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1. SUMMARY

A "Surface Transportation Users Conference on Navigation" was conducted in Washington, D.C., on November 16-17, 1982. The purpose of the Conference was to present to the users and suppliers of navigation equipment the status and current evaluation of Federally-provided systems which are to satisfy marine, inland waterway, and land user requirements for radionavigation services, in the post-1995 time period.

This information relates to the selection of a future mix of radionavigation systems, as required by the Federal Radionavigation Plan (FRP). An opportunity was provided to users to participate in the meeting and make their comments on presentations by DOT modal organizations, and other government agencies.

The response of the participants was fairly uniform. In the words of William Mohin, moderator of the panel discussions:

> "The unanimous opinion of users and manufacturers present at this conference appeared to be that the current DOT systems are useful and required, and that NAVSTAR GPS could be highly beneficial in the future, if the price and accuracy were competitive.
>
> This was the first time that a sensible "marketplace" type of approach seemed to be universally acceptable. This is encouraging and indicates that the DOT effort to take an honest look at GPS is finally being believed. Future planning and budgeting will be measurably easier if this attitude can be maintained and encouraged by realistic projects.
>
> Overall, the user likes what he is getting, wants to keep getting it and will like GPS if he can get the same (or more) service for the same money."

Copies of these proceedings are available in limited quantity from the address below. In addition, copies of the 4-volume Federal Radionavigation Plan may be obtained from the same source. Direct your inquiry to:

DOT/TSC, Code 54
Kendall Square
Cambridge, MA 02142

This as many of you are aware was when Loran-C was selected as the navigation system for the Coastal Confluence Zone and the Coast Guard announced a schedule for the phase out of Loran-A. The Federal Radionavigation Plan (FRP) was first published in July 1980. This document which has since been refined and updated now provides the general thrust of federal planning for radionavigation. The current issue dated March 1982 details the planning process that we must follow in determining what the future radionavigation system mix for the country will be. That brings us back to the present and our purpose for being here.

The Coast Guard, as a provider of Radionavigation systems and as set forth in the FRP is required to provide input to the Secretary of Transportation regarding the future mix of radionavigation systems in the U.S. That input along with input from the other modes of DOT will be the basis of a recommendation which will then be combined with DOD's recommendation to provide a joint DOD/DOT 1983 preliminary recommendation. That preliminary recommendation will lead us, after additional considerations to a 1986 decision at the national level. One of the tools the Coast Guard is utilizing in developing its recommendation to the Secretary of DOT is an economic model that was developed over the past three years as a joint venture of the Coast Guard, Federal Aviation Administration and the Research and Special Projects Administration. This model has an extensive data base of user groups, receiver costs, system cost and other data necessary to allow us to run scenarios with various mixes of navigation systems. We will have a detailed presentation on the model this afternoon. In addition to utilizing the economic model the Coast Guard has conducted various studies and analyses to determine the capability of existing navigation systems to meet the requirements detailed in the FRP. Some of these will be discussed in detail during this conference.

At this point, I think a quick overview of the radionavigation systems we are considering is appropriate. If I might for a moment appear a bit parochial, I'll start with the Coast Guard operated systems:

Loran-C, a medium range hyperbolic system has the capability to meet coastal navigation requirements and some Harbor/Harbor Entrance requirements. Its limited range does not permit its use for most ocean phase navigation.

OMEGA in contrast to Loran-C offers sufficient range for ocean phase navigation, but its accuracy limits its usefulness in terms of Harbor/Harbor Entrance navigation. Current indications are that OMEGA is used much less in the marine community than it is in the aviation community. The Coast Guard is currently conducting studies and has recently installed a Differential OMEGA station in Puerto Rico to determine the desireability of installing Differential OMEGA sites in selected areas.

The second major consideration is those items called institutional issues. The Federal Radionavigation Plan addresses the following three major institutional issues regarding radionavigation systems: (1) Cost recovery for radionavigation services, (2) signal availability and accuracy in times of national emergency and (3) international acceptance of radionavigation systems.

Currently Navstar GPS is the only radionavigation system used, or proposed for use, by the mariners with any scheme developed or partially developed to implement a direct user charge. While DOD proposed user charges for Navstar GPS appear high when compared to the currently limited or non-existent charges for other systems, it must be considered that user charges may eventually be instituted or increased for other systems also. The Coast Guard does not currently have a plan for assessing charges for use of the navigation systems it operates.

The second institutional issue, Signal Availability and accuracy in times of national emergency is the most complex. There is very little information available to the user concerning the availability of systems in time of national emergency. This in turn leads to innumerable concepts in the users minds regarding the availability of various systems.

The third institutional issue is International Acceptance. The international character of the OMEGA system may increase its acceptability with the navigational communities of the world. Conversely, the U.S. defense oriented systems may be less acceptable. Navstar GPS, being DOD controlled, suffers most in the eyes of prospective users in terms of international acceptance and perceived questionable availability in time of national emergency. Loran-C may fall somewhere between OMEGA and Navstar GPS in terms of how the user perceives its availability in terms of a U.S. national emergency. Transit, although initially a military only system, has found considerable acceptance in the international community. This is in spite of the DOD position that civilian use of Transit is opportunistic and that DOD has no responsibility to provide the service other than for their own requirements.

In closing I again solicit your help in providing input to assist us in making our recommendations to the Secretary of Transportation. There are several areas in which we are seeking your assistance - such as your ideas on user charges; What the government's role should be in providing precise positioning information above and beyond that required for navigation; and will a requirement for Loran-C remain when Navstar GPS becomes operational? I am sure many other issues of mutual interest will surface if we have planned this conference correctly. It is not a one way street - your input will be the primary product of this meeting. Welcome and Thank you.

certification of LORAN-C for enroute navigation in Vermont, and demonstrated the use of retransmitted LORAN-C position, for helicopter flight-following in the Gulf of Mexico.

For LORAN-C marine applications, the Department has conducted cost/benefit analyses of the expanded use of LORAN-C, in the Eastern Caribbean, Hawaii and the North Slope of Alaska. The decision not to expand coverage in the Eastern Caribbean, made by the Commandant of the Coast Guard and concurred with by the Secretary of Transportation was based upon this study. Additionally, the Coast Guard has conducted tests of calibrated LORAN-C systems in restricted waters, in the PLAD and PILOT programs.

For LORAN-C land applications, the Department has contributed to the Los Angeles AVM project, which demonstrated the utility and cost/benefits of sign-posts and LORAN-C applications to fleet management. And for OMEGA marine applications, the Department has conducted studies on differential OMEGA; one such test is ongoing now in Puerto Rico. The Department has conducted many research projects on other systems including many systems required by aviation and maritime users.

More recently, there have been hardware evaluations and technical analyses of NAVSTAR GPS, in aviation and marine applications. These tests and analytical studies will be used as inputs to the decisions about to be made on the suitability of GPS to satisfy user requirements for various phases of navigation.

In addition to the technical aspects of the selection of the appropriate radionavigation system, there are some key issues with regards to economic considerations, which were voiced at the FAA Conference in August, and are worth repeating here:

(1) For a specific class of users in a given geographical area, what level of navigation service can be economically justified?

- o Not all aviation or marine needs are the same even for the same class of user: there are regional differences based on weather, type of conveyance, topography of the land or harbor, and other factors.

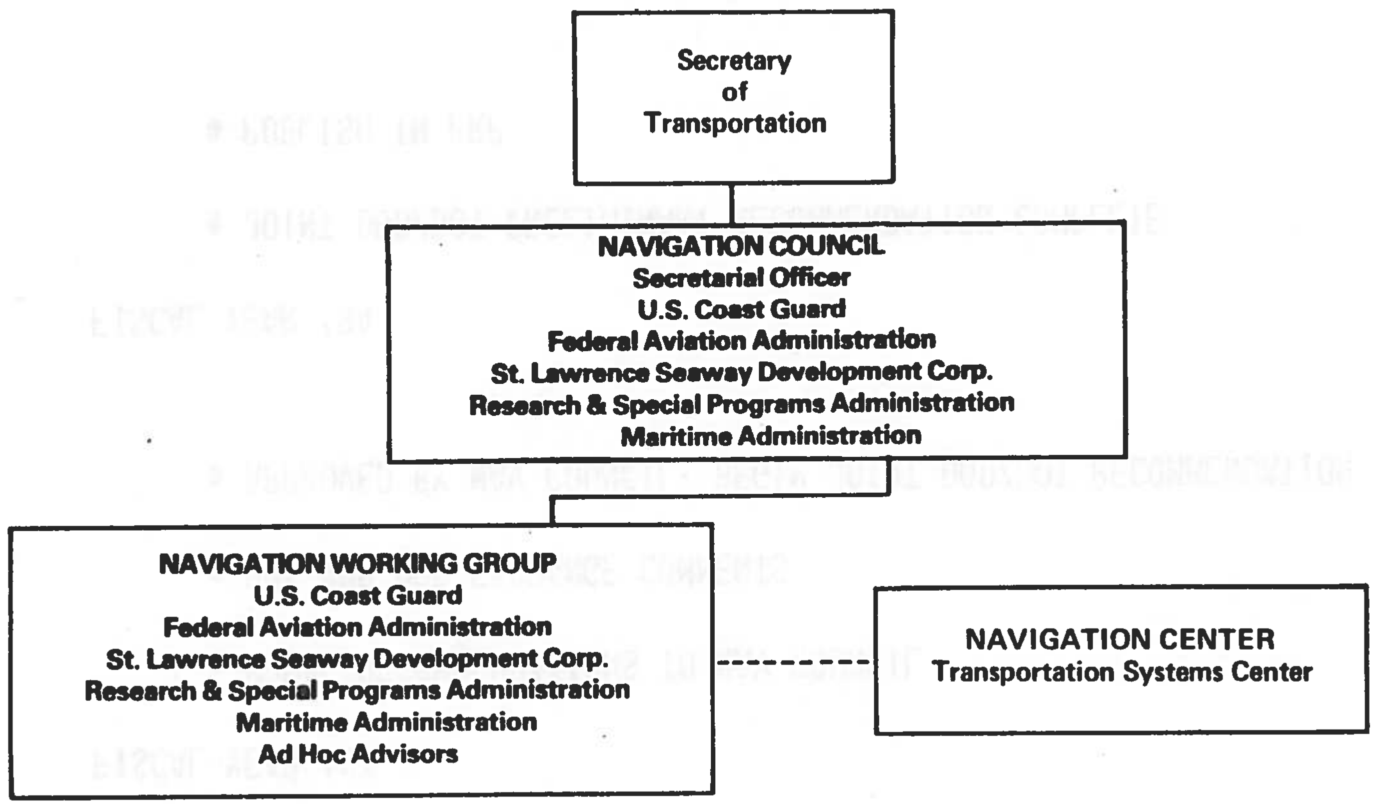
(2) There are diverse requirements for national defense, and civil aviation, marine and land users - what is the most economical mix of navigation systems to meet these needs?

- o All potential users must be considered when recommending a mix of systems, or a single system, and the costs/benefits summarized, based upon projected numbers of users.

(3) What will be the optimum timing, to transition from our existing radionavigation systems, to selected future ones?

- o For how many years should systems be maintained in parallel, and what motivates the users to transition to the new systems during the changeover period?

The remainder of today's agenda will focus on issues related to the recommendation of a future mix of radionavigation systems. Col John Martel (from



Slide 1

DOT Navigation Structure

PANEL QUESTIONS

(1) NEED FOR A CHANGE IN CURRENT SYSTEMS ?

(2) BENEFITS OF A SINGLE (MIX OF) SYSTEM(S) ?

(3) IMPROVEMENTS TO PRESENT SYSTEM ?

(4) IF NAVSTAR GPS ACCURACY IS 500 M., WHAT REQUIREMENTS WILL IT FULFILL ?

(5) RADIOLOCATION SYSTEM USERS ?

(6) USER CHARGES ?

Slide 3

next month. We plan on integrating these into a number of host platforms in all the military services and running through a fairly extensive test and evaluation program leading to a decision in FY 84 (in about May of 84) as to whether or not we'll proceed with the acquisition of the military user equipment.

As a result of our finally convincing the Congress in FY 82 that they should provide monies, we did have sufficient monies appropriated so that we were able to initiate the procurement of our operational satellites. We have gone on contract with Rockwell in early September for the first batch of operational satellites. We're buying these on a multi-year basis, and we have initiated this multi-year contract with Rockwell. I think this is a firm indication of the DOD's commitment to pursue and continue with a NAVSTAR GPS program. As I indicated, we are looking at a final 18 satellite operational constellation. This satellite constellation will be operational by the end of 1988, providing us full 3D coverage by that time. About a year earlier we'll have about 12 to 14 satellites in orbit, and this will provide a world-wide 2D coverage. The ultimate constellation, as I indicated, will be operational at the end of 1988.

Enough now about GPS. Let's talk a little bit about some of the other systems that are perhaps more familiar to the people here in the room, and give you an idea of where we're heading in this direction. As I indicated, we are committed to terminating our operation of the systems shown here. There will be, of course, a transition period from the time we begin equipping our various military platforms with NAVSTAR, until the time we have all 20,000 or so military platforms equipped with GPS. But the start of the phase-out period of the various systems is as shown here on the chart, starting roughly in the late 1980's, and proceeding for about 10 years thereafter. We plan essentially being out of the LORAN business by 1993, and the OMEGA business, as far as the Air Force and the Army are concerned, by 1992. The Navy is planning on evaluating, as NAVSTAR GPS comes on line, the continued use of OMEGA in certain of its selected platforms as a back-up to GPS. That decision has not as yet been made, but nonetheless, that's the way the Navy would like to go at this point in time. The final two systems, of course, are perhaps not as much interest to this group, as they were to the FAA and to the aviation comunity, but nonetheless our status as far as these other systems are concerned is shown here at the bottom of the chart. Again, we're reflecting something on the order of this 10 year transition period from the time we start equipping military platforms with GPS until the transition is completed. But we would anticipate being out of the VOR/VORTAC/TACAN role by the mid to late 1990's.

Perhaps of even more significance to the folks represented here this morning are our plans for TRANSIT. As indicated in the Federal Radionavigation Plan, we do intend to cease operation of TRANSIT as GPS becomes operational. We plan on starting the phase-out again in the late 1980's. We plan on essentially shutting down TRANSIT by the end of 1992. Now, as I talked with the various folks here in Washington, the question always seems to arise, "what if somebody else wants to take over a TRANSIT operation?" To date, there has been no serious proposal put forward by anyone for continued operation of TRANSIT once the DOD gets out of the business. And I don't want to give you the impression that I'm here today soliciting such a proposal because it certainly is not a DOD initiative to initiate such a proposal. If such a serious proposal were in fact put forward, we would certainly take it under advisement and evaluate it and come back with a DOD position on that subject.

year. In this plan, we indicated that it would be our intent to charge for access to both the PPS and the SPS. The annual charge on a user set basis, per user basis, for access to the PPS, we would anticipate it be on the order of $3700. The annual fee for access to the SPS would be approximately $370. We have formally announced our intent to charge our NATO allies for access to the PPS, $3700 a year, and we're in the process of formalizing policy as regards the standard positioning service. We'll go public with that here very shortly. Although, and I might add that this is really an area that is quite foreign to the Department of Defense, we're not really in the business of charging for access to various systems, so it's been a fascinating study that we've had on our hands, fraught with many, many implications. As my boss likes to refer to them, GPS raises a number of very poignant social, political, and economic issues that we in the Department of Defense don't normally deal with on a day-to-day basis, but nonetheless, we're getting our feet wet on this one. Even though we were relative "babes in the wood" as far as user charges were concerned, we weren't so naive as to think that all we had to do was announce the fact that we wanted people to send in money, if they happened to tune into a GPS, and put it in an envelope and send it to my office. We realized that if we were going to have user charges for GPS, we couldn't rely upon "good will" kind of things like this and we'd have to build some failsafe mechanism into the system. As far as the precise positioning service was concerned, we're relatively fortunate in that, as I indicated earlier, it is an encrypted system and requires a cryptographic device to get access to the PPS. So as far as access to PPS is concerned and user charges are concerned, we will provide to our NATO allies, and if there are in fact civil interests that are granted access to the PPS, provide to these civil interests the necessary cryptographic devices to decrypt the precise positioning service portion of the GPS signal and extract the $3700 annual fee for the cryptographic devices. Not part of the current system design is a similar device in the standard positioning portion of the system. We are looking, however, right now, at making changes to the system to incorporate an encryption device in the standard positioning service portion of the system so that we can do the same thing as far as it's concerned. We think we have just about reached the decision to do that, and thereby having a crypto-device in both legs of the system, if you will, and using the sale of the crypto-device, the commercial crypto-device in the case of the standard positioning service, and the NSA-approved military crypto-device in the case of the precise positioning service, as the vehicle for enforcing user charges.

That concludes my brief prepared presentation this morning. I'd be glad to take the remaining portion of my time slot, to answer any questions you might have. I plan on being back tomorrow for the panel discussion and question and answer period to follow it, so I'll be available at that time to answer any questions if you can't think of any here this morning.

NAVSTAR GPS STATUS

- FULL DOD FY 83 FUNDING REQUEST APPROVED
- SIX R&D SATELLITES IN ORBIT
  - MINIMUM OF 5 SATELLITE CONSTELLATION TO BE MAINTAINED
- FULL SCALE DEVELOPMENT OF ALL SEGMENTS PROCEEDING
- INITIAL USER EQUIPMENT PROTOTYPES TO BE DELIVERED IN DECEMBER
- OPERATIONAL SATELLITE PROCUREMENT INITIATED
- 18 SATELLITE CONSTELLATION TO BE OPERATIONAL BY 1988

DOD TRANSIT PLANS

- DOD TO TERMINATE TRANSIT OPERATIONS AS GPS BECOMES OPERATIONAL
- PHASE OUT STARTS IN 1987
  - TO BE COMPLETED IN 1992
- NO CURRENT PROVISIONS FOR TRANSITIONING TRANSIT OPERATIONS TO NON-DOD AGENCY
  - NOT DOD INITIATIVE

GPS USER CHARGES

- DOD DIRECTED BY CONGRESS TO PLAN FOR GPS USER CHARGES
- CURRENT PLANS
  - — PPS—$3700 PER YEAR PER USER
  - — SPS—$370 PER YEAR PER USER
- ENFORCED THROUGH SALE OF SIGNAL DECODING DEVICES
  - — SYSTEM WILL NOT OPERATE WITHOUT APPROPRIATE DECODER

system is reported to be a 9 to 12 satellite constellation, and it's also advertised to be a world-wide aviation system. Those two statements simply don't go together. It's impossible to have a 9 to 12 satellite constellation and yet provide world-wide 3D coverage. There are a number of contradictions that are floating around. I think the only thing that I would add to what you have seen in "Aviation Week" is the fact that we believe the Soviets are, in fact, serious about a satellite navigation system. We don't anticipate its being as accurate as GPS, nor do we anticipate it being operational as soon as GPS would be operational. And I'd prefer not to talk any more about that subject, if you'll permit me not to.

Question - Gerald LaChapelle, Shell-Canada

We have been GPS users for two years, and we are of course pleased with the type of accuracy that we have been able to get. And one of the questions that could be raised in a panel discussion is the effect of the 500 meter accuracy. Now we are already looking into the possibility of using GPS in such a degraded mode, using certain differential techniques. One question which is raised at this point is the type of degradation that would take place, because this would affect tremendously the type of differential techniques that would be available. Could you comment about the type of differential schemes, the type of distance that would apply, and so on?

Answer - Martel

Only very briefly. As you might expect, and again I don't mean to be in my defensive crouch on this thing, but as you might expect, the specific techniques that we're using to achieve our so-called selective availability are themselves classified, and I really can't get into them in a great amount of detail. I am told, first of all, the DOD is not actively pursuing a differential mode in GPS at this time. We have done some preliminary testing of GPS in a differential mode; we've got some very promising results. We are not actively pursuing differential GPS for any of our applications, so I really can't speak authoritatively toward the subject, although I do understand that a number of folks out there are looking at GPS in a differential mode, and that they promise tremendous potential accuracies in a relatively limited geographic area, on the order of two or three hundred miles. Tremendous accuracy. But beyond that I don't know, and perhaps in a panel discussion tomorrow, some of the folks who are there will be in a better position to comment on that than I, since we are not actively pursuing it in the Department of Defense.

Question - Phil Stutes, John Chance and Associates

You indicated on one slide to begin phasing out of TRANSIT in 1987, to be completed in 1992. What kind of deterioration or things can we expect to see in the use of TRANSIT beginning in 1987?

Answer - Martel

Phil, I think probably, the way I would interpret that if I were you, would be that the military will start taking its receivers off-line in the 1987 time frame. I would anticipate that TRANSIT, that you've grown to know and love over these years, will continue to be the same TRANSIT right up until the end time. We simply flip the switch at the end of 1992 and it goes off the air. But up until that time, I will anticipate, and I don't want you to take that as a firm commitment because we haven't totally fleshed that out yet, but I would anticipate that you'd continue to see TRANSIT as you've grown to know and love it over the years.

turn in GPS, it'll be a consistent value for a period of time.

Question - Bill Thrall, Chief, Radionavigation Branch for LORAN

I'm curious as to your 500 meter accuracy right now. We advertise in our charts 500 meter accuracy. We're talking about worst case, at particular signal noise ratios for the first time in a given area, but after that, our precision repeatability accuracy is within the 25-30 meter range. Are you saying that with GPS we'll get 25 meter repeatable accuracy, or that we'll always maintain 500 or whatever figure you give us initially?

Answer - Martel

I'm saying, and again we get into that definition question, repeatable, instantaneous. As a GPS user, as you turn on your set and you lock onto a GPS signal, you get 500 meter accuracy. Instantaneous, real-time, usable accuracy.

Question - Dave Carter, JAYCOR

You mentioned that even with the full deployment of satellites that you might not get 24-hour complete coverage, at least for your PPS accuracy. Will this same condition exist, and for what periods of noncoverage, if there are any, for the SPS type accuracy?

Answer - Martel

The outage condition is independent of which signal you're locked on to. There are periods of time, because of the geometry--essentially what you're doing as you know in GPS is locking on to a number of satellites and then doing multilateration to zero in on your position. Now, the geometry will get bad at various times and your accuracy will simply go off the chart, if you will, hundreds of meters of accuracy for a 10 minute period. As I indicated in the U.S., we plan on fielding our constellation such that we will not have this situation. We'll have continuous 24-hour coverage throughout the U.S., over the continental U.S. But there are places, periodically, whereby---and many of these places are twice a day, periodically for some 10 minutes or so--your accuracy will essentially go off the chart. GPS will be, for all intents and purposes, not useable for, at that particular point on the base of the earth, for 10, 20 minutes or so, at a predictable time every day. It simply won't be there.

Question - Rueben Maine, SPERRY

Can you elaborate on the two-dimensional coverage in the same situation?

Answer - Martel

The problem is more a 3D kind of problem, because we've looked at it primarily from an avionics kind of situation. It's more a 3D problem than it is a 2D problem. I forget sometimes the audience that I'm addressing, your problem of course is a 2D problem more than a 3D problem. For the kind of operation that you folks would be most interested in, I think that's probably a non-issue. The coverage question is really a non-issue for the maritime kind of operation. The problem I've addressed myself to is a 3D kind of problem.

Question - Kells Boland, Marine Consultants, Consultants International

I'm just curious what your outlook would be if the USSR does come up with a good GPS system and doesn't charge anything?

Answer - Martel

I don't think that would change anything that we're doing. We're committed to our course of action, we've been directed by the U.S. Congress to proceed with the user charges program, and we intend to do that. I've heard it, and the point was raised here this morning, institutional issues, the question of whether a large portion of that potential 500,000 user group that I addressed earlier would ever want to use a system operated by U.S. DOD. If I were a free-world user of navigation systems, I sure as hell would want to use a GPS that was operated by the U.S. DOD before I'd use one, even if it were offered free, and operated by the USSR. Just my personal view of the problem. But I don't anticipate that the Soviet GLONASS development will have any affect on our GPS plans whatsoever with the possible exception that if GLONASS does come to fruition very soon, does provide accuracy that has been advertised, then there's probably no real reason for us to withold accuracy as far as GPS is concerned any longer, and it might accelerate that point in time whereby the DOD could make higher accuracy from GPS generally available to the civil community.

fifty nautical miles of the continental United States or in the Great Lakes will always be in range of at least one radiobeacon. This insures that a mariner within this fifty nautical mile envelope will always have at least one line of position available and a homing signal to use for return to a known position on the coast. The radiobeacon system is also configured such that a mariner within fifty nautical miles of the continental United States or on the Great Lakes will be within the range of at least two radiobeacons more than 95% of the time. The bearing of two radiobeacons will provide a navigation fix. Radiobeacon coverage for the state of Alaska exists only in areas of interest to the mariner. There is no marine radiobeacon coverage for the coastal areas of the state of Hawaii.

The coverage areas for the marine radiobeacon system are determined as the area within which the radiobeacon provides a prescribed field intensity. The prescribed field intensities for United States marine radiobeacon signals, are as established by the International Telecommunications Union (ITU) Administrative Radio Conference of 1949 and additional ITU regulations of 1959. The specific field intensities are:

50 microvolts per meter North of 40 degrees North
75 microvolts per meter between 31 and 40 degrees North
100 microvolts per meter south of 31 degrees North

The marine radiobeacon system currently consists of 199 beacons. The equipment at the majority of the beacon sites is in excess of 20 years old. The U.S. Coast Guard instituted a radiobeacon improvement program and sought funding to upgrade all the beacon sites in 1974. This program is at its peak at this time. The equipment to modernize all 199 existing marine radiobeacon sites and to establish 21 new sites is under contract. The modernization is expected to be complete in 1984.

The marine radiobeacon system's greatest advantage is its costs. It is an extremely economical system for both the user and the Government. User equipment can be purchased for as little as $300.00 and operated successfully with little or no training. The entire system, when renovation is complete, will cost the Government less than $200,000.00 per year in operating and maintenance expenses.

The marine radiobeacon system has two significant disadvantages. It is not a precision navigation system and it is an extremely short range system.

The next U.S. Coast Guard operated system that I would like to address is the OMEGA system. OMEGA is the newest of the marine radionavigation systems. The eighth and final OMEGA station came on air in August 1982. OMEGA is an internationally operated marine radionavigation system. Of the eight OMEGA transmitting stations the United States operates two. The other stations are operated by Japan, Australia, France, Argentina, Norway and its world-wide all weather coverage and the fact that it is internationally operated and used. The significant disadvantages of OMEGA are its limited accuracy (4 nautical miles 2drms), "holes" in the existing coverage area, and unpredictable propagation anomalies.

The limited accuracy of OMEGA can be greatly improved through use of a Differential OMEGA system. A Differential OMEGA system employs an OMEGA receiver at a known location that acts as a reference station to determine the real time phase corrections necessary to compensate for local propagation variations. The phase corrections are then transmitted through modulation of an existing radiobeacon. Users of Differential OMEGA can expect an accuracy of 0.3 nautical miles within 50 nautical miles of the reference station that gradually deteriorates to 1 nautical mile at 500 nautical miles from the reference station. There are currently thirteen Differential OMEGA stations operating and three planned. These stations are primarily in Europe and Africa.

There is only one Differential OMEGA station operating in the United States. It is operated by the U.S. Coast Guard at Punta Tuna, Puerto Rico. This station is experimental. Evaluations of its capabilities and costs will help determine the future of Differential OMEGA in the United States.

The major advantage of the Differential OMEGA system is that it is a low cost way for the government to provide reasonably accurate navigation in selected areas. A Differential OMEGA site can be installed for less than $150,000. The major disadvantage of Differential OMEGA is the high user equipment cost.

The next radionavigation system that I would like to discuss is the Loran system. Loran is probably the best known of the radionavigation systems operated by the Coast Guard and it is the most extensive, continuous, all weather, precision radionavigation system. Loran was originally developed for the military, but as with many military systems it has gained wide spread civilian acceptance. Loran-C was designated as the U.S. Government provided navigational system for the Coastal Confluence Zone of the United States in 1974. The older Loran-A system was phased out in favor of Loran-C on December 31, 1980. The only Loran-A existing today is on the east coast of Canada and in Japan. The Canadian Government plans to phase out their remaining Loran-A in favor of Loran-C on December 31, 1983.

Loran-C is a phased hyperbolic navigation system operating in the 90-110 kHz frequency band. It provides users, within its coverage area, with all weather, continuous, navigation information that has a predictable accuracy better than 0.25 nautical miles and a repeatable accuracy of between 18 and 90 meters.

There are presently seventeen Loran-C chains in operation and four in various stages of construction. The U.S. Coast Guard participates in the operation of fourteen of these chains. The military operating areas of the Northwestern Pacific Ocean, South Korea, the North Atlantic Ocean, the Norwegian Sea and the Mediterranean Sea.

The United States Coast Guard is engaged in two major modernization programs affecting the Loran-C system. These programs are designed to improve the reliability of the system and to reduce its operating costs. The most visible of these projects is the one to replace some of the oldest Loran-C transmitting equipment with new transmitters. The transmitters scheduled for replacement are the 1950's vintage equipment located on transmitting stations in the northeast United States, Alaska and the central Pacific Ocean. I cannot discuss the cost of or the schedule for this project as a contract for the equipment is currently being negotiated.

The second major renovation project is an internal cost savings project that will be transparent to users of the Loran-C system. We call the project the Remote Operating System (ROS). The ROS will allow the Coast Guard to operate many of the Loran-C stations, that are now staffed with from eleven to twenty-two people, with a staff as small as four. The personnel reduction is accomplished by remoting many of the watch standing functions. Remote operation of a Loran-C station is currently being conducted by the Canadian Coast Guard at the Port Hardy, BC station and by the U.S. Coast Guard at the Raymondville, TX station. The complete plan for remote operation of Loran-C stations is contained in a report titled "Comprehensive Plan for Unmanned Loran-C Operation" that was submitted to Congress by the Secretary of Transportation in February 1982. The project for remote operation of Loran-C stations is a follow on to the transmitting equipment replacement project as the old equipment does not have the stability or the controlability for remote operation.

The U.S. Coast Guard has been conducting research into the adequacy of Loran-C as a harbor or restricted waterway navigation system. The initial research was conducted in the St. Marys River. This research produced the prototype for two user devices. One of these devices is the Portable Loran Assist Device (PLAD). PLAD, as its name implies, is a portable device that a pilot can carry on board a vessel. PLAD tells the distance right or left of track and distance to the next waypoint. A prototype PLAD system is being used today by some of the pilots on the Delaware Bay where accuracies better than fifty feet have been reported. The other device is the Precision Intracoastal Loran Translocator (PILOT). PILOT is a permanently installed equipment that provides a microprocessor generated graphic display of the vessels present position, heading, course to steer, cross track error and several other bits of information that are useful to the vessel operator. The PILOT system gains a degree of local knowledge through pre-recorded tape cartridges containing a sequence of digitized chartlets and other navigation information. The PILOT system proved its excellence through a series of tests

The Racon's advantage, when used to mark navigation aids and obstructions in confined waterways, is the fact that it has all of the navigation precision of a navigational radar. The other advantages of Racons is the fact that they do not require any additional user equipment on a vessel and that their small size and low power requirements allow their use in remote locations.

The primary disadvantage of Racons is their relatively short range that requires many of them to be installed to adequately mark a channel. The requirement for many Racons in a harbor increases the cost of the system and can cause problems due to the quantity of information presented on a vessels navigation radar.

I have presented an overview of the present day status of radionavigation systems that are operated by the Coast Guard. An area that I am sure is of interest to many of you is what does the Coast Guard see as the future of these systems for maritime use? Especially now that NAVSTAR-GPS is nearly a functional reality.

The radiobeacon and the Racon systems will be unaffected by GPS. The radiobeacon system provides a very low cost service for the recreational boater and provides the shore facility for the radio direction finding equipment required on vessels over 16,000 tons by the Safety of Life at Sea (SOLAS) Conference. The Racon system marks items of navigation interest in waterways, a feature not available in GPS.

The OMEGA system will not be greatly affected by GPS. OMEGA coverage roughly duplicates the coverage that will be available from GPS. OMEGA navigational accuracy is considered sufficient for OMEGA to be retained as a backup for GPS.

Loran-C will be directly affected by the implementation of GPS. The initial effect will be the withdrawal of support for Loran-C chains that are funded in support of United States military operations. Barring any delay of GPS we expect to terminate support of the North Atlantic, Norwegian Sea, Mediterranean Sea and Northwest Pacific Chains at the end of 1992 and terminate support of the Commando Lion Chain at the end of 1996. Governments in the areas affected will be offered existing equipment and technical assistance to continue Loran-C service. As it stands now there is no plan for the United States to fund or support continued Loran-C service in these areas.

Loran-C in the United States will be replaced by GPS; however, no phase out date has been set. The questions of GPS user charges and denial of GPS accuracy must be satisfactorily resolved before plans can be made to phase out Loran-C. There are two aspects to the user fee issue. The first is the method of assessment and collection. The second is the fee itself. The fee must offset the cost of the system yet it cannot be excessive. An excessive user fee would deny the safety of a precise

6. MARAD OUTLOOK ON RADIONAVIGATION SYSTEMS

Joseph Walsh
Office of Advanced Ship Operations/MARAD

This paper will first address some of MARAD's past and present activities in the area of maritime navigation, and then indicate where it is anticipated that these efforts should lead. As most of you know, MARAD has done extensive work in evaluating, developing, and promoting various types of navigation systems through the MARAD Research and Development Office in Washington and the Computer Aided Operations Research Facility (CAORF), Kings Point, New York. The CAORF efforts have stressed the evaluation of automated and combined equipment and displays in terms of their technical capabilities and, more importantly, their impact on bridge personnel performance. Some of the key systems that were developed and tested included an early version of collision avoidance equipment which provided significant input to the international specification for the Automatic Radar Plotting Aids (ARPA), a Marine Radar Interrogator Transponder (MRIT) which demonstrated the strengths and weaknesses of this technology, and special displays which provide integrated presentations of own ship, target ship(s), heading and speed, channel boundaries, aids to navigation, etc., features which are now available in a number of commercial displays. Testing of these systems using a wide variety of ship's crew subjects on the CAORF simulator has consistently demonstrated that use of this type equipment significantly reduces the navigation load on bridge personnel and allows these personnel to operate more safely and efficiently. MARAD has just recently gone the next step to improve operation on the bridge, including the navigation function. This was the development of proposed standards for future ship bridge design. Application of these standards should insure that advanced navigation equipment is properly positioned on the bridge for optimum personnel performance.

All of this background leads to an area in maritime navigation which MARAD believes must be addressed in more detail -- improved navigation in restricted waterways for increased cargo flow and improved safety. This is certainly not a new concept since it has been addressed by the U. S. maritime industry and several government agencies over recent years. Industry equipment and system development, MARAD testing at CAORF, and Coast Guard projects in the St. Mary's River and the Delaware Bay indicate the importance of this area of maritime navigation. However, considering all of the system development and tests that have been accomplished and the technology presently available, it would appear that a comprehensive system or group of systems for optimum restricted waterway operation should be defined over the next few years.

In one specific area of interest, the U.S. and the Canadian Governments are involved in discussions concerning a possible joint project to evaluate and develop a prototype restricted waterways system for the Great Lakes and the St. Lawrence Seaway. Navigation aids in the Great Lakes and St. Lawrence Seaway have traditionally been visual aids. These aids become less effective under poor visibility and icing conditions and cause restrictions in lake-seaway traffic. It is anticipated that new differential technologies for LORAN-C, and possibly GPS, may improve position accuracy to under a hundred feet. New RACON and MRIT (radar transponder) technologies also offer precision in the same order. MARAD has already supported development of a precise radar maneuvering and docking system utilizing shoreside passive retro reflectors which could also become a part of an overall navigation system. Shore-based radar with adequate communication links might also provide adequate precision if information can be transmitted for appropriate display on transiting vessels.

Question - K.C. Torrens, Council of American Master Mariners

I know that I was involved with the APL (Applied Physics Laboratory) studies that were made for a low-cost TRANSIT receiver. I believe the basics of that study was a very sound one and that it developed a receiver which has been taken on by the electronics community and come up with some very sophisticated and relatively low-cost TRANSIT receivers, we've come to love, as we heard COL Martel say. But as far as the GPS receivers, does MARAD feel that they have an obligation to the marine community, or do they feel that they're going to start with any kind of a project such as that?

Answer - Walsh

At the moment, I don't believe so. We've talked to a number of manufacturers, and a number of companies are looking into developing receivers, but it looks like really a long-term project. And right now there is no firm project laid out by MARAD. That's not to say that if a need arose something could probably be done. But it's not firm at this time.

also set and enforce vessel speed limits in the waterway, for the protection of life and property.

The Saint Lawrence Seaway Development Corporation is financed entirely by user charges, collected in the form of tolls on vessels and their cargoes. Seaway navaids in U.S. waters are thus currently financed directly from user charges, and it is reasonable to assume that any improvements will be similarly funded.

St. Lawrence River traffic is largely comprised of two types of vessels -- the so-called "Laker" fleet, primarily Canadian bulk carriers of maximum Seaway size, and the "Salties", that portion of the ocean fleet (about 75%) which is not constrained by the limiting lock dimensions (width and length). The maximum Seaway vessel is 76 feet in beam, 730 feet long, and has a maximum draft of 26 feet. In 1979, a total of 6363 transits were made at Eisenhower Lock, comprised of 4633 Commercial transits, 439 non-cargo transits, and 1291 transits by pleasure craft. The commercial vessels moved some 55.3 metric tons of cargo through the St. Lawrence River in 1979.

The current navigation season runs from about April 1 to December 20 each year. The system is thus shut down due to weather and ice conditions for about 100 days each year.

THE SEAWAY NAVIGATION PROBLEM

Two measures of system performance are important to the operating entities and to the vessel operators. System capacity is the measure of the ability of the system to move cargo per unit of time and is usually expressed in transits per day or in tons per year. Capacity is normally constrained by the time required to process a vessel through the slowest lock. However, in times of low visibility or when floating, lighted navigation aids are not available in specific channel reaches, the capacity constraint shifts to those reaches. The second performance parameter is vessel transit time required for negociation of the Montreal to Lake Ontario section of the Seaway. This translates directly into vessel operating costs.

At the beginning of each navigation season the commissioning of floating lighted aids is delayed up to four weeks due to ice in the River, which complicates setting buoys, and which may damage them or move them off station. Toward the end of the season the floating, lighted aids must usually be decommissioned before the close of navigation, again because of ice. There are also periods throughout the navigation season when visibility is too low

The provision of navigation aids and vessel traffic control services has significant legal implications with respect to potential liability on the part of the entities for the safety of the vessels, their contents, and their crews. These implications must be considered when contemplating any changes in the services provided. Ideally, some means for a vessel master to verify the accuracy and reliability of his guidance information should be provided, so as not to infringe upon his responsibility for the safety of his vessel.

CURRENT STATUS

An international, interagency steering committee, comprised of the two Seaway entities and the two Coast Guards, was established one year ago to formalize the mechanism for coordination and cooperation on the Seaway precise navigation problem. This arrangement builds on the significant experience of the U.S. Coast Guard with LORAN-C piloting systems, from COGLAD on up to PILOT and PLAD, which have been demonstrated rather extensively on the St. Marys River, between Lakes Superior and Huron, and on Delaware Bay, respectively. Major tasks for the group include:

- Definition of system accuracy and reliability requirements
- Examination of the potential role of LORAN-C
- Survey of other candidate systems
- Recommendations to management on a Precise Navigation System for the Seaway

PRELIMINARY CONCLUSIONS

The St. Lawrence Seaway precise navigation problem is relatively unique and technically demanding.

No single electronic positioning system can provide the necessary combination of accuracy and reliability required to allow all-weather vessel movements throughout the system in the absence of conventional navigation aids.

The current accuracy requirement is estimated by the Seaway entities at ±7 meters meters (or just under ±25 feet), absolute. This clearly implies that the NAVSTAR Global Positioning System (GPS) can not contribute meaningfully to the solution of the Seaway problem if the most accurate mode is not made available. The accuracy and reliability requirements for a replacement system must be expressed in absolute, rather than probabalistic terms, since no vessel master can be asked to subject his vessel to a 5 percent or even a 1 percent probability of grounding or collision.

8. ECONOMIC MODEL POLICY STUDIES

Dr. G. William Dick
DOT/TSC

Introduction

Plannning in the radionavigation area is based upon an evaluation of a number of factors, technical. operatonal, and economic. Political and international considerations also play in important role. This paper will describe how the Department of Transportation (DOT) has gone about evaluating the economic impact of various alternative radionavigation system mixes and implementation secenarios, and in particular will address concerns of the marine community.

The DOT has developed a computer model, in concert with Systems Control Technology, Inc. The overall objective of the model is to calculate system costs to the government and users' benefits and costs in response to different radionavigation system scenarios.

In 1976, the FAA initiated a study of alternative air navigation systems, which was completed in April 1978 (with a supplement published in October 1979). An OTP report, circulated by OMB in 1977, and a GAO report on navigation planning, circulated in early 1978, strongly advocated a rapid transition to the NAVSTAR Global Positioning System (GPS). Results of the FAA study and other analyses of the GAO/OTP reports raised questions about that position and resulted in a decision to study the alternatives more thouroughly. Later in 1978, a rider on the International Maritime Satellite (InMarSat) Act directed the President to develop a study and plan for navigation. As a result of this Congressional mandate, the Federal Radionavigation Plan was developed jointly by DOT and DOD and DOT expanded the FAA model, which addresses air navigation systems only, into a multi-modal model to analyze the economics of land and marine radionavigation systems as well. The DOT Radionavigation Economic Planning Model will improve the capability of DOT in determing an optimum mix of radionavigation systems beyond the 1980's.

The model and its data base were installed on the Transportation Systems Center (TSC) computer earlier this year and the model has been successfuly operated since then to evaluate various validation and policy scenarios. The validation process consists of first making base year runs to confirm that the model is properly equipping vessels to meet their navigation requirements in the base year, when actual equipage is known. Then a few groups are processed through several scenarios to determine if they transition in a rational manner as the systems they are using are replaced. Finally, selected scenarios are applied to all user groups of interest and the results and behavior of the users are analyzed.

Model Structure

The radionavigation economic planning model is driven by an input scenario, consisting of system implementation and discontinuance schedules. For a given input scenario, the model processes a comprehensive data base to predict users' responses to that scenario and calculate system costs to the government and users' benefits and costs.

group consists of ocean-going tugs, greater than 4000HP, operating between the Pacific coast, Alaska, and Hawaii of which there are 39 vessels. The following table lists a few other illustrative user groups.

Vessel	Use	Operating Regions	1980 Population
U.S. owned, foreign flag, tanker, 1.6-80K tons	Foreign commerce	Ports, waterways, coastal, and oceanic	211
Yacht, power, 26-40 feet	Recreation	Atlantic ports, waterways, and coastal	110,226
Yacht, power, 40-65 feet	Recreation	Atlantic ports, waterways, and coastal	16,191
Yacht, power greater than 65 ft.	Recreation	Atlantic ports waterways, coastal, and oceanic	1,117
Fish, greater than 300 tons	Commerical fishing, tuna	Pacific/Hawaii ports, coastal, and oceanic	137
Sport fish, greater than 40 feet	Sport fishing	Gulf ports, waterways, and coastal	409

The vast majority (about 90%) of the marine fleet are recreational vessels, as indicated in the following summary table:

Use	No. of Groups	Population
Recreation/Sport Fishing	55	404,293
Commercial Fishing	68	25,980
Domestic Commerce	58	7,970
Passenger	27	3,839
Oil (crew, supply, tow, research)	28	3,153
Foreign Commerce	16	947
Other	29	970
TOTAL	281	447,152

related to the various system/equipment performance measures. The performance measures for marine radionavigation systems and equipment are coverage, reliability, repeatable accuracy, predictable accuracy, fix rate, and ease of use.

For example, an ideal benefit of $18,725 per year was established for Pacific/Hawaii tuna purse seiners greater than 300 gross tons. This benefit was based upon the average annual catch of these vessels of about $3 million.[1] The sensitivities of benefits to system/receiver performance were estimated through discussion with personnel of the American Tuna Boat Association and are shown in the following table:

Performance Measures		Benefit Multipliers
Coverage (%):	100*	1.0*
	0	0.0
System Reliability (%):	100	1.0
	99*	1.99*
	0	0.0
Equipment Reliability (MTBF, months):	24	1.0
	20.4*	0.95*
	12	0.833
	3.3	0.0
Predictable Accuracy:	0.1 miles	1.0
	200 meters*	0.998*
	0.5 miles	0.96
	5.0 miles	0.0
Fix Rate:	15 minutes	1.0
	4080 seconds*	0.929*
	90 minutes	0.90
	12 hours	0.20
	3 days	0.0
Ease of Use:	1 LOP	0.5
	2 Waypoint	0.6
	3 Lat-Long*	0.95*
	4 Video Display	0.975
	5 Track Plotter	0.975
	6 All	1.0

The values marked with an asterisk are those for Transit and a single channel SAT NAV receiver currently being used by this user group. The product of these benefit multipliers is 0.8283 and this value multiplied times the ideal benefit of $18,725 yields an annual Transit benefit for vessels in this user group of $15,510.

1. Helicopters used to spot fish generally receive 10% of the gross value of the catch. It was estimated that the value of SAT NAV as currently used is about 5% of the value of the helicopter, or about 0.5% of the gross value of the catch. Thus, the value of SAT NAV is $3,102,000 X 0.5%, or $15,510, and working backwards with the SAT NAV benefit multiplier of 0.8283, the ideal benefit of $18,725 is established.

Radionavigation Equipment

The model data base also includes detailed data for marine radionavigation equipment - LORAN-C, NAVSTAR GPS, Transit and OMEGA receivers. For LORAN and OMEGA receivers, three different levels have been defined to represent the variety of functional capabilities that is generally available:

1. Line of Position (LOP) receiver
2. LOP receiver with waypoint navigation and autopilot interface
3. Lat-Long receiver with way point navigation and autopilot interface

Only the third level applies to Transit and NAVSTAR GPS receivers. Transit receivers are categorized as either single or dual channel and NAVSTAR GPS receivers as either Standard Positioning Service (SPS) or Precise Positioning Service (PPS).

Then, for each type or configuration of equipment, three quality grades have been specified to differentiate between equipment accuracy, reliability, and price.

A. Quality grade A equipment is the low price, low reliability, low accuracy equipment nominally used by recreational vessels.

B. Quality grade B equipment is the medium price, high reliability, moderate accuracy equipment nominally used by small commercial vessels.

C. Quality grade C equipment is the high price, high reliability, high accuracy equipment nominally used by large commercial vessels.

For each of these many pieces of marine navigation equipment,. the model data base contains data on price, performance, and operational lifetime. The price data is summarized in the following table (1980 $).

Equipment	At Actual 1980 Volume			At 20,000 Units		
	A	B	C	A	B	C
LORAN-C, LOP	1600	2000	3800	1600	2000	3000
Waypoint	2000	2700	4400	1700	2200	3300
Lat-Long	2400	3200	5100	2000	2600	3900
NAVSTAR GPS, SPS	5000	6800	11100	4200	5200	7300
PPS	7400	10100	16400	6200	7700	10800
Transit, Single	4000	5300	7000	3400	4300	5300
Dual	4300	5600	9900	3600	4500	7500
OMEGA, LOP	1400	2700	4200	1200	2300	3200
Waypoint	1600	3000	5300	1300	2300	3500
Lat-Long	2000	3700	6100	1700	2800	4000

The NAVSTAR GPS scenario (#200) was run for 5- and 15-year transition periods (1989 to 1993 and 1989 to 2003, respectively) as well as for the nominal 10-year transition period and both NAVSTAR GPS scenarios were also run with NAVSTAR GPS receiver prices cut in half.

Results

Given an input scenario defining when and where certain radionavigation systems are operating the model processes the nominal data base, determines the equipment purchases of each user group, and calculates user and government costs year by year. Figure 1 shows the results of this process for a single user group, the Pacific tuna purse seiners, for the baseline scenario and the NAVSTAR GPS scenario. Results are similarly calculated for all user groups and are then aggregated to show the impact of any given scenario on the entire marine community, or any portion of that community. Such aggregated results are shown in the following tables. User costs are users' cumulative after tax cash outlay for the purchase, installation, and maintenance of radionavigation equipment. Government operator costs are the cumulative costs to implement and continue operating the various radionavigation systems specified in the scenario.

Cumulative 1981 - 2005 Cost (Millions of 1980 $)

Users		Scenario 1	Scenario 200	Scenario 202
Air		4,267	5,005	3,998
Marine:	Recreational	1,054	1,578	1,054
	Commercial Fishing	227	278	227
	Other Commercial	138	123	112
	Total Marine	1,419	1,979	1,393
Total Users		5,686	6,984	5,391
Operators (DOT)				
USCG:	LORAN-C	1,064	818	1,064
	OMEGA	190	144	144
	NAVSTAR GPS	0	4	4
	Total USCG	1,254	966	1,212
FAA		831	2,184	2,360
Total DOT		2,085	3,150	3,572
USER AND DOT TOTAL		7,771	10,134	8,963
DOD (NAVSTAR GPS)		0	6,359	6,359

Change from Baseline Scenario in
Users' Cumulative After Tax Cash Outlay

	Change from Baseline to Scenario			
	200		202	
	$*	%	$*	%
Marine Users	+ 560	+39	- 26	- 2
Recreational	+ 524	+50	0	0
Commercial Fishing	+ 51	+22	0	0
Other Commercial	- 15	-11	- 26	-19
Air Users	+ 738	+17	-269	- 6
Total Users	+1298	+23	-295	- 5

* Millions of 1980 $.

Approximate Average Annual Cost per Vessel, 1989 - 2005
(Population Weighted Averages, 1980 $)

	Scenario		Change	
	1	200	$	%
Recreational	300	500	+200	+70
Commercial Fishing	700	900	+200	+30
Other Commercial	2900	2000	-900	-30

Among the conclusions that can be drawn from these tables are the observations that marine user costs are about one-third of air user costs and that all user costs, air plus marine, are more than double government system implementation and operating costs, excluding the DOD cost to implement and operate NAVSTAR GPS.

From the user's point of view, air and marine alike, the least costly system mix is provided when they are left with a choice between NAVSTAR GPS and the systems they are currently using (i.e., scenario 202). However, this alternative is the costliest to the DOT because they must continue to operate the present systems rather than turning them off and yielding to NAVSTAR GPS.

Considering both users and the DOT, the least costly radionavigation alternative is to simply continue operating the existing systems to provide the radionavigation services presently being provided.

Within the marine community, the brunt of the increased cost of transitioning to the NAVSTAR GPS radionavigation system is born by the small recreational boater who must replace his relatively cheap LORAN-C set with a fairly expensive

Question - Unknown

Let me just ask a very, very simple question. Why is it that you and the Federal Radionavigation Plan differ by roughly a factor of two in the number of LORAN users? I think you're right, but why the difference of approximately a factor of two?

Answer - Dick

The Federal Radionavigation Plan has users of navigation systems which are foreign as well as U.S. owned.

Question - unknown

Except they have about half yours.

Answer - Dick

I was responding, thinking of TRANSIT and OMEGA as well as LORAN. We've done some recent surveys, and the numbers that we have in here for LORAN users are sort of tentative numbers recently developed since the last issue of the Radionavigation Plan, with a much more careful look at the recreational boating community use of LORAN, so I think that's why the numbers that we have here are somewhat larger than the FRP. They're more recent numbers.

Question - unknown

And you haven't done the same for TRANSIT yet?

Answer - Dick

We've done the same for TRANSIT. We've wrestled with ourselves as to some of the discrepancies we get from different sources. The TRANSIT users, because we look at the marine community simply the population of vessels, and come up with the idea that the number of TRANSIT users that we see can't be much more than about 1500 U.S. owned vessels. Unless there's a lot of recreational boaters using TRANSIT, and I don't think so.

Question - Unknown

Which there are.

Answer - Dick

Obviously, again, we're looking for these type of comments. What you're suggesting to me is one of the next rounds I'll make is maybe we'll double the lifetime and see if that affects the results significantly.

***Question -

I would suggest that you ask any salesperson from a marine supplier of equipment and find out whether he can sell a new piece of equipment to somebody he sold one to seven years ago.

Answer - Dick

Well, that's where we got the seven years was by talking to salespeople and users.

***Question -

Okay. I question it seriously.

Question - Hal Solomon, Systems Control

Did you consider the GPS user charges in the costs that were reflected on your charts? I've got two questions when you're done with this.

Answer - Dick

We didn't consider the GPS user charges. On the last chart I simply showed the DOD cost of putting up NAVSTAR GPS. Implicitly to show, if we went to user charges, what the numbers might look like.

Question - Solomon

So that's a conservative number with respect to the GPS charges that you show?

Answer - Dick

For the users, yes. Essentially, if you took that dotted-line portion that was over on operator cost and took that over and stuck it on the user bar; if you were to take all of the DOD costs and make them into user costs. I guess the number I've heard bandied about is 80% of those.

Question - Solomon

My second question is, did you utilize residual values when you went through the transition period sensitivity? Was it residual values on user equipment?

Answer - Dick

Essentially, what we've done in the model, --- we did use the residual value, which is really like a salvage value, in order to take care of when you cut off at the

Answer - Dick

The bar reflects a constant, up to the time of transition. Remember that the bars you saw were cumulative costs from 1980 through the year 2005. If I were to cut off the bottom part of the bar, up to the beginning of the transition period, then I think the two to one effect that you saw would be true for the remaining piece of the bar. See, a large part of the bar is constant across all the scenarios.

***Question -

People aren't going to start investing in GPS receivers until there's a GPS coverage.

Answer - Dick

That's true. You're right, and that's reflected in the model. But the way the results were presented, which may be slightly misleading in obscurring some of the relative impact, is cumulative cost from 1980 through the year 2005. In other words, the height of the bar for all three scenarios and all the sensitivities would be the same, all the scenarios are the same, through the beginning of any transition period. So what you'd really like to see is, probably, chop off that bottom part of the bar, or draw a line across the diagram showing the height of the bars regardless of what scenario. Because it's the relative effect above there that you'd like to see.

***Question -

What you're saying is they go on investing in their existing system up to some point, and then they transition over.

Answer - Dick

Right. And that simply the manner in which the results were presented. It's not suggesting anything one way or the other. It's just the way we happened to present the results. I think it would probably have been clearer - I think the best way to have handled it would have been to draw a line across there and say, "below this line is the same for all scenarios because this is what happens up through the beginning of any transition period." So the relative impact is only above this line.

of a civil marine navigation system as outlined in the FRP. The scope of the project includes investigation of the civil marine navigation potential of SPS GPS, static and dynamic receiver tests using the Z-set GPS receiver, and low-cost receiver technology studies. The FRP divides the civil marine navigation realm into four specific zones; Ocean, Coastal Confluence (CCZ), Harbor & Harbor Entrance (HHE), and Inland Waterways. Even with Selective Availability in effect at the 500 meter level, the performance of SPS GPS is adequate to meet the accuracy requirements of the Oceanic Zone. The thrust of the study is therefore directed toward the Coastal Confluence Zone and the Harbor & Harbor Entrance areas. The studies to date have all been performed assuming full accuracy SPS GPS. The implications of Selective Availability will be discussed later. Accuracy is not the only factor which determines the acceptability of GPS as a civil marine system. The system price should be within the range of the potential users. To this end, a significant portion of this project is devoted to studying the cost/performance tradeoffs involved in receiver design in an attempt to estimate the costs of a minimum performance civil receiver in the 1990 time frame.

Our primary tool for gathering real world GPS data has been the Z-set GPS receiver. The Z-set was designed and built by Magnavox for the Joint Program Office as one of the four classes of Phase I user equipment. The Coast Guard has been using the Z-set since 1979 as part of a joint MARAD/USCG test agreement. The Z-set was the only Phase I receiver design to use SPS only. The DoD has since decided not to include any SPS only receivers in their inventory of future equipment. The receiver is a single frequency, single channel, sequential tracker which was designed for use in low dynamics air craft. The unit tracks four satellites and provides a full 3 dimensional navigation solution. There is a provision for altimeter aiding which we did not use during our tests. Before describing the test results, let me give a brief history of the evolutionary changes made to the receiver over the last three years. The basic receiver configuration which I just described was used for the first series of static tests in 1979. Although the receiver performed admirably, it was obvious from these first tests that the basic Z-set was not suitable as a "test and evaluation" receiver. The data resolution was limited to one arc-second by the display and there was no provision for direct data recording. A special interface was designed to integrate the Z-set with a Hewlett Packard HP 21MX computer and tape drive which not only provided the means to record high resolution GPS data, but also provided the capability to integrate Loran-C and OMEGA receivers into the data collection system. We could now record simultaneous time tagged data for later analysis. This configuration was used for the at-sea tests performed aboard the RV GYRE. We found that the altitude solution was generally the first parameter to "blow up" when the satellite constellation geometry became poor, a situation which occured regularly while working with the limited constellation. In general, since the antenna height is known and generally remains fixed, the altitude computation is superfluous for marine navigation. Arrangements were made with Magnavox to modify the Z-set program to permit the set to operate in a fixed altitude navigation mode. In this mode, the operator inputs the antenna height above mean sea level and the receiver uses this value for all subsequent navigation computations. The fixed altitude mode permits navigation on three satellites thus extending the usable tracking time with the present partial constellation. When four satellites are available, the receiver can perform an overdetermined solution which desensitizes the solution to the problems observed during the test runs. Most of the problems observed fell into the "THEY WILL GO AWAY WHEN THE FULL CONSTELLATION IS UP" catagory. While performing tests with the present limited constellation, the affects of high Geometric Dilution of Precision (GDOP) on the navigation solution were observed. In many cases, there were no alternate combinations of satellites which would provide a significantly better constellation geometry. The software to provide fixed altitude, 3 satellite navigation had not yet been installed, further limiting the choice of constellations with acceptable DOP's. It is obvious that when more space vehicles are available, then it will be possible to change constellations to maintain more acceptable geometry. During the tests, some unforseen problems were encountered during constellation changes. Normally when a handoff occurs, there should be no appreciable shift in the indicated position. During some of the handoffs, position shifts ranging from 3 meters up to 400 meters were observed. On one occasion, an unexplained shift of over 1000 meters was recorded. Because of the limited number of space vehicles to choose from, some of the resultant constellation were not much better geometrically than the originals. Another contributing factor may have been space vehicle #4, which was operating on a crystal oscillator, and was invloved in all of the handoffs. Similar position shifts have been observed after ephemeris updates. Since the Z-set does not continuously monitor the data message, it does not know precisely when ephemeris changes have occurred and may operate on old ephemeris data for a time. Although the user does not know precisely when the Z-set reads a new data message, shifts in the data tracks of 6 meters to 43 meters have been observed occurring within an hour or so after ephemeris changes. It is assumed that when the full monitor network is operational and uploads are occuring on a more regular basis, that these types of shifts will be minimized.

The problems, outlined above, may very well disappear when the full 18 to 21 satellite constellation is in place but this fact will have to be confirmed before making any final decisions concerning the ultimate suitability of SPS GPS, particularly for use in restricted navigation situations where such position shifts could be disasterous. Let me say again that all of these tests have been conducted during local darkness. We have not had the opportunity to conduct any controlled tests during daylight hours when the ionospheric disturbances are greatest.

The third leg of our involvement in the civil use GPS program involves the study and demonstration of receiver technology as applied to the civil marine area. We are coordinating a series of studies to address specific issues related to civil marine applications of SPS GPS. Since the Department of Defense has no more interest in SPS GPS for navigation purposes, any future equipment development using this system must come from without. At this point in the program, with all of the uncertainties regarding funding support, ultimate system accuracies, and the question of user charges, it is not suprising that there is lack of active commercial interest in SPS GPS at this time. In the absence of any large scale commercial involvement, we are embarking on a series of design/idea studies. The intent is not to design a receiver for production, but to gain insight into the cost/performance tradeoffs invloved in a "low cost" SPS GPS reciever and to try to project the receiver cost/performance into the

Question - Tom Nolan, Maritime Institute

A question in my mind keeps coming up: why can't we utilize the ultimate accuracy of the SPS and, in time of conflict, degrade the accuracy as required by the environment which we find ourselves in militarily?

Answer - Wenzel

That's my question too - I'm not able to stand up here and give you an answer - and I'm serious.

I didn't mean to be glib about that. You look at this issue and say "Suppose you're counting on this system when they degrade the accuracy, so you end up going aground and spilling all that oil on the coast. If it's in time of war - who cares? By then, all the rules have changed - they've thrown the book out." Even the Air Force does that in time of war - one of the first things they do.

Again, I don't know.

Question - Vern Baxter, University of Louisville

I have a problem here trying to decide - why 500 meters? Maybe it was taken from LORAN-C? It seems if I have an adversary that has a system that I would like, and he's benefitting from it, and he has a lot of satellites, what am I going to do with it? I'm going to take his satellites out of position quick. What makes them think this thing is going to stop that situation? Why don't they get realistic for once, and forget this mess, and give it to everybody?

Answer - Wenzel

I think that's a real good question - like you, I can only guess at the answer. I think, first of all, the 500 meter thing came about because that's close to a quarter nautical mile - that was the only hard and fast number in planning documents when the Denial of Accuracy thing first came up. Everybody knew that LORAN-C is the Coastal Confluence Zone system and to replace LORAN-C you have to meet that requirement. We forgot that it's also the Harbor/Harbor Entrance system and provides much better accuracy - though we haven't said how good yet. But, basically, the stated goal in the Coastal Confluence Zone is a quarter nautical mile and there was no identifiable pressure at the time - from any organized user group - to provide anything better. I think it's just that simple.

I think that whatever you do to the enemy by making it a 500 meter system as opposed to 10 or 28, you could accomplish essentially the same purpose by making it 200, probably even 100. The only change is that with the smaller figures you really have a nice payoff for commercial users. I think this whole issue is going to have to be attacked. We still have time - boy, do we have time. I remember coming here in 1980 and thinking I was late, thinking "I've got to catch up to this thing called GPS". Well, there's still time.

always have to do simulator tests as part of R&D. Just take the Z-set, put it on the simulator...it wouldn't work. Their simulator was built to be "another type GPS receiver built backwards." So there we were, sitting there with our receiver, and all of a sudden the signals we were tracking went away - because they figured their receiver would have switched satellites by then -but we wanted to wait a bit longer. I just want to throw these thoughts out - some things you hear make you think we're ready to "throw the switch" on existing systems. It's so early in the game we don't even have - the Air Force does not even have - a decent simulator right now, like you do for the other systems.

I don't know what all this means, but it's just early in the game. There's plenty of time to bring reason to all of this.

Question - Tom Nolan

Is the Coast Guard going to pursue a low-cost GPS as they did a number of years ago with a low-cost LORAN receiver development?

Answer - Wenzel

Not right now. It's too early. And I don't think we'll have to. I'm not sure we really did anything, I'm not sure we bought anything with that low-cost receiver project for LORAN-C. I think it's just happening on its own for LORAN-C. I don't know, somebody else may feel differently, but I think the receivers we ended that study with - they were the best before. So I don't think we made much difference. Another thing - the Coast Guard just doesn't have the funding to put seed money out there. It's just going to have to take off on its own - and it can if we let it.

BACKGROUND

While many aspects of the Selective Availability program are classified, it is known that the satellite signals will be modified by: (1) introduction of errors which would cause position measurements to wander; and (2) introduction of errors which would confound velocity measurements.

The current plan promulgated by the NAVSTAR GPS Joint Program Office calls for a horizontal position accuracy of 18 meters (2drms) with the Precise Positioning Service (PPS) when the system becomes operational in 1987. This policy is stated in the Federal Radionavigation Plan (1). PPS will be available to civil users only by special permission. Most users will only have access to the SPS. Under Selective Availability degradation of the accuracy to more than 500 meters could be employed if security considerations required it. The more likely scenario is that the accuracy will be improved, eventually providing SPS having accuracies approaching 20-40 meters (2drms). Beser and Parkinson of Intermetrics, Inc. (2) hypothesized a potential enemy navigation capability scenario that would eliminate the primary need for denial of high accuracy of the unencrypted signal in 1990-1994. Thus it is reasonable to anticipate marked improvement in available NAVSTAR GPS accuracy during the 1990's. There are a large number of levels of accuracy that can be provided between 500 meters and 20-40 meters. The decision to introduce SPS at the 500 meter level is not irrevocable, so it is important to identify the beneficiaries of improved accuracies and determine the impact on their operation.

Examination of the requirements set forth in the Federal Radionavigation Plan (3) shows that the 500 meter accuracy level of the SPS is adequate for Marine Oceanic and Coastal navigation safety requirements. Applications not met at the 500 meter level but which would be met at the 20-40 meter level include the following:

- Marine commercial fishing
- Search and rescue operations
- Land survey and tracking requirements

are classified, some of the statistics of the signals are not. Through the NAVSTAR GPS Joint Program Office the Department of Defense provided the Department of Transportation with declassified segments of the Selective Availability "waveforms" in order to enable the DOT to assess the impact of the imposition of Selective Availability. These segments were analyzed to determine the distributions of the pseudorange errors, their rates of change, and their second derivatives. From these properties the effects of Selective Availability on the navigation solution, on receiver performance, and on the design of differential stations were inferred.

The pseudorange errors translate into horizontal navigation errors via the dilution-of-precision measures. Specifically, if the standard deviation of the satellite pseudorange errors at a specific time and place were 100 meters, and the HDOP were 2, the RMS error in position (1drms) would be 200 meters, and the 2drms error would be 400 meters. The two-dimensional navigation error distribution thus depends on the HDOP distribution over time and user position. The HDOP distribution in turn depends on receiver/processor mask angle, satellite selection algorithm, and position computation algorithm. To estimate the navigation errors introduced by Selective Availability, HDOP distributions were computed for several of these design choices. The comprehensive marine receiver simulation model MARINEGPS resident at TSC was exercised using the Selective Availability data segments. The resulting tracks provide a comparison between the navigation position estimates provided by a marine receiver/processor and the true positions.

The first and second derivative distributions of the Selective Availability "waveforms" determine the data update rate required by a differential system to provide a given level of accuracy. In particular, even if a differential transmission provided an exact correction at one instant, the variations in the signals would render that correction useless within a minute or so. Therefore the corrections must be updated often enough to maintain the desired accuracy. The update requirements are treated here using both pseudorange corrections and pseudorange plus range-rate corrections. The differential design considerations are described in detail in a TSC project report to be issued (8).

Since latitude and longitude are orthogonal, the 2drms error in horizontal position is given approximately by:

$$\varepsilon_h = 2 \cdot \sqrt{XDOP^2 + YDOP^2} \cdot \sigma_{pr}$$

or

$$\varepsilon_h = 2 \cdot HDOP \cdot \sigma_{pr}$$

(1)

Figure 1 shows the probability density and cumulative probability curves associated with Selective Availability delays, which dominate the satellite pseudorange error ε_h. The plots were derived from declassified samples of the Selective Availability errors, expressed as equivalent time delays. The data base consists of 90-second samples from four satellites, taken every hour for one week. Each 90-second segment of data is characterized by one value of pseudorange. Thus there are 24 x 7 x 4 = 672 samples in the sample set. The density function is roughly Gaussian in shape, and has a mean of 2.7 nanoseconds and a standard deviation of 485 nanoseconds. The 2-sigma value is about 975 nanoseconds. This means that in geometries that have HDOP's of 1.5, the 2drms error will be about 435 meters, or 1/4 of a nautical mile.

The distribution of HDOP's at different times and at different locations determines the navigational accuracy for a given level of Selective Availability error. For a given satellite constellation, the HDOP depends on a number of receiver/processor design factors:

a. Mask angle: the elevation angle of a satellite below which it is ignored.
b. Satellite selection algorithm: options include best-set-of-four, best-set-of-three, and all-in-view.
c. Navigation solution algorithm: three-satellite or four-satellite solution

The mask angle is typically 5-10 degrees. Low-lying satellites are most affected by blockage, reflections, and effects of the troposphere.

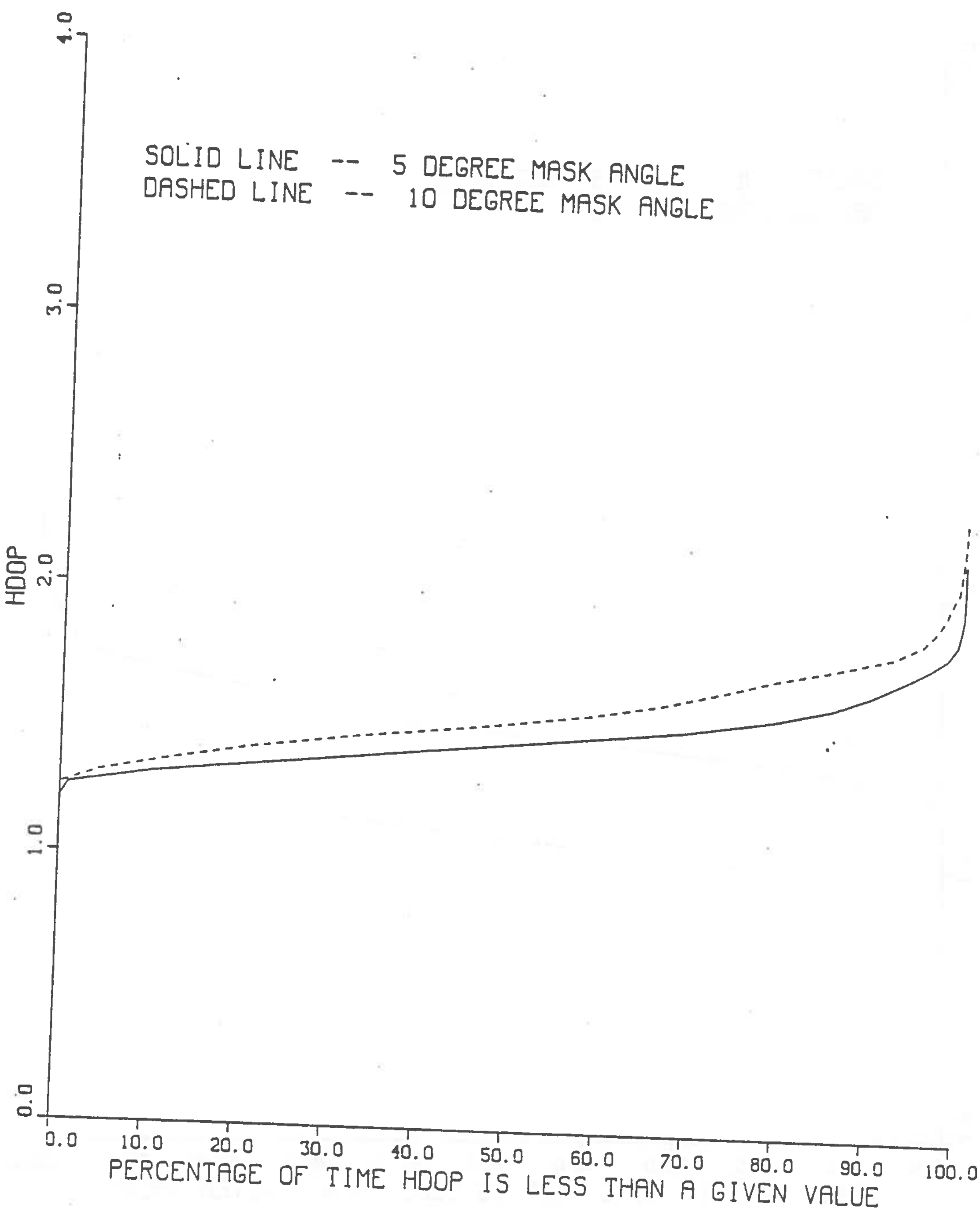
The satellite selection algorithm of most receivers designed to date is the best-set-of-four. However, this design choice is premised on having no prior knowledge of any navigation coordinate. If vertical position is known, or independently measured or established (and available to the GPS processor), only three satellites are required. The best-set-of-three satellite selection algorithm can then be used. For marine users, the vertical coordinate is known approximately: distance from earth's center can be approximated by the WGS-72 earth geoid. The effects of remaining vertical uncertainties (e.g., from tides and antenna placement) on the X-Y position calculation are small.

The all-in-view satellite selection strategy results in a significant reduction in HDOP, and appears to be quite attractive. The design implications though are quite different for parallel and sequential receivers. For a parallel receiver to accommodate the all-in-view strategy without time-sharing the channels, eight channels would be required; this is an unlikely design choice. Sequential receivers, wherein one channel time-shares all satellites in view, must assure that sufficient dwell time is available to obtain a good pseudorange measurement. Given the time available between data updates for most marine and land applications (5-10 seconds), this appears to be a feasible approach.

The navigation solution algorithm either solves for three dimensions plus time (four-satellite solution), or incorporates the known vertical component and solves for the other three (three-satellite solution).

Figure 2 shows a typical set of HDOP's over the CONUS, along with the number of satellites visible from each point. Figures 3 and 4 show the HDOP distributions for mask angles of 5 and 10 degress, and for best-set-of-three and all-in-view satellite selection algorithms. All distributions in these figures employ the three-satellite solution. They were computed at 5 degree increments between 25 and 50 degrees North Latitude, between 70 and 125 degrees West Longitude, and every ten minutes over a 12 hour period. These values were chosen to give HDOP's encountered in the CONUS. The satellite constellation used was the 18 satellite, 6 x 3 constellation assuming three active spares. The differences in mask angle are evident in Figure 3: a lower mask

FIGURE 3. HDOP DISTRIBUTION, 3-SATELLITE SOLUTION, BEST SET STRATEGY



angle enables more satellites to be available to the satellite selection algorithm. Thus some fraction of the time the low-lying satellites will improve the HDOP. Also apparent is the benefit of the all-in-view strategy, where the median HDOP is 1.20, as opposed to 1.43 for the best-set-of-three strategy. It should be noted that the HDOP measure does not uniquely determine the accuracy of the GPS; at low elevation angles, for example, the pseudorange errors increase, which reduce navigational accuracy. Thus the actual accuracy achieved by an all-in-view-receiver would approach, but not meet, the figures predicted by the HDOP.

To a first approximation the median HDOP can be used to estimate the navigational accuracy under Selective Availability from equation (1). Table 1 shows the resulting accuracies in meters and in nautical miles. This approximation is valid to the extent that the HDOP distribution is linear. An examination of Figure 3 shows that the assumption is quite reasonable for the three-satellite solution. For the constellation considered here, the four-satellite solution distribution becomes non-linear beyond the 95% level (see Figure 5). This means that the accuracy figures of Table 1 are slightly understated for the four-satellite solution. The accuracy figures of Table 1 are thus believed to be a good predictor of NAVSTAR GPS performance under the stated level of Selective Availability.

TABLE 1. Achievable Accuracies Under Selective Availability (2drms)

No of Parameters in Solution	Satellite Selection Algorithm	Mask Angle	Median HDOP	Accuracy	
				meters	N.M.
3	Best set of three	5°	1.43	415	0.22
		10°	1.52	442	0.24
	All-in-view	5°	1.08	314	0.17
		10°	1.20	349	0.19
4	Best-set-of-four	5°	1.50	436	0.23
		10°	1.60	465	0.25
	All-in-view	5°	1.13	328	0.18
		10°	1.32	384	0.21

To demonstrate the manner in which a GPS receiver/processor responds to a signal with Selective Availability, some runs were made using the MARINEGPS computer simulation at TSC. The simulation was exercised using the following conditions:

a. Best-set-of-four, four-satellite solution
b. Six-state Kalman filter (horizontal position and velocity, user clock frequency and phase)
c. Selective Availability capability
d. Sequential operation
e. Nominal satellite transmitter power
f. Antenna pattern rolloff
g. A straight-line trajectory of 45 seconds, followed by a 90 degree right turn.

Figures 6-10 show the resulting estimated and actual tracks for different Selective Availability values. The processor is initially given the true coordinates of the vessel. Subsequently the estimated position is determined by the measurements. The navigation solution smoothly tracks the signals, which vary relatively little during the 90-second run, but the solutions are significantly offset from the true track. The effect of the initial transient is apparent: the tracker downgrades the initial measurements, because the tracker was told not to expect such large errors. The response is sluggish until the errors have become small.

FIGURE 6b. ERRORS, NO SELECTIVE AVAILABILITY

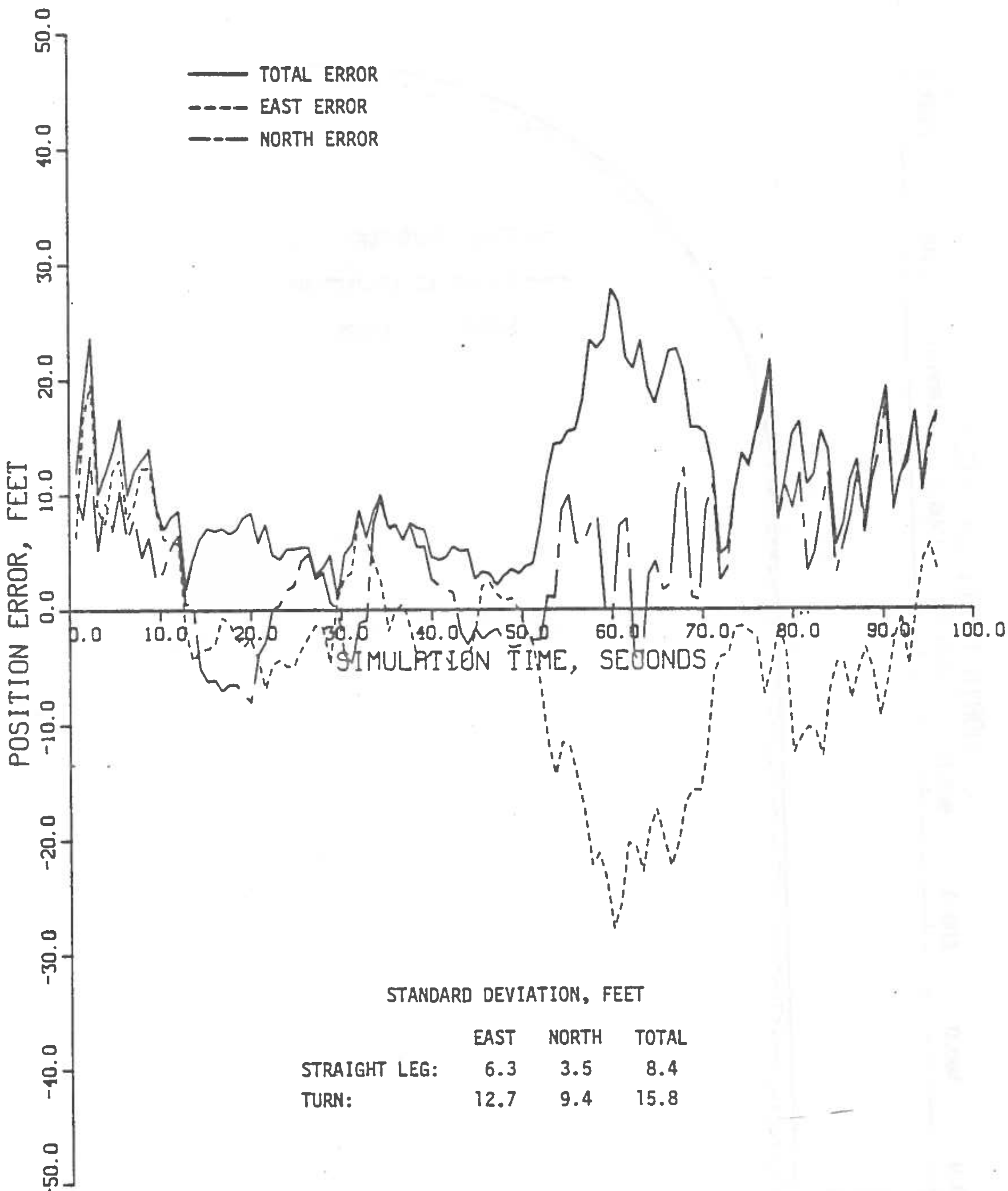


FIGURE 7b. ERRORS, SELECTIVE AVAILABILITY SAMPLE NO. 1

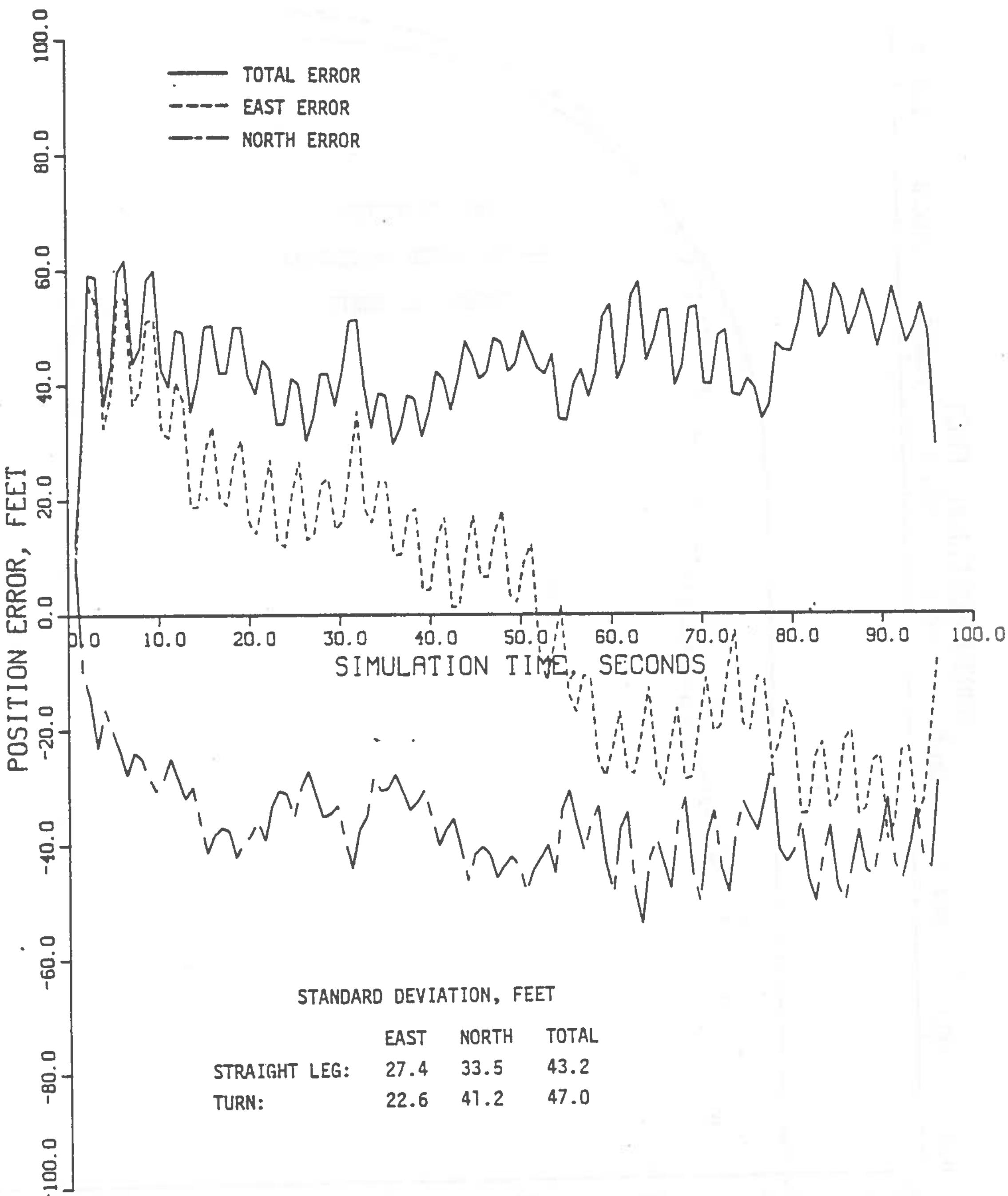
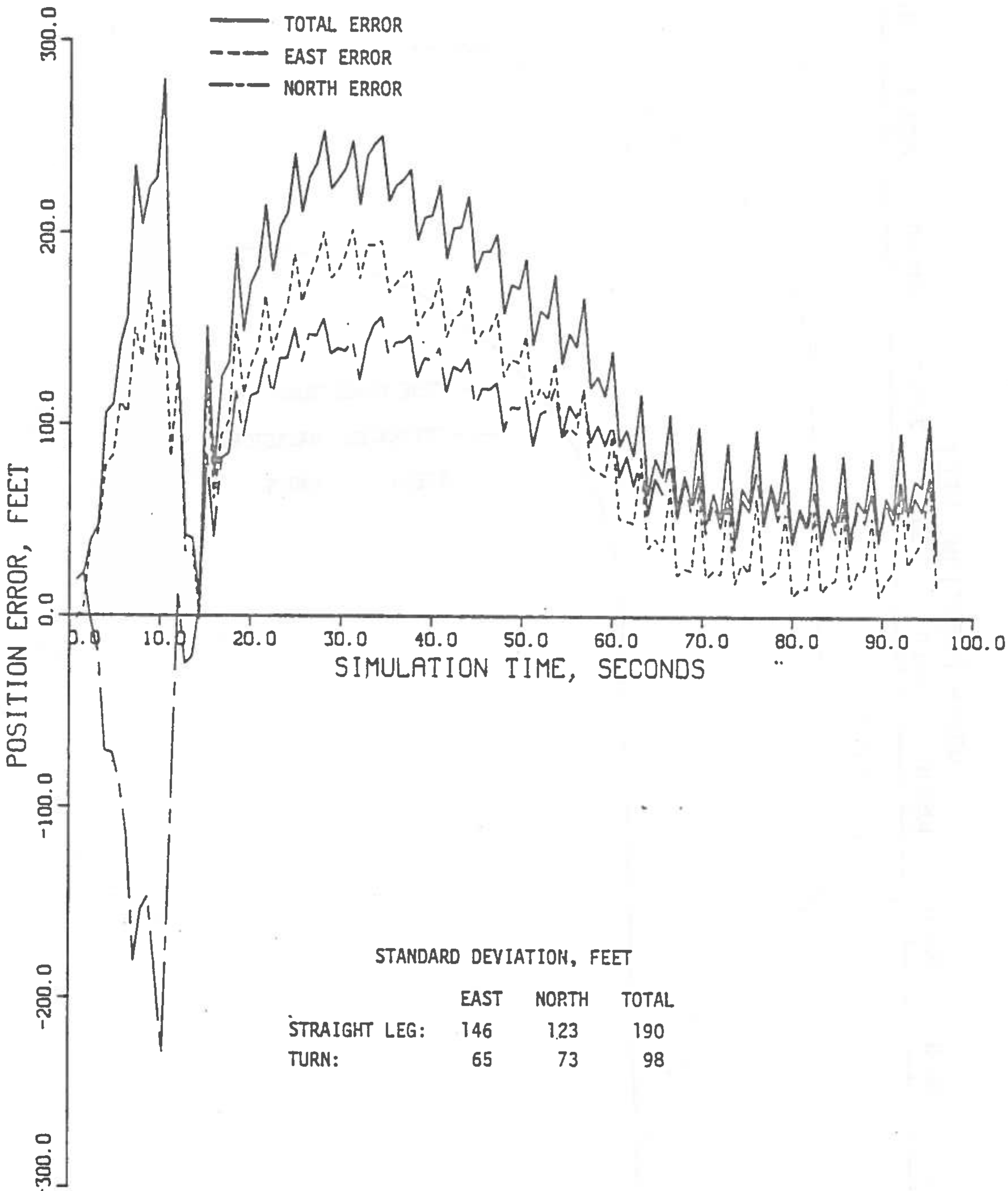


FIGURE 8b. ERRORS, SELECTIVE AVAILABILITY SAMPLE NO. 2



STANDARD DEVIATION, FEET

	EAST	NORTH	TOTAL
STRAIGHT LEG:	146	123	190
TURN:	65	73	98

FIGURE 9b. ERRORS, SELECTIVE AVAILABILITY SAMPLE NO. 3

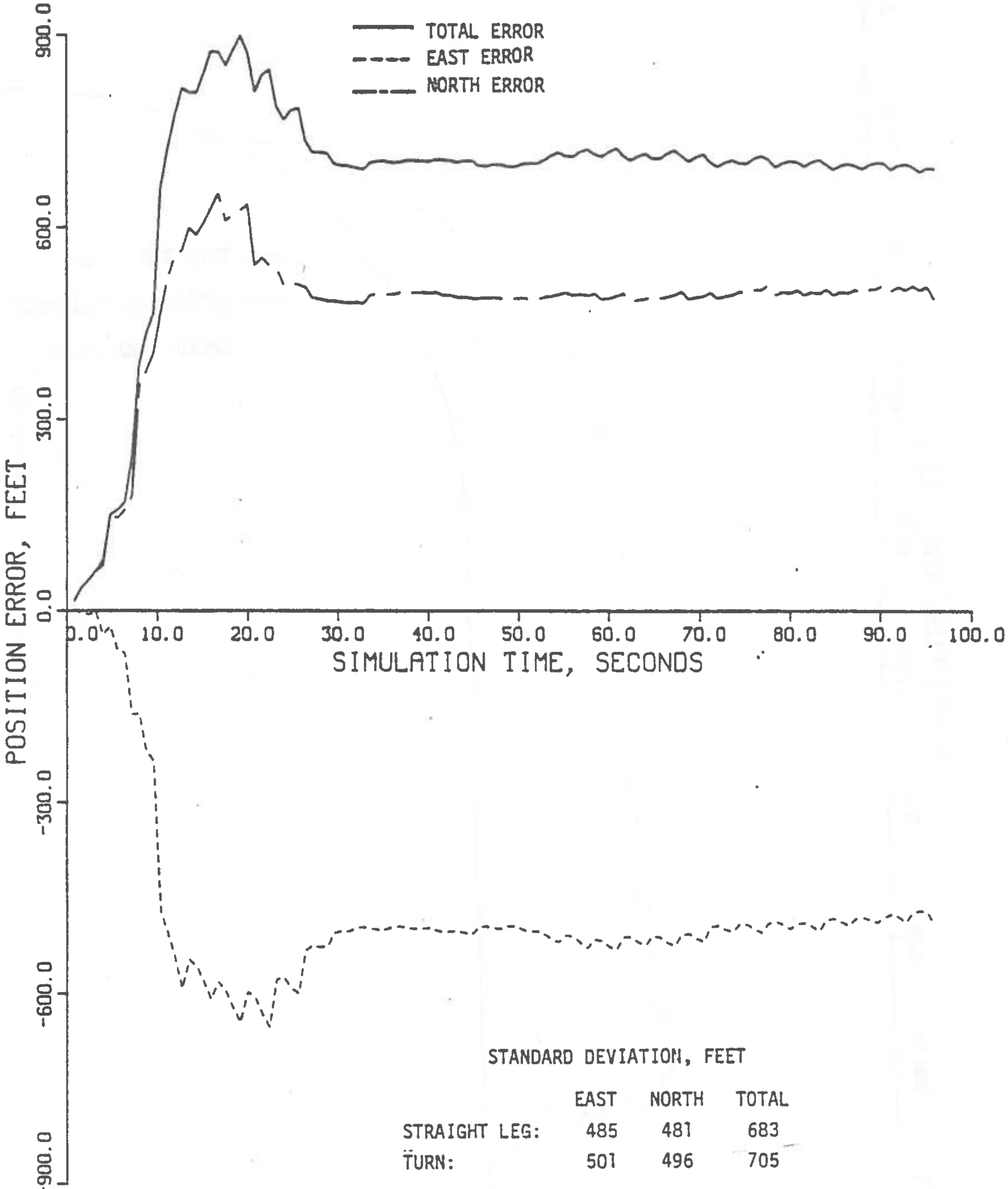
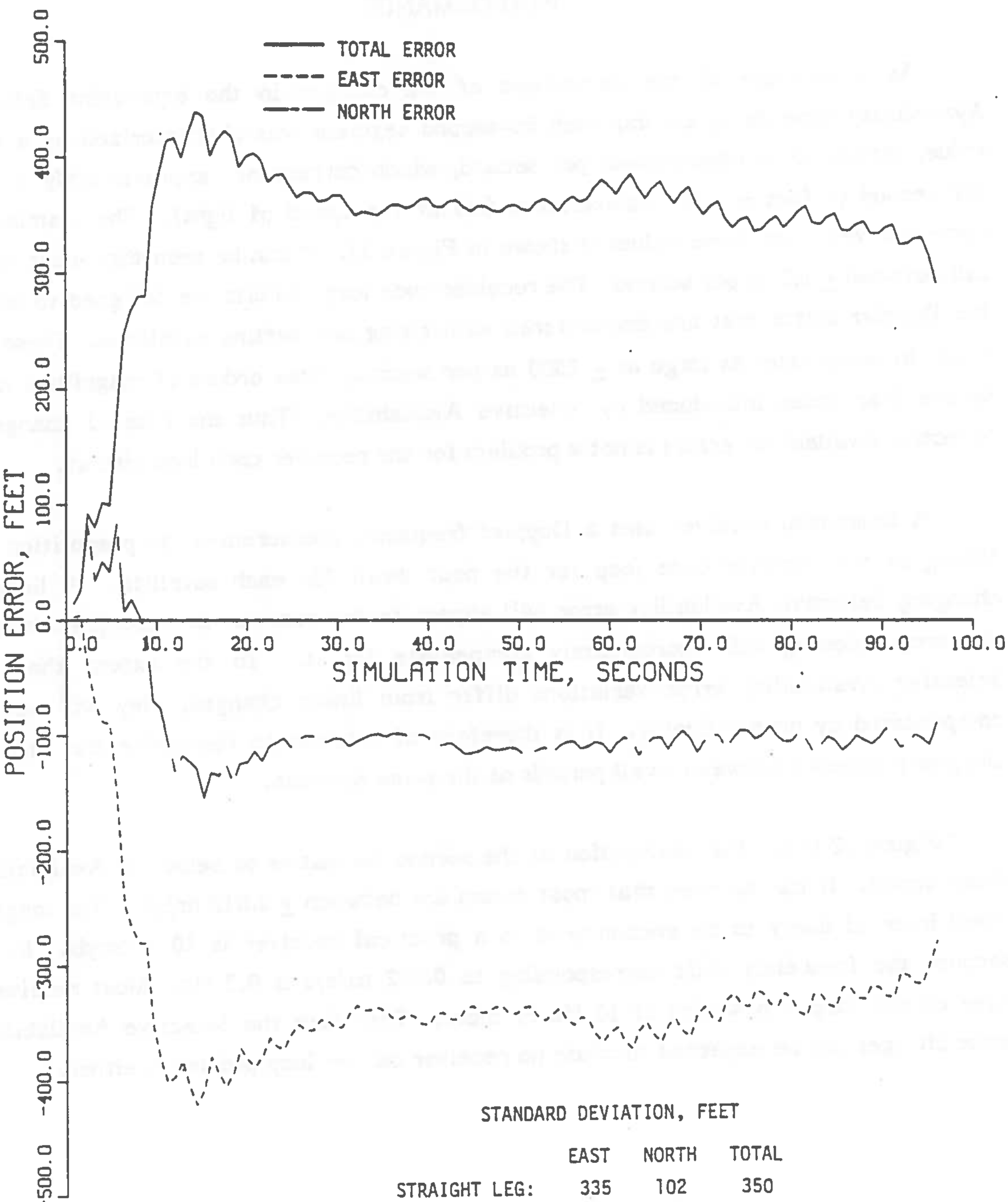


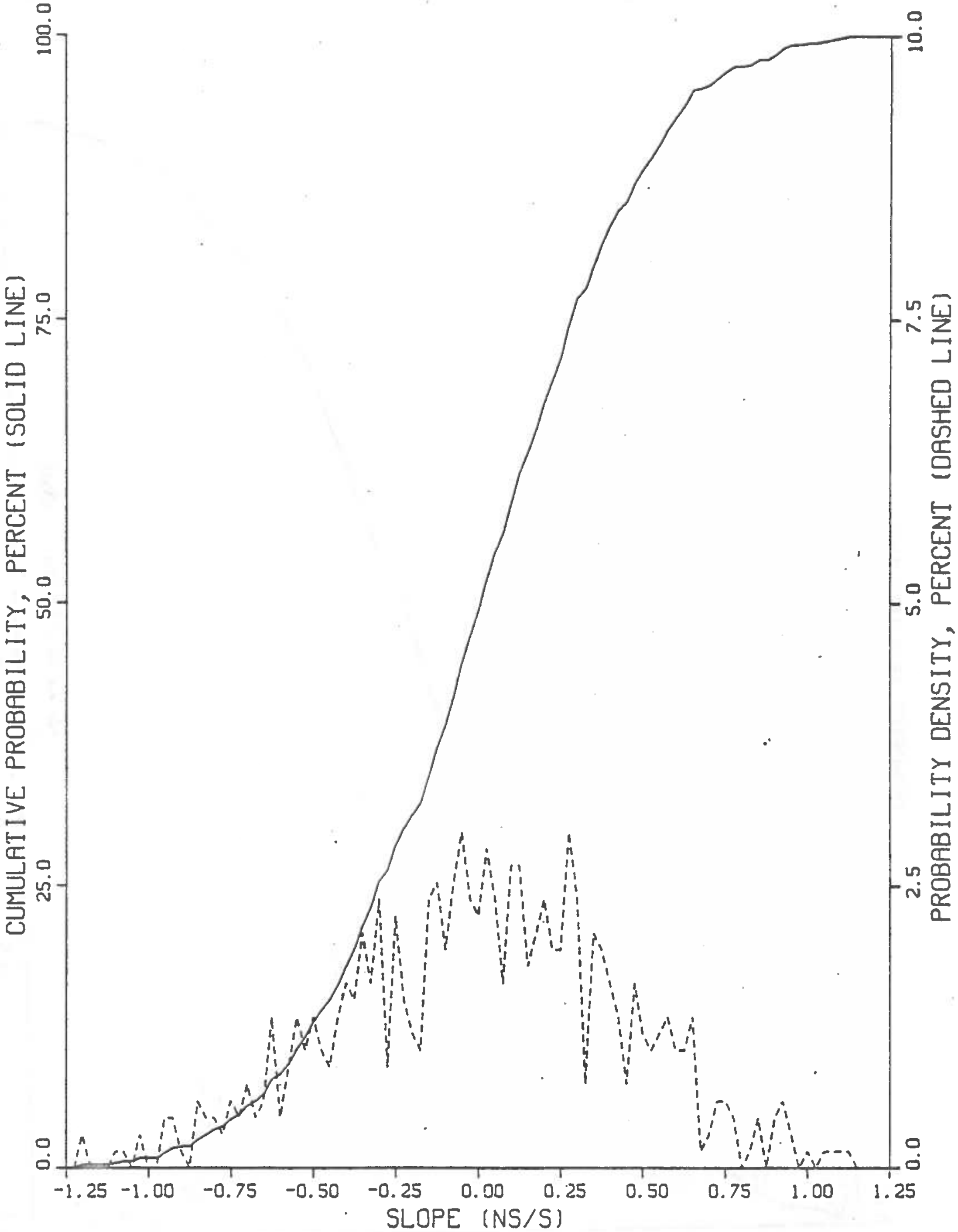
FIGURE 10b. ERRORS, SELECTIVE AVAILABILITY SAMPLE NO. 4



STANDARD DEVIATION, FEET

	EAST	NORTH	TOTAL
STRAIGHT LEG:	335	102	350
TURN:	337	105	353

FIGURE 11. SELECTIVE AVAILABILITY RATE DISTRIBUTION



DIFFERENTIAL SYSTEM CONSTRAINTS

Previous studies (4-7) have shown that the corrections obtained by a stationary differential receiver at a precisely known location are applicable over a wide area. These corrections remove much of the bias errors that would otherwise be present. The total accuracy attained by a user's receiver depends on noise errors as well as bias errors. For a typical receiver, positional errors due to noise vary from 10-20 meters (2drms) depending on the processor tracker and receiver designs, and the receiver trajectory. A differential unit, designed specifically for stationary operation, could achieve positional errors due to noise of about 7 meters (2 drms).

There are several factors which limit the area of applicability of differential corrections (8):

a. Geometric decorrelation - ephemeris errors are not completely cancelled by differential corrections; the uncancelled error is proportional to the user-station separation.
b. Ionosphere/troposphere - the signal paths to a satellite from user and differential station traverse atmospheric volumes that result in slightly different signal delays.
c. Earth curvature - a satellite visible to the user may not be visible to the differential station.
d. Blockage and multipath - buildings, structures, or terrain may shield satellites visible to the user from the differential station, or cause strong reflections.

Geometric decorrelation effects are quite small for local applications of differential corrections. Figure 13 shows a spatial bias (ephemeris) term of about 1.2 meters for user-station separation of 50 km.

Ionospheric and tropospheric delay effects are complicated by the fact that the NAVSTAR GPS provides a set of coefficients which can be employed by a user to improve his pseudorange estimates, based on a model of the ionosphere. Thus if differential corrections are to be useful, both differential station and user must incorporate the same model. It should be noted that it accomplishes nothing to have a highly precise P-code receiver at the differential station, because using the two-frequency model of such a receiver would cause in a large user error due to model mismatch.

Figure 13 shows the contribution of uncancelled ionospheric errors to the total user receiver error in pseudorange. The "ionospheric bias" term is due to ionospheric irregularities, while the "ΔE ionospheric bias" accounts for differences in path delays due to the differences in satellite elevation angle as seen from the user and differential sites. Tropospheric bias is negligible, because of the goodness of the tropospheric models. Tropospheric noise is not cancellable; it constitutes a noise error source to user and adds uncertainty to the differential correction.

Earth curvature effects depend on the user and differential station mask angles. The differential station would use a lower mask angle than the user, since it would have a better antenna characteristic and could accommodate lower signal-to-noise ratios. Figure 14 shows the maximum distance of the user from the differential station as a function of differential station mask angle, for user mask angles of 5 and 10 degrees. Tropospheric and multipath effects will limit useful operation to differential station mask angles of about two to three degrees. Thus earth curvature effects limit practical coverage ranges of a differential station to about 200-300 km.

Blockage is a matter of practical siting, and elevating the differential station antenna to reduce the effect. In the CONUS latitudes, most low-lying satellites would be found to the south of the station, so the primary concern would be with blockage in the south. Multipath can also cause serious errors if siting results in strong reflections.

The most straightforward method of implementing correction terms is to broadcast latitude and longitude (lat/lon) differences from the differential station. That is, the differential processor would determine the estimated position from the measurements, subtract the known lat/lon coordinates, and transmit the differences. The user would then subtract the same differences from his estimated coordinates. However, this is not a desirable approach to developing diferential corrections for the following reasons:

a. The user may employ a different navigation solution, e.g., a three-satellite solution rather than a four-satellite solution.

b. The user may employ a different mask angle or different satellite selection strategy, e.g., all-in-view rather than best-set.

c. Even if the algorithms are the same, distant users may process different satellites.

Any of these conditions would result in different satellite sets being processed. The resulting navigation errors would be large compared to the differential system error, but somewhat smaller than the normal system error (8). Since there is no current restriction on the design of a civil receiver, different manufacturers may design their sets in different ways. Therefore the transmission of lat/lon corrections is not a viable approach for precision differential corrections.

A more useful approach for a differential design consists of transmitting the pseudorange corrections for each satellite. The user processor then subtracts the correction from the measured pseudorange prior to determining the navigation solution. The data message will thus consist of station identification, plus satellite identification and pseudorange correction for each satellite in view of the station. Of course, the format must be standardized at least on a national basis, a not insignificant undertaking.

The task of communicating the corrections to the users poses a whole new set of problems. In addition to the problems of standardizing the format, obtaining a frequency allocation and adding complexity to the user's processor, there is the problem of providing adequate coverage. There are several types of communications that could be employed:

1. Line-of-sight (e.g., VHF, L-band, microwave), wherein the transmitter tower must be strategically located and tall enough to be visible to the users in the coverage area.

2. Ground-wave (e.g., radiobeacons), wherein the frequency is low enough to reach targets beyond the horizon.

3. Satellite relay, whereby signals are transmitted to a satellite relay station, and retransmitted to earth.

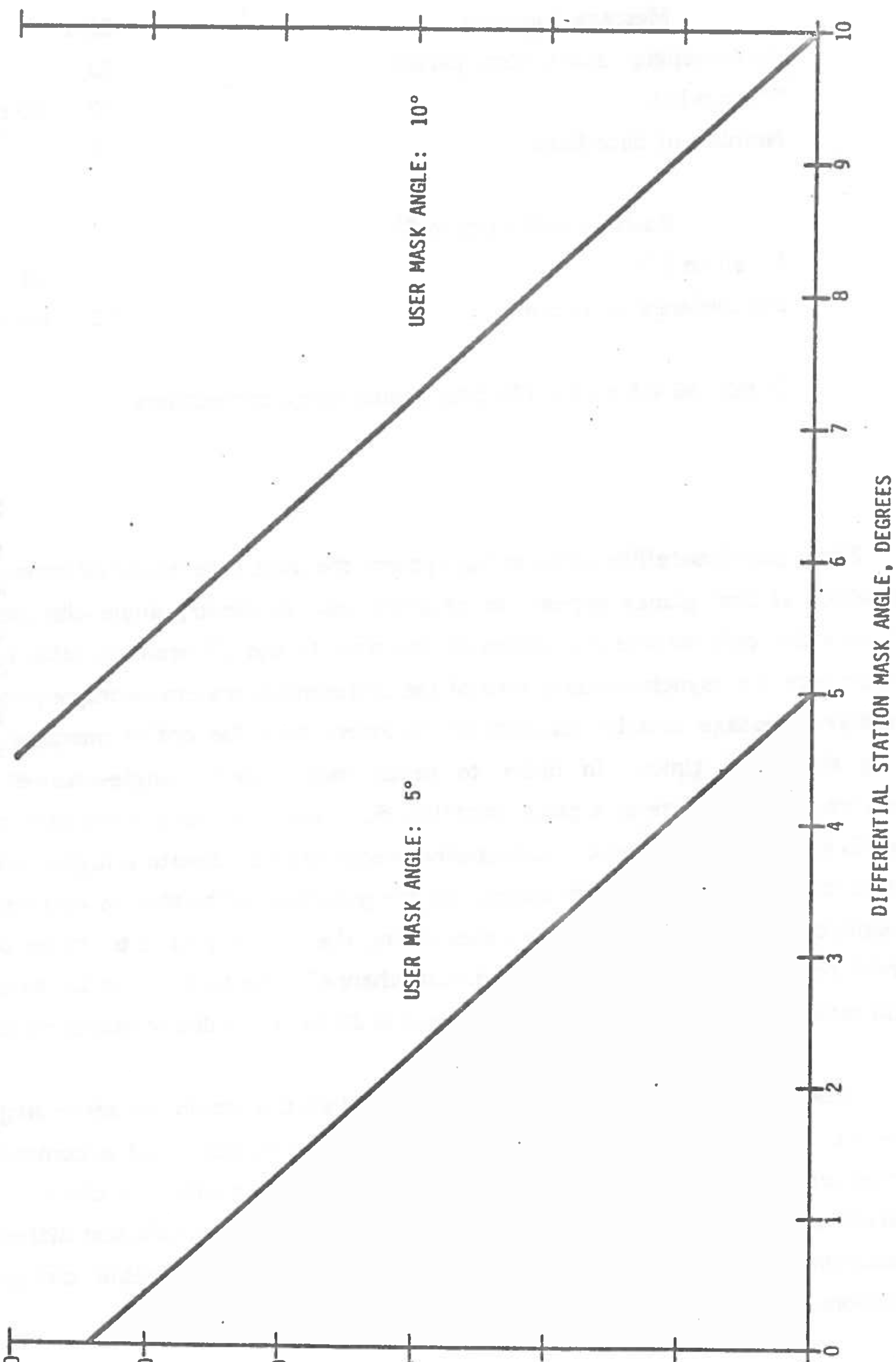
The drawback of this technique, in addition to its line-of-sight limitations, is the potential for user receiver interference due to the large signal level variations near the differential station. For example, if a receiver could only accommodate signal levels up to 20 dB greater than nominal satellite signals, and assuming that a nominal signal level were provided by the differential transmission at 40 km, then receivers closer than 4 km to the station would not function. The seriousness of this problem has not yet been assessed.

The discussion so far has been confined to one station and one user. Coverage of a large region would require a number of differential stations with overlapping areas of influence. In such an environment a user would frequently be closer to one station than another, but a useful satellite visible to the user could be hidden from the nearer station while being visible to the one further away. Enabling the user to get this information requires that differential stations communicate with each other; or, if differential stations and communication sites are separated, the communications sites would have to talk to more than one differential station. In either case, the differential system designer faces the problem of integrating the multiple differential station inputs.

Data update rate is a key parameter of a differential system. If a differential station issued pseudorange corrections periodically, users in the area could achieve momentarily high-accuracy positioning by incorporating these corrections. After a period of time, however, the Selective Availability errors would change, and the users' navigation solutions would deteriorate back to the normal SPS accuracy. To determine this period of time, and thus to determine the required differential correction update time, it is necessary to examine the rate of change of the Selective Availability pseudorange errors, and the system design accuracy that is desired.

Referring to Figure 11, most rates of change fall between $\pm.85$ ns per second, the standard deviation being 0.43 ns per second. This translates to a 2 drms value of positional change of about 0.4 meters per second, which suggests that in 30 seconds positional error would typically grow to 12 meters. To this 12 meters must be added (in root-sum-square fashion) the differential receiver error and user receiver noise error contributions to obtain the total system error after a period of time.

FIGURE 15. DIFFERENTIAL PSEUDORANGE ERROR



CONCLUSIONS

Selective Availability introduces large pseudorange errors which vary more rapidly than other bias-like errors. Differential operation can ameliorate these errors to an appreciable degree. The conclusions of this analysis are the following:

1. NAVSTAR GPS Standard Positioning Service accuracy for a marine user will average 350-480 meters (2drms) under Selective Availability, depending on receiver design.
2. Selective Availability is unlikely to cause carrier or code loop loss of lock or other erratic receiver behavior.
3. Differential operation under Selective Availability can achieve navigation accuracies of about 15 meters (2drms) for a good marine receiver.
4. Differential corrections should take the form of pseudorange corrections, rather than latitude/longitude corrections.
5. In order to counteract Selective Availability, data update rate should be about once every 28 seconds, broadcasting pseudorange corrections from the differential station.
6. Manual entry of differential data with Selective Availability present is not feasible.
7. A pseudosatellite differential station, which operates in such a manner as to "look like" a satellite to the user, could not serve a user with a single channel receiver.

There are several issues that have not yet been addressed. The differential receiver design parameters need to be determined, and the question of whether a sequential receiver is adequate for a differential station, needs to be settled. The differential station tracker should use prediction techniques to project corrections into the broadcast period rather than merely estimate previous corrections. The multipath environment needs to be analyzed to determine its effect on land-based receiver measurements. Finally, the question of whether the pseudosatellite approach is worthwhile needs to be resolved.

Question - Tom Nolan, Maritime Institute

The pseudo satellite, I presume it's acting as a satellite, therefore transmitting at the same frequency that the satellite would. Would that not limit the range of its useability tremendously?

Answer - Kalafus

That's correct. That relates to the power, the interference problem I was talking about. Because when you turn the power up to reach your furthest user, the user that gets close to the station will just saturate the receiver, or else it will cause a false correlation in the correlator. But we don't know exactly what those numbers are, and we want to follow through to see if that's really a problem. It might be just very close to the station where it wouldn't really affect anyone operationally.

Question - unknown

Have you looked at, in coding the differential correction, giving two terms rather than a single term, so that perhaps you can go for a little longer time interval?

Answer - Kalafus

Yes. About a week ago I removed it from the paper because it looks like the difficulty in accurately predicting what that rate would be, did not look feasible. That is, the tropospheric error that you get when you make your differential measurement and the receiver noise, you have to look at a history of it and say all right, we can project the slope, and that's going to be valid for that next segment. And the numbers do not look friendly. So we removed that as one of our recommendations. Also, at a 28 second mark, even if you could do it, it only bought you about, I think we calculated 35 seconds rather than 28, so it didn't appear to be a large gain.

Question - LaChapelle, Shell Canada

Can you discuss accuracy as a function of distance?

Answer - Kalafus

My claim is that communications is your biggest problem. First of all, and as far as the distance, that is written up in a number of documents. I think Magnavox has an article, as in the report. In a number of places. I think, Beser and Parkinson have it in one of the ION journals.

II. LAND POSITION LOCATION EVALUATIONS

Clayton Erickson
Sandia Labs/Department of Energy

One of the tasks assigned to SNL (Sandia National Laboratory) is to provide technical support to DOE (Department of Energy) in the area of transportation of extremely valuable cargo. To this end Sandia has aided in developing a nationwide communication system that provides 2-way, 24-hour-per-day contact between a control location in Albuquerque and vehicles traveling anywhere in the continental United States. The system utilizes HF radio in conjunction with several ground stations to provide the communication link for digital messages. Part of the information conveyed in the messages from the vehicles is present location, vitally needed if help is required immediately because of vehicle breakdown or armed attack. (Fig. 1)

The present technique of determining vehicle location is relatively primitive, relying on maps and observation of landmarks by vehicle personnel. It also requires manual insertion of prearranged codes into the transmitted message. SNL is researching and developing techniques to automate that process and increase the accuracy of determining location. (Fig. 2) (Fig. 3)

The criteria SNL/DOE have adopted for APL (Automatic Position Location) includes the following considerations:

1. Inaccuracy on the order of one or two miles is acceptable. Better accuracy is desirable but does not seem reasonably and consistently attainable at the present time.

2. The system must operate anywhere in the continental US and be available for use at all times. This means elements of the system beyond DOE's control must have no "down-time" affecting its availability.

Two remaining wide area navigation systems are satellite-based: TRANSIT and GPS. Since implementation of GPS is so far in the future, we are developing a system using TRANSIT and DR. Because of inaccuracies in DR caused by compass errors and anomalies, this combination will not provide a comfortable margin over our accuracy requirement of two miles. Still, it is the only system available now that is readily usable and continually available anywhere in the US. We have also performed a short road test using a GPS receiver which indicated that it will meet all our objectives using the C/A signal. (Fig. 5)

There are many potential users of a land position location system. In October 1979, DOT sponsored a workshop for Civil Radionavigation Users, inviting participation from the air, marine, and land user communities. While air and marine users are fairly well-defined groups, land users are not. This workshop was the first to officially recognize a need to consider providing for radionavigation on land. Since that meeting, there have been no further extensive discussions, in any navigation organization, addressing ways to meet the needs of the land users groups recognized in the workshop.

Sandia and DOE believe that the availability of an inexpensive APL would be welcomed by many users of land vehicles for cargo movement. The TRANSIT system is barely adequate for land APL because of the large gaps in satellite "visibility." GPS will solve that problem and at the same time afford faster as well as continuous and accurate determination of location. SNL/DOE are planning to use the GPS system if receivers truly become as inexpensive as industry now states they will be. The presently constituted C/A signal seems to be completely adequate for long range land vehicle APL. However, the TRANSIT system must be continued, despite its limitations for APL use, until GPS is operational and inexpensive receivers become available.

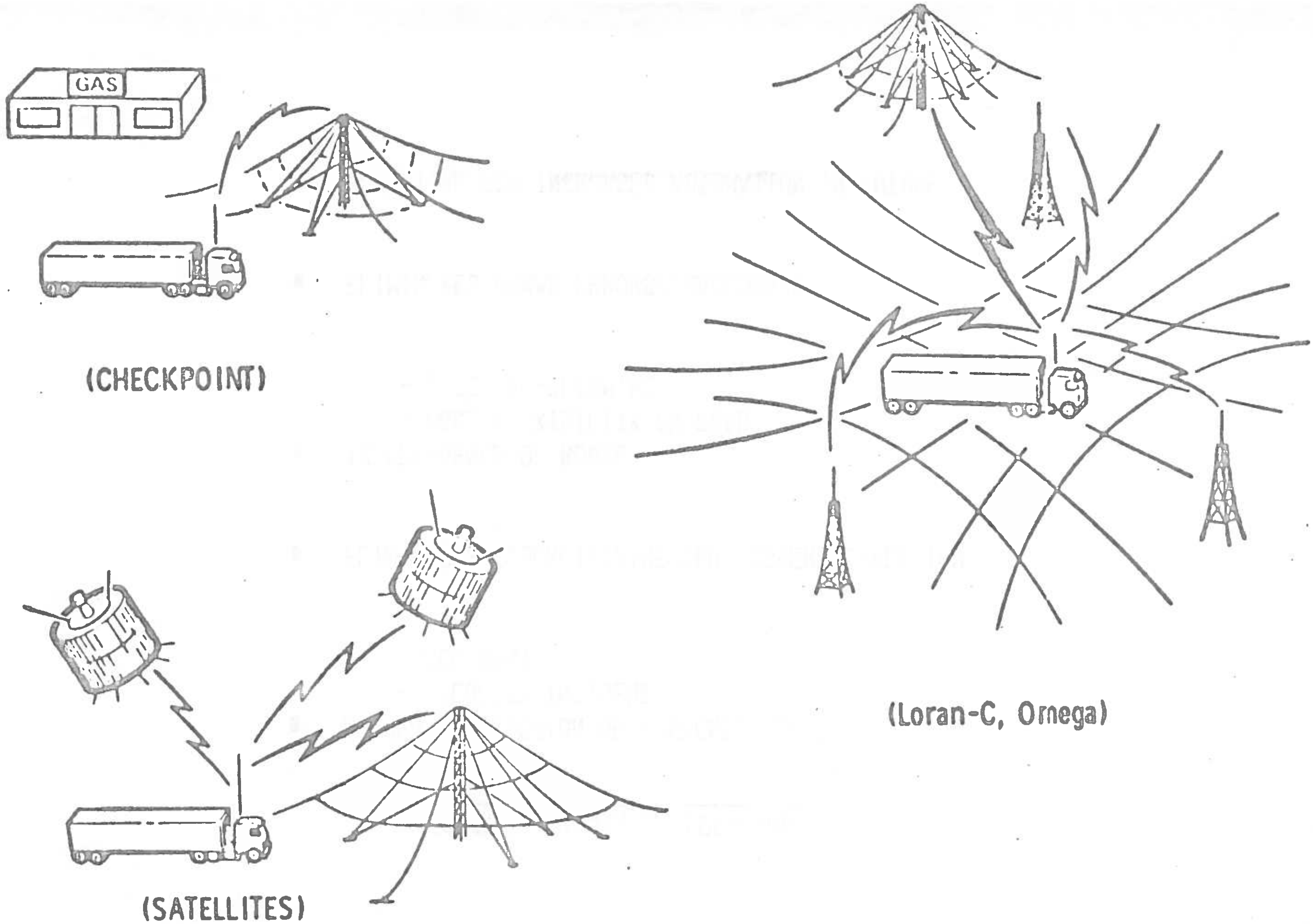


Figure 2

APL SYSTEMS STUDIED

- LORAN - C
- OMEGA
- OMEGA/DEAD RECKONING
- TRANSIT/DEAD RECKONING
- GLOBAL POSITIONING SYSTEM

Figure 4

Question - unknown

On this scale in the previous slide, what were the units on that?

Answer - Erickson

They were miles, statute miles, and it can build up to 10, 15 statute miles over a long period of time. We're kind of quoting dead reckoning as being, nominally, about two miles per hour, for two miles and sixty miles. Sometimes it will exceed that, sometimes it will be better than that. It's kind of an average.

***Question -

Like four percent.

Answer - Erickson

Yes, roughly.

Question - Unknown

Is there any reason why they haven't tried a gyro compass instead of magnetic?

Answer - Erickson

We looked into the gyro, but we didn't feel that for the price, the low price that we have to meet, that a gyro could run five days a week, several weeks a month, all year, without a lot of maintenance and replacement costs. So to that extent, we haven't followed up on the gyro.

Question - unknown

What was the total system cost?

Answer - Erickson

Well, we're aiming to come up with a system that will cost somewhere around six to ten thousand dollars, hopefully around six to eight or less. TRANSIT receivers, as you know, are getting very cheap. The compass that we're using sells for a little under a thousand dollars. The odometer is like a hundred (dollars).

Question - unknown

Exclusive of communications costs?

Answer - Erickson

Yes, the communications is already in existence for another purpose, primarily to communicate with the vehicle and pass messages back and forth. We're just adding something to an already existing communications system.

In any case this conference is aimed at stimulating your comments. The panel session this morning is probably the best way of accomplishing this. At this point I will turn over the podium to Bill Mohin so we can begin the discussion. Best of luck to all of you and I hope you are able to participate to the fullest extent possible.

DECCA would have loved him to say that. And they chose the system. That's what the DOT and DOD have to do. They have to make a decision, they have to work toward that decision. If that decision proves in the years down the road not to be viable then they have to be able to turn around. But they can't go as they have gone in OMB and GAO with arguments that say we have to have everything because.

The six questions which we have asked our panel members to address in their remarks today are:

1. The following systems are currently being used in the designated phases of navigation:

   OCEANIC: LORAN-C, OMEGA, TRANSIT, and celestial navigation.

   COASTAL: LORAN-C, marine radiobeacon, radiodirection finders.

   HHA: fixed, floating visual aids, plus radar, RACONS, and audible signals;

   LORAN-C being investigated

   LAND: LORAN-C, TRANSIT

   Do you see a need for a change in the navigation system mix? (In the near term, in the long term)

2. Do you see a benefit in transitioning to a single, or to a mix of, radionavigation systems?

   (To what systems?.......for what applications?)

3. Do the present systems need improvement and if so, how should they be improved?

4. If NAVSTAR/GPS accuracy is limited to 500 meters, for what applications will it meet the requirements, and what radionavigation systems will it possibly replace, and when? If full accuracy is provided, what will be the applications?

5. Systems in the FRP such as LORAN-C and TRANSIT are often used in special applications that are not necessarily transportation oriented. How should the needs of radiolocation system users be accommodated when planning the future mix of radionavigation systems?

6. What effect, if any, would user charges have on the future mix of radionavigation systems to be implemented? In particular, what effect would a proposed DOD user charge have on the implementation of NAVSTAR GPS for civil use?

degradation of it is a step in the wrong direction. I think that any user fees, the idea of user fees, should be abandoned, and that the present proven systems be maintained and developed to their full capability until such time as NAVSTAR has proved itself.

I think a lot of things have got to be defined a little bit. There is a difference, and a very diametric difference, between aviation and marine. They're two different fields. In fact, there are very few things in which they are alike. VTS for one. Safety, as opposed to protection of the environment. There are too many things that are crammed down people's throats because it's for safety, but when the regulations are written, they're not for safety, they're for protecting the environment. The environment belongs for all of us, all tax payers, not just the mariner. There's a big difference between user requirements versus what is available and what we can have to give to the user. What his needs are, as opposed to, the luxuries he might like to have. As I say, there's no reason for antagonism between the user and the Coast Guard or the government agencies. It serves no purpose whatsoever. The Coast Guard, as a user, we feel that the Coast Guard is our voice in Washington to get the navigational requirements and needs that we have to operate our ships. When I say safely, safely and economically. A ship can be operated safely with very limited number of navigational tools aboard, as long as those tools can be depended on.

And the reliability of those tools has to be gained, the master has to gain their credibility through constant use and the ships that I sailed on that had none of these things were equally as safe as they are today, and probably more so because people didn't rely on something that might change. However, they could not operate viably and economically in today's market without these refinements, which are assets to the marine user, but they are not "needs" as they are to many of the other people. I think the Department of Defense has a need for NAVSTAR, a very, very basic need. I think as a user, I think it would be a great luxury to be able to use what they have. If they give us 500 meter accuracy, I think that's very nice. But if they take away the TRANSIT which gives us .1 mile accuracy, I think that's a disservice. If they charge us user fees for something which they need, and which we don't need, I don't think we should be required to pay for it. I think that it creates a real "ball of wax" to even think about user fees because you cannot define the user, you cannot define the reason why he needs it and how he needs it, and no matter what the system is, there's somebody out there that's going to beat it. And in my life I've never found a system yet that couldn't be beaten. So therefore the person who is paying the tab is going to wind up being suckered, and the other guy's going to be getting the benefit from it without paying the tab.

Secondly, we talk about user fees; -- early nav-aids that we have grown to become familiar with were funded, and they were funded because of commerce, not because of safety, they were put in there because of commerce. And there were tonnage taxes that were paid. They're still paid by every ship that comes into a port. You pay a tonnage tax, or a light due. These all go into the general coffers. I always considered these to be user fees. I don't know whether they are now. I guess once they get into the general funds, they are no longer user fees. There are also customs duties. Along with user fees, customs is generated by the ships that come in and out of port. These could well be thought of in some ways as user fees, or could be used, for something other than what they're presently being used for. Thirty percent of all customs goes directly into the Department of Agriculture, which I don't see. A user fee is put on the mariner, why should the rest of these funds be going to something which has nothing to do with commerce or mariners or safety or whatever you want to determine it as.

Comment:

What do you think, that the government can't turn the stars off?

TORRENS:

They may cloud the issue considerably, I'm sure. As far as the coastal phase, LORAN-C was touted for its quarter mile accuracy. It's an absolute lie. By the charts you can tell that it's not quarter mile accuracy in many cases because the charts have not been brought up to date. I think that LORAN-C is again a very great tool, and it needs to be improved so that the lines are as close as possible to the latitudes and longitudes and terrestrial objects as possible. The use of radio beacons is still very, very evident in all of the small boat communities and I think it should be -- the radio beacons have got to be, should be, continued to be improved and should be kept up to date. A few years ago there were several outages that should have been corrected and weren't, but now I think that they are coming back on line. Although there might be people who would object to it, I feel that there are improvements in the radiobeacon area that there might be a use for, e.g., VHF directional antennas. I think this has two uses, one is not navigation, unless it could be used for radar identification purposes that when you hear someone talking on VHF, you at least know what direction he's speaking to you from. There are some things on the market today, but I think they should be encouraged and made more accurate. Radio direction finding stations, I almost thought that they were extinct, but I'll have to go back and look in the light list and see if there are some. I have never used one in my life, and I really don't know of anybody else that uses them.

As far as harbor entrances and approaches, I'd throw LORAN-C in there because I think that that is a definite use of LORAN-C. I have seen some things that, which, using a good shift with LORAN-C where you get 50 foot accuracy. I have talked to people who have used the PLAD (Portable LORAN Assist Device) for the pilot. If there are no other ships on the river, when you have a pilot (whose reputation depends on it) who can say that he would take a ship down the channel without looking out the window, just on the PLAD, a portable hand-held thing, I think that speaks for the system. Anybody else I would say he was out of his mind.

As far as radar, although this is not a "navigational system" that's covered in the FRP, I believe that radar is by far the greatest navigation, electronic navigating aid that's used today by all ships, and any improvement such as RACON that can utilize the radar to a greater extent is a great step in the proper direction, because the radars are aboard the ships. I think that great advances can be made in color radar, and radars that have higher definition, computerized radar presentations, and perhaps identification of objects on shore and elsewhere which can be identified above and beyond RACONS but by some reflective means.

As far as land usage, I don't think that this should be in a DOT presentation at all, except for the areas that were presented yesterday, transportation related areas of trying to keep track of hazardous materials.

Question 2 was the benefits of transition from a single to a mix. I see, again, the needs that we have are being accomplished right now with a mix. A mariner, or navigator, always wants redundancy, he has to have something he can fall back on, and it has to prove that the system is reliable. Therefore, there should be a mix until

15. Panel remarks by John Fuechsel (Capt, USCG, Retired) National Ocean Industries Association.

I will get to the specifics, and look at the questions. I want to start by saying that we appreciate this symposium. I think it's a positive step. We can probably make some constructive suggestions on going farther than this sort of symposium for a more organized ongoing advisory relationship between representative user groups and the Coast Guard and DOT. But this is a very encouraging beginning. I want to make a few remarks before I give you my industry association's point of view on behalf of the RTCM, because as you know I've been chairing their navigation planning special committee. I'm not going to belabor this because all of the members of your panel today in one way or another are drawn from groups that are represented in the RTCM and indeed on our navigation committee. But I thought it would be significant to summarize the essential points that have already been made by this group in response to the Federal Radionavigation Plan.

I'm referring now to a report we filed in October of 1981, which many of you have seen. It's recommendations are virtually as good today as they were the day they were made, because there hasn't been too much progress in accommodating those recommendations, and I appreciate the time that it takes. But one of our key points was there should be more civil participation in the radionavigation planning process, and I consider this symposium a very positive step in that direction. We felt that there should be a much stronger partnership between government and industry in the United States. That's a general feeling but particularly in the nav planning area. I've spent a lot of time in Europe, and I've seen how effective this can be in other governments where they do work closely with their industry, and I'm not sure how we got in this mode of a semi-adversary relationship between industry and our government. It certainly is not productive, and none of us wants it to continue. And I look forward to a healthier atmosphere in that respect in the future.

We feel in the RTCM that there needs to be more specific sponsorship of satellite navigation user requirements by DOT and the Coast Guard. It pains me as a retired Coast Guard officer to see the Coast Guard on hard budget times forced to say, those satellite navigation systems belong to somebody else so whatever problems you have, take them to the Department of Defense. Indeed, my industry association has done that, and we're very pleased to have a direct interface with the program managers, but something is missing here because the Coast Guard and DOT have a very broad statutory responsibility to sponsor, if you will, those legitimate navigational requirements of the civil community, and that simply isn't being fully accommodated when you defer all the questions to another department which operates the system.

We have felt that national planning should address international issues. Just as this country can no longer afford duplicative radionav systems because of the cost, I don't think the world at large can afford to duplicate things, and we're now deploying global navigation systems. Surely it makes sense that we direct that planning towards international cooperation and world-wide planning in the navigation area. The RTCM feels that the master timetable has been unduly optimistic in several areas, and I won't recap all of them but a very specific example is TRANSIT. The planned phase-out five years after introduction of GPS is viewed as totally unrealistic by our group. For one thing, we don't feel that TRANSIT can be discontinued until the accuracy available in GPS is at least that good. And I don't know whether the plan is telling us in an oblique

Benefits in transitioning to a single or a mix of nav systems? I guess from our industry's point of view, we're certainly tolerant of other systems that we don't use. We've spent a great deal of money over the years in providing short-range survey quality systems for our operations, and we look forward to being able to do that with a global navigation system. Because after all, we've been limited, in some cases it's the line of sight or at least a couple of hundred miles. I can assure you that with the industry moving toward deep water technology, farther and farther off shore, we're running out of range of our own terrestrial systems, and we'll absolutely have to go to something like NAVSTAR GPS.

Do present systems need improvement? Well, that's one of the unfortunate facts of life that several years ago, when NAVSTAR appeared on the horizon, it had the immediate effect of killing almost all R&D money for any other system because all the planners figured, "well, it will be replaced in time, no need to develop it any further." But there are things that need to be done. The TRANSIT system could use better information distribution right now by the system manager. We've had some explanations yesterday how it was really being provided for a unique Navy application and they were satisfying their own requirements. But it's being used by an awful lot of people who, if they're clever, can get a lot of system operating information. But we still have to deal with a public relations problem which not too long ago resulted in a satellite being redrawn from service, rather preemptively. As it turned out the reason for doing it was entirely appropriate, but the lack of an announcement to the user community caused unnecessary disruption to the operations. My industry group in RTCM is primarily interested in satellite navigation. That doesn't mean we don't use the other systems, but we're not active in advocating activity there. But the RTCM group is very heavily LORAN oriented. There's been a lot of concern about what I choose to call the calibration of the system: the fact that, with the advent of coordinate converters, that you can ignore the charts, or you might try to ignore the charts and come into the harbor using coordinates alone and that's not worked out very well. A massive calibration and remapping program is underway, but it's taken a long time to get it going, and it appears to be still one of the primary concerns of the user groups, and partly because they don't know how far it's going. Our constituents in that area, again, are very strong on RACONS. They're pleased to hear the Coast Guard say good things about RACONS and their plans to deploy more,, but there still aren't very many in this country, and that would be a big help to mariners, as would some better development of inexpensive short-range systems for recreational boating community. That's an extremely large community. It's not realistic to expect that most of them will buy such sophisticated nav systems as NAVSTAR GPS.

How about the accuracy question? Well, 500 meters is probably okay for high seas and coastal but it obviously isn't going to handle most of the high precision requirements. I'm afraid that 500 meters is so far away from the numbers that we'd like to see that it will either inhibit applications of GPS in the civil community, or it will lead people almost immediately to try to develop differential systems. And while that may be worthwhile, I'm apprehensive about the cost of differential systems, and I'm afraid it may be difficult to get widespread deployment if the cost is extreme. The special applications for LORAN-C and TRANSIT, I think we've already treated. We can't rely on safety of navigation alone. We're going to have to recognize the legitimate requirements of the radiolocation users. I certainly feel that to the extent that we can replace some systems and put more efficiency, more cost-effectiveness into the system, that I'd be happy to see the navigation system mix reduced if that can be done without excluding any major user group.

Certainly in the case of satellite systems which are global we see the government's predicament. The traditional ways of collecting user charges are fuel taxes, port entry fees, license fees, and things like that. When you're dealing with a TRANSIT system, which is, last time I looked, about 55 or 60 percent foreign operation, and these are Japanese fishing vessels and people that never come into a U.S. port unless they've been seized and dragged in, they're not going to pay that kind of a user charge. And my industry is in a very competitive posture worldwide. We're not at all interested in seeing our foreign competitors have free use of a system that we have to pay for. And while we're not unduly disturbed at the projected cost of the P-code or PPS service under GPS under the DOD study, we certainly feel very keenly that it would have to be equitably applied to our competitors or we would find it intolerable.

If a single system can do everybody's job it deserves consideration. If it costs more than all of the other systems combined it loses some of its appeal. If the single system is for national security and will be funded for that reason then the cost issue becomes moot providing that the secondary users are not asked to pay more than they are now paying for service and providing the hardships caused by transition are not too great.

In any event, complete dependence on a single system violates the concept of independent redundancy as means of assuring continued service under all conditions. In any vital, safety related user application, a fall back capability is mandatory.

Question 3 asks what improvements are needed to present systems and how should they be made. Volumes have been written on this subject and major R & D programs are underway to improve our present navigation systems. I note however, that the FRP has little to say on this subject. The marketplace will undoubtedly take care of improvements in user equipment with characteristic vigor. We can only hope that the providers of navigation services will pursue improvement programs with equal enthusiasm.

Question 4 asks what applications will be affected if NAVSTAR GPS accuracy is limited to 500 meters or if full accuracy is provided what will be the applications.

My own view is that virtually all applications would be adversely affected by limiting the accuracy of NAVSTAR GPS to 500 meters. In marine applications the limitation in accuracy would rule out effective use of NAVSTAR GPS for harbor and harbor approach use. It would be of little use in offshore oil exploration programs and the navigational accuracy would be insufficient to assure visual contact with fixed and floating navigational aids, picking up a buoy with 100 feet visibility for example. The repeatability of LORAN-C is considerably better than the 500 yards limiting accuracy, therefore, the substitution of limited accuracy NAVSTAR GPS would be a step backward achieved at great expense to users.

An important philosophical principal is involved in this question. If NAVSTAR GPS is to be used in safety related service, then denial of accuracy to a segment of users would almost certainly place the burden of liability on the providers of the service or onto those responsible for denying needed accuracy to a safety related service.

Question 5 asks how secondary users or special applications users can be accommodated in planning the future mix of navigation systems. The answer would appear to be dependent on whether national interest is involved and in the ability and the obligation of the potential secondary user to pay a fair share of user charges.

The final question asks what effect, if any, would user charges have on the future mix of radionavigation systems to be implemented and what effect would a proposed DOD user charge have on the implementation of NAVSTAR GPS.

The substantial user charges proposed by DOD for commercial users of NAVSTAR GPS will almost certainly create a strong lobby to continue present systems.

As a small boat operator living in Annapolis where I am in touch with many recreational boat operators, I believe that it is safe to say that most of the boat owners will vigorously oppose a user charge. The DOD estimate of a large market for a degraded NAVSTAR GPS is, in my opinion, grossly inaccurate.

down to what they said was less than 50 yards, and they could come up to the reefs, drop their gear, catch their fish, and make some money. Without those accuracies, they would lose some of their gear, catch less fish, and of course, not make as much money. So we learned all about the black books. I'm sure that there are entries being made into black books now, for LORAN-C. Use of a NAVSTAR satellite navigation system might not set well with the people who are getting LORAN-C up to the point where they thought they had LORAN-A. And it kind of bothers me to think that our government comes out with better ideas, provides improved service for a short period of time, and then tells the public we have something else in mind which we're going to charge you for, and we might have to turn off the system you are now using. The user fee system certainly is something that's uppermost in the minds of the towing industry because it's not only for aids to navigation, but it's also for channel maintenance, channel improvements and so forth. So we are very wary of anybody who says, "how much would you be willing to pay for something, that we don't know quite well what this service is, but we do know that it's going to be something better than you have?" So we're waiting, we're willing to look at it, but we're not willing to buy off on something that we don't know too much about, and they tell us that we might have to pay for it.

As far as navigation mix is concerned, we think what they have now is pretty good. OMEGA's a mid-ocean system, I don't know too much about it as far as our industry is concerned because we don't operate too much in the mid-ocean. I'm sure that some of our people who do operate in mid-ocean do use OMEGA and they probably use TRANSIT too. However, most of our people are coast-wise and would be more concerned with something like LORAN-C. We think that LORAN-C, like I said, can be improved upon and probably will be improved upon automatically as the people use it more and more. We're aware of what's going on in the Delaware Bay area with this black box (a PLAD system) and I've talked to the man who uses it and he says that it's great. He doesn't rely on it entirely by closing his eyes and piloting his ship by instruments, but he says it's doing what it's intended to do, and he finds it very useful. I think something like this could be used by towing vessels and other people, too.

As far as the question regarding NAVSTAR, if the accuracy is limited to 500 meters, would it be acceptable or useable by our industry? The answer is no. Why should we accept something that gives us nothing better than we have now and then be asked to pay for it. As far as the special applications are concerned, we think there may be a good use for LORAN-C in the transponder mode for locating vessels and so forth in areas of high congestion. Even in the river systems, such as the New Orleans harbor area. We think that LORAN-C might be used in the inland river system to identify underwater obstructions. In building and channelizing the rivers, the Corps of Engineers have put in many wing dikes or wing dams, that taper off from the shoreline and wind up some distance offshore submerged. We have no way of marking these submerged obstructions with short-range aids because the buoys just don't stay in place. I think if LORAN-C, or some system such as LORAN-C, were ever developed to the point where you could get the accuracies down to 10 meters or thereabouts, we could identify electronically these underwater obstructions and get some good use out of LORAN-C. This is maybe pretty far off into the future, because right now if you talk LORAN-C to somebody on inland rivers, they look at you and say, "well, we don't need it; our short-range system does the job."

The last question, what effect, if any, user charges have on the future mix of the radionavigation system, we think it will have a great effect. As I mentioned, we are

18. Panel Remarks by Thomas Stansell, Magnavox Corporation

Let me run through the questions first, and then a few general comments. First, do I see a need for a change in the navigation system mix? I think the question is wrong. This is not an issue of need, it's an issue of opportunity. So I think the real question is how do we use the opportunity of the coming availability of GPS, not do we need a change. The issues of taking advantage of that opportunity have been discussed before. There are three. Primarily cost, performance, and redundancy issues.

Let's talk about performance first. As Rudy Kalafus said yesterday, the full capability of the GPS SPS equals or exceeds everything available, LORAN-C included. Secondly, the DOD has certainly made plain that the SPS will have full accuracy at the earliest date consistent with national security. I would assume that in private conversations with the DOD and the DOT within the next few months, a projection of when that date will be could be established. So it seems to me we should be planning on the basis of the equal or better capability GPS, vis-a-vis all other systems, and that date be established, if it has to be privately, between the DOD and the DOT, i.e., the performance is there. Secondly, redundancy. We already have it. If we have full capability SPS GPS, we really don't need any other redundant systems that already exist. We have visual, we have radar, we have depth sounders, we have beacons. OMEGA is so complex and so full of errors that it seems to me that it makes a very poor back-up system to anything, and LORAN-C could be easily accommodated by GPS. The third issue is GPS equipment cost, and here's a very sticky one. GPS is inherently more complex than LORAN or TRANSIT equipment, therefore given an equal market volume, GPS should cost somewhat more, perhaps 10% to 30% more. At most 30%, more like 10%, is a reasonable guess. However, the market will not be equal. The GPS market is world-wide, not just local. The GPS market is not restricted to the sea. It also includes the air, which is a very large market, and the land, which in the long-term, believe it or not, will be the largest market. GPS is simpler to use than the other systems. There's no question about lane slips, am I working on skywave, is my receiver tweaked up? A GPS system gives you your position and it tells you if something is wrong with the equipment. Using differential GPS techniques, it provides the highest accuracy we can get from any other system, so all of the attributes are there. Therefore, the market will be very large, much larger than for the other systems.

Let's take a look at some equivalent costs, let's look at TRANSIT equipment costs. I'm very familiar with that. In mid-1976 we introduced a TRANSIT navigator at $25,000. At that big number it was still the cheapest TRANSIT navigator available. About six years later in January of this year, we introduced a satellite navigator for less than $3,000. That's a 32% per year decrease in the price of the cheapest satellite navigator you can buy. That's an amazing decrease, but it's real in this kind of market. So I'm absolutely confident that in 1988, roughly another six years, that there will be GPS receivers at less than $3,000 available to the general public. I mentioned automobile use. I also believe that we'll see volume sales of GPS sets for--you know, this is "James Bond-like navigators" in automobiles. That isn't as unreal as you might think. The Ford Motor Company is experimenting with TRANSIT satellite navigation right now for its luxury cars. Honda and other Japanese firms have introduced automobile navigation instruments, primarily dead-reckoning instruments. The interest in and the need for this kind of navigation is going to blossom in areas that we never even thought of before. So to the fundamental question, which I rephrased as how should we use this opportunity of GPS, I say we should plan to transition fully to GPS, but on a rational schedule. And I'll talk a little more about that.

per user, of the SPS system. Eventually though, I believe that's too high a number and should move down toward more like $100 a year as the number of users increases. Finally on user charges, there's a very important point that I'd like for you to pay attention to in here if you read it, and that is the American advantage. The American taxpayer and the American industry and government have developed the GPS system, at great cost, and the user charge mechanism is a way of providing an American advantage. For example, those who buy foreign-built equipment probably ought to pay somewhere between 10 and 100 percent more per year for use of the system than those who buy U.S.-built equipment.

Let me move to the rational transition policy. I suggest that there are two key criteria for transitioning from any system to GPS. One is the transition should begin only when GPS has demonstrated an equivalent capability. For example, both TRANSIT and LORAN should be retained until something like the 30 meter GPS accuracy is being provided, and then the transition begin. Secondly, the transition overlap interval should be long enough to prevent panic buying. Consider just the simple supply and demand issues associated here. The implication of replacing something over 100,000 LORAN-C units, and something on the order of 35,000 world-wide TRANSIT units, in say five years, is an enormous logistics issue. The probable result of such a rushed overlap would be inferior equipment, short supply of equipment, and higher prices than would otherwise would be necessary. So I suggest that something on the order of 10 years overlap from a demonstrated GPS capability is far more rational.

Finally, I'd like to almost throw out a challenge, if you will. I don't mean this in any antagonistic way, but I would like to recommend that the Department of Transportation shift away from a reactionary role vis-a-vis GPS. And seize what would be more of a leadership role. And the leadership role would be based on an advocacy position. An advocacy for the civil users of all navigation systems. An advocacy with Congress and an advocacy with the DOD. Not simply sitting back and saying to the DOD, "what will you give me?" but, "this is what our users require." Talking to Congress in terms of this is what is needed if this system is going to serve the needs of this broad range of civil users. Some of the issues that I think should be dealt with on an advocacy basis. They should call for and work for at least a seven, and preferably a 10 year, overlap interval on all present systems, including TRANSIT. They should lead the way in establishing differential GPS requirements and establishing and publishing specifications, even considering the use of LORAN-C facilities, such as antenna, or transmitter, if that's reasonable, for differential GPS. Become involved in the user charge issue. Somebody's got to collect user charges. It shouldn't be the DOD, as a military organization. It ought to be a civil organization. Perhaps it ought to be an independent corporation like Comsat is, perhaps it ought to be the Department of Transportation. And also the DOT should be responsible for communicating with all users. Unfortunately, they backed away from it on TRANSIT. I think that was a big mistake. They certainly ought to be the communication agent between civil users and the GPS system. If possible, call for something like the CA code or other means of getting access to the L2 signal. I think they should press, not just accept but press for the best accuracy consistent with national security, perhaps suggesting that accuracy be denied only in times of conflict. And finally, I believe the DOT should actively schedule a phase-out of existing systems based on the rational issue that I mentioned before; namely, that there be a long overlap interval and that there be an adequate capability on the part of GPS.

:onclusions. LORAN-C operates at low frequencies and it requires a moderate amount ›f processing power. GPS operates at L band, and requires a significantly greater ımount of processing power. Now, if you look at the advances in LSI and VLSI echnologies, in particular CMOS and if you look at where they're going to be in the ıext five, ten, fifteen years, and you take things such as switch capacitor filters, ligital signal processing, micro-processors and so on, it's not difficult for someone :onversant in the technology to visualize their application in an LF-receiver with nodest processing requirements long before a similar implementation exists for an L-›and receiver with significantly higher requirements. The conclusion I would draw is or the next 10 or 15 years, a LORAN-C receiver with the characteristics that I've just poken of will be significantly less costly than a GPS receiver. And to give you an idea .bout what significantly means, the gentleman sitting next to me mentioned a $3,000 igure for a GPS receiver in the 1988 time frame. I think that is quite probable, and by uite probable I would say certainly 90% confidence in this number, that if a market eveloped in the land mobile segment for LORAN-C we would be looking at, in the 988 time frame, a $300 LORAN-C receiver. I think that eventually technology will rive the cost of the actual electronics to the point where you're not paying for the lectronics any longer in the 15 year time frame, what you'll be paying for is the box ou put it in, the cables that connect to it, the people who sell and market it, the istribution chain, the advertising: the electronics will become a small factor in the 15 ears, certainly 20 year time frame. But for the next five to ten years, that won't be he case. So assuming that all factors are equal, and I say that this has to be emonstrated yet in the case of GPS, I think LORAN-C over the next 15 years, for the pplications that I'm interested in, is certainly the system of choice in any kind of a :ee market environment.

Question - unknown:

I would like to address the question to Mr. Stansell and put it this way, in view of the comments that Captain Torrens made about user charges and the fact that it would be very hard to control users, the use of equipment in the field, and in view of the ease in which the software industry, or the problems I would say that the software industry has had in pirating, would you comment on how you view the control?

Answer - Stansell:

I think without going into the details, I ought to really refer you to the article I mentioned because it does describe a technique which is sufficiently pirate free not to have that problem. Now, whether the DOD will follow that technique or some other technique, they are programming money to study exactly that issue, and I fully believe there are techniques that are, from a commercial point of view, adequate safeguards against piracy.

Question - Phil Stutes, with John Chance and Associates:

I'd like to ask a question of the panel, or perhaps Col. Martel, but one issue we have seemed to skip over in this conference is selective availability. Is that totally out of the question in the Department of Defense's mind now, to maybe give PPS access to certain people that could prove it would be in the best interest of our country to do so?

Answer - Mohin:

Well, I think the Defense Department has the answer to that question. In fact, they answered it two years ago when the first FRP came out. They said that they would examine those requests and where minimum safeguards could be maintained, they would allow access to the P-code. That was a public statement they made over two years ago. I don't know if I answered your question. If any of you have a question, Col. Martel has come over and volunteered to be part of this panel. He's here in the front row. So, if anybody has any questions for him, he's also here. Was I wrong in that, John?

Answer - Martel:

No, I thought I made that point yesterday. We'll certainly look at a case-by-case basis, and if the national interest is served and people can comply with security regulations, then I think it'd be considered favorably.

Mohin:

I think the only problem we had when that first came up was friendly-foreign civilian users, and we never really did address that.

Question - Vernon Weihe:

There has been considerable discussion since 1979 of position reporting, radio location, as discussed here. There is a common need for a single network to serve many different types of users because there are users out there who cannot support a network privately for their use. And I want to recommend that you look at the airline ACARS as a model for a common user network for radio location for a multiplicity of users.

APPENDIX A

Vritten Comments received after the Conference

\-1: Bureau of the Census

\-2: Defense Mapping Agency

\-3: Radio Technical Commision for Maritime Services

APPENDIX B

ist of Attendees

UNITED STATES DEPARTMENT OF COMMERCE
Bureau of the Census
Washington, D.C. 20233

NOV 24 1982

Mr. David C. Scull
Communications and Radionavigation
Program Manager, RSPA
Department of Transportation
Washington, D.C. 20590

Dear Mr. Scull:

The Bureau of the Census is exploring the possibility of using LORAN-C or other navigation systems to determine the location of rural housing units lacking standard-street addresses. Experience has demonstrated that rural units of this type are most likely to be overlooked during census enumeration, are the most difficult to identify and describe for followup and coverage control operations, and are most difficult to properly select for inclusion in a sample survey. Because of our interest in this technology, two representatives of our Division attended the Surface Transportation Users Conference at the Department of Transportation on November 16-17, 1982.

The following are our responses to the six questions discussed by the conference panel on November 17.

. LORAN-C seems to be the best system for our purposes; none of the others appear to be adequate. The comment was made that NAVSTAR/GPS readings shifted when a different configuration of satellites was used, as when one went out of service. The amount of this shift raises doubts about the suitability of this system for our purposes, even under the best of conditions. Without LORAN-C, our interest in such systems probably will disappear.

. We have a single application (as we see things at present); we recognize that others (such as mariners) have a variety of applications. Therefore, our response is that we are not concerned as long as a system that meets our needs is available; the presence or absence of other systems is irrelevant.

. The present system could always be improved in terms of resolution until the ideal goal of absolute accuracy is attained. Since this probably is impractical, we would like to see 10-meter relative resolution (between two objects or locations, or between two observations at the same location at different times) and improved accuracy in relation to the Earth's grid. With such improvements, we could consider applications in selected, if not all, urban areas.

. If NAVSTAR/GPS accuracy is limited to 500 meters, the system will be useless to us. If full accuracy is provided, it seems to be no better than LORAN-C (except that it would provide nationwide coverage without additional surface stations) and with the added problem of increased variability between readings as the satellite configurations vary.

DEFENSE MAPPING AGENCY
BUILDING 56, U.S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20305

2 FEB 1983

Mr. David Scull
Executive Secretary
DOT Navigation Working Group
Department of Transportation
Room 8407
400 7th St., N.W.
Washington, D.C. 20590

Dear Mr. Scull:

The DOT Surface Transportation Users Conference, 16-17 November 1982, provided an invaluable forum for exchange of information on presently available and prospective marine navigation systems. The Defense Mapping Agency (DMA) welcomed the opportunity to participate.

In your concluding remarks at the conference you invited submissions by attendees who recognized a need for further discussion of significant aspects of surface navigation. As an agency which provides navigational products and services for both military and civil users, DMA has explicit responsibilities for advising the user community of limitations imposed on those products and services by geodetic datum differences. Thus we would greatly appreciate the inclusion in conference proceedings of the follow-up comments enclosed.

Your cooperation in this matter is greatly appreciated.

Sincerely,

Capt. D.B. Eichmuehe, USN
for THOMAS O. SEPPELIN
Assistant Deputy Director for
Production and Distribution

Enclosure a/s

Through the auspices of the International Hydrographic Organization, the United States is promoting WGS as the internationally recognized coordinate system to which most of the various national datums on the charts can be referred. Decision No. 28 at the XIITH International Hydrographic Conference held at Monaco in April 1982, in fact, recommended that WGS be used as a basic worldwide reference system with the International Hydrographic Bureau acting as the focal point for distributing WGS transformation parameters, initially provided by the United States.

Improvements in worldwide navigational accuracy, which are anticipated with the implementation of the NAVSTAR Global Positioning System (GPS) in the late 1980's will be significant. However, one's ability to safely navigate with relation to hazards along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features - all positioned on the same satellite-based WGS reference system - are not available.

Readers who desire additional information on nautical chart datums should contact:

Director
Defense Mapping Agency
ATTN: PPH
Building 56
U.S. Naval Observatory
Washington, D.C. 20305

The second edition of the FRP that was published in the summer of 1982 incorporated some of the RTCM recommendations but omitted others, presumably due to time limitations and questions as to the desired scope of the FRP. Although verbal acknowledgements have been complimentary of the RTCM effort, there has been no definitive government response to the RTCM Report. A recent review of the report confirms that the vast majority of the RTCM recommendations remain current and valid. Since the FRP is the fundamental government policy document in radionavigation, your attention is again invited to the RTCM Report.

The RTCM Special Committee to review the FRP has recently been rechartered and given a broader and continuing mandate. The new committee is the RTCM "Oversight Committee on Radiodetermination Planning and Policy" and has the following Terms of Reference:

- To maintain an overview of National and International Radiodetermination Planning and Policy including review of the Federal Radionavigation Plan (FRP) from the point of view of all maritime interests and to make such recommendations to the Board of Directors as may be appropriate,

- To take note of new radiodetermination developments and follow similar activity being conducted by other national and international groups, maintaining liaison as appropriate, and

- To identify significant issues concerned with radiodetermination policy and make recommendations to the Board of Directors for establishment of Special Committees as appropriate.

Our purpose in highlighting the new Oversight Committee structure is to encourage a continuation of the excellent dialog generated by SC-78 and to renew the offer of RTCM assistance in the radionavigation planning process. We would also be pleased to designate liaison representatives to your Navigation Working Group or provide briefings on special user interests.

The RTCM members attending the Conference were unanimous in recommending to the RTCM Board of Directors that this letter be sent to the Departments and Agencies concerned with navigation planning, not only to reinforce our earlier recommendations in the SC-78 report, but to commend your Department for initiating the Conference and to renew our invitation to study specific issues in maritime navigation planning. There are additionally two points which were raised at the Conference which deserve more emphasis, as follows.

You will note that the new RTCM Committee is identified with the national term "radiodetermination". This is a broad term including both radionavigation and radiolocation, the latter describing posi-

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