the system or government assurance as to the "continuity" of operation and level of performance.

4.3.1.2 Signal Accuracy Available for Civil Use

The basic accuracy of the GPS signal exceeds the requirements of all but a very few of the presently identified civil radionavigation users; however, the level of accuracy made available for civil use, if considered to be a degradation of economically obtainable accuracy, will materially impact the civil use of the system.

4.3.1.3 System Life

System life, or anticipated length of time the GPS will be supported, maintained, and operated in conformance with the general purposes for which the system was established, has a major impact on the civil users.

A potential user of the GPS is faced with investing in the purchase or lease of new user equipment, either for the first time or as a replacement or addition to an existing system. The manufacturer is confronted with the investment costs of developing and/or producing GPS user equipment. Therefore, it becomes quite apparent that life-cycle policy decisions will exert great impact on acceptability of the GPS for both National and international civil use.

4.3.1.4 Operations and Maintenance Standards

The civil user community of radionavigation is more diverse and less structured than the military user community. Therefore, standards governing the availability, accuracy and performance of the system must be established and made available to the civil users. Procedures will also have to be established to provide information on system operational status to the various civil users as well as military users.

4.3.1.5 Cost of Operation and Maintenance

Unless joint use entails system design to accommodate civil users, the basic operating costs of the GPS should be the same as if operated strictly as a military or joint civil/-military system. However, the costs of interfacing with the civil users (such as providing operational information, system monitoring, certifications, etc.) will increase the overall system operational and maintenance costs.

4.3.1.6 Information Distribution

In order for a system such as GPS to be fully responsive to the maximum number of users, appropriate information, pertaining to system operation or status, availability, accuracy, coverage, and reliability should be promulgated in such a manner as to be readily available. This information should include appropriate data to aid the user in proper use of the system. Provision of this kind of information should probably be the responsibility of individual user group representations - DOD for military users, civil agencies (FAA and CG)

for U.S. civil users, and individual foreign governments for their constituents.

4.3.1.7 International Agreements

To achieve full utilization of the GPS, it should probably be accepted both as a national and international standard. A major institutional or management decision will be if and how GPS can be offered for international use.

There is no precedent for the operation of an international radionavigation system, but there is precedent for multi-nation operations and/or use of "military" as well as civil systems. For example, VOR/DME (VORTAC) is operated by each host country in accordance with an agreed to set of standards; OMEGA is operated by host countries in accordance to standards set by the U. S.; TRANSIT, LORAN C and LORAN A are used internationally, although they have no international guarantees.

4.4 System Management, Control and Operations

The primary factor affecting the joint utilization of a system such as GPS for joint civil/military use may well be the question of system management or control. Historically, U.S. civil systems, most joint use civil/military systems and some military systems have been "operated" by civil or non-DOD entities.

The procedures and authorities for civil agency operation of radionavigation systems are well described in the DOT National Plan for Navigation and is vested mainly in the Department of Transportation Act (Public Law 89-670), the

Federal Aviation Act of 1958 (Public Law 85-726), and Section 81 of Title 14, United States Code.

Title 14, which applies directly to the Coast Guard, is the most definitive of these statements of authority.

Specifically, it authorizes the Coast Guard to establish, maintain and operate:

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

These policy statements seem all inclusive as to the provision and operations of civil and joint civil/military systems. However, closer examination of the overall management control and operations of joint use of systems, such as LORAN and OMEGA, show that they are, in reality, joint DOD (Navy) and DOT (Coast Guard) operations. In the case of both of these systems, the Coast Guard physically operates the systems and interfaces with the civil user population. The Navy funds, in part or completely, the systems operations, provides differing degrees of systems management inputs as to facilities, performance, and system characteristics to the Coast Guard, and interfaces with the military users. Also, as an exception, the TRANSIT System, which is being jointly used by civil and military, is being operated and controlled by the military. Therefore, under present arrangements or practices in these joint use systems, each entity—civil and military—have certain specific authority which need to be and are being exercised irrespective of the physical operator of the system.

Based on present practices in the joint civil/military controlled radionavigation systems, it becomes evident that the system operator, per se (civil or military), is not as important as the overall control and U. S. Government's policy as to operations and maintenance of the system.

Thus, if GPS is to be utilized as a joint civil/military system versus a "strictly" military system, the overall management control and operations mechanism must also provide means

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for DOD and DOT to exercise their respective authorities.

The present bilateral arrangements between the Coast Guard and Navy appear to be working well for LORAN and OMEGA. However, the potential impact of the GPS on total DOD operations and upon civil air, sea and possibly land users indicates the need for a broader or more formal approach.

This could be accomplished by the formulation of a Joint GPS Office with representatives provided by the principal organizations that have statutory responsibilities relative to the provisions of radionavigation services. This would provide a focus and focal point for GPS operations and also protect the interests of each agency and/or user groups.

A proposed management structure is depicted in Figure 4-1. The Executive Director would be responsible for overall operations of the GPS system under the overall guidelines laid out by the Joint Radionavigation Steering Committee. The support group would include agency representatives who would be responsible for planning and funding for his specific interest group and to maintain laision with the operational entities of his agency.

Under such an arrangement, the physical operator of the system, whether DOD, DOT or a civil contractor would not appear to be of prime importance as the policies of operation would be controlled by the responsible agencies. However, because of the priority for National Security that is being assigned to GPS, the Executive Director or Vice Director should be a DOD

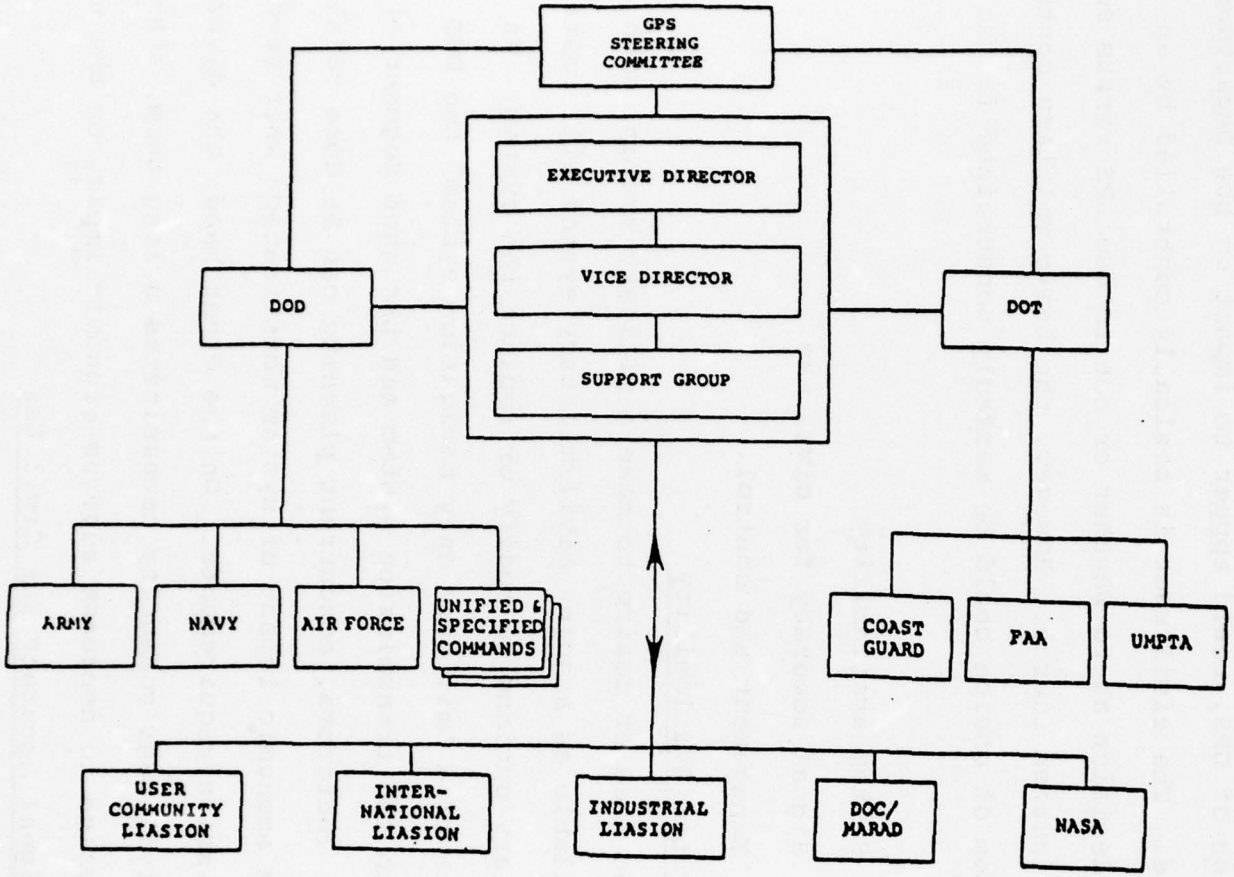


Figure 4-1 GPS Management Organization

representative who would assume control in times of National Emergency.

4.5 Constraints

The major constraints, as a result of joint civil/military utilization of GPS, would appear to impact on the Department of Defense. The civil user is basically controlled by an economic decision as to whether or not to use GPS versus some other navigation source. However, the basic military control and freedom of choice could be markedly constrained in the areas of:

(1) System availability

(2) Signal accuracy for civil use

(3) Management and control.

4.5.1 System Availability

The need or desire to make a military system, such as GPS, available as a joint civil/military system will restrict the military options to modify or replace the system. In the operations of a 'military only navigation system' the DOD controls both the transmission system and the user segment of the systems. Therefore, concurrent planning can be done to alleviate the economic impact of system modification when needed due to new mission requirements. On the other hand, the diversity of the civil user community necessitates a long term, stable system design to decrease adverse economic impact on the users.

4.5.2 Signal Accuracy for Civil Use

The 'value' of a satellite navigation system for civil

use is dependent to a great degree on the accuracy of service obtainable from the system. Therefore, it is understandable that civil users will want to have access to the maximum accuracy available from the system.

The value to the military of a satellite navigation system is not only dependent on the accuracy or service obtainable from the system, but also dependent on the improvement of the U. S. military position in regards to the military position of potential enemies.

In a military system, the system access or accuracy can be controlled or denied, as desired, but in a joint system, standards must be established and complied with. Therefore, the military will be constrained to establish certain levels of accuracy for the civil users.

4.5.3 Management and Control

Joint civil/military management and control will be necessary to achieve shared utilization of GPS. The basic control of the system could remain under DOD, but the control must recognize and be receptive to the civil users. Standards must be established and adhered to which protect or provide for the civil user. The management will entail both the DOD and civil community, thus, will have to be shared between DOD and non-DOD entities, such as DOT. Interfaces with civil users, as well as military users, will have to be established and any management decision will have to be evaluated with respect to their impact on civil as well as military users.

4.5.4 Evaluation

The major constraints arising as a consequence of joint civil/military utilization of the GPS will be imposed on the Department of Defense. The military options to deny access to the system, to modify the system, or to terminate the system, if no longer needed by the military, will be restricted if not precluded. The overall management and control of the system will be more complicated and the overall cost of the system will be increased.

5.0 CIVIL USER IMPACT ON THE NAVSTAR GPS PROGRAM

5.1 Introduction

Although the Navstar GPS is a single, integrated navigation system designed for military application, there exist a number of user segment equipment classes to satisfy the wide variance in specified missions.

Table 5-1 identifies a summary of user equipment classes that are associated with the X, Y, and Z developments. In general, as Table 5-1 indicates, the progression of equipment designs is from high to medium performance. The degree of performance can be related to user equipment cost.

In the interest of applying Navstar GPS as a National asset, shared by both military and civil user communities, there is currently on-going activity in examining, more closely, the potential use of GPS by the civil community of users. It has become evident that the Navstar GPS does possess the potential for providing radionavigation services that satisfy almost all known civil requirements. In view of this potential, there is considerable interest in the investment cost required of a civil user. Cost becomes an important parameter for individual segments of the user population in their choice among available alternatives.

If one initially considers the military lower performance set as representative of a low cost equipment, there are a number of variations of this concept that have emerged as candidates for the achievement of an inexpensive design.

TABLE 5-1

USER EQUIPMENT CLASSES

GENERAL CLASSES	TYPICAL USERS	ESTIMATED NUMBER	APPROACH
CLASS A: HIGH AJ, MED. DYNAMICS	B-52, F-111 F-14, F-15	1,000	X-Set Aided, Unaided Y-Set Aided, Unaided
CLASS B: HIGH DYN, MED. AJ	F-14, F-15, Helicopters	10,000	X-Set Aided, Unaided Y-Set Aided, Unaided
CLASS C: MED DYN, LOW AJ	C-5, C-141, KC-135	10,000	Z-Set
CLASS D: HIGH AJ, LOW DYN	WARSHIPS, TANKS	3,000	X-Set, Unaided
CLASS E: HIGH AJ, ZERO DYN	MANPACK	6,000	Manpack/Vehicular
SPECIAL: UTILITY CONCEPT	SUBMARINES LAUNCH VEHICLES SATELLITES AZIMUTH BEARING UNIT, ETC. TRIDENT	--- --- --- --- ---	
COMMERCIAL	NON-MIL-SPEC. ENVIRONMENT	---	Low Cost Z

This section reviews the approaches identified to date, discusses the impact of each on the GPS Program, and presents a relative cost comparison for two alternative civil strategies.

5.2 User Segment Organization

Functional outlines of the X, Y, and Z sets are shown in Figure 5-1. The X-set can accommodate two antennas to combat shadowing and is also designed to operate in a hybrid mode with external aiding. The X-set receives on four radio channels simultaneously, thus requiring four carrier channels. The single code channel is shared sequentially among the four carrier channels.

The process controller provides all satellite channel assignments and scheduling, and also provides software loop filters to the carrier tracking loops. The data processor calculates position, velocity and time from the pseudorange and delta range measurements and drives the control display unit.

The X-set represents the highest performance consistent with military navigation requirements.

The X-set will provide accuracies on the order of:

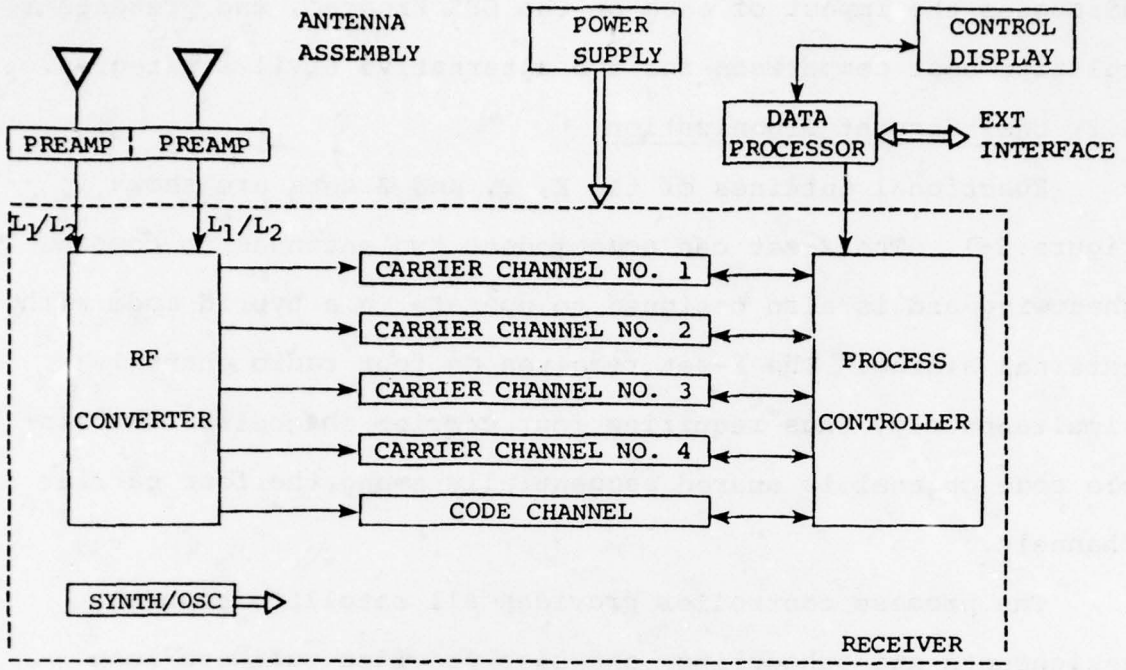
$8\ m(2\sigma)$ - P signal

$100\ m(2\sigma)$ - C/A signal

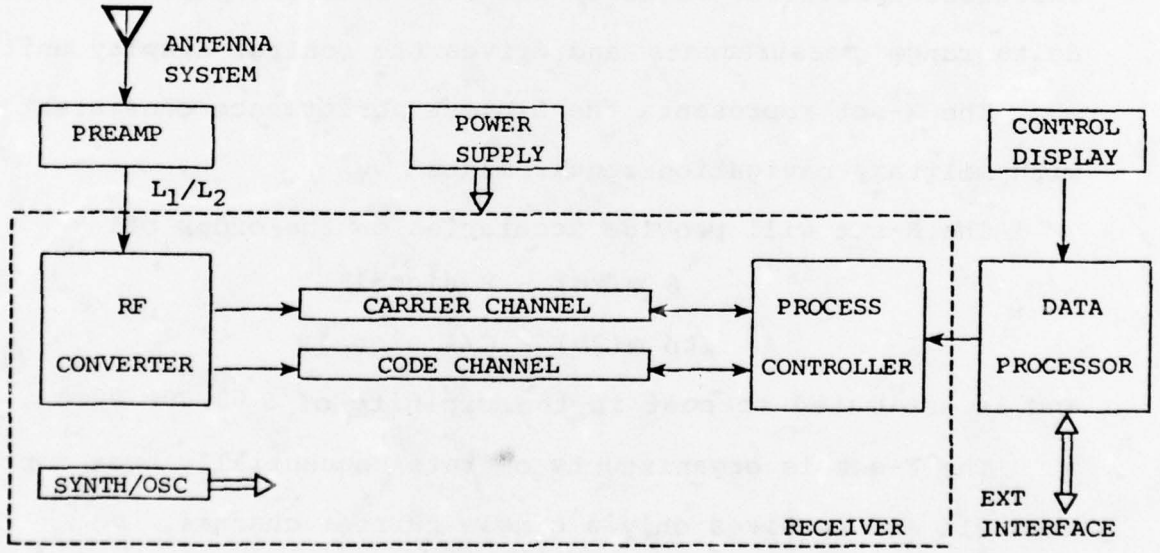
and is estimated to cost in the vicinity of $ 60,000.00.*

The Y-set is organized to operate sequentially over four channels and requires only a single carrier channel.

*The estimated costs are included for general orientation; costs are in 1979 dollars.

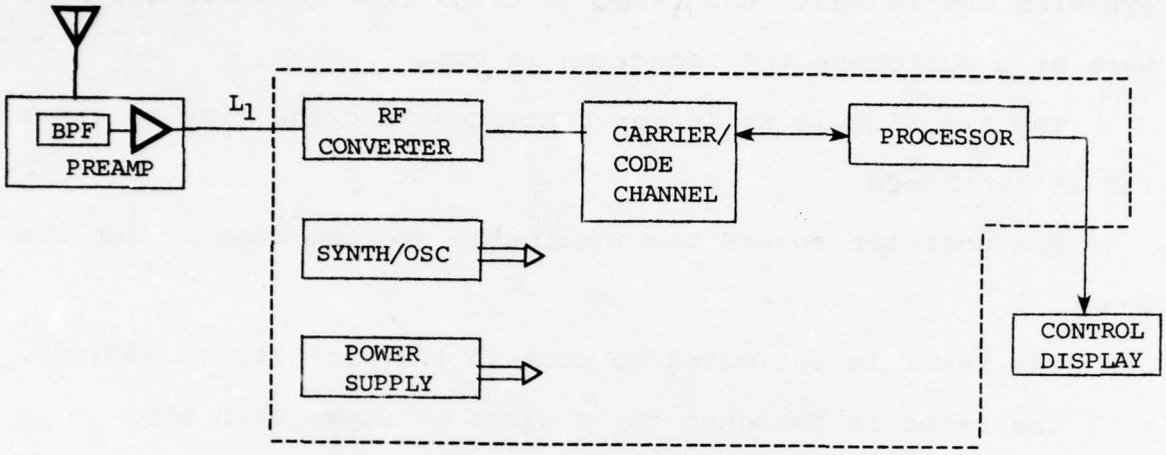


X-SET FUNCTIONAL PARTITION



Y-SET FUNCTIONAL PARTITION

Figure 5-1 User Segment Configurations



Z-SET PARTITIONING

Figure 5-1 User Segment Configurations (Continued)

The reduction in carrier channels eliminates three carrier tracking loops and reduces the process controller load. Intended for users who will operate under a lower jamming and vehicle dynamics environment, the Y-set contains less hardware and software at a corresponding reduction in cost.

The tracking is no longer continuous and the time to first fix is lenthened.

The position accuracies obtainable are the same as for the X-set.

The Y-set is estimated to cost in the vicinity of $35,000.

The Z-set is designed for a class of users with more modest performance requirements which allows a further decrease in cost. The Z-set receives sequentially on a single channel and tracks the C/A code provided on the L_1 carrier frequency. These modifications reduce the obtainable accuracy due to the slower chipping rate of the C/A code and the absence of the ionospheric correction information derived from L_1/L_2 path comparison.

The Z-set will provide position accuracies of 100 m (2σ) at an estimated cost in the vicinity of $15,000.

5.3 Alternative Modification Categories

5.3.1 General

The alternatives for designing a commercial class set or a low cost civil equivalent can be assigned to three categories that aid in the assessment of the impact to the Navstar GPS Program.

Category 1 - refers to those modifications that are isolated

from the space vehicle and control segments and are directed toward improving the cost-effectiveness of the civil user segment.

Category 2 - refers to those modifications that impact the space vehicle, but are collectively within the scope of an evolutionary block change.*

Category 3 - refers to those modifications that impact the space vehicle and the control segments within the context of a new system design.

The three categories defined provide a measure of impact upon the Navstar GPS Program. Category 1 will exert no discernable impact upon the program. Category 2 will exert an impact that has been determined and bounded by the GPS Program Office and included in their development program. Category 3 will exert a considerable impact on program schedule and cost. The extent of the impact is related to the number and complexity of the design changes. Category 3 also includes a considerable and undetermined risk factor associated with unvalidated modifications.

5.4 Alternative Design Considerations

5.4.1 Introduction

The various alternative design modifications may be placed in one or more of the impact categories defined. In general, the grouping of modifications may be described as follows:

*A block change to the space vehicle system is an evolutionary development progressing beyond the Phase 1 configuration. The block change will provide for 3-6 db of increased power, extension of mean mission duration to six years, and addition of two secondary payloads.

(1) Class 1 - with Category 1 impact.

This class of modifications is addressed solely to the civil user segment and basically involves cost-performance trade-offs that operate on the fixed signal structure available from the space vehicle.

(2) Class 2 - with Category 2 impact.

This class of modifications is addressed to the potential provision of an additional payload dedicated to providing radio-navigation services to the collection of civil communities.

This class of modification must be considered within the total Navstar GPS System Context in that the additional payload capability is bounded and the number of candidate packages exceeds the capability. From this point of view, a priority structure is implied that is beyond the scope of the present study.

(3) Class 3 - with Category 3 impact.

This class of modifications is addressed to the introduction of changes to the space segment navigation signal structure that may result in a relative increase in cost-effectiveness for the civil user. Any changes considered would also have to be assessed in terms of performance/cost penalties imposed on the military user community.

5.4.2 Class 1 Modifications

The approach followed for Class 1 modifications assumes that the signal structure as designed is optimum in response to military navigation requirements within the constraints of

power and radio frequency/propagation limitations. The civil user environment exhibits less stringent requirements in a number of areas relative to signal acquisition times, position up-date intervals, position accuracy, interference (jamming), vehicle dynamics and physical environment (i.e., temperature, vibration, etc.).

A number of lower cost receiver approaches have been advanced* and reviewed for potential cost reduction impact. The specific lines of approach can be summarized as taking one of the following directions:

(1) Deletion of Receiver Functions

The most common approach in this direction is to utilize a single channel receiver with sequential tracking of satellites. There results a reduction in the number of carrier channels from four to one. Tracking is no longer continuous and signal acquisition/up-date interval times are extended. It is further assumed that the receiver will track only the C/A signal so that the dual channel (P-C/A) ionospheric delay correction data are unavailable with a subsequent degradation of accuracy.

Since a substantial portion of civil requirements require two-dimensional (X, Y) position, the receiver need only track three satellites rather than four. These modifications can reduce the number of hardware and software elements required.

(2) Relaxation of Receiver Performance

The military user segment is designed to function in

*1."Design Development Study for the Global Positioning System Spartan Set", Magnavox 850010421R-5321, Sep 1975.
2."The Impact of Increased Power on the GPS C/A Sequential Receiver", MIT Lincoln Laboratory W.P. 41WP-5025, Dec 1978.
3."GPS Signal Design for the Civil Community, Lincoln Laboratory Study and Stanford Communications, Inc., Commentary", STI February, 1979.

a high dynamic, high interference environment. For civil applications, it can be assumed that the vehicle dynamics extend to substantially lower levels and the potential for intentional interference is low.

There has also been added a positive increment of available power margin that may range from 6 to 10 db. With additional power, low expected interference and more modest dynamics, the signal detection and processing circuitry within the receiver may be simplified to operate at higher thresholds. Although the basic carrier and code tracking functions are still necessary, the additional signal margin and reduced doppler frequency increments allow performance-cost trade-offs.

(3) Use of Lower Cost Components

The translation from military specifications to standard commercial practice allows the use of lower cost components for the user segment.

(4) Application of Advanced Technology

An expenditure of funds for development of advanced technology can result in a lower unit cost in which the development cost is amortized over a number of years.

Two areas offer potential reduction in civil user segment costs. First, the development of LSI technology in which functions are integrated on single chips with high density packaging offers a cost advantage over the discrete circuit application.

Second, the advances in CCD (Charge Coupled Device) technology makes feasible the application of pseudonoise matched

filters (PNMF) for civil user receivers. The technology is attractive for the shorter codes (1024 chip) associated with C/A signaling. A singular advantage of CCD PNMF technology is the capability for parallel search for code phase, which results in greatly reduced code acquisition time. State-of-the-art in PNMF technology provides for 512 stage devices that may be operated in tandem to achieve the 1024 chip code length.

(5) Application of External Aiding

The use of four satellites for 3-dimensional position ranging is required to compensate for local (user) clock errors. With relatively short mission times and the availability of an externally supplied local clock correction, there exists the potential for tracking one less satellite. The external aids can take the form of fixed, calibrated GPS receivers with clock transfer capability.

5.4.3 Class 2 Modifications

Class 2 modifications are associated with the design of a secondary payload intended for civil user application for radionavigation. Since the CDMA spread spectrum signaling structure carries a substantial AJ capability, the approaches to civil applications tend toward more narrow band pulsed systems that are time multiplexed. The TDMA approach is considered to be more consistent with a sequential receiver operation as planned for low cost implementation.

Two approaches in this class have been reviewed*. The Rockwell Spartan approach recommends major modifications to the

*1. Global Positioning System Spartan Receiver/Processor", Rockwell SD75-GP-0006, April 1975.
2. "The Impact of Increased Power on the GPS C/A Sequential Receiver", MIT Lincoln Laboratory, W. P. 41WP-5025, Dec. 1978.

GPS signal structure, which could only be accommodated in a separate package (i.e., secondary payload).

The configuration recommended utilizes pulsed FSK with TDMA for sequential access. The chosen radio frequency of 400 MHz increases the error due to group delay from 15 m (at L-Band) to 250 m. The low chipping rate (32 kbs) degrades the pseudo-range accuracy to 1000 ft. The total error budget approaches 6000 ft. (1 nm) for the system proposed.

The power budget calculations require a transmitter power of 476 watts (56.8 dBm) and a space vehicle antenna gain of 8 dBi The resulting flux density is approximately 9 dB over the -152 $dBw/m^2/4kHz$, as prescribed in the Manual of Regulations and Procedures for Radio Frequency Management.

It is also suggested in the approach that if 400 MHz proves unavailable, then the technique could be applied at L-Band.

Operation at L-Band would require 16 times additional power for the same signal/noise. The L-Band transmitter would therefore have to provide 7.6 kw, which may prove unrealizable with current technology.

Estimated costs are provided for two classes of user segments based on 15,000 units:

Class A - $1,655.00*

Class B - $1,465.00*(requires almanac for satellite ephemeris data).

The accuracy (approximately 1 nm) does not make this an attractive alternative. The choice of a UHF frequency and the

*1979 dollars

excessive flux density raise the uncertainty and risk of such an approach. The costs quoted do not include distribution costs which are normally assumed to approximate 100% for commercial manufacturing activities.

The costs quoted also do not include design/development which is estimated (in the report) at 1.5 million dollars.

The Lincoln Laboratory approach also recommends a shift from the GPS CW radio system to a pulsed TDMA system, thus eliminating the requirement for coherent detection of the carrier. Since no AJ margin or security is necessary for the civil sector, the spread spectrum is eliminated and replaced with a pulse burst technique that sequentially transmits ranging code and data within each time multiplexed pulse interval. The ranging code sequence length of 512 is selected as the starting point in the design approach to be consistent with state-of-the-art CCD matched filter technology. (Actually, this is not a constraint since pseudonoise matched filters can be operated in tandem to achieve 1024 or longer lengths.[1]) The chipping rate is increased to 4 MHz (over that of the C/A 1 MHz) to combat the effects of multipath distortion.

The Lincoln Laboratory power budget is based upon a 2 kw (33 dBw) transmitter power for a received signal power of -143 dBw. If a 3 dB link margin is added to the power budget, the signal power requirement is increased to 4 kw.

Peak power outputs at this level on satellite vehicles may well carry substantial technological and operational risks.

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1. "Charge Coupled Device Pseudo-Noise Matched Filter Design", Proc. IEEE, Jan 1979.

The estimated accuracy of 100 m is consistent with military Z-set performance.

The cost advantages for this approach are associated with the elimination of both the carrier and code locking loops.

The carrier is not required for incoherent detection of the pulsed carrier and code acquisition and tracking is accomplished with CCD matched filter technology. The modified Z-set operating on the GPS signal structure can also replace the present delay lock loop used for code acquisition and tracking, with a CCD PNMF.

The Lincoln Laboratory approach appears reasonable in that the spread spectrum technology that is optimum for military application is compressed to a conventional pulsed technique which is suitable for sequential (i.e., TDM) user operations and also allows the use of less sophisticated receiver circuitry.

5.4.4 Class 3 Modifications

Class 3 modifications are those that would serve to substitute a general purpose military/civil radionavigation system through a redesign and development of the current GPS system structure. No approach for this class of modifications has emerged. This class of modifications presents a formidable task for the following reasons:

(1) The GPS was designed specifically to respond to military requirements including those for National Security. The signaling structure represents the most advanced technology

available with spread spectrum techniques consistent with acceptable risk. Any perturbation of the design must provide assurance of no degradation of performance for military users.

(2) Since the original design effort analyzed all forms of signaling and selected optimized (with respect to E/No) modulation, it is unlikely that the performance parameters can be improved upon.

(3) Less sophisticated techniques appear to provide some increment of cost reduction but applies only to civil use and would prove completely unacceptable for military missions.

(4) The impact of a redesign on the Navstar GPS program must assume severe proportions in both cost and schedule with no apparent justification.

5.4.5 Summary Impact Statement

Of the three classes of modifications defined,

Class 1 - Category 1 impact → 0

Class 2 - Category 2 impact → block change; secondary payload.

Class 3 - Category 3 impact → severe.

Class 3-cannot be justified on any basis at the present time. Class 2-represents a bounded approach that may be accommodated by the block change development as scheduled by the SAMSO Program Office. However, this approach does not yet exhibit any significant performance or cost advantage to merit the substantial development and risk assessment involved.

Class 3 represents the most favored approach at this point in time since a civil user segment can be developed at essentially zero risk; the cost will converge to a value somewhere between 1-5 thousand dollars (with several models available); there is a zero impact on the progress of the Navstar GPS Program; and finally, there is no potential for degradation of military radionavigation services.

The following subsections provide an estimation of cost for GPS Civil User Sets.

5.4.6 Alternative Design Trade-Offs

The most advanced user segment, the X-set, is a sophisticated receiver that provides 4-channel continuous tracking of the C/A-P; L_1, L_2 signals with inertial aiding.

All operations are computer controlled through a sequence of phase and code acquisitions, tracking and handover between the C/A and P signals as well as L_1/L_2 comparisons. The computer also monitors the reception of the information bearing data that is modulo-2 added to the ranging sequence.

The Z-set, which serves as the basis for a low cost receiver, from which both commercial and civil set designs evolve, comprises a single (or dual) channel sequential tracker using the L_1 signal with no external aiding. Figure 5-2 shows the TI low cost version which retains the basic operations as originally conceived for the GPS waveform. As can be seen from the figure, phase lock (Costas Loop) and code lock (Delay Lock Loop) circuits are employed to provide narrow band acquisition and tracking

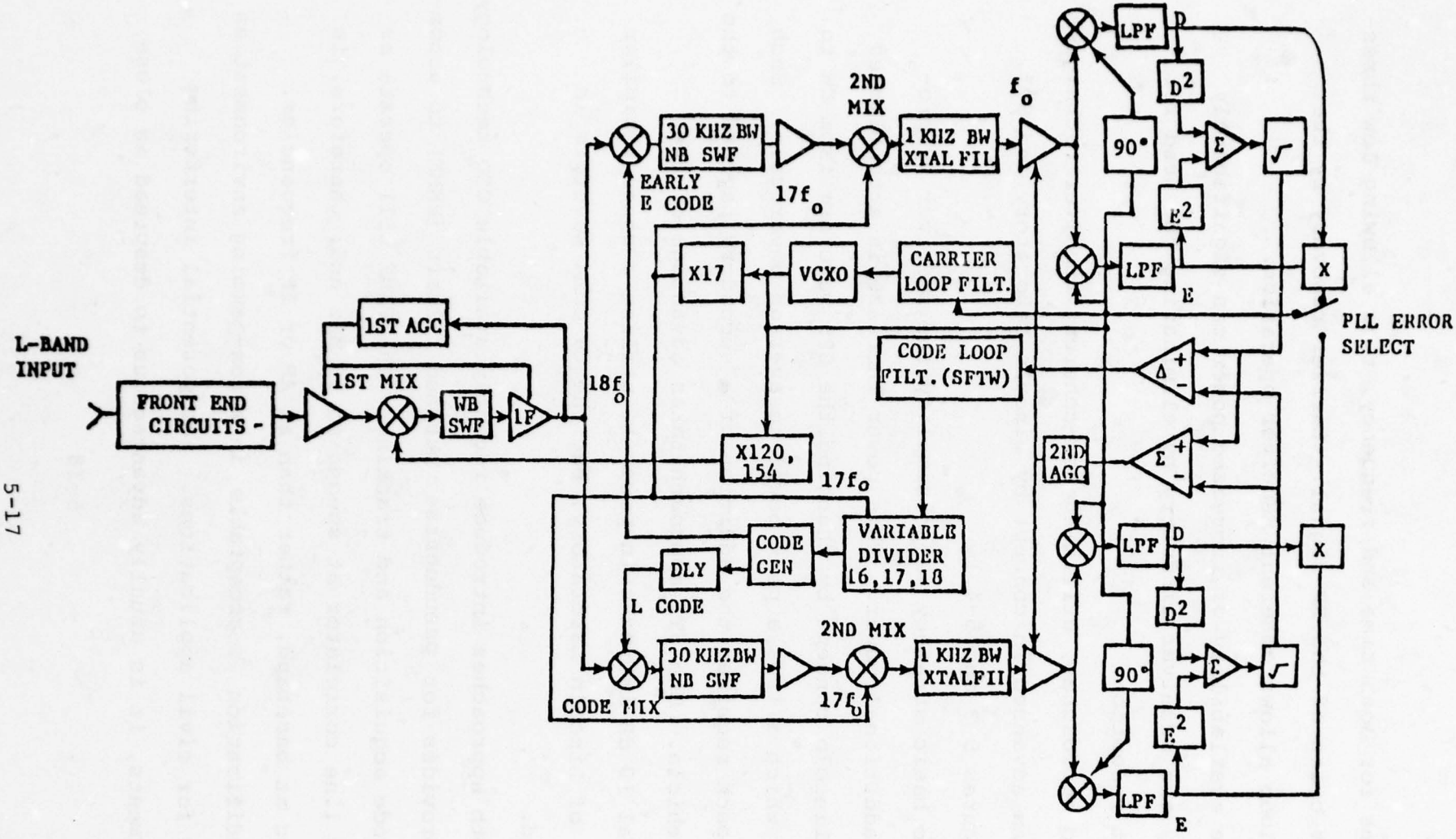


Figure 5-2 Texas Instruments Receiver Block Diagram

(Source: NASA CR-145059, November, 1976.)

functions for both time and frequency, thus allowing low threshold detection of the RF signal. Carrier recovery by the Costas loop allows coherent receiver operation.

The availability of increased power can significantly simplify the receiver circuitry by eliminating the need for coherent reception.

Two approaches, utilizing non-coherent receiver techniques, have been advanced in concept by Lincoln Laboratory and STI. (See Figures 5-3 and 5-4.)

The basic strategy is to simplify the receiver by providing additional power. This power increase is accomplished in the Lincoln concept by changing the GPS waveform from CW to pulsed, which allows a peak power to average power gain. Such an approach requires the addition of a secondary payload to the space vehicle. The STI approach takes advantage of the potential 10 dB increase in power to utilize a concept similar to that of Lincoln Laboratory, but the CW CDMA waveform is retained.

Both approaches introduce recently available CCD technology which provides for pseudonoise matched filters (PNMF) to accomplish code acquisition and tracking. The PNMF will operate as a delay line correlator at speeds to 10 MHz and, therefore, is employed at baseband, rather than at RF or IF frequencies. This modification is acceptable in a non-jamming environment as assumed for civil applications. For potential interfering environments, it is usually advantageous to despread as close

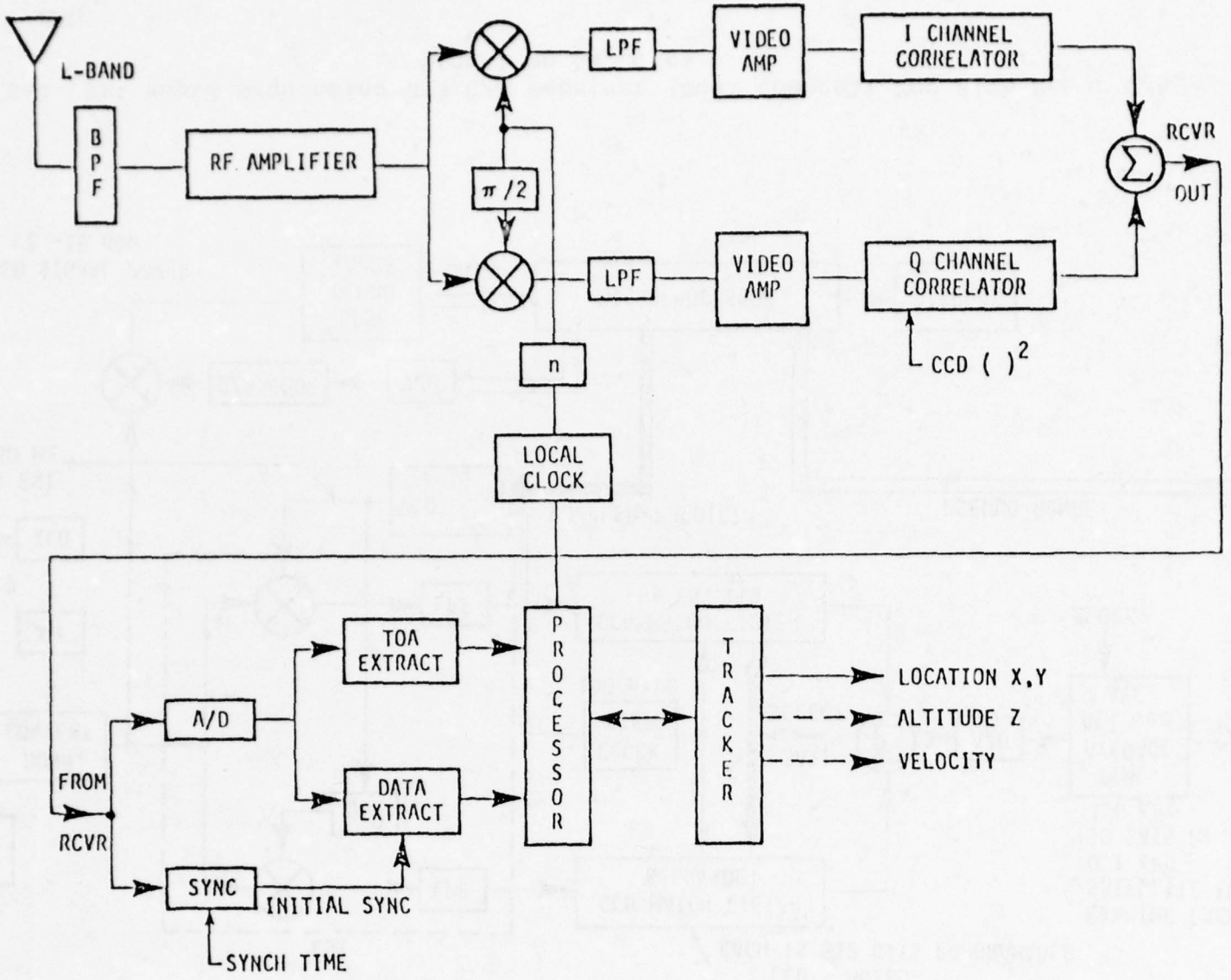


Figure 5-3 Lincoln Laboratory Receiver Block Diagram

(Source: MIT Lincoln Laboratory)

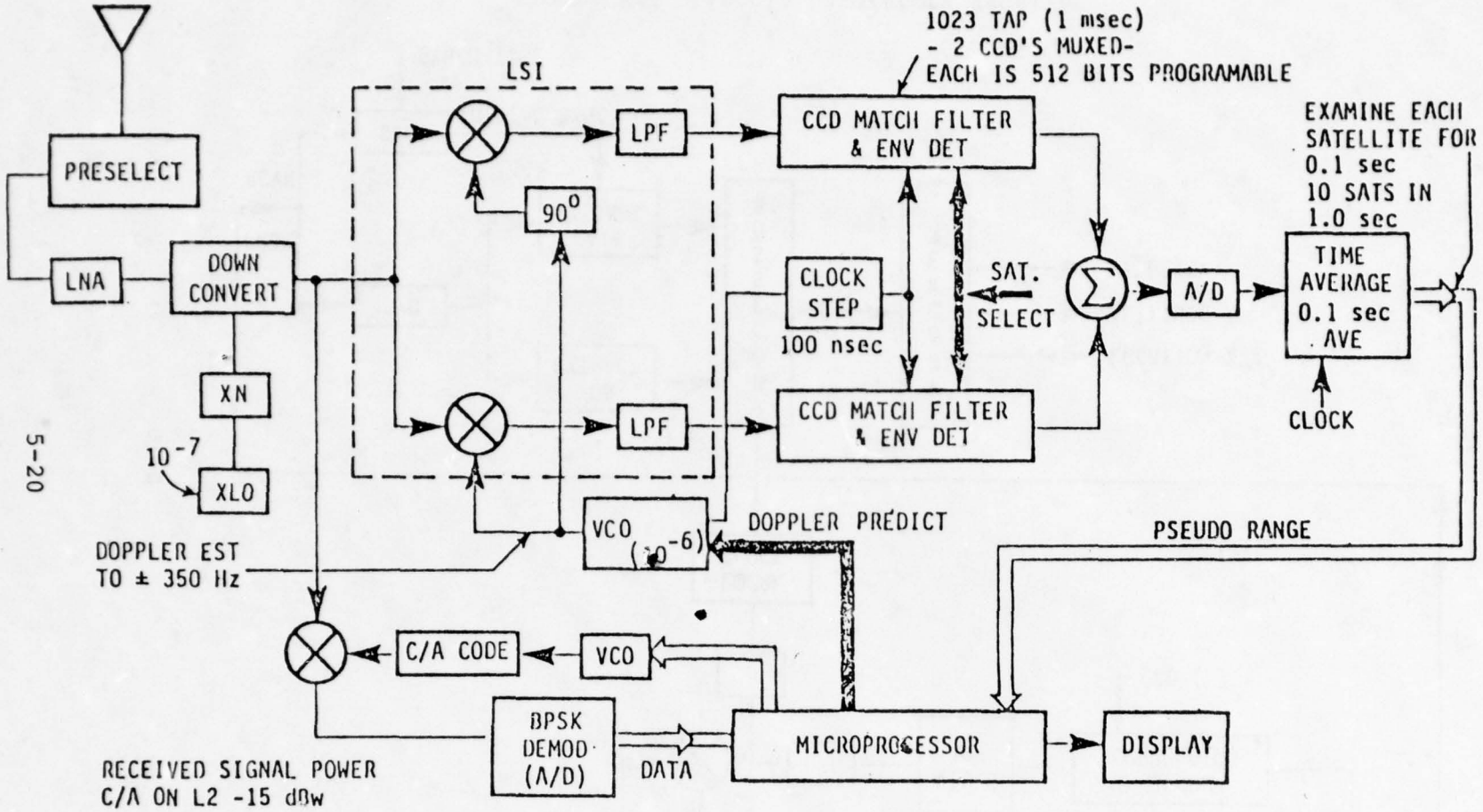


Figure 5-4 STI Rapid Sequencing GPS C/A Receiver (Dual Channel) For High Power C/A Signal on L2 Codes

(Source: STI)

to RF as practical. There results a considerable simplification of circuitry in that the delay lock correlators are eliminated and code acquisition time is almost instantaneous since the search is accomplished in parallel rather than sequentially. The PNMF is programmable so that the resident code may be changed to match the particular satellite transmission.

The PNMF is particularly adaptable to the shorter code C/A signal as state-of-the-art devices have been demonstrated by Fairchild for 512 cell CCDs which can be operated in tandem to achieve 1024 cells.[1]

The Lincoln Laboratory concept would fall in Category 2, described above, and would require a block change modification to the space vehicle.

The STI concept falls in Category 1 and exerts zero impact on the GPS program. No concept for a redesign of the GPS waveform to accommodate both military and civil users appears practical since the AJ requirements can only be satisfied with the optimized signaling structure currently planned. Thus, Category 3 does not offer a feasible alternative.

The increased power concepts as represented by the pulsed Lincoln Laboratory approach and the CW CDMA STI approach are not substantially different and it is likely that the cost differential between the two is incremental. It, therefore, does not appear reasonable to adopt a pulsed approach which will impact the space vehicle and introduce some factor of risk and uncertainty relative to high peak power satellite

[1] "Charge-Coupled Device Pseudo-Noise Matched Filter Design", Proceedings of the IEEE, p50, January, 1979.

transmission.

The above considerations lead to a choice of Category 1 modifications which concentrate on the design of a Civil set that will operate with the current GPS waveform structure.

5.5 Cost for Modified GPS Z-Set

The ARINC Research Corporation, under contract to FAA, has recently completed a cost study for civil application of the GPS (FAA-EM-79-1).

The design chosen for cost evaluation was a military Z-set configuration as developed by Magnavox.

The signal format, signal acquisition, frequency conversion, data processing and display were retained without modification so that the costing exercise comprised placing values on a bill of materials as supplied by Magnavox. The Z-set costed also provided both C/A and P code reception and processing. Although it was not possible to obtain a copy of the Magnavox design, the principal features are similar to the design by TI as shown previously in Figure 5-2.

ARINC developed two cost estimates: one for a high performance avionics receiver (Table 5-2) and a second for a low performance avionics receiver. The low performance version introduced changes in components from MIL SPEC to commercial grade, consistent with general aviation manufacturing procedures.

The low cost results are shown in Tables 5-3 and 5-4. The costs shown are based upon a production of 3000 units with the development costs amortized over the production run.

TABLE 5-2

ACQUISITION COST OF HIGH-PERFORMANCE AIRCRAFT GPS AVIONICS						
Equipment	Cost (1977 Dollars) by User Category					
	Parametric Method				Accounting Method	
	Development Only	Production Only	Air Carrier*	General* Aviation	Air Carrier	General Aviation
Receiver	681	9,131	9,812	12,756	8,811	11,454
Control and Display	92	1,208	1,300	1,690	1,223	1,589
Preamplifier	56	671	727	945	708	920
Antenna	25	205	230	299	230	299
Total Cost	854	11,215	12,069	15,690	10,972	14,262
*Includes development costs.						

(Source: FAA-EM-79-1)

TABLE 5-3

GPS LOW-PERFORMANCE AIRCRAFT RECEIVER COST DEVELOPMENT (1977 DOLLARS)											
Cost Element	Module Cost in Dollars										
	Receiver	Processor 1	Processor 2	Processor 3	RF/IF	Synthesizer	Power Supply	Enclosure and Chassis	Oscillator	Assembly and Test	Totals
Material Cost	201.89	229.08	64.60	96.61	32.34	87.74	18.19	24.10	71.40	-	825.95
Material Handling (10%)	20.19	22.91	6.46	9.66	3.23	8.77	1.82	2.41	7.14	-	82.59
Labor ($4.00/Hour)	21.94	13.75	9.12	13.21	8.43	15.17	4.10	9.63	-	10.50	105.85
Burden (135% Labor)	29.62	18.56	12.31	17.84	11.38	20.48	5.53	13.00	-	14.18	142.90
Subtotal	273.64	284.30	92.49	137.32	55.38	132.16	29.64	49.14	78.54	24.68	1,157.29
G&A (20%)	54.73	56.86	18.50	27.46	11.08	26.43	5.91	9.83	15.71	4.94	231.35
Total Direct Cost	328.37	341.16	110.99	164.78	66.46	158.59	35.45	58.97	94.25	29.62	1,388.64
Profit (15%)	49.26	51.17	16.65	24.72	9.97	23.79	5.32	8.85	14.14	4.44	208.31
Selling Price	377.63	392.33	127.64	189.50	76.43	182.38	40.77	67.82	108.39	34.06	1,596.95
Distribution (100%)											1,596.95
List Price											3,193.90

(Source: FAA-EM-79-1)

TABLE 5-4

GPS LOW-PERFORMANCE AIRCRAFT CONTROL AND INDICATOR COST DEVELOPMENT (1977 DOLLARS)

Cost Element	Module Cost in Dollars						
	Display	Driver	Control	Power Supply	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	19.33	35.83	58.38	10.93	26.96	-	151.43
Material Handling (10%)	1.93	3.58	5.84	1.09	2.70	-	15.14
Labor ($4.00/Hour)	5.40	6.07	6.28	3.67	6.69	9.10	37.21
Burden (135% Labor)	7.28	8.20	8.47	4.96	9.03	12.29	50.23
Subtotal	33.94	53.68	78.97	20.65	45.38	21.39	254.01
G&A (20%)	6.79	10.74	15.79	4.13	9.08	4.28	50.81
Total Direct Cost	40.73	64.42	94.76	24.78	54.46	25.67	304.82
Profit (15%)	6.11	9.66	14.21	3.72	8.17	3.85	45.72
Selling Price	46.84	74.08	108.97	28.50	62.63	29.52	350.54
Distribution (100%)	46.84	74.08	108.97	28.50	62.63	29.52	350.54
List Price	93.68	148.16	217.94	57.00	125.26	59.04	701.08

TABLE 5-5

GPS LOW-PERFORMANCE AIRCRAFT AVIONICS SINGLE SYSTEM (1977 DOLLARS)

Equipment	Cost
Receiver	1,597
Control and Display	351
Antenna with Preamplifier	75
Factory Sell Price	2,023
Distributor Mark-Up	2,023
List Price	4,046

(Source: FAA-EM-79-1)

The study appears to accurately represent estimates of actual component costs based on a production bill of materials for a GPS Z-set. The low performance avionics cost estimate is based upon the lower costs associated with commercial grade components (i.e., relaxed temperature range and plastic rather than ceramic packages).

The Z-set non-MIL SPEC configuration serves as a basis for introducing further cost reduction techniques.

5.6 Cost Estimation for GPS Civil Set (C-Set)

5.6.1 Approach

The approach employed for estimating cost follows three steps that provide an approximation and bounding process within the time available.

(1) The ARINC cost for the GPS Z-set as an upper bound to a low cost user segment.

(2) Recent data, as generated by AEL/NARCO, indicate that lower cost components (relative to the ARINC exercise) are available as developed for the MLS program.

(3) The CCD PNMF technology substitution together with the additional power available in the space vehicle allows a substantial simplification of the Z-set configuration.

The upper bound cost for a C-set is as provided by the ARINC study:

Factory Sale Price:	$2023.00
Distributor Mark-up:	2023.00
List Price:	$4046.00 (TABLE 5-5)

5.6.2 C-Set Cost Estimation

Table 5-6 shows a cost comparison as developed by AEL for a recent proposal*. The receiver design concept is matched to the GPS waveform structure and cost reduction is achieved through the use of low cost commercial type components as applied by NARCO (a team member) who manufacturers medium to low cost avionics for the general aviation community. Additional reductions are provided by the AEL experience in designing a low cost MLS receiver and by data processing simplifications introduced by Texas A&M University (another team member).

The parenthetical column was added to make the cost figures equivalent to the ARINC cost study by adding G&A and profit.

Table 5-7 partitions the user segment into identifiable packages and shows the equivalent ARINC and AEL developed cost figures. A third column is added which represents a basis for planning estimates.

The third column shows an estimate between the ARINC costs which are derived from a military Z-set design and the AEL costs which in some instances are based on a degree of risk or excessive austerity.

The bounded costs shown (ARINC high and AEL low) represent engineering estimates for the receiver configuration chosen.

The planning estimate (Column 3, Table 5-7), is based upon a compromise between full MIL SPEC costs and competitive commercial practice. The numbers can be verified by generation of a

*Low Cost Navstar GPS Receiver, March 1978, AEL.

complete receiver design and production bill of materials similar to that by Magnavox and ARINC.

The considerations for cost have been based upon production lots of 2000 to 3000 units.

If a particular manufacturer were to assume a dominant market position for the provision of GPS C-Set, then it may be feasible to consider larger production runs approaching 10,000 units.

In order to apply GPS civil sets to various user populations, three receiver cost estimates are developed:

(1) Low Cost C-set - $2020 (Table 5-7)

(2) High Performance C-set - $10,972 (Table 5-2)
This cost coincides with that developed by ARINC for Air Carrier application.

(3) Medium Cost C-set - $5477.
A medium cost C-set is derived by interpolation between the low cost and high cost units. A factor of 2.7 (2.7 x 2020 = $5477) was chosen to represent the average of an expected distribution of prices in the medium performance market. Interpolation factors are based upon experience with similar available equipment classes such as LORAN and OMEGA. (See for example: "Economic Requirements Analysis of Civil Air Navigation Requirements Alternatives", Volume II, Table B.5, FAA-ASP-78-3, April 1978.)

TABLE 5-6 GPS RECEIVER COST COMPARISONS (LOADED LABOR AND MATERIAL)

ASSEMBLY	MAGNAVOX SPARTAN GPS	ROCKWELL SPARTAN GPS	AEL LOW COST GPS	AEL LOW COST MLS
RF HEAD	432	216	40 (55.20)	33
IF'S	573	94	25 (34.50)	18
DETECTOR(S)	+ 209		50 (69)	30
SYNTH & REF OSC	782	94	75 (103.50)	64
PREPROCESSOR	289	1222	50 (69)	42
PROCESSOR/MEMORY/INTERFACE	791	1410	170 (234.60)	42
POWER SUPPLY	255	94	24 (33.12)	24
MECHANICAL PACKAGE	845	....	40 (55.20)	38
DISPLAY	372	9	20 (27.60)	....
TOTAL:	$3766	$3139	$499	$291

Note: ( ) Loaded Labor and Material + 20% G&A + 15% Profit.

TABLE 5-7 COST FACTORS C-SET

PACKAGE	ARINC/ MAGNAVOX	AEL/NARCO	PLANNING ESTIMATE
ANTENNA & PREAMP	75.00	55.20	56[1]
RF + IF	76.43	103.50	152[2]
RECEIVER CHANNEL	377.63		
SYNTHESIZER & OSCILLATOR	290.77	103.50	145[3]
DATA PROCESSOR	709.47	303.60	355[4]
POWER SUPPLY	40.77	33.12	35[5]
ENCLOSURE & CHASSIS	67.82	55.20	56[6]
CONTROL & DISPLAY	351.00	27.60	176[7]
ASSEMBLY & TEST	34.06	34.06	35[8]
FACTORY SELL PRICE:	2023.00	715.78	1010
LIST PRICE:	4046.00	1431.56	2020

TABLE 5-7 COST FACTORS C-SET (Continued)

1. An AEL development for the MLS receiver has integrated the antenna, RF amplifiers and filters into a single RF head using stripline techniques. A similar device for the GPS application is costed at $55.20 (adjusted for G&A, Profit) by AEL.

2. The RF, IF and various detection acquisition and tracking circuitry are costed as a total of $454.06 in the ARINC study. This cost assumes detection and tracking of the P code as well as the C/A code. The cost also assumes a Z-set configuration with the full complement of delay lock and Costas loops for code and carrier reception. The AEL/NARCO figure of $103.50 may require the addition of an intermittant pilot carrier to eliminate the Costas loop in favor of a simpler phase lock loop. It does appear evident that the additional power provided, that makes possible the use of an incoherent receiver with matched filter reception (PNMF), will effect a substantial reduction in the acquisition and tracking circuitry.

   The reduction is approximated as one-third (1/3) the ARINC figure of $454.06 or $152.00.

3. AEL has demonstrated a low cost crystal oscillator with a frequency stability of 3×10^{-7}/6 months. They also recommend a frequency synthesis procedure utilizing ICs with digital count down loops as used for commercial CB

TABLE 5-7 COST FACTORS C-SET (Continued)

radios. Since the oscillator and synthesizer, as costed by ARINC, includes P signal reception by the receiver, there is some degree of over engineering relative to C/A signal reception.

Because of uncertainty in the realistic application of digital countdown techniques as applied to a C-set, the AEL cost may be overly optimistic. The planning estimate used is one-half (1/2) the ARINC value of $290.77 or $145.00.

4. The data processing costed by ARINC appears inordinately large and may be due to the additional processing and control required to store and process the interface operations between C/A and P signals. The use of matched filter code acquisition eliminates the sequential chip searching routine resulting in a further cost saving. With the elimination of P code processing and minimization of code search algorithms, it is likely that the data processing can be accomplished with a 16 bit microprocessor. A new generation of 16 bit processors are becoming available with higher speeds and power:

   Fairchild F9440-9445

   Zilog Z8000

   Intel 8086

   Motorola MC68000

The planning estimate employed for data processing is

TABLE 5-7 COST FACTORS C-SET (Continued)

one-half (1/2) of the ARINC estimate of $709.47 or $355.00. This cost is slightly higher than the AEL cost.

5. AEL/NARCO can demonstrate an avionics class requlated power supply for the price indicated. This cost was therefore used in the planning estimate.

6. Same logic as Footnote 5.

7. The control and display can be a highly variable configuration depending upon the features provided in terms of readouts, auxiliary information, etc. The AEL cost is valid, but represents an austere, no frills package. The planning estimate is a compromise set at one-half (1/2) the ARINC estimate of $351.00 or $176.00.

8. The same assembly and test estimate is used for all columns.

TABLE 5-8 GPS CIVIL SETS (ESTIMATED COSTS)

NAVSTAR GPS CIVIL SET COST BASIS (1979 DOLLARS) 3000 UNIT PRODUCTION	
Low Cost: GPS_1	$ 2,020
Medium Cost: GPS_2	$ 5,477
High Cost: GPS_3	$10,972

6.0 COMPARATIVE COST ANALYSIS

6.1 Introduction

The decision to utilize the Navstar GPS for civil radionavigation depends upon a number of considerations; one of which is concerned with relative cost.

INTRADYN has engaged in a preliminary cost analysis that can serve as an input to the decision process.

As will be noted from the discussion, there exist a number of uncertainties, principally in the area of civil radionavigation effectiveness. It is beyond the scope of the present study to perform the analysis required to develop quantitative measures of effectiveness and equivalent cost-benefits.

In the approximation process that follows, it is assumed that the Navstar GPS is a valid military program funded by DOD sources and becoming available for operational use in 1986. This assumption is an important factor in that the cost estimation assigns costs to the civil sector in two categories: (1) user costs allocated to radionavigation receiver equipment and (2) civil sector government costs allocated to required ground segments for supporting the various radionavigation systems.

6.2 Rationale

The considerations relative to the potential utilization of the Navstar GPS can be expressed as an optimization process. In general, with several alternative systems available, it is of interest to determine the most cost-effective approach.

This approach can be stated as a constrained optimization

problem; where it is desired to maximize:

$$N_v = V(Z) - h(X)$$

subject to the constraints: $Z \leq g(X)$

N_v = net value

$V(Z)$ = value of system (effectiveness)

$h(X)$ = value of resources (cost)

$X = (x_1, x_2, \ldots x_n)$ = quantity of resources employed

Z = quantity of system elements

$g(X)$ = production function.

The evaluation procedure employed can either fix the level of effectiveness required [i.e., $V(Z)$] and maximize the net value N_v by minimization of costs, $h(X)$; or fix the available budget, $h(X)$ and maximize N_v by a maximization of the effectiveness $V(Z)$.

Several problems exist in carrying a net value optimization, primarily due to the large degree of uncertainty in the determination of the system effectiveness level. For civil use of navigation, the required level of effectiveness is embedded in a complex and widely diversified relationship among the system users and their economic environments. It is proving extremely difficult to ascertain with any confidence the cost-performance relationship as applied to civil air or marine user groups.

The present analysis is therefore carried out with system effectiveness uncertainty and is directed toward a comparative cost analysis performed for two alternative approaches.

Sufficient background and experience exist with current navigation systems to assign their use to specific missions.

For the missions considered, it is also evident that the Navstar GPS may be assigned to all - on the basis of expected performance.

Table 6-1 shows the civil mission basis for air and marine applications together with the assigned radionavigation system alternatives.

It should be noted that the performance or effectiveness levels are represented by the specific radionavigation system characteristics for each mission; for example, to operate VFR G/A, it is adequate to employ a VOR. For an international air carrier to operate, it is required to employ the combination shown.

The GPS performance characteristics are such that it can be assigned as an alternative radionavigation system for all the missions listed in Table 6-1.

In terms of the optimization process, the following assumptions are employed.

1. V(Z) for the current radionavigation systems, as applied to the missions in Table 6-1, varies over the missions.

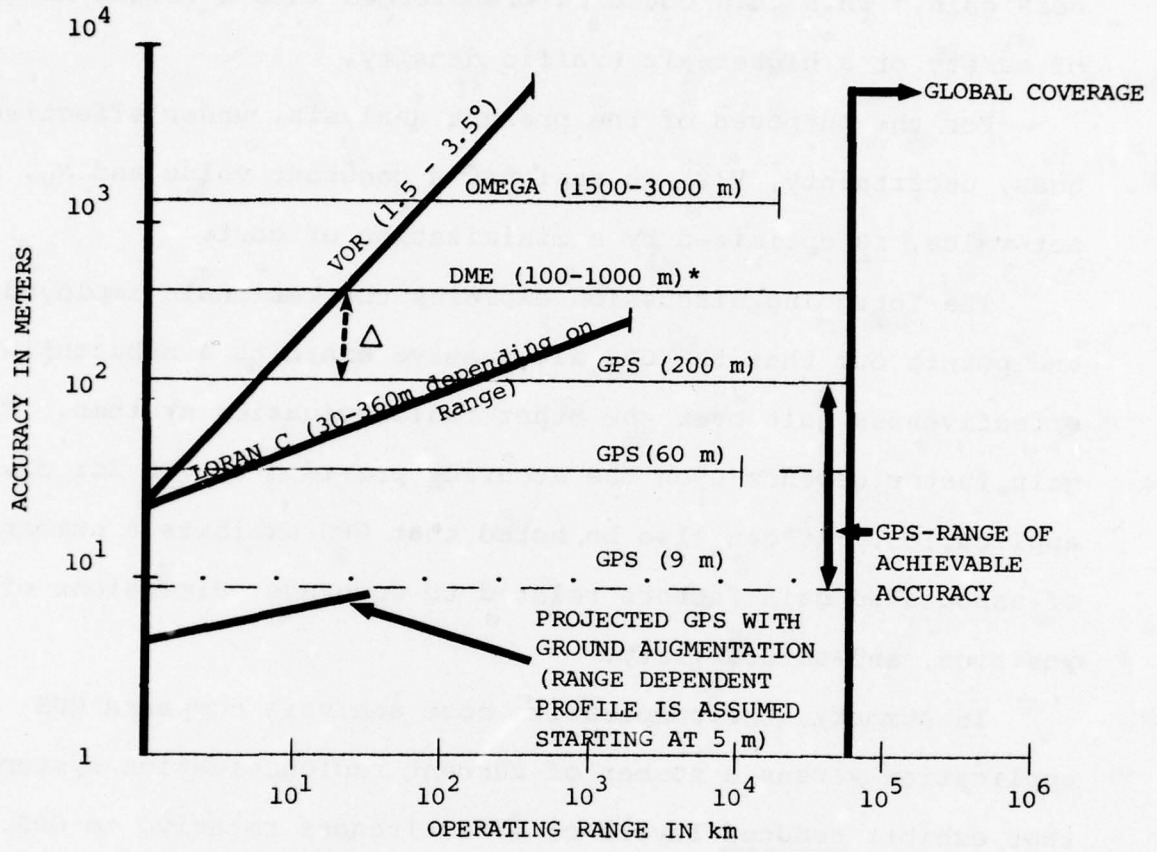
$$V(Z) = V(Z)_1 \; ; \; V(Z)_2 \; ; \; V(Z)_i \; ; .. \; V(Z)_n$$

2. V(Z) for GPS is a constant value. Therefore, it follows that V(Z) for GPS = Max $V(Z)_i$ (i.e., in order to satisfy all civil missions).

Figure 6-1 illustrates the accuracy component system effectiveness for the various radionavigation systems.

TABLE 6-1 CIVIL MISSION BASIS

CIVIL MISSIONS	REPLACEMENT PROGRAM ALTERNATIVE #1 SYSTEM	DISPLACEMENT PROGRAM ALTERNATIVE # 2 SYSTEM
CIVIL AIR		
VFR G/A	VOR	GPS
IFR G/A	VOR/DME	GPS
IFR G/A/RNAV	VOR/DME/RNAV	GPS
AIR CARRIER (DOMESTIC)	VOR/DME/RNAV	GPS
AIR CARRIER (INTERNATIONAL)	OMEGA/VOR/DME/RNAV	GPS
CIVIL MARINE		
OCEAN AREA	OMEGA/LORAN C	GPS
COASTAL AREA	LORAN C	GPS
RECREATIONAL	LORAN C	GPS



*Depending on Price

Figure 6-1 Comparison of Conventional System Accuracy With GPS

The delta or difference in accuracy, as shown for example, between GPS and VOR as 400 m is a very significant effectiveness gain. This gain could be transformed into a larger margin of safety or a higher air traffic density.

For the purposes of the present analysis, under effectiveness, uncertainty, V(Z), is assigned a constant value and N_V, the net value, is optimized by a minimization of cost.

The foregoing discussion explains the rationale employed and points out that the GPS alternative exhibits a substantial effectiveness gain over the other radionavigation systems. The gain factor depends upon the accuracy provided by GPS for civil application. It can also be noted that GPS exhibits a number of associated gain factors related to coverage, dimensions of position, and saturability.

In summary, the comparative cost analysis compares GPS application versus a number of current radionavigation systems that exhibit reduced levels of effectiveness relative to GPS.

6.3 Radionavigation System Cost Basis

6.3.1 General

The cost basis is developed to allow the Government, in the role of decision-maker, to select among a choice of alternatives. Two alternatives are considered for cost estimations.

Alternative 1 - Termed the Replacement Process

This alternative assumes a continuation of current application of radionavigation systems. A life-cycle of 10 years is assumed, so that each user will replace his radionavigation

system each 10 years. Additionally, as the user population grows, new users will purchase a radionavigation system consistent with the missions described.

Alternative 2 - Termed the Displacement Process

Beginning in 1986, users will initiate a displacement of current radionavigation systems with GPS. Based on a 10 year life-cycle, each user will approach wearout of current equipment and displace such equipment with GPS. New users will purchase GPS.

The period of interest is chosen as the 20 year period from 1986, when GPS becomes available, and 2005, inclusive.

A 10 year transition period is postulated to allow an efficient displacement process with no penalty to users (i.e., double buys).

Thus, by 1996, all users will have converted to GPS and will thenceforth replace GPS with GPS as wearout occurs.

In order to maintain linearity, the displacement and replacement processes are assumed to occur at a value of 10% per year.

For the same reasons, a linear population growth is assumed for the various user groups.

6.3.2 Cost Time Stream and Decision Space

Although GPS is not assumed available until 1986, the Government must make a decision prior to 1986 and must make that decision known in the form of a policy statement. Even at this point in time, users buying radionavigation equipment will not

repurchase until 1989.

The Issue for Decision - Should the civil user community shift to the employment of the Navstar GPS for radionavigation?

An Input to the Decision Space - Is there a cost advantage associated with the civil utilization of GPS?

Since GPS will not be available until 1986, the cost comparison most useful to support a decision is based upon a cost stream beginning in 1986 and continuing through 2005. The decision value refers all costs to a present worth assigned to the year 1986.

The present worth derived is equivalent to a minimization (between 2 alternatives) of h(X).

$$P_w = \sum_{i=0}^{19} C_i (1 + r)^{-i}$$

where P_w = Present Worth (1986)

C_i = Costs for year i

r = Discount rate = 10%, i.e., r = 0.1

6.3.3 Civil User Cost Basis

Table 6-2 shows the civil user cost basis for the alternative Replacement (R) or Displacement (D) Programs. Each system is assigned a cost per unit in 1979 dollars. The basic 1979 cost for the GPS systems are as developed in Paragraph 5.0 (Table 5-7). The current radionavigation system costs are consistent with representative industry prices for the equipments shown.

The 1979 costs are projected to 1986 costs by assuming

TABLE 6-2 CIVIL USER COST BASIS

CIVIL MISSIONS	R PROGRAM SYSTEM	R PROGRAM COST/UNIT 79 DOLLARS	R PROGRAM COST/UNIT 86 DOLLARS	D PROGRAM SYSTEM	D PROGRAM COST/UNIT 79 DOLLARS	D PROGRAM COST/UNIT 86 DOLLARS	REDUNDANT FACTOR	R COST BASIS	D COST BASIS
AIR									
VFR G/A	VOR	1,560	1,794	GPS	2,100	2,415	1.0	1,794	2,415
IFR G/A	VOR/DME	6,437	7,402	GPS	2,100	2,415	1.5	11,103	3,622
IFR G/A/RNAV	VOR/DME/RNAV	9,864	11,343	GPS	5,697	6,551	1.5	17,014	9,826
AIR CARRIER (DOMESTIC)	VOR/DME/RNAV	29,740	34,201	GPS	11,410	13,121	2.0	68,402	26,242
AIR CARRIER (INTERNATIONAL)	OMEGA/VOR/DME/RNAV	48,062	55,271	GPS	11,410	13,121	2.0	96,124	26,242
MARINE									
OCEAN AREA	OMEGA/LORAN C	16,640	19,136	GPS	11,410	13,121	2.0	33,280	26,242
COASTAL AREA	LORAN C	5,943	6,834	GPS	5,697	6,551	1.5	10,251	9,826
RECREATIONAL	LORAN C	2,200	2,530	GPS	2,100	2,415	1.0	2,530	2,415

(1) an inflation rate of 7% per year and (2) a technological improvement rate of 5% per year. Thus the costs increase by a 7% inflationary factor and decrease by a 5% technological improvement factor resulting in a net cost increase of 2% per year.

The cost per unit shown is converted to a cost per user by multiplication by a redundant factor which varies between 1 and 2. The far right columns of Table 6-2 represent the Replacement (R) and Displacement (D) cost basis employed for civil missions.

6.3.4 Population Factors

The new purchases of receivers is based on (1) the influx of new users to the user population and (2) the replacement of aged equipment with new equipment. Equipment (regardless of scenario) is assumed replaced after a 10 year life. User population increases were assumed to be constant (i.e., a linear population growth) with a base year of 1985 (Table 2-12). For the eight civil missions examined, the base population and the annual growth rate are shown in Table 6-3. Replacement of aged equipment over the 20 year period consisted of two parts:

1. 10% of the respective 1985 civil mission user population annually.
2. The new users in the 1986 - 1995 period replacing their equipment in the 1996 - 2005 period (10 years after purchase).

6.3.5 Relative User Cost Estimates

TABLE 6-3

CIVIL MISSION 1985 POPULATION AND GROWTH RATE

CIVIL MISSIONS	1985 USER POPULATION	ANNUAL GROWTH RATE
AIR		
1. VFR G/A	68,800	4,896
2. IFR G/A	67,500	4,332
3. IFR G/A/RNAV	97,400	8,671
4. Air Carrier (Domestic)	3,300	94
5. Air Carrier (International)	570	13
MARINE		
6. Ocean Area	18,500	46
7. Coastal Area	26,200	969
8. Recreational	44,000	4,943

Table 6-4 shows the annual and cumulative user costs associated with the alternate strategies of Replacement or Displacement for the civil air and marine missions.

The costs shown are based upon an annual appreciation of 2% per year over the base 1986 cost for each system.

The costs are referred to a Present Worth Value for 1986 as calculated using the formula in Paragraph 6.3.2.

As previously defined, the alternatives costed are (1) Replacement and (2) Displacement. For the replacement alternative, all users for the different civil missions continue to use their respective navigation systems. The basic factors over the 20 years are:

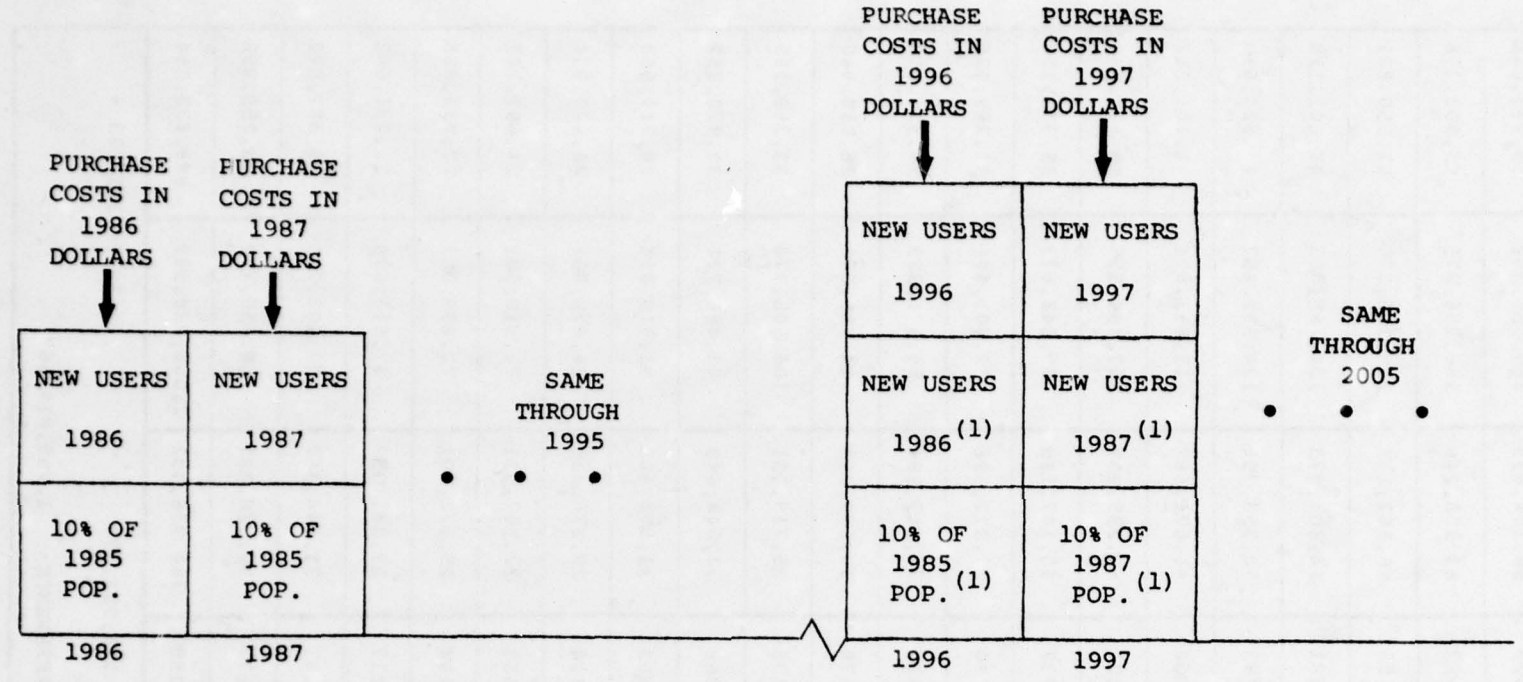
1. Every 10 years the users of a system replace their equipment with new equipment for the same system.
2. The receiver costs appreciate annually.
3. New users in any mission category purchase equipment for the system used by that mission.
4. As a basis, 10% of the 1985 users, for any mission, replace their equipment annually.
5. There is no GPS system.

The model for future worth cost computation for any of the eight civil missions is shown in Figure 6-2. After the 20 year values are computed, based on this model, the costs are converted to 1986 dollars to allow direct comparisons. The displacement alternative assumes that GPS will displace current systems over a ten year period (1986-1995). For the second ten years (1996-2005), users who purchased GPS equipment during the first ten

TABLE 6-4 ALTERNATIVE SCENARIO COSTS COMPARISON
(1986 - 2006) PRESENT WORTH 1986

	REPLACEMENT COSTS (1)		DISPLACEMENT COSTS (1)	
	AIR	MARINE	AIR	MARINE
1986	306,383,029	68,108,599	169,051,532	59,953,641
1987	284,100,627	63,155,246	156,756,875	55,593,376
1988	263,438,763	58,562,137	145,356,375	51,550,221
1989	244,279,581	54,303,073	134,785,003	47,801,114
1990	226,573,793	50,353,758	124,982,457	44,324,670
1991	210,040,062	46,691,667	115,892,824	41,101,057
1992	194,764,421	43,295,909	107,464,255	38,111,889
1993	180,599,737	40,147,116	99,648,673	35,340,116
1994	167,465,210	37,227,326	92,401,496	32,769,925
1995	155,285,922	34,519,884	85,681,388	30,386,658
1996	206,393,578	39,599,063	114,535,643	36,018,960
1997	191,383,136	36,719,131	106,205,778	33,399,399
1998	177,464,362	34,048,649	98,481,721	30,970,352
1999	164,557,863	31,572,383	91,319,414	28,717,963
2000	152,590,018	29,276,210	84,678,002	26,629,384
2001	141,492,563	27,147,031	78,519,602	24,692,701
2002	131,202,194	25,172,701	72,809,085	22,896,868
2003	121,660,217	23,341,959	67,513,879	21,231,642
2004	112,812,201	21,644,362	62,603,779	19,687,522
2005	104,607,677	20,070,227	58,050,777	18,255,702
TOTAL:	3,737,034,958	784,956,432	2,066,738,559	699,433,164
	4,521,991,390		2,766,171,723	
	DIFFERENCE: 1,755,819,667			

(1) Present Worth (1986)



ANNUAL COSTS = # OF USERS PURCHASING X PURCHASE COSTS (IN APPROPRIATE DOLLARS)

(1) These users are replacing equipment purchased 10 years before.

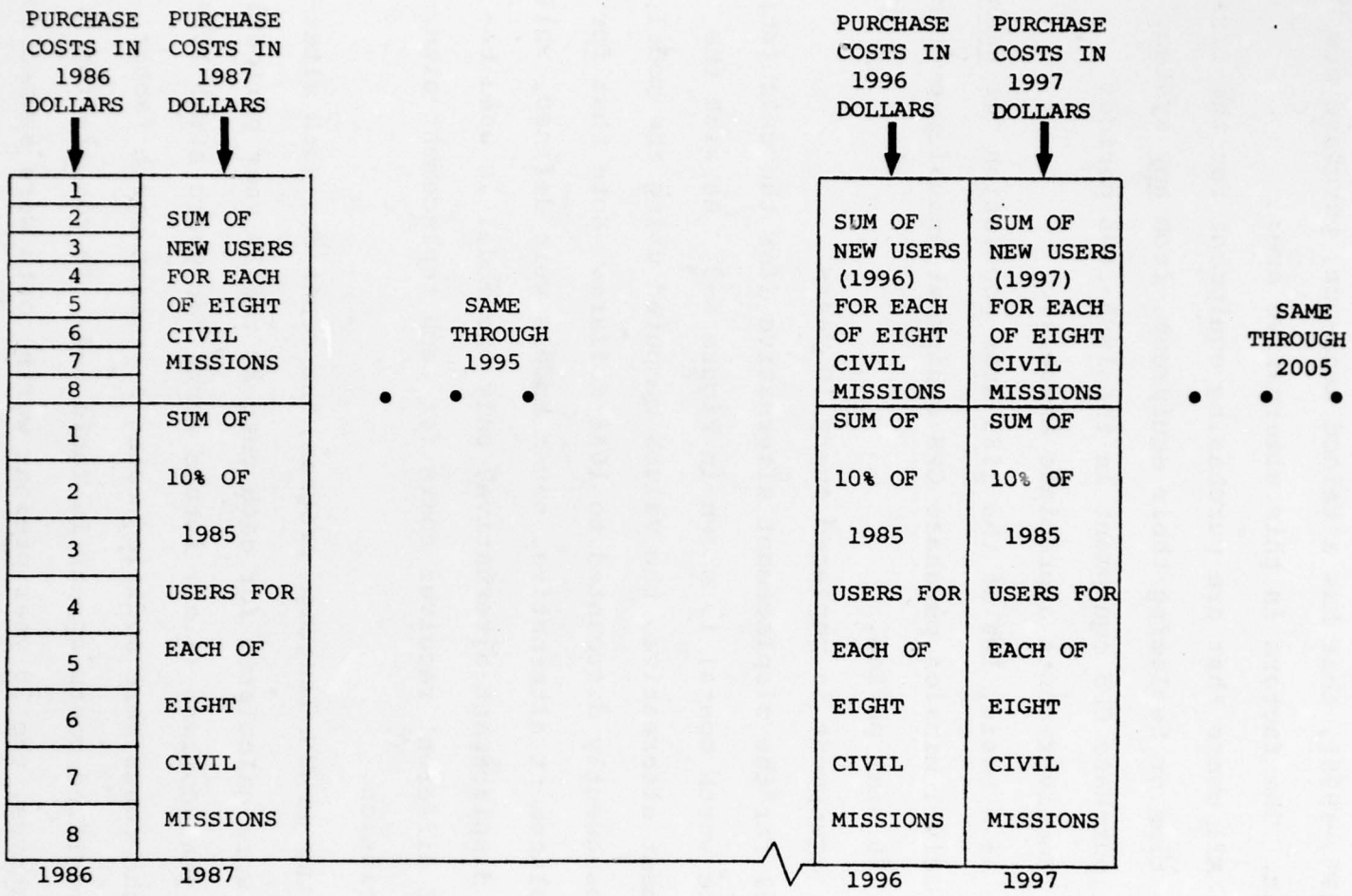
Figure 6-2 Replacement Alternative Model

years (1986-1995), that has attained wear-out, purchase new GPS equipment. The factors in this alternative are:

1. All users that are purchasing equipment for the first time or replacing their equipment, from any system, purchase GPS equipment in the 1986-2005 period.
2. Receiver costs appreciate annually.
3. As a basis, 10% of the 1985 user population for each civil mission purchase GPS equipment annually over the 20 year period.
4. Equipment is replaced every 10 years.

The model for the displacement alternative (for the calculation of future worth costs) is shown in Figure 6-3. As with the replacement alternative, the values computed using the model were subsequently discounted to 1986 dollars. Note that for the replacement alternative, seven models were defined, while for the displacement alternative, only one model is used because of different receiver costs for each replacement alternative mission.

Using an APL language program, the costs for each alternative were calculated for each year in the 20 year period in actual year dollars (i.e., future worth for years after 1986). Then, the costs were modified using a present worth factor. These modified costs appear in Table 6-4. To compare the two alternatives, the 20 year present worth costs were summed for each alternative. Finally, the difference between the totals was calculated. It is noted in Table 6-4 that the total user



ANNUAL COSTS = # OF USERS PURCHASING X PURCHASE COSTS.

Figure 6-3 Displacement Alternative Model

costs for the Replacement alternative approximate 4.5 billion dollars, while the costs for the Displacement alternative approximate 2.7 billion dollars. The selection of the Displacement alternative (utilizing GPS receivers) results in a 1986 present worth saving of approximately 1.7 billion dollars.

6.3.6 Civil Sector Ground Segment Cost Estimation

The civil sector ground segment costs are determined by summing the annual O&M costs for ground transmitter stations for each of the radionavigation systems required in support of the Replacement and Displacement alternatives. It is assumed that the civil sector ground segment costs for the Displacement alternative approach zero in 1996, since the conversion to GPS eliminates all the various transmitting stations.

The 1979 dollar estimates for the various radionavigation ground segments are shown below:

LORAN C	- 7.2 million annually
VOR/DME	- 20.0 million annually
OMEGA	- 5.5 million annually
Total Civil Ground Segment Costs	- 32.7 million annually

The ground segment costs are appreciated at a 7% inflation rate with no factor for technological improvement.

The annual and cumulative figures are converted to present worth values for the base year of 1986, using a 10% discount rate.

Table 6-5 shows the total ground segments costs for each alternative. Starting in 1996, the Displacement alternative

TABLE 6-5 CIVIL SECTOR GROUND SEGMENT COSTS

(1986 DOLLARS)

	REPLACEMENT	DISPLACEMENT
1986	52,509,054	52,509,054
1987	51,076,989	51,076,989
1988	49,683,980	49,683,980
1989	48,329,962	48,329,962
1990	47,010,900	47,010,900
1991	45,728,784	45,728,784
1992	44,481,635	44,481,635
1993	43,268,500	43,268,500
1994	42,088,450	42,088,450
1995	40,940,583	40,940,583
1996	39,824,022	0
1997	38,737,912	0
1998	37,681,424	0
1999	36,653,748	0
2000	35,654,101	0
2001	34,681,716	0
2002	33,735,851	0
2003	32,815,782	0
2004	31,920,806	0
2005	31,050,239	0
TOTAL	817,873,447	504,941,864
	DIFFERENCE:	312,931,583

shows a zero ground segment cost since the GPS ground segment is funded by DOD.

6.3.7 Total Civil Cost Differential

A decision to utilize Navstar GPS for the civil community's radionavigation requirements results in an overall relative reduction in total cost of:

1,755,819,667	User Segment
312,931,583	Ground Segment
2,068,751,250	TOTAL

This represents a cost saving of over 2 billion dollars based on a 1986 present worth comparison.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.1.1 Civil Utilization of Radionavigation

In order to satisfy the air and marine requirements for radionavigation services, there have evolved a number of radionavigation systems that exhibit substantially diverse performance characteristics. The level of performance required to gain entry or operate within air and marine environment is based upon the particular system performance characteristics that apply to specific areas of operation.

Since no current radionavigation system can provide the required service for all civil operations, the civil sector is forced to employ a collection of radionavigation equipments and supporting ground segments. A significant number of civil users, whose missions require operations in several diverse radionavigation service areas, must carry several different radionavigation equipments.

An attractive alternative is to provide a single, integrated radionavigation service for civil use. The potential cost savings depend upon the provision of a radionavigation user segment that is cost competitive with current systems. The phasing out of multiple ground segment configurations would result in a reduced total cost to the government.

7.1.2 Military/Civil Radionavigation Requirements

Examination of both military and civil requirements for radionavigation services shows that the aggregate of civil

requirements from a subset of military requirements.

Although the civil sector may engage in missions that are somewhat different from those of the military, the missions of themselves do not generate navigation requirements that are unique or different in relation to the total range of military requirements.

There exist several high accuracy requirements within the civil sector, associated with air terminal operations and marine signal structure available for civil use.

Depending upon the accuracy provided by GPS for civil operations, and consideration of localized GPS reference signal aiding, it appears that the application of GPS could well be extended to include localized relative navigation service for air and marine terminal/harbor operations.

Civil land requirements for radionavigation were reviewed and considered too speculative for any meaningful analysis at this point in time.

7.1.3 Impact of Civil Use on the NAVSTAR/GPS Program

Several alternatives were analyzed that exerted varying degrees of impact on the GPS space segment. It was concluded that the most reasonable approach is to engage in a low cost receiver development for civil use that operates on the waveform structure as currently designed.

With the planned increase in signal power margin, it appears feasible to develop a civil user segment that will be cost competitive with current radionavigation receivers.

Such an approach exerts a zero impact on the GPS development program.

7.1.4 Impact of Joint Military/Civil Use of Navstar/GPS

The major constraints, as a result of joint civil/military utilization of Navstar GPS, would appear to impact on the Department of Defense. The civil use of the system appears to be technically and economically feasible and, in most cases, the civil user has a viable alternative; therefore, the civil user is basically controlled by an economic decision as to whether or not to use GPS versus some other navigation source.

In the operations of a 'military only navigation system', the DOD controls both the transmission system and the user segment of the systems. Therefore, concurrent planning can be done to alleviate the economic impact of system modification when needed due to new mission requirements. On the other hand, the diversity of the civil user community necessitates a long term, stable system design to decrease adverse economic impact on the users and thus restrict the options to modify or replace the system.

The 'value' of a navigation system for civil use is dependent to a great degree on economics that accrue from the accuracy of service obtainable from the system.

The value to the military of a satellite navigation system is not only dependent on the accuracy or service obtainable from the system, but also dependent on the improvement of the U. S. military position in regards to the military position of potential enemies.

In a military system, the system access or accuracy can be controlled or denied, as desired, but in a joint system,

standards must be established and complied with. Therefore, the military will be constrained to establish and maintain certain levels of accuracy for the civil users.

7.1.5 GPS Civil User Set Cost Estimation

Employing the military Z-set as an initial cost basis, it was determined that a low cost civil user set may be produced in 3000 unit quantities for a price of $2020 in 1979 dollars. The cost reductions are obtainable through the use of commercial grade subsystems and components and the simplification of receiver circuitry through the use of recently developed pseudonoise matched filters.

7.1.6 Cost Savings Associated With the Introduction of GPS

The introduction of GPS as a civil radionavigation service beginning in 1986, demonstrates a total dollar savings of approximately 2 billion dolars, expressed in present worth (1986).

The savings are accumulated over a 20 year period (1986-2006) and indicates a transition period of 10 years to allow the phasein/phaseout process to occur without penalty to the users.

The alternative to GPS introduction that was costed for comparison comprised a continuation of current radionavigation systems, replaced as required by wearout every 10 years. Projected user population growth was considered for both alternatives.

7.1.7 Management and Operation of Navstar/GPS

Joint civil/military management and control will be necessary to achieve shared utilization of GPS. The basic control of the system could remain under DOD, but the control must recognize and be receptive to the civil users. Standards must be established and adhered to which protect or provide for the civil user. The management will entail both the DOD and civil community, thus, will have to be shared between DOD and non-DOD entities, such as DOT. Interfaces with civil users, as well as military users, will have to be established and any management decision will have to be evaluated with respect to their impact on civil as well as military users.

7.1.8 Summary Conclusion

The Navstar GPS offers an attractive and cost-effective potential for the provision of radionavigation services to the civil community.

Consideration of past experience with military developed radionavigation systems indicates that civil utilization of GPS will evolve as the system becomes available.

In the absence of government policy regarding the provision of GPS for civil use, there will result a continuation of all the current systems as well as GPS, adding to the proliferation of user and ground segments.

There exist a number of policy, technological, and economic issues that require resolution prior to a final decision on the civil use of Navstar GPS.

7.2 Recommendations

(1) Perform the necessary analysis to make a determination

that defines the navigation accuracy (consistent with the requirement for National Security) to be made available for civil domestic and international operations.

With this determination of accuracy, document the application of GPS to civil user requirements that can be satisfied.

(2) Extend consideration of GPS application to the international environment and formulate an evolutionary plan that allows for eventual adoption of GPS as an internationally accepted standard for radionavigation for air and marine operations.

(3) Formulate a policy and implementation plan that provides for joint military/civil management and operation of the GPS. Such policy must be consistent with U. S. National Security objectives and, at the same time, prove acceptable to the domestic and international communities of civil users.

(4) Encourage and participate in the development of a low cost civil user segment for GPS.

(5) Engage in a more comprehensive cost-effectiveness analysis that couples GPS operations with military/civil communications and surveillance systems.

Although radionavigation has been treated as a stand alone system in the present study, it really operates as a subsystem of an integrated information and control system comprising navigation, surveillance and communications. Without a complete system evaluation in the total context of integrated operations, it is impossible to accurately assess the cost-benefits associated with GPS applications. The introduction of GPS, coupled

with communications can respond to a large number of surveillance requirements with improved coverage, accuracy and update rate.