PRECISE TIME AND TIME INTERVAL USERS, REQUIREMENTS AND SPECIFICATIONS

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ABSTRACT

Concurrent with the advanced technology for providing more accurate PTTI through improved devices and a greater variety of dissemination systems, the functional areas of application of Precise Time and Time Interval (PTTI) have also expanded. A comprehensive overview of the PTTI requirements and applications would provide an opportunity for individuals working in a specific functional area to identify mutual problems, requirements, applications or successes shared by those in other functional areas.

Based upon the results of a two year study conducted under the sponsorship of the USNO, this paper presents a compendium of PTTI requirements, applications and the means of meeting the requirements among Department of Defense components, other government agencies and major commercial users. In the course of the investigation it was found that the planning process for PTTI support for new acquisitions or new programs was less than a well defined, coordinated process. This paper describes the processes in general terms and presents a generic model for requirements determination and subsequent coordination which may enhance the planning process and introduce cost benefits to the program.

INTRODUCTION

In January of 1980, functioning in the role of the Department of Defense PTTI Manager, the U. S. Naval Observatory initiated a study of PTTI requirements. Although the central focus of the study was the DOD requirements, the scope of the effort was expanded to include the requirements of the other government agencies and significant commercial users of PTTI since many of them must maintain reference to the U. S. Naval Observatory master clock time. The purpose of the study was to gain an insight into the magnitude of current uses of PTTI, and projected requirements, in order to determine the objectives for upgrading the master clock system to provide the most accurate and cost effective service to the users. The identification of the users and their broad requirements were deemed sufficient to meet the objectives. Consequently, the details of specific systems equipments and wiring diagrams were not necessary. Key elements such as accuracy required, the type of standard used, the reference system for maintaining the standard and the functional areas of operation (e.g. communications, navigation etc.) provide sufficient information to establish the USNO objectives for improvements in the master clock.

APPROACH

The first step in determining the broad user requirements was to identify the users themselves. This effort had a two-pronged approach best described as a "top-down" and "bottom-up" approach.

The top-down approach began at the top level headquarters of the respective DOD components and other user agencies. In most cases the contact was made by a personal office call. However, some contacts were in group meetings and in a few cases where follow up action was not deemed necessary, contact was made by telephone only. The DOD Directive governing precise time and time interval (DOD DIR 5160.51) required the various components to issue implementing directives and provide copies of these directives to the OSD(C^3I). By tracing the implementing directive to the responsible staff agencies in each component the personnel most involved in PTTI matters were located. This approach also identified the next lower echelon assigned responsibilities for PTTI matters and lead ultimately down to the field activities maintaining PTTI. At first glance, the top-down technique exhibited all the promise of the most efficient and economical means of gathering the desired information. It was envisioned that within each component the higher level staff would have at hand the aggregate requirements of subordinate commands. These would then be available at a central location and serve to identify the PTTI users at the next lower echelon as well as the quantitative requirements as approved/understood by the higher authority. If the level of detail concerning the requirement was insufficient, it would at least provide the investigator with the identity of the source of further details. By virtue of centralized data sources, the top-down technique would economize on time and travel expenses as well as facilitate the compilation process for displaying the data and the subsequent analysis process. By definition, the top down approach would appear to be the best means to work down to the investigator's perception of "broad" requirements without becoming enmeshed in the diverse details of a multitude of users and their overlapping requirements.

In some instances this technique did not provide a well defined track to the individuals who had a comprehension of PTTI requirements. In many instances, although well aware of an overall program and an appreciation of a need for PTTI, the quantitative aspects of the requirement, and the means whereby it would be satisfied, were not clearly visible at the upper echelon of authority.

In an effort to isolate the elusive requirements information, a questionnaire was designed. Conceptually, the questionnaire would be directed to the PTTI participants identified in the top-down approach with the idea that they in turn would forward it down through the staff or command chain to the various levels where the requirements data were more accessible and better understood. It was a multipurpose questionnaire. A portion of it was designed to gather information on the management structure and organizational relationships and the remainder addressed the requirements.

Although the responses to the questionnaire proved informative in certain areas, they were not 100% effective in filling the gaps.

The combination of the initial staff contacts and a preliminary analysis of the responses to the questionnaire indicated that there existed a level of PTTI requirements that was eluding scrutiny. Those were the requirements associated with systems in the hierarchy of the planning and programming system which were not yet operational. In an effort to ferret out the PTTI requirements in this category, another format was designed with the intent of circulating it to selected program, acquisition, or system managers to provide the specifics on their respective PTTI requirements. Preliminary discussions with selected program sponsors and others in senior staff positions created some reservations about the circulation of the revised format as an augmentation to the questionnaire. In general, it was concluded that it would not be propitious to encumber an already overburdened system with the additional administrative details of responding to yet another inquiry. However, the search for the basic information was not abandoned. The data for selected systems were derived through research of various documents, papers presented at symposia, and through contact with knowledgeable individuals directly associated with these programs.

Concurrent with the "top-down" approach described above, a "bottom-up" approach was implemented. The basic philosophy supporting the bottom-up approach was to identify the myriad of PTTI users, aggregate their requirements and divide them into specific functional categories of use such as navigation, communications, etc. Having developed an aggregate display by category, then seek to identify the operational capabilities which established the PTTI requirements. As a departure point, the computer printout of the distribution list for time service announcements from the USNO was reviewed. Each user, by DOD component, was listed along with the type of announcements received. The objective here was to try to determine the principal functional category in which that user was operating by the very nature of the time service announcements received. In some instances the title of the using unit provided an insight to their principal functional category.

As an adjunct to the techniques applied in the top-down and bottom-up approaches, every effort was made to investigate all available data sources. Other sources of data included periodicals, individual papers published for symposia, government reports, directives and support agreements, contractors equipment specifications, and vendors editorial observations related to innovative means of dealing with PTTI requirements.

FINDINGS

Figure 1 presents a summary display of the DOD PTTI requirements compiled from the results of the investigative process described above. Also included in the summary are some other selected major users who are external to the Department of Defense. The first section of the display shows the major dissemination systems. These are referenced throughout the chart as the means whereby the users are calibrating their respective systems. Each component's data is provided under a separate heading.

Although the requirements vary over a wide range, many of the requirements are common to several components. In some instances the means of satisfying the requirement must vary due to the operational environment. Of particular note is the Navy's requirements. The Navy's requirements were compiled in a display which shows the separate requirement by ship class, aircraft class and shore installations. However the data in that form is classified and is available at the Naval Observatory in a separate report. By virtue of long term deployment covering most of the globe and independent operations, the Navy operational requirements are probably the most complex. The National Security Agency's requirements are also classified and are incorporated in the same report at the USNO.

Generally speaking, the most stringent requirements are associated with research and calibration facilities. Fortunately these activities are fixed installations and can provide controlled, stable environments for their standards. Most of the requirements range from 1 part in 10^{12} to 1 part in 10^{14} for frequency stability. The principal means of monitoring these systems is by portable clock, TV-10 and Loran-C. NASA presents the most stringent requirements, both current and projected, for a variety of programs such as space tracking, geodesy, and other investigative projects.

USER	PRECISION REQUIRED FREQ.	PRECISION REQUIRED TIME OF DAY	REFERENCED TO	STANDARD	PRINCIPAL USE
DISSEMINATION SYSTEMS					
Portable Clock	$1X10^{-13}$	100ns	Master Clock	Cs	Calibration/Synchr.
Defense Satellite Comm. System (SATCOM)	$1X10^{-11}$	100ns	PC, TV	Cs	COMM
Navy Navigation Satellite System (TRANSIT)	$1X10^{-11}$	100ns	PC	Rb	NAV
Geostationary Operational Environment Satellite (GOES)	$3X10^{-11}$		PC	Cs	NAV
OMEGA	$1X10^{-11}$	30μs	PC	Cs	NAV
LORAN-C	$1X10^{-11}$	1μs Gnd 50μs Sky	PC	CS	NAV
TV-10	$1X10^{-12}$	1μs	PC	Cs	Calibration
Global Positioning System (GPS/NAVSTAR)		1μs	PC, LORAN-C, TV-10	Cs	COMM/NAV
HF Radio	$1X10^{-7}$	1000μs		Hm, Cs	Calibration
VLF	$1X10^{-12}$	1-10ms			Calibration
NOTSS (Richmond)	$1X10^{-12}$		PC, TV, LORAN-C	Cs	Calibration
U.S. AIR FORCE					
Aerospace Guidance and Metrology Center (AGMC)	$1X10^{-12}$		PC, LORAN-C, TV-10	Cs	Calibration/Reference
Precise Time Reference Stations (PTRS) (24 in number)		2-40μs	VLF, LORAN-C, TV-10	XTAL	Calibration/Reference
Precision Measurement Equipment Laboratories (PMELS) (117 in number)	$1X10^{-10}$ to $5X10^{-11}$		VLF	VLF Phase Comp. (Cs)	Calibration

REQUIREMENTS SUMMARY
Figure 1

USER	PRECISION REQUIRED		REFERENCED TO	STANDARD	PRINCIPAL USE
	FREQ.	TIME OF DAY			
U.S. AIR FORCE (Cont'd)					
Hanscom AFB	$1X10^{-11}$		LORAN-C	Cs	Research
AF Communications Facilities	$5X10^{-10}$		Self-Sync.	XTAL Oscill.	Communications
AF Aeronautical Laboratory	$1X10^{-11}$		PC	Cs	Calibration/Research
MSL Warning Squadron	$1X10^{-11}$		PC	Cs	Synchronization/ Time
Eastern Test Range	$1X10^{-11}$		PC, LORAN-C, VLF	Cs	Range Tracking/Time
Western Test Range		$\pm$ 2μs	PC, LORAN-C, VLF TV-10	Cs, Rb	Range Tracking
Air Defense Command	$1X10^{-10}$		PC	Rb	Communications/Time
FUTURE SYSTEMS					
SEEK TALK I & II		3ms	-	Rb or XTAL	Secure Tactical Comm.
HAVE QUICK		3ms	Transit Satellite	Rb	Tactical Comm.
MEECN				Cs	Emergency Comm.

REQUIREMENTS SUMMARY (Continued)
Figure 1

USER	PRECISION REQUIRED		REFERENCED TO	STANDARD	PRINCIPAL USE
	FREQ.	TIME OF DAY			
U.S. ARMY					
U.S. Army Metrology & Calibration Center (USAMCC)	$1X10^{-11}$		WWV, VLF	Cs	Frequency Calibration
U.S. Army Electronics Research & Development Cmd (ERADCOM)	$1X10^{-11}$		LORAN-C	Cs	Frequency Calibration
U.S. Army Communications Cmd Timing Division (Code CCNC-TWS-T) White Sands, NM		+1μs(USNO)	LORAN-C	Cs (Four)	Range Timing
U.S. Army White Sands Missile Range (Code QA-CB)	$1X10^{-11}$		LORAN-C, PC	Cs (Three) Rb (Two)	Range Tracking
U.S. Army Test & Evaluation Cmd Yuma Proving Gds, (Code STEYP-MOP-E)	$1X10^{-11}$		PC (USNO)	Cs (Two)	Range Timing
U.S. Army Area Calibration & Repair Center, Aberdeen Proving Gds, MD	$1X10^{-11}$		VLF, WWV	Cs (on order ETA 11/81)	Calibration
U.S. Army Area Calibration Laboratory, Lexington Bluegrass Dept., Lexington, KY	$1X10^{-12/13}$		VLF	Quartz Crystal (Victorian 33)	Calibration

REQUIREMENTS SUMMARY (Continued)
Figure 1

USER	PRECISION REQUIRED FREQ.	PRECISION REQUIRED TIME OF DAY	REFERENCED TO	STANDARD	PRINCIPAL USE
FUTURE SYSTEMS					
Modular Integrated Communications & Navigation System (MICNS)	$1X10^{-10}$		-	Rb	Navigation & Communications Data Link
Single Channel Objective Tactical Terminal (SCOTT)		± 20μs/7 days	-		Armored Vehicles Tactical Satellite Link
Single Channel Ground Air Radio System (SINCGARS)			-	Cs	Tactical Communications
Advanced Quick Look	(in Bidders Competition)		-		EW
NATIONAL AERONAUTICS & SPACE ADMINISTRATION					
Space Tracking & Data Network	$1X10^{-14}$	25μs	PC, LORAN-C, HF	Cs	Space Tracking
Tracking & Data Relay Satellite System (TDRSS)	$1X10^{-14}$	40ns	PC, LORAN-C	Cs, Hm	Space Tracking
Laser Ranging Network	$1X10^{-14}$	± 1μs	PC, LORAN-C, TV	Cs, Hm, Rb	Laser Range
Space Shuttle	$1X10^{-15}$	< 1μs	PC, LORAN-C, TV	Cs, Hm, Rb	Shuttle, VLBI Lasers
SIRIO/LASSO	$1X10^{-15}$	ns	TDRSS, GPS, Laser, TV,PC	Cs, Hm, Hg	VLBI, Crustal Dynamics Scientific Satellites Deep Space Mission GRAVSAT

REQUIREMENTS SUMMARY (Continued)
Figure 1

USER	PRECISION REQUIRED FREQ.	PRECISION REQUIRED TIME OF DAY	REFERENCED TO	STANDARD	PRINCIPAL USE
U. S. Navy					
Ship Platform	$1X10^{-10}$ to $1X10^{-12}$		PC, DSCS	Cs, Crystals	COMM. NAV
Air Platforms	$1X10^{-11}$		PC, VLF	Rb	
SHORE Installations	$1X10^{-12}$		PC, LORAN-C TV-10, Hm	Cs, Hm	COMM, Calibration, Research
DEFENSE MAPPING AGENCY					
Elmendorf AFB, AK	$1X10^{-11}$		PC	Cs	Geodesy
Herndon, VA	$1X10^{-11}$		PC	Cs	Geodesy
Warren AFB, Geodetic Squadron, WY	$1X10^{-11}$		PC	Cs	Geodesy
DMAAC/RDGS, St. Louis, MO	$1X10^{-11}$		WWV	Crystal Oscillator	Geodesy
DMA, New York, NY	$1X10^{-10}$		VLF	Crystal Oscillator	Geodesy
DMA, Thule, Greenland	$1X10^{-10}$		VLF	Crystal Oscillator	Geodesy
DMA, Mahe Island, India	$1X10^{-10}$		VLF	Crystal Oscillator	Geodesy

REQUIREMENTS SUMMARY (Continued)
Figure 1

USER	PRECISION REQUIRED		REFERENCED TO	STANDARD	PRINCIPAL USE
	FREQ	TIME OF DAY			
FEDERAL AVIATION ADMINISTRATION					
FAA Technical Center, Atlantic City, NJ	$1X10^{-10}$		WWVB (Switching to GOES)	Cs	Navigation Test Range
U. S. COAST GUARD					
LORAN C	$1X10^{-11}$		PC	Cs	
OMEGA	$1X10^{-11}$		PC	Cs	
SMITHSONIAN INSTITUTION					
Astrophysics Lab		+ 2-6μs	PC, OMEGA LORAN-C	Cs/Rb	Satellite Tracking

REQUIREMENTS SUMMARY (Continued)
Figure 1

USER	PRECISION REQUIRED		REFERENCED TO	STANDARD	PRINCIPAL USE
FUTURE SYSTEMS JOINT	FREQ.	TIME OF DAY			
HAVE QUICK		3ms	Transit Satellite	Rb	Communications
MEECN (616A)		3ms		Cs	Communications
TRI-TAC	(a) $1X10^{-11}$ (b) $1X10^{-10}$ (c) $1X10^{-7}$		Autonomous	(a) Cs (b) Quartz XTAL Oscillator #1 (c) Quartz XTAL Oscillator #2	Communications
CIS		10µs		Rb	Identification
DCS TIMING	$1X10^{-11}$		LORAN-C	AN/GSQ 183	Communications

REQUIREMENTS SUMMARY (Continued)
Figure 1

The next level in the hierarchy of requirements appears to be at the test ranges, Eastern and Western test ranges under the Air Force, and Yuma and White Sands under the Army. The requirement is in the order of 1 part in 10^{11} and time of the day to within $\pm$ 2 microseconds of the USNO master clock. Again portable clocks, Loran-C and TV-10 are the princiapl sources of reference. Very close to this level of accuracies, 10^{-11} to 10^{-10}, is a wide range of communication systems and data links which relies on timing for security of digital transmission of large volumes of data. Fortunately, all of the components share these requirements. Since the systems are tactical or strategic systems deployed with operational forces, the standards which support the system seldom enjoy the luxury of a controlled environment. Additional performance criteria must be considered such as size, weight, acceleration sensitivity, temperature range, warm up time and power supply. Delicate trade offs are necessary to achieve the operational objective at a reasonable cost. For some of the "future systems" listed in the chart, these tradeoffs are currently in process and the data needed to fill in the chart are not readily available.

The Air Force has widely-dispersed forces. However, their facilities are geographically fixed in nature and independent deployments are of relatively short duration. They have structured their PTTI facilities to cover their needs through the geographical distribution of some 24 Precise Time Reference Stations, each equipped with a standard Time Console unit containing two reference clocks, Loran-C receivers and VLF receivers. In addition there are one hundred and seventeen Precision Measurement Equipment Laboratories worldwide. Their equipments vary in nature from VLF comparators to cesium standards depending upon the nature of the facility being supported.

If one focuses on the future requirements of the Services, it becomes apparent that the operational requirements and the nature of PTTI problems are converging to a common ground. This is driven primarily by sophisticated communication systems and position location equipment which will be widely dispersed in tactical deployments. For example the Army is developing the Single Channel Objective Tactical Terminal (SCOTT) which will require time of day within $\pm$ 20 us and may conceivably require the deployment of several hundred cesium or rubidium clocks. Other future Army systems such as Single Channel Ground Air Radio System (SINCGARS) and Modular Integrated Communication System (MICN) may also add cesium or rubidium clocks to the operational forces. These deployments will clearly change the complexion of the program from that of a laboratory, fixed-installation problem to those problems similar to the Navy's in support of deployed operational forces. There are many joint systems under development which will inexorably spread the problem uniformly among the services as common users.

PTTI REQUIREMENTS PLANNING

The investigations implemented in researching the requirements, revealed some interesting facts regarding the PTTI requirements planning process. For the purposes of this discussion the PTTI users within the components can be divided into three functional communities; the R&D community, the Logistics community, and the Operational community. PTTI requirements are viewed from a different perspective in each of these communities. One of the first key observations which can be made with few exceptions is that there is no central overseer in the components who transcends the individual boundries of these communities in order to translate the separate requirements into a common statement of the overall component requirements. Consequently, in researching requirements, each community within the components had to be queried separately. With different perspectives, the statement of requirements takes on a different form. A statement of requirements from the operational community is in operational terms. For example, the requirement may be to achieve secure communications between points A and B, or determine position location, worldwide, to a specified accuracy. The operational representative may or may not be aware of the fact that precise time or time interval is a necessary element of the system to achieve the objective. The investigation then shifts to the logistics community and specifically the acquisition manager; or for systems currently operational, to the metrology and calibration support agencies. The acquisition manager, on the logistics side, is more technically oriented and will generally acknowledge the need for PTTI. However, the manner in which it is to be provided and the specific criteria are not always known. The PTTI portion is viewed as a subsystem to the prepared design which will meet the operational requirement. As we follow the track to the design engineer, to subsystem engineer, etc. the availability of data on PTTI increases considerably. In some instances the final answer rests with the commercial contractor who is assembling the entire system and knows precisely how the timing problem is to be solved. The R&D community has a split view of the issue. On the one hand their attention is directed to their own internal PTTI requirements, on site, for use in research. On the other hand they must be constantly aware of the operational objectives to insure that they keep pace with the requirements. This community shares the frustration of not having a central point of contact which can bring together information regarding PTTI requirements and related activity in the other communities. The net result of the current process is a somewhat fragmented process in PTTI requirements development.

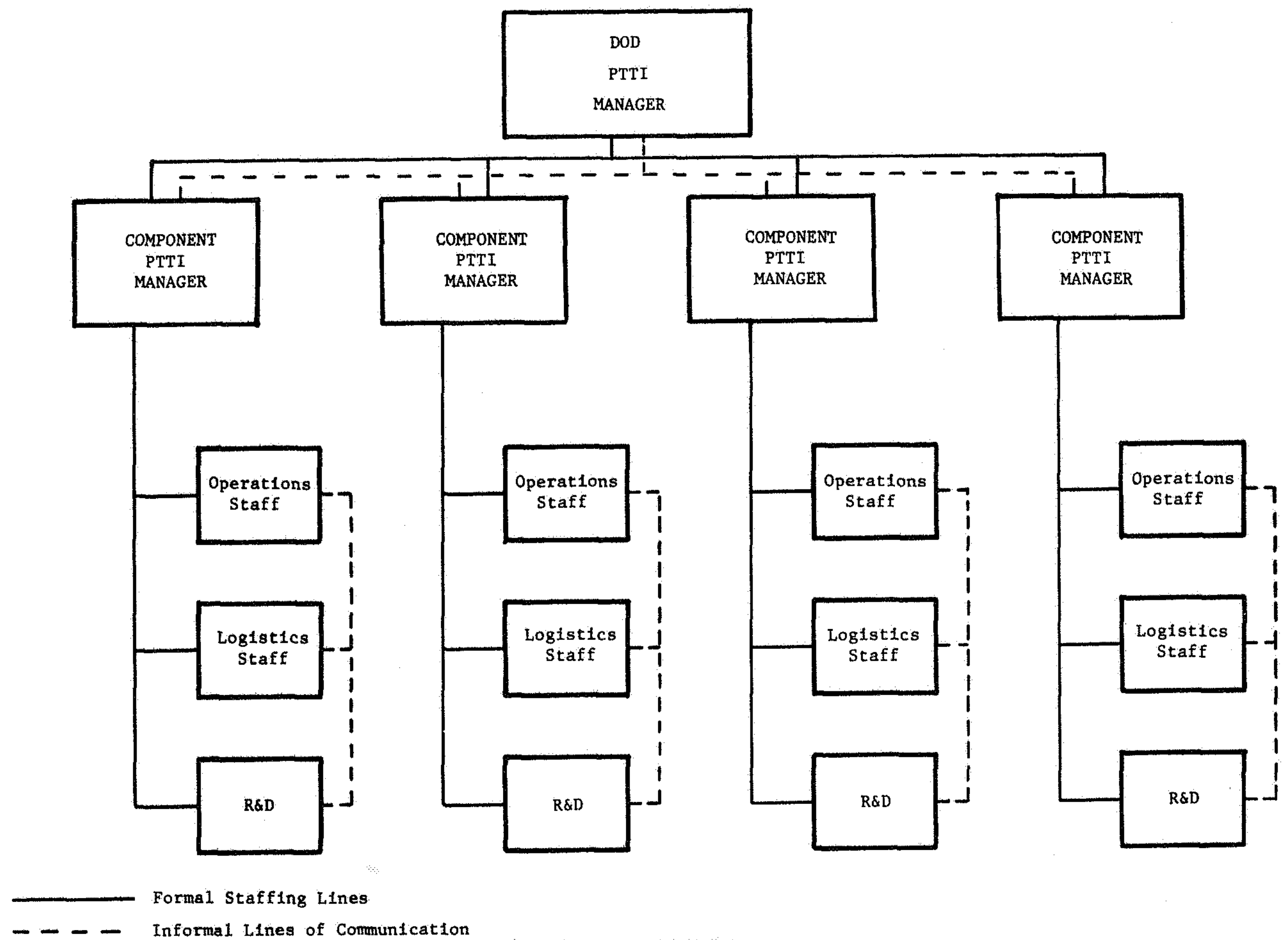
Given the above facts, we might well question how the PTTI program continues to function as well as it does. It does so through the initative and dedication of the participants who are willing to override the lack of a formalized staffing system and to communicate with one another to the degree necessary to accomplish their tasks. There is a complex information exchange network among components, among communities, and even from one component's community to a different community in another component. Although functional, it is time comsuming and less then efficient.

A clearly-defined PTTI requirements development process requires a well-delineated organizational structure within which it operates. One such structure is depicted in Figure 2. Each component would have a central PTTI manager assigned, preferably operating on the highest staff level in order to exercise coordination over the separate communities in each component. This is not essential if the necessary coordination authority is unequivocally established in the governing directives and clearly recognized by all participants. A central point of contact is available, and known, to the DOD PTTI manager. Within each component the requirements are brought to a central point where the activities of the other communities are also known. The manager would be able to match current metrology and calibration capabilities with new requirements; provide feedback to the R&D community as to operational requirements and insure that the operational community is afforded the most cost effective and efficient support for his system. By requiring formal coordination with the PTTI manager, early identification of PTTI needs is achieved. All participants become aware of the requirements and a solution is drawn from a full knowledge of the technology available to the entire program. This in turn would tend to converge on standard equipments and common techniques for accessing dissemination systems and maintaining standards. Production line items would begin to replace development models thus providing for economies in acquisition cost, commonality of maintenance and support, uniform training, and a basis for gathering meaningful statistical data on performance parameters which in turn can be used to focus the efforts of the R&D community on the problem areas.

The DOD PTTI Manager would become an active participant in the planning process with well-established lines of communication to centrally-managed programs. With better visibility of the DOD requirements and active participation in the process, the DOD PTTI manager will be better able to meet his responsibilities of providing an efficient and cost-effective DOD program.

SUMMARY

Current PTTI requirements cover a wide range of criteria with space systems and basic research heading the list of the most stringent demands for accuracy and stability. Users' requirements are being accommodated through a variety of time dissemination means. The reliance on portable clocks is declining as improved systems and techniques are developed. Almost uniformly throughout the user



CONCEPTUAL PROGRAM STRUCTURE

Figure 2

community, GPS/NAVSTAR and the realization of its full potential is viewed as one of the most important factors in future planning. With the advent of the more sophisticated communications systems and data links which are becoming common to all components, the character of the components programs are merging to a single identity. The time is propitious to institute management initiatives which will insure a fully coordinated DOD program. This can be accomplished without any great reorganization or cost and the return on the investment can be realized in all aspects of the program.