INTRODUCTION TO PLANNERS PANEL

DR. WINKLER: Thank you, Nick. I think we should go right ahead and ask the panel to comment on future time requirements as they can be expected from the point of view of systems. May I ask the first.

MR. CITTADINO: Okay. Thank you. What we will attempt to do is to try to give you a view as we see it of the requirements for timing from four different perspectives. I will speak very briefly on the perspective of the Department of Defense with respect to communications, command and control and intelligence systems. I'll be followed by Dr. Stover who will speak on the requirements from the communications point of view as seen from the Defense Communications Agency. Dr. Goblick will talk from his experience in the laboratory which is working on numerous projects which rely very greatly on precise timing. And then Dr. Garvey will speak from an industry point of view, what he sees coming down the pike in the relatively near term from his viewpoint in industry. So, without further ado, let me get into what I'd like to say.

PLANNERS PANEL

Panel Chairman: John C. Cittadino, Director, Theater and Tactical C^3, Office of Secretary of Defense

When Nick Yannoni asked me to participate on this panel, we agreed that it would make sense that I talk about the importance of precise timing to military operations and military command, communication and control (C^3) sys-systems. All my life I've read and heard war stories and how important timing has been in the winning and losing of the key battles in most of the world's great wars. But being an expert in neither warfare or the science of precise timing, I felt compelled to go to the history books in an attempt to establish the origin of the use of timing in warfare. And as near as I can pinpoint it, it all began with Alexander the Great early in his career during the war with Tyre in 332 B.C.

It seems that Alexander was having a very hard time with the Tyrians who had for seven months resisted the siege of his forces. It eventually became apparent that his difficulties were caused by the failure of the various legions under his command to coordinate their attack. Those of you familiar with Alexander's accomplishments will recall that he was the first advocate of truly balanced and combined arms warfare; bringing together legions of sword carrying infantry with those made up of spear carriers, archers, javelin throwers and finally cavalry. Sitting despondently in his tent one evening after another severe setback, he racked his brains trying to come up with the solution to his dilemma. He knew that he must snychronize his attack, but exactly how remained the question. Then recalling the teachings of his mentor Aristotle, to always look to science for the answer to seemingly unsolvable problems, he remembered the discovery of one of the alchemists who was part of the large entourage of scientists and engineers who were an integral part of Alexander's army. It seems that a dye had been produced which possessed the remarkable characteristic of always changing color from red to green with the same precise time interval after the mixing of the individual components.

He summoned his alchemists and had them mix a large amount of the dye and then used it to color strips of rag. He next summed his combined arm commanders and laid out the plan for a new attack the next day on the Tyrian forces. He emphasized that the attack must be initiated, enmasse, at precisely the right time. They would know the right time by watching the rag bands, which they would each tie around their wrists - and he proceeded to hand out the rags with the special dye.

Of course, I'm sure you've already guessed the rest of the story, the battle was a rout; Alexander overthrew Tyre and with his use of finely coordinated combined forces, using the newly invented technique for precise timing he went on to conquer the lands from Southern Europe across the Mediterranean and as far east as India. And it all happened because of the world's first Alexander's rag time band.

But in thinking seriously about time, it seems that those of us in the systems business tend to take it for granted. We generally tend to put timekeeping into one of two categories. The first is when we take a quick glance at our wrist, where we see a device that has served us pretty well over the years. In this day and age even those watches we used to see in the TV commercials strapped to the tip of a ski jumper's ski or sumerged for days under the ocean have gone to quartz technology. They boast of accuracy on the order of one or two seconds per month. As long as it continues ticking after unspeakably inhumane treatment and provides reasonable accuracy, what more could be asked of our trusty time-pieces. Or on the other hand, we may not take quite such a cavalier attitude toward time. We recognize that accuracy and precision are necessary in certain walks of life. We tend to think, however, that precise time is somehow the province of the research scientist secluded away somewhere in his laboratory, who needs to split the second into ever shrinking, but more precise, increments to satisfy his scholarly pursuits.

I'd like this morning to depart from both of these views of time and assure you that we in the systems business need to become much more cognizant of the absolutely critical role precise time will play in the "Real World" of future military operations.

Accurate time is indispensable for numerous technological, commercial and scientific purposes. Closer to home, command, control, communications and intelligence (or C^3I) systems -- both those currently in operation and those still on the drawing boards -- and our very ability to successfully employ sophisticated electronic systems in battle is intimately tied to the timing sources dispersed through the various echelons of our military forces. In general, C^3I systems timing requirements fall into either one or two of two major categories. First, are the various communications systems requiring synchronization to on the order of tens of microseconds, or less, due to the increasingly high data modulation rates, time division multiplexing, and the use of precisely synchronized spread spectrum transmission techniques. Second are users of synchronization for positioning systems. Time and frequency are also essential for identification systems such as Identification Friend or Foe (IFF) or collision avoidance systems.

I'm told that a famous astronomer once observed that, "We don't know what data astronomers will want in the next twenty years, but we are sure that they want it with much greater accuracy." I can't speak for the astronomers of the world, but I do know that a similar statement could be made of needs for increased timing accuracy with DoD C^3I systems. Moreover, I don't expect it to take twenty years before we see extremely stringent timing demands becoming an integral part of the specification for all of our evolving command and control systems.

Today the state-of-the-art in the timing world will support, and consequently we have to be satisfied with, atomic frequency standards which provide precisions of a few parts in 10^{11} and support time synchronization to 100 nanoseceonds, this only on a local level. Emerging C^3 systems will require rugged frequency standards with much greater long-term stability and with global time synchronization to 100 nanoseconds. NAVSTAR GPS hold real promise for global time synchronization to the 100 nanosecond level. In fact, prototype receivers have been checked out that provide time transfers on the order of 30 nanoseconds.

A study of future timing requirements across the US government has recently been completed. This study confirmed that timing accuracy requirements are, in fact, expected to become even more severe. Generally speaking, the most stringent requirements would appear to be associated with research and calibration facilities. This is probably a fortunate happenstance since these activities are generally fixed installations where controlled, stable environments for the timing standards can normally be made available. It was interesting to note that on the unclassified requirements in this category, NASA's were generally the most stringent for a variety of programs such as Space Tracking, Geodesy and other investigative projects.

However, there is a wide range of emerging systems to be fielded that will impose requirements nearly as stringent as those imposed on the calibration or laboratory instruments. Already on the drawing boards and, in some cases, nearing actual deployment to the field is a wide range of communications' systems and data links that rely on timing for security, integrity, and jam resistant digital transmission of a large volume of data.

On the positive side is the fact that the emerging operational requirements and the nature of the timing problems are converging to a common ground. This is driven primarily by the sophisticated communications 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). This system will require time of day with $\pm$ 20 microseconds and could conceivably necessitate the fielding of several hundred atomic -- cesium or rubidium -- clocks. Other planned Army systems such as the Single Channel Ground Air Radio System (SINCGARS) could also add cesium or rubidium clocks to the operational forces. Such additional programs as Have Quick, JTIDS, PLRS, TRI-TAC, and the Combat Identification System will all carry with them stringent requirements for accurate time synchronization in order to function effectively in their planned environments.

As these and other planned C^3I systems move from the drawing board into the operational inventory, the complexion of the DoD's timing program will clearly change from that of a Laboratory, fixed installation problem to the problem of supporting deployed operational forces. As the complexion of the program switches from the relatively benign controlled laboratory environment, a whole new set of design and performance criteria must come into play.

Consideration must be afforded such additional criteria as size, weight, acceleration sensitivity, temperature range, warm-up time, and power consumption. The timing sources must be reliable under field operationing conditions and supportable when deployed. Most importantly, our timing sources must be affordable. We are taking measures to encourage the services to standardize on a family of common timing components, so that costs of both production and logistics will be reduced.

The need is there. Electronic systems of all kinds, navigation systems, communications systems, weapons systems, radar systems, missile systems, computers, and many others are going to be increasingly dependent upon precise time. If our weapons systems of the future are going to be able to do their job, either singly or collectively, a precision timing system is of the essence. Both the timing system and the host systems themselves will need to be affordable, economic in operation, and capable of worldwide use. This challenge is there for all of us, then. It will take individual expertise in our respective areas and a close harmonization of our efforts to assure meeting this challenge and deploying the effective and affordable C^3I systems that will be needed to support our combat forces on any future battlefield.

PLANNERS PANEL

Panel Member: Dr. Harris A. Stover, Defense Communication Agency

A worldwide switched digital communications system has never existed, but in the future the Defense Communications System (DCS) is expected to be such a system. This will result in timing problems not faced before.

At the present time, the DCS is an analog system that uses considerable digital transmission. The signals are returned to analog form at switches, and they can be retimed during analog to digital conversion. Also, at the present time, those signals which must pass through the system in digital form are usually applied to modems for transmission over these analog channels. there are many advantages to replacing these analog channels with digital channels so that all signals will be carried in digital form throughout the network. When this is done, the opportunity for retiming during analog to digital conversion at switches will be gone, time division multiplexing will be more extensively used, and digital switching will employ time slot interchange. Digital channels from many origins will have their bit streams interleaved in a pattern that changes as the connections through the network change. In such a digital network it is very important that a bit originating anywhere in the world be available at the instant when it is needed at every communications node through which it passes. Note that this is a phase (or time) control problem and not just a frequency control problem.

There are many methods by which the required phase coordinations can be provided. However, most of them will not satisfy the requirements of a wartime defense communications system. All of the different methods employ buffers for the temporary storage of bits to accommodate variations in signal propagation time and small clock errors. When the phase errors exceed the capacity of the storage buffers, a slip occurs. This is a timing event that will disturb the normal flow of traffic. In civilian digital voice systems slips are normally made exactly one frame at a time. In these systems, by doing it this way, the result is either the deleting or repeating in each channel of just one of the 8000 Pulse-Code Modulation (PCM) voice samples that occur every second. This is a minor disturbance. When other types of voice coding are employed, which do not use PCM samples, the effect can be much more severe, and it can also be more important for some types of data transmission. Furthermore, when encryption is used, it isn't so simple to slip exactly one frame at a time. This becomes particularly important if both link encryption and end-to-end encryption are employed. In a switched digital military communications system, where all channels are digital, a timing slip might commonly cause the interruption of traffic while several pieces of equipment are sequentially resynchronized. Therefore, timing slips are much more serious in a military application than in a civilian application.

The major difference between military and civilian applications comes from the requirement for military communications to survive in a wartime environment, even in the face of a concerted enemy effort to destroy them. The survivability of nearly slip-free communications in a switched digital communications system is dependent on the survivability of accurate system timing. Accurate timing can also be an aid to reestablishing communications that have been lost. At present we employ precise clocks at major terminals of the Defense Satellite Communications System (DSCS) to aid the rapid synchronization of spread spectrum receivers in the presence of jamming.

Because of the importance of survivable system timing to a worldwide switched digital military communications system, at this meeting in 1979, I presented a set of "attributes for timing in a digital DCS" and explained the importance of each attribute. Those attributes were later published by the Defense Communications Engineering Center in Engineering Publication 1-80. Our studies have shown that the technology to provide these attributes exists. No breakthroughs are required, and the cost is not much greater than for any of the other approaches considered.

These desired attributes can be listed briefly as: (1) reference to Coordinated Universal Time (UTC) whenever such a reference is available, (2) specification of tolerances in time or continuous phase, (3) freedom from dependency on any particular facility, (4) self-organization, (5) availability of timing so long as any communications link to a node survives, (6) ability of nodes to rapidly reenter the network, (7) timing disturbances not propagated through the network, (8) avoidance of traffic interruption to reset buffers, (9) capable of most effective use of a free-running mode, (10) systematic self-monitoring, and (11) open options to apply new technology as it develops.

These attributes can be interpreted as saying that our network must be self-sufficient in its timing capability. Each major node must have its own clock together with those alternates required for reliability. These clocks should be coordinated with a timing reference distributed through the communications network. The master clock for the network and paths by which timing is distributed must be automatically selected. Even this selection process must be distributed throughout the network so that every node can automatically make its own decisions with no centralized decisions made anywhere in the timing system. Then any facilities can be lost, and the network can undergo massive destruction, but both the selection process and the rest of the timing system will still work properly. If the network becomes fragmented, each fragment will automatically select its own master and the paths for timing distribution. That master will be referenced to UTC when such a reference is available. This has the advantage of permitting any node to use an optional UTC timing reference from a navigation system if it is available. Referenceing to UTC could sometimes be helpful in restoring operation between fragmented portions of the network.

Since any major node in the network is capable of serving as master for the entire network or any fragment of it, the system does not require UTC in order to operate properly. By maintaining timing system accuracy and preventing timing disturbances from propagating through the network, both of which are practical, a high degree of timing stability can be maintained. This could be very useful in a free-running mode to help a node reenter the network after temporarily being separated from it, particularly if spread spectrum signals must be acquired in a jamming environment.

All of these things put together will provide synchronized clocks at each major node in the network for so long as any communications link to the node is operational and for a considerable period of time following the loss of the last link to the node.

It might seem that providing all of these things would be very complicated. It is not! Most of the algorithms employed are very simple, once they are understood. However, a microprocessor is required at each node to carry out the algorithms and provide the needed automation. It would not be possible for the system operators to do this.

In present civilian practice, the lowest level of digital voice multiplexing, which carries 24 voice channels, provides 8000 synchronization bits every second. Once synchronization bits are available, the addition of a few hundred bits per second on each transmission link will make possible the network timing capability that I have just discussed. Since a system with stable timing capability needs but a small fraction of the 8000 bits per second for link synchronization, some of those unneeded synchronization bits could be used for the other system timing bits. Alternatively the other timing bits could use a portion of a service channel.

The most complex algorithm under consideration for communications system timing is one related to predicting clock errors and removing those predicted clock errors when it is necessary for a clock to free-run following a period of normal operation during which calibration procedures are applied. Successful application of this algorithm could permit the use of lower cost clocks at some locations, or improvement in operation during a free-running period, or both. Studies for use of this last algorithm and the integration of it with other algorithms are still to be completed. Whether this last algorithm is implemented or not, it is practical to use the other algorithms to provide a very survivable, accurate, timing capability for nearly slip-free operation of a worldwide switched digital defense communications system.

PLANNERS PANEL

Panel Member: Dr. Thomas Goblick, Lincoln Laboratories

I have a few remarks I'd like to make from the system designer's point of view, and have some view graphs. I'd still like to use them if I can set up the machine.

From my position in viewing a number of large scale systems with many hundreds and thousands of users in the tactical environment, these are some of the key applications of precise timing and timing measurement. We know what the classical position location problems, two-way ranging radars, but currently we see more of the trend to one-way ranging. Deriving the position of users in a communication system where the users are tightly synchronized, passive multi-lateration systems are of great interest where time differences of arrival measurements at remotely located points are important to bistatic radar. Synchronization of communication systems is also a very important aspect. The time to enter a community of communications users depends on how far off the new users clock is, signal acquisition time and that also is directly related to the amount of processing that must be done to acquire a signal in the net and that depends on the time of uncertainties. Time division multiple access systems divide the time line precisely and the more precisely it can be divided without guard intervals the more capacity one might be able to get. In all these intercommunication systems relate to just how much overhead the communication system must provide, must carry out in order to maintain time synchronization to get users in the system and to keep their processors from being overloaded.

The tighter the time synchronization the simpler the system can be, and the less transmission can occur or need occur just for the purposes of synchronization and this leads to tighter transmission control and this is a very important factor in a tactical environment.

The last item I have is security. We talk of encrypting messages and we must insist that it is function of time as the position doesn't change for a very long time, conceivably an enemy could intercept one of the transmissions and use it for his purposes.

And so, for an active exploitation type of mode. Let me discuss, a little bit here, the one-way ranging problem which is more stringent than the two-way. I have plotted here the fractional timing error required as a function of the synchronization interval, of the users' clock and the upper right curve one-way ranging to an accuracy of 10 microseconds. This is the curve I'd like to talk about.

This curve is a trade-off curve, in my view, for a one-way ranging system which would provide an accuracy of 10 microseconds. My approach would be to take the approach that JATIDS (Joint Tactical Information Distribution System) took and design a system architecture around a set of protocols that pass time around constantly within the system.

So that a user can enter the system with a poorly synchronized clock and eventually synchronize that clock and then be a full participating user and if his clock is a very good one, he in turn may have time accuracy eventually good enough to pass on to someone else.

The synchronization interval in a system like JATIDS is a fraction of a second. And for this level or even the one microsecond level of one-way ranging accuracy you see the clock demands for that kind of JATIDS terminal are pretty miniscule. But the system has paid in terms of complexity and in terms of extra time to do the processing and in terms of the use of the system, how much transmission takes place.

On the other hand one could take the other approach that one had a really stable clock. One wanted to simplify the system, one could say, I'd like to synchronize the clock at the beginning of a mission and then not have to worry about the clock from then on.

That would say, that a several hour mission would lengthen the synchronization interval to something like 10^4 seconds. And now the clock requirements get to be considerably more. So, if in a tactical environment that sort of a clock is available, the system can be simplified. The multilateration systems are more demanding because of the geometric dilution of precision in locating users and their requirements are such that they have no possibility of doing very accurate location of targets without constantly resynchronizing the clock during the course of the mission.

And system designers take this into account, as I illustrated in the JATIDS case there is a trade-off. One can trade system complexity for the clock quality or one can try to build a good clock into the system to simplify the design.

I'd like to talk a little bit about Identification Friend or Foe (IFF). IFF is the system in which an encrypted interrogation is sent to a target which then if its a friendly target can send an encrypted reply back. It is essentially an electronic password system.

These are some of the uses of IFF equipment ranging from an airborne surveillance system which is very important on a very large platform to a sophisticated but a very densely packed fighter aircraft which provides a particular type of physical environment, to a roaming land vehicles to provide air defense support, to some other very sophisticated radars and missile systems and even man portable systems. Now, the kind of clock one would put on an AWACS aircraft is very different from the kind of clock we would put on this ground vehicle or on that man portable unit.

I'd like to just illustrate that latter case, a little bit more clearly. This is a photo of the stinger weapons system with IFF interrogator. Now the airplane is a cartoon, but this soldier person, I'm not sure of the gender, has the weapon in the tube on his or her shoulder aiming through the visual sight here, the optical sight, and these elements are two YAGI elements of the IFF interrogator, they are the antenna. The IFF electronics are in this box and via this cable, connect into the handgrip, which has the control switches.

The IFF system is a fairly potent weapon system and an IFF system that maintains time synchronization so that encryption can be changed as a function of time very quickly must contain this kind of constraint. Where this soldier can't have very much of a fancy clock. He must power it by battery also carried by the same person. It cannot be resynchronized by a time distribution system using satellites or some other sophisticated network; probably has to go at least 24 hours without resynchronization.

If this terminal needs one millisecond accuracy through the course of the day that's a fairly demanding requirement that the clock occupy a small part of the electronic box and be powered by batteries all of that time, even if the rest of the electronics are shut off.

That could well be the driving clock requirement in an IFF system, not the AWACS requirement or the fighter plane requirement. So, clock stability is one aspect in tactical systems, but there are others.

I just want to emphasize that, precise timing, of rubidium and cesium clocks they are fine and they are needed in a system, perhaps, in the time distribution system but they don't make a large difference to this particular weapons system.

This weapons system has to get by another way. In fact the IFF system may have to be designed to provide him updates via the radio links.

So, in summary, I'd like to readdress the question of why don't we hear system designers screaming for many orders of magnitude improvement in clocks? In the tactical business, system designers like their jobs. They like to be employed. And, therefore, they're going to design systems around the kind of hardware they can get their hands on. And, they're not going to design a system with 30,000 terminals, and design it around unproven clock technology. So, you don't hear that kind of push on clocks that have to be resynchronized as often as you should.

There are other aspects too and I'd like to point them out today. There's another answer, answer B, and this is that you see good systems designers can make do with what's available.

In terms of meeting the environmental spec as well as meeting the stability and performance spec. They will design the system to operate with existing clocks and keep the timing accuracy to the level required by provision within the system of passing time around and resynchronizing clocks. In the case of JATIDS, a great deal of the architecture is laid out to do just this function. Then as we get a little bit smarter, there is another level of answers where you find really good systems designers will make provision for improvement in clocks such that when a clock that is an order of magnitude or two better comes along, a module can be replaced. If the system was properly designed the overhead that was paid in the beginning operation of the system to use a poorer clock, can be taken advantage of by dropping the overhead of synchronizing and gaining some other asset for the system, such as perhaps increased capacity or increased performance. I can't point to any real systems like this, so maybe we really don't have any really good systems designers.

But, I must say that, very seldom is the question asked that the system has to be designed that way. As a postscript, I would like to add that, of course, in order of magnitude or two is always appreciated; that the tactical environment also has other specifications that are difficult to meet and as I pointed out in the Stinger application.

I guess that's about all the remarks that I have. We can get into questions on what I have said later on.

PLANNERS PANEL

Panel Member: Dr. Michael Garvey, Frequency and Time Systems, Inc.

I'd like to make some comments this morning from the industry point of view. I haven't coordinated with my collegues in industry, so what I'm saying might prompt some discussion from them.

I'm trying to draw obvious conclusions. I would like to address the topics of technology advances which we see; which we might predict. Mechanisms for accomplishing this and different forms that the advancement may take.

I'd also like to address some issues, which I think have been pointed out in previous discussions even this morning of the industrial implementation of clocks and clock systems, in a timely and affordable way.

I think to look into the future is a dangerous task to do that, one needs a crystal ball which might be looked at with the same sort of task in mind of introducing a new crystal cut.

In this case, it might be a spherical resonator. But to try and make some predications anyway, I think that it's safe to say that progress is the result of hard work, it is based on existing technologies and experience.

It's based on the applications of new technologies for the most part existing concepts and systems. I think if we look at new ideas in time and frequency, one might advance that there is nothing truly earth shaking ready to appear on the marketplace.

I think there are some very interesting ideas in the laboratory at the moment and examples there might be the ion storage work at NBS, some optical pumping work which I think has very interesting potential to enhance not only reliability but performance of frequency standards.

I think some of the concepts of cryogenic and passive crystal resonators that have been explored in the laboratory also offer some promise.

However, these are I think, still in the laboratory stage and that's the way everything starts after all. If we look at the technology of cesium, we have come 30 years to obtain the current status of being able to launch a cesium standard on a satellite if you like.

To ask how technology proceeds, I think that there are three ways that technology may go forward. Technology may go as it is pushed. By that I mean that technology may be pushed to exploit some new issue in the marketplace and take advantage of some new need or some new system requirement.

It may also be pushed by the market and I think this is particularly germaine to the audience in discussion of this conference because it's, I think, unique to military system and DoD procurement activities where the marketplace pushes the technology in a particular direction.

There is, of course, the requirement in that respect for smaller, lighter, more rugged devices. I think the example of the Stinger System was a very good one.

You can envision that this system has to run rain, shine, night, day, snow, heat, etc. In these tactical applications I think are probably very significant technological challenges for the clock designer.

On the other hand, from sort of the other side of the coin, as technology makes advance when we look for enhanced performance and primarily there are non-tactical applications.

A few comments to say about that later. I think tie in a very interesting way the system design concepts, which were discussed in the last view graph.

The second way that I think that the technology can be pushed forward, is that there are obvious advances in technology in other realms of electronics, of physics, of optics, of communications, if you like which can be very conveniently applied and in an available basis.

These are logical, they occur because of their logic. They are self-justifying, usually enhancing cost, performance, size, weight, etc. Examples there might be the integrated circuit, hybrids, more recently, microprocessors, which are becoming so prevalent, easy to use and cost effective.

The third area where technology may be advanced are technological changes which are focused primarily at increase in performance. Some examples there might be the BVA resonator, BVA oscillator concept which has been explored. Optical pumping and beam devices and a few of the other laboratory applications which I discussed earlier. I think all of these techniques are appropriate at times, sometimes the techniques go astray.

I think it's worthwhile to now interlace this idea a bit with procurement aspects because I think that's a very crucial interface between the system designer who configures the system, who creates a concept around which the system will evolve and, ultimately, its realization in the industry from the people who are going to have to create, build, test and maintain the hardware.

One should be always beware of the repackaging in the guise of technology improvement. I think this is a fallacy which is perhaps only realized with difficulty that merely changing dimensions of an object may necessitate complete redesign of the instrument.

I would implore the system designers to realize that clocks themselves are systems, that few systems are created without learning curves and I think the learning curve for many of the clocks we have today has been a long one.

I think it's a very solid one and based upon a lot of experience we shouldn't neglect the opportunity to exploit that. Particularly when total system performance depends intimately on clock performance. It is crucial that the system designers be sensitive to the realization that use of proven clock designers will result in a system with a basis on which good performance can result. System designers would ideally make efforts to accommodate the system to the complexity of the frequency standards and I think to support the last view graph to anticipate improvements which will occur in clock systems and to allow these improvements to be employed within the system. To focus a bit on financial aspects of this, as I'm sure everyone realizes, any coherent program probably has a life span of longer than a year, and I think funding programs often neglect the realization that the planning and recruitment and assignment of key personnel to development projects cannot proceed in time frames of less than a year. It is very disruptive to industrial, I think in general, activities to anticipate that you can reassign key personnel to different programs in time frames shorter than a year.

To focus a little bit on the third type of technological change which I discussed before, that is technological change for enhancement of performance. I think there's an increasing realization and implementation of the idea that both government and industry can work in a cooperative mode to accomplish this sort of an advancement. An example has been demonstrated numerous times with the cooperative programs with the Bureau of Standards in the parallel effort of development of concept, demonstration of feasibility and a transfer of technology from the laboratory into the industrial marketplace.

One, I think very important aspect of this, is that the efforts must proceed in parallel not necessarily from the initial stage in both fields, but to say that a design can be presented in the industrial marketplace as a stack of schematics and parts list, I think is naive.

The industrial mode of operation has people who are keyed to parts acquisition to testing. There is an available labor force to buy, build, to complete in-process testing. There are procedures available to support these and the design has to be sensitive to these requirements.

I think the obvious advantage of these parallel efforts is that there is an allocation of talent and resources where they exist. Puts tasks where they belong. Importantly, it provides a rather quick mechanism to produce statistical hardware. By that I mean, that it's very difficult to talk about a design until you have built 10 of something or 100 of something, depending on a little bit upon its complexity.

So we face now the question of how, and who in order to approach this solution to technological advancement. I think the answers to those questions are revolutionary, perhaps, a different approach may be taken, depending upon the task.

I think there's a front-end need for planning and funding for the whole project and not just on the short time or time available basis. A committment of resources, of personnel planning would wind up and wind down activities.

These are particulary crucial to us, as I mentioned in the application of key personnel.

To address the issues of affordability, I think the suggestion of standard components is probably a good one. That's not really however a task which I think industry can undertake and impose upon the DoD procurement activity. I think industry is very willing to respond to that sort of a design concept and it has, I think, some very good advantages particularly with respect to affordability.

It's I think not realized by people who have not had intimate contact with how costly and expensive it can be, merely to support the documentation to add or move a single connector. So some sensitivity to these concepts, I think is important.

In terms of deployment at the systems level, I think the integration of proven and existing clock designs is a valid and defensible design technique. I think that the time and frequency reference needs to be integrated into the system not necessarily as given at the beginning, but the advantages which can be accrued from such a technique, are I think very clear.

Thank you.

PLANNERS PANEL

Panel Chairman: John C. Cittadino, Director, Theater and Tactical C^3, Office of Secretary of Defense

We'll take a few minutes for any questions, or perhaps before we take any questions, I might ask if any other pannelist have any questions or cross talk they might like to get involved in. Okay, are there any questions from the floor? There's one way back there.

QUESTION FROM THE AUDIENCE: I was under the impression there is a new directive from DoD for P^3I on all new systems?

MR. CITTADINO: I wouldn't say that P^3I is a requirement on all systems. It's certainly is something that is being considered for all systems that come through the development cycle. It is one of the alternate approaches in the development of the system. I think perhaps I missed some of the beginning of your questions, so if I'm not quite getting at the heart of it, please repeat it.

But if the question is, "Is P^3I a requirement on the development of all systems within DoD?", it is not a hard fast requirement.

Well, P^3I is a management technique that each development activity is being asked to consider as to whether or not it applies to the development of that individual system based on the requirement that is coming along.

And there are numerous factors that would come in to play. For instance, numerous requirements can be satisfied with just off-the-shelf type hardware.

And when you've got that type of situation and you fully can satisfy the requirement at a reasonable cost. Then, in that particular case, there's no need to consider P^3I. But, when you've got a situation where you have a need for a particular system, and is utilizing such technology where there is a recognition that improvements would be coming down the pike as the system evolves, then it makes sense to build the system in various increments. Getting the usable capability as soon as possible and building the system for growth or evolution as the case may be and I think that's certainly the way I interpret that policy. I don't know, others might give you a different story.

DR. WINKLER: We have a few more minutes. I think that if we continue the discussion for 10 more minutes, it may be useful. I have found in each of your comments something which I find exceedingly important; of course affordability one always looks at the total system costs; meaning not only acquisition, but logistics, training required, life time and incidental operational costs, which in the case of atomic clocks can be much larger than the initial acquisition cost of an atomic clock.

And if we talk about improvements coming down the pike in industry, something struck me and that is, that in our present system we really do not pay enough attention to the building of capable teams and maintaining these teams. Our start/stop kind of contractual operation is really a disaster when it comes to maintaining capability in high technology. As Mike Garvey mentioned, it is not possible to move these key people around more quickly than at most I would say once a year and even that is a disaster.

So that the question of new developments and what is really critical today is really exceedingly complex. Let me mention another point which occurred to me, when I listened to Dr. Goblick's excellent presentation of the three types of systems designers. I think one has to distinguish between tactical clocks, particularly crystal clocks, which is one group by itself and the atomic clocks. Because they have their own individual and different problems. For tactical clocks, it is really weight, power consumption and this kind of thing and costs, because usually they are procurred in greatest numbers. When it comes to atomic clocks exactly the opposite problem exists, cost here is less of a problem as compared to reliability. And it appears to me despite everything that you hear about new technology that that is the major problem still, because clocks operate somewhere inbetween our digital equipment and other more mundane things as power supplies, batteries, generators and so on. They contain after all, atomic clocks contain a physics package. The physics package contains analog circuits still. These are exceeding complex, in fact atomic clocks, I think, are those kinds of systems which should place the greatest requirements on subsystem performance. And for that reason some systems such as power supplies, phase detectors and so on have to be custom designed. And then of course that brings in immediately the reliability problem, because you can never, when there is an order of 10 or 20 or 50 units, go through the debugging and through a really high reliability procurement. So there are quite a few things which one, I think, has to keep separate.

Where finally something struck me when I listened to Stover's 12th commandment. The Good Lord had only Ten. Well, I think he said 11 principles. These principles are undoubtly exceedingly important, they have been discussed before. We have heard them discussed here in previous meetings. As I see the systems being developed; they will not be implemented all at once. I think, there is one requirement which has been left out, and this is the gradual evolutionary development of more complicated systems.

After all we are not going to turn off our present operations on one day, and start the new ones the next day. In the meantime, we will have an agonizing transition period. In fact, I think, we are in that transition period right now. And it may preclude the adoption of all these sound principles of which I have mentioned. I wonder if you have any thoughts of that?

What are we going to do in the meantime?

DR. STOVER: As you said we are going to start out with only part of the timing capability that we need for a digital system and progress toward adding the rest. But, as you do that (this is where the last attribute comes in); you have to look to the future and prepare the road starting now, so that you can provide all of the needed attributes when the time comes -- when you have the ability to do it, and when the need for them is even more demanding. Obviously we cannot afford to put it all in at one time. We can't afford to go out there and completely replace an existing communication system.

DR. WINKLER: What I was aiming at was the fact, in a moment, a number of systems come into use. In fact, the one which I mentioned, the Army systems, which right now, are procuring or thinking about procurement of large numbers of atomic clocks, and how are they going to be interfaced with existing operations. These are digital systems. Can you say something about that?

DR. STOVER: Of course the interfacing with existing systems is where I put the emphasis on UTC, to cause everything to come to a common standard. That way, we can use the Navigation Systems as a reference temporarily. In our first implementations we are now using and plan to make further use of LORAN-C. But LORAN-C is not a real survivable system. We need a much better system for a wartime digital communication system.

DR. WINKLER: Well maybe, could you paraphrase that and say that affordability and a smooth transition period will be assured if we learn to use all of our resources, whether they are in our own baliliwick or available someplace else. Such as, for instance electronic navigation systems, to be used as time reference by communications systems and others. Of course, in coming back to your initial comments about the astronomers, when we look at managers of the future, there is one thing quite certain. We'll want to have more done, at less expense. And when it come to military systems, we'll not only want to have them not only less expensive and more reliable, but also less vulnerable to jamming, to interference of all kinds, and to outages in certain areas.

This is, I think the real reason behind the push for more clock use in electronic systems. The main benefits which they give is that they make systems less vulnerable. They provide a greater access capability, at less signal-to-noise, if you narrow the time window; for instance, for an acquisition of a PRN system. So this brings me back to a comment that one always will welcome greater performance, because a well designed system will be able to utilize greater performance and offer payoffs that I haven't had too often in my contacts with system designs, yet. I am very greatful that you have made that point.

MR. CITTADINO: I just like to elaborate on one point that Dr. Winkler made, and that is with respect to the continuity of keeping teams together and having the clock technologist -- I find that the system development activities these days, system designers who are very pressured to meet milestones to design systems to prove that the system will work and there may be alternatives to designing very sophisticated systems but it may take resources that would have to be allocated to the development or refinement of clock designs.

When that comes to the systems designers' desk, most of the time the clock development is relegated to a few phone calls to find out what is available and then they put the money on the matched filters, transmitters, antennas and things of that sort.

I have seen this, and although systems designers could do a lot with better clocks, there is a very weak linkage between those people designing systems in full-scale engineering development to milestones that they have agreed to, and the technology community in general. That's too bad, because it seems the systems designers wind up making phone calls to companies and clock experts and I have to do this, too? I'd call up Nick Yannoni regularly with these kinds of questions, and to get a list of contacts. And similarly with the clock community.

I have the same kind of feelers coming to me saying, what kind of clock would you like in the future? But it isn't promoted in some centralized way, the government funds the clock technology, the government funds the systems development. But, I guess that's disturbing to me that you don't find systems designers screaming to the clock community: "Immediately I need this and I'm willing to pay you for it, and I want you to develop it on this time table."

The bulk of that kind of money and development sweat and effort will go into the basic system.

DR. WINKLER: Yes, and thank you, I'd like to mention that one of the nice features of the proceedings of this conference is a list of all participants and we hope that the main benefit of the conference will be to enable you to establish these contacts.

DR. KELLOGG: Is there any payoff in the transition in looking at an ensemble of existing mechanisms versus the hope for the future?

DR. WINKLER: You're the system expert.

MR. CITTADINO: I'm not sure I understand the question, could he say that one again?

DR. KELLOGG: If one rubidium clock doesn't work very well, the possibility of trading in an ensemble or a slightly higher reliability of 10 versus the hydrogen maser which is still breaking down in the laboratory.

DR. WINKLER: This is a very pointed question of course, my answer would be a very definite "yes". There is a tradeoff, in fact, that is precisely the policy which we at the Naval Observatory have adopted since many, many years.

Our time scale is based on the very large ensemble and the combined benefits of a very high reliability provided the clocks are in individually separated locations, with the benefit of a superior long-time performance.

I would say definitely, "yes". The only qualifying statement is that of course you buy additional troubles also because you must have a system controller, you can not do it really with just 3 or 4 in order to have any benefits. You would have to look at 6 or more of these clocks.

Rubidiums may not really be a simple thing because they have drift and it is easier to use groups of cesiums, in which I have a little bit more experience than groups of rubidiums.