Ten commandments for managing the development of tactical computer programs

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INTRODUCTION

The million-word AEGIS computer program has been successfully completed.

We think that the successful development of this computer program has been due to a number of management decisions and policies used during the life of the contract. The purpose of this paper is to express these principles so that we can be sure to adhere to them during the next phase of AEGIS development and so that others may be able to adopt those applicable in their projects. Obviously many of these management ideas are used by others, but possibly not nearly to the degree as in AEGIS.

BACKGROUND

AEGIS is a shipborne anti-air warfare system consisting principally of a phased array radar (AN/SPY-1), a weapon direction system (MK 12), a missile launcher (MK 26), Fire Control System (MK 99), the SM-2 missile, Control Command System (MK 130), and other related components including a number of AN/UYK-7 computers. Under phase 1 of the present engineering development contract we are building a minimal system to test AEGIS feasibility. This was put together first at a Land Based Test Site (LBTS) in New Jersey and checked out against live targets. It is now being installed in USS NORTON SOUND for tests at sea.

The digital computer program generated for AEGIS is a large and fundamental part of the system. It has always been anticipated that generation and integration of these programs would be one of the high risk technical endeavors in the development of the system. While there have been problems there has been none of any great significance.

A very considerable computer programming effort has been made for EDM-1, the first engineering development model, for it requires four AN/UYK-7 computers, each about the operational equivalent of an IBM 360/65. There are well over a million words of code, half operational and half support.

As this is written at the end of the test at the Land Based Test Site, the AN/UYK-7 computers (there are now 11 under AEGIS control) and their programs are performing very well. However, there have been considerable difficulties in the past. AEGIS was the first project to receive AN/UYK-7 computers. Serials 3, 4 and 5 were delivered in the spring of 1970. Some 6 months later a major change (addendum 4) was made which changed the character of the computer, programming-wise. Then for the next 2 years we had all the infantile problems of a new computer design. The usual manufacturing errors and design deficiencies were found the hard way by the computer programmers. The maintenance men also had to learn.

There were more than usual initial problems with computer programming. Essentially the computers came bare.

There were delivered the Ultra 32 assembler, a factory acceptance test, and a few utility programs (load, dump, decimal to octal, octal to decimal). There was no compiler, no operating system, no executive, no standard set of utility programs, and not even a maintenance/fault isolation program. All of these had to be developed. However, the compiler, not developed by AEGIS, gave the most trouble.

The compiler (now known as CMS-2Y) was scheduled to be delivered to the contractor as Government Furnished Equipment in June 1971. We needed it a year earlier, so we accepted as an interim compiler, the CMS-2Q, which operates on the 642B computer to generate code for the AN/UYK-7. This caused some inefficiencies, but in order to meet our production milestones we have continued with it. However we plan to change to the CMS-2Y for the next phase of AEGIS program development.

MANAGEMENT DECISIONS AND POLICIES

Let us now look at some of the management decisions and policies that have made the computer programming successful in spite of these difficulties. No one of these is the reason for our success, however we feel it would be risky to drop any, or even let any of them deteriorate. Certain of them are sine qua non. These will be starred in what follows. We feel that continuation of all of these will assure success in developing the computer programs for the DG, the first AEGIS ship of the fleet. There is no significance in the order in which the following management decisions and policies are presented.
Most of them are performed by many organizations. The significance of our implementation is that we do each of them to the Nth degree.

a. We have one prime contractor. The programming was done by two subcontractors under supervision and management of the RCA, the prime. Moreover, RCA is responsible for building and integrating the entire weapon system which greatly simplifies things. (The development of the MK 26 launcher and SM-2 missile are by other primes, but RCA is responsible for integration. Besides, these do not involve the computer programming under discussion.)

b. We use only unit computers. Four computers are used in operation of the first engineering development model, two of which are required to operate the radar. Many have questioned why we did not use multiprocessing since a great deal of information is passed from computer to computer during every second of time. We felt in the beginning (and even more so now) that multiprocessing introduces a whole new set of problems. We have found only one pre-AN/UYK-7 tactical military system that uses multiprocessing, though many systems are planning multiprocessing and some are having difficulties.

We are not against multiprocessing. We are planning memory sharing for our DG operation and will leave open an option to go to multiprocessing. However, we feel that for tactical systems the multiprocessing problems are very real and very subtle. We would like for others to solve them. We have our hands full (and have been successful) making our computer programs for AEGIS without taking on the task of tactical multiprocessing.

c. Programming-wise, we divided AEGIS into five autonomous computer programs. Instead of having a single computer system developed by a single group of people we have five groups, relatively independent, each writing a separate computer program. The programs are:

- Radar Control
- Weapons Control
- Control Command
- ATEP (the executive)
- ORTS (Operations Readiness Test System) which resides in the radar and weapons control computers.

Each of these was developed separately from documentation through test and integration. Each was monitored and accepted by a different group in the Navy. Reducing the total programming effort to five smaller homogeneous pieces has made it possible to "eat the elephant" even without indigestion.

d. We have a Computer Program Integration Document (CPID). In order for the five autonomous programs to mesh several hundred times per second, all the interfaces must be clearly defined and enforced. The CPID is a working document that does just that. Each message from one segment to another is defined to the bit level and the manager of each segment must sign agreement. Without this document, integration would have been essentially impossible. CPID has been one of the most successful documents published in AEGIS. It is a living workers' document that at one period was changing almost every week. However, every change must and does carry the signature of both parties to the interface.

The Navy can take no credit for CPID. It was generated by RCA when they saw the need early in the program. It is not described in the contract but is informally given to the Navy. It will be required in the next phase of AEGIS.

e. We developed the AEGIS Tactical Executive Program (ATEP) as the common executive for use in all the computers. ATEP is an extremely versatile executive able to handle the requirements of the radar, the weapon system, and the control command system, and it handles all of them very well. It has also been very helpful to have only the one executive. Priorities originating in one segment are carried across segment boundaries. Intersegment interfaces are greatly simplified. Programmers can be shifted from segment to segment with changing work loads because they all interface with the same executive.

f. We placed the equipment and computer programs (hardware and software) under the same man in each segment. The computer programs that make the radar work are just as essential to the radar system as the phase shifters. Therefore, the man in charge of the radar development must also be the one in charge of development of the computer programs that control it. This is also true for the weapons segment, the Control Command segment and the ORTS segment. Each segment has its own group of computer programmers that operate under the same overall ground rules and control. Each segment manager is responsible for the entire development of those programs from requirements through integration. Interfaces between computer program and equipment are worked out at a very low level. Changes in interface can be made without making a federal case. Interpretations of interface descriptions are ironed out at the working level. The normal fingerpointing between programmers and equipment builders is eliminated and integration is much, much simpler.

g. We have a Computer Program Development Plan. This has not been a one-time publication, but has been a living document reissued as the occasion arose or our procedures developed. It has not been just a document for show (though we are proud of it) but a document that is used by the Navy and the prime.

h. We use the "build a little, test a little, integrate a little" procedure. Instead of writing the whole program for a segment and then testing and then integrating
with the equipment, we do it in small pieces. As small portions (modules and usually sub-modules) are completed they are tested. But it does not stop there. These small portions of computer programs are integrated with the equipment. In fact, in the radar, weapons, and ORTS segments, the order in which pieces of equipment and computer programs were developed was coordinated so that the program could be integrated with the equipment as each was being developed. This was possible because both were under the same lower level management. This was also done across segment lines: program modules from SPY-1 and program modules from Control Command were passing messages computer to computer almost a year before either program was complete. These were informal tests and integrations. However, this has paid off exceedingly well in the formal test and integration.

1. We have comprehensive test plans. We realize that no matter what the requirements are, you get nothing beyond what is required to pass tests. The testing of computer programs is done just as is the testing of equipment. We have a test plan document to describe how the test plans are written, how the test procedures are written, and how the tests are to be conducted. With each sub-test, pass/fail limits are specified. The Navy program experts responsible for each test witness that test and verify the results to the bit level. When short-fails develop the program is corrected and all related tests are done over.

Another important thing about acceptance tests: all of them are conditional. The contract requires that the prime makes the AEGIS system operate. Conceptually it is possible for RCA to pass all the individual tests and the system not operate. (Several years ago this happened in another service.) In which case the contractor would have to fix the system so it would work.

j. The Navy project office has computer experts. The manager of each of the five segments with computer programming either is a computer expert or has a consultant whom he freely uses. These experts take part in all reviews (formal and informal) and oversee the contractor down to code level. The AEGIS Project Manager has a computer expert on his personal staff. The duties of these experts are not only fiscal and managerial but principally technical.

k. The Navy computer program experts visit RCA, CSC and Raytheon. Since the beginning of the contract they have averaged spending more than one working day in 8 at the contractor's facility. They know the managers and chief programmers. They follow the schedule and fiscal operations. They witness all the demonstrations and tests to the bit level. They reviewed the performance and design specifications.

l. Additionally we have computer program experts in the Technical Representative Office. This Technical Representative Office is an extension of the Navy Project Office in the prime contractor's building. Both this office and the Project Office have a Navy expert for each of the five programming segments. Hence there is daily contact. The Technical Representative Office is in addition to the normal Defense Contract Administration Services Office.

m. We held thorough design reviews. The Preliminary Design Reviews (PDR) and Critical Design Reviews (CDR) were "knock down—drag out, bloody" affairs that took months. Every paragraph in every specification was questioned in detail. The Navy participated at the same depth as the contractor. Eventually a step-by-step procedure for CDR's was worked out and published as guidance to all. Some of the specifications went through several iterations before acceptance. It was a very painful experience for the Navy, the prime, and the subs; but it paid off. We got excellent, detailed specifications that we all understood and interpreted the same way.

n. Naval uniformed personnel operate the computers. They are given several hours each week to sit at the consoles and operate the computers as they control the AEGIS equipment. They conduct all the demonstrations for the Navy Project Office and visitors.

This has assured us the console procedures and their computer programs follow standard Navy practice and that they are adequately described so that prospective users can actually use them. Such personnel have been most helpful in keeping AEGIS operating procedures in the real, practical world.

o. We have made great use of simulators. The Weapons Control Segment has a simulator for the interface of the radar segment and another for the Control Command segment so that the Weapon program can operate as if the other segments are present and operating. Likewise the radar and C C segments simulate each other and the weapons segment. There are also simulations of the launcher, the illuminator, a ship's motion simulator, etc. These simulator computer programs are all checked out and authenticated. They usually (but not always) run in another computer. Programs are first tested against simulators before being tested with equipment or other programs.

p. We have realistic scenarios for test and demonstration. These have enabled the Navy to gain confidence, besides being very useful debugging tools.

q. We have very rigid configuration control of computer programs. Master tapes are kept in two places under lock and key. Changes in computer program are made only after very elaborate procedures. Since the programming is done by subcontractors, each change is separately authorized by the contracting officer at RCA. Current "father," and "grandfather" master tapes are maintained in the library.

r. The Navy placed the computer equipment under configuration control. The computers and their peripherals were procured over a period of years. "Minor" manufacturing changes have been such that computer
programs would not have been interchangeable except for the rigid configuration control of the project office. Likewise, the maintenance would have been different in the older and newer computers.

The computer programming has received topside attention. The head of the AEGIS office has taken personal interest in the computer programs. “The computer program is as integral a part of the system as is the equipment.” The computer program development in each segment receives full attention of top management and is discussed at (essentially) every Navy review. Problems that arise in computer programming go to the top for solution just as easily as those in equipment design. This support to the Navy personnel responsible for these programs has been invaluable.

CONCLUSION

We are quite sure that by carrying out these management policies we have:

a. reduced the high risk of computer program development.
b. had fewer than anticipated difficulties with integration (e.g., the radar demonstrated computer controlled tracking capability in half the anticipated time).
c. held down the cost of program development (though aggravated by problems with a new computer).

Therefore to others faced with development of large tactical computer programs we recommend adoption of these management policies.