

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

ADDRESSING THE UNITED STATES NAVY NEED FOR SOFTWARE ENGINEERING EDUCATION

by

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September 1999

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**ADDRESSING THE UNITED STATES NAVY NEED FOR
SOFTWARE ENGINEERING EDUCATION**

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Submitted in partial fulfillment of the
requirements for the degree of

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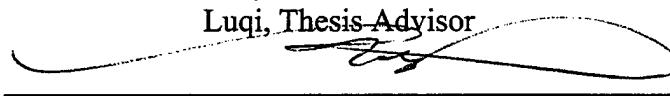


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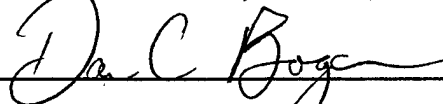
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ABSTRACT

Computer technology use as a highly effective tool is ever increasing in the modern world, including the warfare arena. Manning issues due to budget concerns mandate a smaller future military workforce, while theater conflicts will continually grow in complexity. Computers are powerful tools that can aid the warrior's ability to fight amidst this onslaught of information.

Unfortunately, a computer cannot simply be dropped onto a ship to create miracles on its own. Computers are only as intelligent and useful as they are engineered to be. The costs of this highly difficult and expensive task can be mitigated by proper utilization of personnel specifically educated to plan and produce these systems and the associated software. The Navy can produce these personnel from within its ranks, via a curriculum in Software Engineering at the Naval Postgraduate School; however the effectiveness of this program is not currently being maximized.

This thesis develops and implements a program to address the Navy's needs for software engineering, helping successfully combat the Navy's current void in software engineering education. This should ultimately lead to an increase in the Navy's knowledge assets, and subsequently to better opportunities for Naval utilization of the technology available to improve warfare capabilities.

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I. INTRODUCTION

A. BACKGROUND

Computers are having a profound impact on today's society. They have proven to be very useful tools, performing tasks that cannot be performed solely by humans, doing so with otherwise unattainable accuracy, and processing vast amounts of information not otherwise possible. Their speed has progressed to a point where an increased human dependence on computers' abilities to analyze data and make decisions has come to make sense.

As the 20th century nears its end, computer use to automate tasks and simplify life has become prevalent in the world. This is true in homes and in the workplace. This is no different for a future warrior than for an average businessman. Combat theaters are too complicated not to take advantage of this powerful asset. Many military systems are so complex that the thought of operating them without the aid of computer technology seems foolhardy. Missile and other combat systems, as well as guidance, navigation, and propulsion systems are just a few of the many examples of systems heavily dependent on computer technology.

Manning issues will increasingly become a larger problem as the defense budget continues to shrink. Thus, it is logical to presume that computers will need to be called upon to assume more of the burden in the *Department of the Navy* and to lighten the load of already overworked sailors.

Over the last few decades, computer use has infiltrated the military world. Unfortunately, computer technology is not easy to integrate automatically or without significant effort, and the implementations have not been organized as efficiently as possible, directly resulting in many problems since computers must be properly engineered to perform the desired tasks. This can be excruciatingly difficult and quite expensive, however often the cost can be tempered with personnel specifically educated to produce these systems and to develop the associated software.

As future electronic needs continue to grow, the *Department of Defense* can continue with its current trend of not fully pre-engineering system implementations. This method has resulted in problems with software that cannot adequately interface with

hardware, software applications that cannot communicate with other software, and other system failures amongst the significant number of extremely expensive failed software projects undertaken by the military.

Alternatively, the current and future military needs could be addressed by educating personnel now who are and will continue to be needed to help solve the problem before it becomes more unwieldy in the future. These personnel will be the ones who can adequately deal with the complex computer-related issues on the Navy's ships, submarines, and aircraft, as well as other commands. They also will be the ones with the experience and knowledge to make the important high-level decisions which can prevent the systems integration problems currently found on various Naval platforms.

The Navy needs to be more forward thinking. Future "Smart Ship" and "Smart Carrier" technologies will surely solve some of the problems the Navy faces today. But what of information technology as it becomes more ingrained in the business of warfare as the technologies continue to evolve? Personnel must be educated today in order to make informed decisions to push information technology utilization in the proper direction for tomorrow.

The Navy has the ability to produce these personnel within its active-duty officer corps, via programs within the Software Engineering curricula at the Naval Postgraduate School (NPS). Since this is not currently being done particularly effectively, addressing this shortfall is the major goal of this thesis.

B. MOTIVATION

The Naval Postgraduate School and many other Navy and *Department of Defense* organizations have recognized that the military needs to produce highly trained and experienced software engineers. These needs could be filled by educating officer graduate students with prior Fleet experience at NPS with a curriculum in Software Engineering, and subsequently utilizing these personnel and their new skills for the benefit of the Navy. Officers and civilian personnel would use these skills in the development and procurement of new systems, and while interfacing with outside contracting agencies working software issues on behalf of the Navy.

Currently, there are students getting some exposure to software engineering at NPS. All Computer Science students (curriculum 368) are required to take the initial prerequisite Software Methodology course (CS3460) as an introduction to the software development process. Each of these students must also complete one of the specialization tracks within the Computer Science department. Some students specialize their degree by completing the Software Engineering track, which requires them to take several additional Software Engineering courses. Additionally, each Software Engineering track student must complete a thesis on a topic within the realm of Software Engineering. However, for all students in the Computer Science Department, the large majority of their coursework is in the general Computer Science field, and thus the degree awarded upon successful completion of the curriculum is a Master's of Science degree in Computer Science.

A problem observed repeatedly by personnel at NPS is that many students take their newly learned knowledge and move on to jobs that do not adequately utilize these skills. The knowledge learned, and thus all the energy spent by both the students and the faculty creating that knowledge, may be wasted as this knowledge has a propensity to atrophy before being truly utilized. Undoubtedly, many of the principles and practices learned by the student within their studies create life-long usable knowledge. However, in the high-tech world of software, there is a definite, real need to use knowledge and keep it current as the technology continues to rapidly evolve; otherwise the long-term effectiveness of that knowledge decreases. For example, someone who earned a Computer Science Master's degree ten or fifteen years ago but has not been actively using their knowledge in that field is not nearly as strong in dealing with today's computer technology as someone who has a current degree (even a Bachelor's degree), and is familiar with all of the "revolutionary" changes in hardware and software over the past decade. A person must be able to stay on top of the field – on top of the technology – or risks becoming out-of-date with technology trends.

An additional problem that presents itself is that the need identified previously, for personnel who have the ability to properly engineer software projects, still exists. Thus, if the students educated at NPS are not used to fill the needs, those needs must be filled from elsewhere. These services may be contracted out or groomed from a different

source. But, sadly this simplifies to a situation of re-purchasing assets that have already been paid for, paying again for people who are already available if they were only better utilized.

In 1995, the Software Engineering faculty at the Naval Postgraduate School developed a complete non-resident degree program in Software Engineering which awards a Master's of Science in Software Engineering (MSSE). Since its inception, the program has run very successfully with twenty-three program graduates and nearly sixty students currently in the program. To bridge the gap between the Software Engineering academic side at the school and the U.S. Navy side to create a similar program for active-duty Naval officers, someone who knew the inner workings and requirements from the Navy's perspective was needed. As an officer interested in the advancement of the Software Engineering program at NPS, along with some knowledge of the Navy's postgraduate educational system including the *Officer Subspecialty System* and the "Quota" and "Fills" issues, the author was an ideal candidate to help address both sides of the issue and to get a new Software Engineering academic program accepted and subsequently utilized by the Navy.

C. OBJECTIVES

The broad sweeping goals of this thesis are to raise awareness of the Navy's need for software engineering and to propose a means for fulfilling that need. Gaining support from officials high enough in the Navy leadership who were aware (or could be made aware) of the need to groom successful software engineers was vital to ensure that progress could actually be achieved, and that the significant need would really be addressed. Stated another way, there exists the need to address utilization problems involving software engineering postgraduate education student knowledge specialties. This high-level goal can be refined down to several more specific goals to work towards that end.

A program of instruction must be developed that meets the Navy's need for software engineering education. Such a program must be logistically feasible (for example, from the standpoints of scheduling and curriculum length) and also meet the standards for approval by the Naval Postgraduate School's *Academic Council*.

Ultimately however, even a successfully developed program will not succeed without an adequate student base. Therefore, in addition to development of a new Software Engineering curriculum, adjustment of the supply pipeline that provides the students and the demand pipeline that utilizes the software engineers produced must be realized. This is where the Navy's *Officer Subspecialty System* and designations of coded billets must be addressed.

Through various intelligence sources, it was determined that a program combining the aspects of the Naval Postgraduate School's current Combat Systems curriculum with the direct Software Engineering curriculum would address at least part of the current need, and could be widely accepted by Naval leadership. In addition, with the support of the Combat Systems Curricular Officer and the Physics Department, this path appeared to have a reasonable chance of success in actually progressing from development to acceptance and finally to full utilization. The development and implementation of this program is the actual change of Navy policy delivered by this thesis.

A future follow-on goal for the Software Engineering department is to achieve an additional separate subspecialty code for a shorter and more tightly-focused Software Engineering curriculum, in addition to the integrated and longer curriculum proposed and implemented here, which has the software engineering coursework as a portion of a larger combat systems program.

D. ORGANIZATION

This thesis is organized into six chapters. The first chapter contains background information and an overview of the thesis. Chapter II identifies and further explains the Navy's need for software engineers and suggests possible solutions to address the problem. Before proposing a solution to the Navy's future software engineering need, a background discussion on the Navy's postgraduate education system is needed for an understanding of how the solution proposed in the thesis fits in. The third chapter gives this background information about the way that the United States Navy handles graduate education. This leads into the fourth chapter which elaborates on some of the benefits of using NPS as the best solution to provide the needed education and outlines the specifics

of the Software Engineering programs currently in place at the Naval Postgraduate School. Chapter V describes the curriculum developed within this thesis as a first-level solution to address the educational needs highlighted in Chapter II. The curriculum is discussed in detail, along with the process completed to establish the new curriculum as a viable program. The final chapter summarizes the thesis, describing the current state of the newly-developed Combat Systems/Software Engineering curriculum, as well as future plans to improve the Navy's utilization of NPS' assets to better prepare for the future.

Additionally, as an extension to this thesis, investigations were made into further educational opportunities to expand the benefit currently derived from the NPS Software Engineering curricula by the Navy, the other U.S. military services, and other *Department of Defense* agencies. Some of these additional possible educational opportunities are also discussed in the concluding chapter.

Finally, there are several appendices that provide supporting documentation as described within the text of the thesis, including descriptions of the courses included in the new curriculum and the entries describing the program to be included in future editions of the Naval Postgraduate School Catalog.

II. THE SOFTWARE ENGINEERING NEED

"Software is the new physical infrastructure of the information age."

President's Information Advisory Committee Report to the President
February 1999

A. OVERVIEW

The increasing automation and computerization of military systems is a welcome fact of life in the complicated, fast world of military power projection and threat handling. Moore's law states that computer power doubles every eighteen months, resulting in computers now one hundred times more powerful than they were ten years ago and ten thousand times more powerful than 20 years ago¹. With this trend expected to continue into the foreseeable future, systems powerful enough to implement the high-level future technological goals of the Navy should become available.

To take advantage of these powerful systems, designers need to be able to design large, complex programs that are safe, reliable, robust, and work in real-time. In order to develop these programs successfully, software practitioners must apply state-of-the-art software engineering practices. Staying on top of the latest standards and best-practices in the field of software engineering requires instruction in current and future technologies and the ability to put knowledge into practice.

The Navy and the *Department of Defense* rely on the infusion of technology into their systems and software to achieve their goals. Increasing dependence on technology dramatically increases complexity in system requirements. If properly engineered, the complexity of the resulting architectures would decrease. However, this has not been done in the Navy, partially due to the lack of the needed software engineering skills. Another common result of increased technology as observed in military systems is the inability of personnel to effectively utilize the systems under their command because they are unable to understand them.

Software engineering is a field experiencing rapid growth as people come to realized the depth and importance of the future expansion of computer technology, and the need for personnel to ensure that software projects move in the proper direction. Trained software engineers will help the Navy address its system acquisition and development issues, and help improve some of the dismal previous DoD software performance.

"Software is everywhere we look in the *Department of Defense*."

Dr. Delores Etter
Deputy Under Secretary of Defense (Science and Technology)

B. SPECIFIC NAVY ISSUES

There are many reasons why the United States Navy needs to consider software engineering education as it plans for the future. The Navy has a lot of money and resources invested in current computer technology. As is well known however, the state-of-the-art technology is rapidly advancing in a continual pattern. Reflecting on their shipboard tours, many Naval officers wonder why the Navy is not taking full advantage of the technology available to reduce workloads, simplify tasks, and to improve the overall quality-of-life. Many ships are still laden with 1950's technology in many of their systems. Why are tasks continually performed in laborious, manpower-intensive manners when the same tasks could be done easier, quicker, even better, and while the technology to make many such improvements is currently widely available? Computers can do many tasks with much greater accuracy, and in many cases, eliminate the possibility of human error that may often occur in complex, tense, stressful situations where personnel may be overtired and unable to process the entire breadth of information involved.

1. Manning Concerns

One of the toughest issues facing the Navy in the future is manning a fully-operational service while continuing to use a volunteer-only force. The Navy has seen

personnel levels drop significantly over the last ten years. The Navy has transitioned from the huge 1980's Cold War build-up towards a goal of a 600-ship Navy down to slightly more than 300 ships. Much of the decline was desired and intended following the end of the Cold War, but now the service is struggling to retain its current members and to recruit new members to fill its ranks.

The total Naval force decreased by 23% between fiscal years 1992 and 1998. The percentage of the officer corps allocated to attend graduate education during this period was approximately constant around 1.5%, so the actual number of Navy graduate students also fell by approximately 23%. During these same years, the size of the Unrestricted Line (i.e., "warfare") communities of officers also fell 23%. However, the number of these warfare officers obtaining graduate education at NPS fell even further. Surface Warfare Officer students decreased 42% and Submarine Warfare Officers declined 54%, while the number of Aviators at NPS fell a staggering 70%.²

These numbers are indicative of the difficulty these communities have in making graduate education a priority in officers' careers. The fact is: these officers are needed in the Fleet to carry out the jobs there, and funded graduate education is a luxury not available to all warriors.

As of March 1999, the Navy's officer corps was short 850 officers from the needed level. The future looks even bleaker, with a projected shortage of 1800 officers by FY01/02. These projections are even somewhat optimistic, due to an excessive level of Junior Officers. Accounting for the mismatch of officer rank and experience, the *Chief of Naval Personnel* is projecting a shortage of 2400 O-4's (Lieutenant Commanders).³

The real shortfall for officers is for senior Lieutenants and junior Lieutenant Commanders. These are the officers who have served one or two operational tours and possibly a shore tour, ready to rotate back to the Fleet. There are numerous reasons for the decline in the ranks of the officer force, from concerns about the cuts to retirement benefits, overwork, the prosperous U.S. economy driving a civilian job market with good compensation, family separation issues, health care concerns, to many other reasons.

In the enlisted ranks, the situation is just as dire. For the past several years, recruiters have been unable to reach their recruiting goals, for many of the same reasons

that officers are leaving the service as described above. Last year's recruiters fell short of their goal by 7000 sailors⁴. Recruiters are having a difficult time finding properly educated and motivated personnel to enter the service when the civilian job market and the compensation available there may be more inviting than the known hardships of life in the Navy.

What all of the shortages mean is that they are fewer people left in the service, who must now complete the extra work from those billets left unfilled due to personnel shortages. The costs of the personnel shortages are felt mainly in the shore billets, since the operational warfare billets are manned to near 100%. So, if an officer or a sailor does rotate to a shore tour, it is likely to be a hard job just like the operational billets, because more than likely there will be gapped billets at that shore command. This leads to performing two or more jobs at once, longer work hours, personnel becoming overtired and more prone to mistakes, and general displeasure with the service. This lower morale makes retention difficult, exacerbating the problem that much further.

2. The "Smart Ship" USS YORKTOWN

One action to address the manpower crisis was the "Smart Ship" experiment onboard USS YORKTOWN (CG 48), under Commanding Officer Captain Rushton. This experiment was a two-tiered approach to reduce the ship's manpower requirements. One method was a complete paradigm shift in the way the Navy conducts its daily business, with a determination of which tasks needed to be accomplished, and which tasks were accomplished solely due to Naval tradition, and in essence added no real value to the ship's mission. The other method was the integration of technology to assist in the performance of the remaining tasks to lower the crew's workload. With total belief in the "Smart Ship" philosophy, Captain Rushton and crew set out to maximize the automation of tasks. The overall effect of the two initiatives was to lower the manning requirements without any degradation of the ship's overall capabilities. The official tally was a reduction in over one-fourth of the ship's crew (from 389 down to 287 enlisted), and nearly 20% of the ship's wardroom (from 27 officers down to 22).⁵

The experiment was not without problems however. The effort was not pre-engineered as with typical missile systems or aircraft that spend many years in development. In the course of a year, the Naval Systems Sea Command (NAVSEA) identified and evaluated Commercial Off-The-Shelf (COTS) products to facilitate the automation of shipboard tasks. The systems were procured, the contract assigned to the *Sperry Corporation*, and the project implemented on the YORKTOWN. The software systems were compiled rapidly, as were the interfaces between the software and the existing systems on the ship.⁶

One problem was that there were no personnel onboard the ship who were appropriately trained to deal with these complex software systems. When there were system failures (certainly typical for new and experimental systems), the crew was left at the mercy of its raw knowledge of the systems until the contractor could come aboard to fix the problem. Depending on the ship's location and the severity of a given problem, this might require the contractor to fly aboard the ship via helicopter, or perhaps fix the system following the ship's next return to port. This "just in time" service is workable during local at-sea runs, but would not be a realistically feasible option during wartime or if the ship was deployed overseas.

There was one major technical casualty aboard the ship that resulted in the failure of the ship's engines. Despite rumors that the ship had to be towed into port⁷, a few members of the ship's enlisted crew used their informal computer knowledge to create a temporary solution in order to operate the ship's engines and get the ship back into port where a permanent solution was engineering by the contractor⁸.

While the ship managed to restore power after only a few hours, the incident amplifies the need to have a minimum of at least one technically-trained expert onboard who truly understands the software-systems, and can work to fix problems as they arise, in real time. This person would not necessarily be a programming expert, but rather would understand the systems' interworkings and specifications.

Additionally, this specific casualty was initiated when an operator made an invalid entry into a database field. The computer then failed as it tried to make a calculation to divide by zero. This casualty caused the entire onboard computer network

to fail. A proper software engineering process during system design would have prevented this type of casualty from occurring by specifying better error checking and a better system design to prevent one error from crashing the entire network.

Despite the software problems, the entire investment in the experiment "paid for itself" on one particular day when visibility fell to near zero during an Atlantic squall as the ship was entering port. After the day was over and the ship was safely in port, it was believed that the ship would have run aground without the special navigation performed by the onboard computers.⁹

While the concept of the "Smart Ship" was proven successful during the test run, many of the initiatives taken by the YORKTOWN were counter-intuitive to standard Navy practice, and branded as "risky" policies following the departure of Captain Rushton and the experimental crew. With the experiment completed and the concept validated, the new crew did not need to continue with the revolutionary policies. As a result, the ship dropped many of the initiatives and returned to nearly the original manning levels in the period following the experiment.¹⁰

Quality-of-life issues including manpower problems are key issues for the Navy, and the *Secretary of the Navy* has made it a priority to address the quality-of-life issues that have plagued the Navy's sailors. Clearly, as defense budget declines continue and the manpower available onboard ships shrinks, one effective manner in which to compensate is with the use of technology. It seems logical that more shipboard integration of computer technology in the future will be utilized as manpower resources are replaced with advanced technology. As a result of the lessons learned from the YORKTOWN experiment, an upstep in the "Smart Ship" implementation has been ordered. Over the next six years, all of the Navy's cruisers and 28 of the 32 Arleigh Burke destroyers will be equipped with "Smart Ship" improvements. Theoretically, this frees 44 enlisted and four officers per ship, manpower that is to be reallocated within the ship to ease the burden on overworked sailors.¹¹ Additionally, similar efforts are now being planned for aircraft carriers and amphibious ships as well, projects known as "Smart Carrier" and "Smart Gator", respectively. The *Secretary of the Navy* is trying to

promote automation of tasks as much as possible to reduce manpower requirements and thus give more authority to fewer people to increase job satisfaction.¹²

3. The Future of the Navy

Beyond the issues facing the Navy now, there are also numerous plans for future use of technology to advance the state of warfare. Captain Charles Bush, *Aircraft Carrier Program Office Program Manager* at NAVSEA, noted that his Flag supervisor wanted to provide battle group commanders with a live hologram image of the battlespace in the Combat Information Center aboard the next revision of aircraft carriers. When prompted that the task sounded unrealistic, CAPT Bush emphatically declared that it was possible and the project was a serious goal.¹³ Another wide-ranging project for the future is the *Joint Chief of Staff's Joint Vision 2010*, a plan to ensure the success of the U.S. military in the future of warfare.

a. JV 2010

Joint Vision 2010¹⁴ is the conceptual template for how the U.S. military will use its dedicated forces to leverage technological opportunities for the purpose of raising the level of effectiveness in future warfighting. The vision suggests methods for using the military's strengths along with new information-age technologies to ensure American success in the business of war. In order to protect national interests, the Armed Forces will need to be prepared to fight and defeat any adversary in any conflict in any arena.

Throughout American history, technologically superior equipment engineered to provide superior mission performance has been vital to the success of U.S. forces. With accelerating technological change continuing, critical advances are being made. The ability to adapt and implement the new technologies will increase warfighting capabilities in the future; however, the failure or inability to understand and utilize new technologies could lead to premature obsolescence of equipment, the failure to technologically keep up with the rapid advancements of our adversaries, and potential

risks to our personnel in combat. Additionally, the potential for surprise attack via electronic and information systems is high.

With force size declining, every available source of capability must be tapped simply to maintain effectiveness. Maintaining superiority in the future will require tomorrow's warriors to interact extensively with computer technology. Improvements in information systems integration will have a profound impact on future military operations, and information superiority will be a key factor in the ability to manage the vast amount of data available for commanders to make decisions for the military.

It is expected that with advanced information processing systems, battle scenarios will be focused more on real-time parallel planning and decision-making, as opposed to the pre-planning of previous battles. The increased access to information, with faster speed and more accuracy, will be driven by technology.

Additionally, enhanced modeling and simulation of the battlespace will help improve training of the warfighters and leaders, in preparation for true conflict. This will also offer the possibility of testing new concepts and strategies prior to an actual war scenario.

b. Other Sample Future Navy Projects

Beyond the scope of JV2010, there are other large-scale information technology projects the Navy is looking to accomplish. The *Department of the Navy Chief Information Officer* (DONCIO) is working to achieve his goal of a Navy Wide Intranet, as one step towards trying to fulfill his mission statement which is to "put information to work for our people"¹⁵. Dr. Delores Etter, the *Deputy Under Secretary of Defense (Science & Technology)* is separately promoting the idea of cognitive readiness. This is a new concept of designing computerized education systems that determine how students learn best, and adapt their interaction with the students accordingly, providing a more "learner-centric education" than experienced today¹⁶.

While the potential for technology to improve the abilities of the warriors of the future is clear, these are lofty goals. Resources are limited and the military will

need to be selective about the systems it can afford to produce and acquire. Current and shrinking defense budgets will not support the acquisition of all the technologies discussed in JV2010. In order to secure the most effective use of technology, decisions need to be made by informed and educated people who know the technology and have the ability to determine what capabilities are realistically achievable.

C. SOFTWARE IN PRACTICE

Despite the desire to produce highly technical future systems, the track record for production within the *Department of Defense* leaves a lot to be desired. The DoD and its individual military departments have invested billions in the development of large-scale software systems. A 1995 *Electronics Industries Association* study estimated that of \$42.5 billion the DoD would spend on computer systems, \$35.7 billion would be on software. A 1997 survey by a marketing firm which tracks government spending, *Federal Sources, Inc.*, concluded that by 2002, the DoD will spend more than \$20 billion annually on software for weapons systems, C4I systems, and other information technologies.¹⁷

Additionally, despite the prime concerns of reliability, flexibility, and delivery of these systems on-time and under-budget, approximately 60% - 80% of the cost of deployed DoD software is its maintenance and support. Other statistics are just as telling about the state of software production affairs in the U.S.: in 1995, 85% of software projects finished late or over-budget, and half of all projects doubled their cost estimates.¹⁸ As sad as these statistics sound, they are actually improvements from a previous DoD study that found that DoD software projects estimated to take between two and three years slipped an average of 36 months before completion, with one-third of the projects cancelled prior to completion¹⁹.

Nor are these problems limited to the DoD. Costs of failure in the commercial world are high also. System downtime for American Express costs \$167K per minute, while downtime at Charles Schwab costs are estimated at \$1M per minute²⁰.

While there have been huge software project failures, there have been successful software engineering efforts as well. In fact, it is fairly common to find newspaper

articles on a daily basis that describe the latest project that has failed or is providing new capability to a system. While many pages could be written describing all such instances over the past few months, a number of software project examples should suffice to illustrate the value of software engineering. Clearly, software engineering concerns are valid both in the military and in the civilian world.

1. Software Failures

Over the past year, the most prevalent example of a software engineering blunder has been the Year 2000 Problem, or "Y2K bug" as it is commonly known. Many billions of dollars have been spent reengineering systems to prevent system failures when the calendar rolls from year 1999 to year 2000. Simply stated, the problem is that many software applications treat years as two digit numbers, thus a rollover from 1999 to 2000 (i.e., 99 to 00) leaves uncertainty as to whether the application recognizes the upcoming year as 2000 or as 1900. "What we're experiencing with Y2K is simply the result of the drive to cut expenses and failure to look ahead thirty years-ago... People were rewarded, at the time, for solving immediate problems, not future ones."²¹ Essentially, this is one instance where proper software engineering a long time ago would have saved an incredible amount of money and effort today. The Y2K problem also illustrates a problem with maintaining legacy and stovepipe systems well beyond their expected lifetimes.

The AEGIS Weapons System is in wide use today on the advanced destroyers and cruisers in the U.S. Navy's Fleet. The development of this system was a huge effort, containing nearly three million lines of software code. Unfortunately, only 90K lines of this code were reusable, meaning contractors were required to create the majority of the software system from scratch, at great expense to the U.S. Navy. Additionally, the F-22 fighter had less than 38% reusable code in the nearly two million lines of code in its software packages. To make matters worse, funding for the F-22 project is in a very questionable state. The two houses in Congress currently cannot agree whether to cancel the project entirely or just scale it back in order to save money. By contrast, the U.S.

Army's Crusader, a self-propelled Howitzer, required less than two million lines of software code, but much more than half of the code was reusable.²²

One of the most devastatingly efficient bugs ever in a piece of software was the error that destroyed the *Ariane 5* rocket in June 1996. After ten years and \$7 billion of production costs, the rocket (and its payload of four expensive, uninsured scientific satellites) self-destructed 39 seconds after launch due to a programming error. The rocket's control system crashed and caused the missile to self-destruct when it tried to put a 64-bit number into a 16-bit memory location. The programmers had also omitted standard error-protection methods in an attempt to save money and time. After the failure of the first *Ariane 5*, the *European Space Agency* set off to build another *Ariane 5* rocket, although with a "software architect" added to the team to oversee the project.²³

The U.S. Army undertook a multi-billion dollar initiative to upgrade thousands of aging computer systems. The ten-year Sustaining Base Information Services (SBIS) project started in 1992 with the intention of replacing over 3700 automated applications by 2002. However, after investing three years and \$158 million, the Army had not received a single replacement system by 1996. The Government Accounting Office concluded in a July 1995 report that:

Defense continues to spend about \$3 billion annually to develop and modernize automated information systems with little demonstrable benefit. Few redundant systems have been eliminated, and significant savings have not yet materialized.²⁴

Other software glitches abound. The Denver International Airport lost \$1.1 million per day in interest and operating costs due to problems with the software for the baggage handling systems that caused the airport to sit empty for more than nine months after it was supposed to open²⁵. California recently killed its project to link welfare networks after spending \$18 million to try to allow welfare offices in different counties to communicate with each other. The project was the fifth time in a decade that California scrapped a computer project that had "gone so far astray that it would be fruitless to spend any more".²⁶ California is also having problems creating a federally-mandated

computer system to track parents delinquent on child-support payments. Failed efforts to create such a system have cost the state nearly \$200 million and years of work²⁷.

The Federal Aviation Administration's new \$2.2 billion computer system to modernize the aging air traffic controller network was so slow in tests that tasks took at least twice as long as they did on the system to be replaced²⁸. Additionally, according to the U.S. Department of Transportation, about 30 percent of all the nation's major airline flights in June 1999 arrived more than 15 minutes late, a situation airlines blame on an understaffed and underfunded air traffic control system. As many as half of all airline delays can be traced to air traffic control problems.²⁹

2. Software Successes

Despite the well-publicized failures of software systems, not all the news is bad. Many systems have been successfully engineered to provide excellent results. The Navy is currently touting its "Smart Card" as a major benefit to its sailors. Smart Cards are being used to decrease government infrastructure and enhance the potential of military readiness by streamlining business practices in the military, and saving time which can be re-focused on training. The Smart Cards are the size of a credit card and contain embedded integrated circuit chips. The cards can interface with medical, dental, food service, purchasing, and database applications.³⁰

The Army's Crusader project and the fact that a majority of its code was reused were discussed earlier. Part of this success is likely due to the fact that the contractor was well-qualified on software engineering practices.

A new cockpit computer (the Flight Management System) is making airplane flight paths more precise by using global positioning satellites. This effort could reduce delays and minimize airplane noise distractions to nearby residents. The system integrates information from satellites and the airplane's engines and instruments.³¹

Amtrak is performing final testing on new high-speed trains in order to have them carrying passengers between Washington DC and Boston, Massachusetts by the end of 1999. The trains use special computers to control the tilt of the cars. Due to the high speed, the cars' tilt is important to passenger comfort. The computers decide how far to

tilt the car based on the train's speed, bank angle for the tracks, the turn angle of the trucks that hold the wheels, and sideways forces as the locomotive goes around a corner. The computers tilt the cars in sequence, as compared to tilting in unison, to improve the comfort for the passengers.³²

3. COTS Software

Dr. Etter, *Deputy Under Secretary of Defense for Science and Technology*, has noted that "DoD systems are software dependent... Software costs and schedules are starting to dominate acquisitions... Software quality limits DoD's ability to field systems at affordable cost."³³

One solution the Navy has employed to combat the cost of software production is the use of Commercial Off-The-Shelf (COTS) software. COTS certainly has some advantages. The major advantage is the ability to take advantage of "economies of scale", purchasing many copies of the same software for lower prices. COTS also works very well for system standardization, prompting the DONCIO to state that he intends to continue the practice of acquiring COTS in the DoD³⁴. Indeed, *Microsoft's* Windows NT operating system and *Microsoft* Exchange email system are part of the standards in the Navy's IT-21 (*Information Technology for the 21st Century*) initiative³⁵. The idea of reducing the "learning curve" for systems at new commands because the same applications are being used both at sea and ashore does have merit.

At the same time, there are reasons for discontinuing the widespread use of COTS software. First, standardization allows for universal implementation of known security holes to intrude into a system. The widespread proliferation of viruses in the past year that prey on holes in *Microsoft* products is possible mainly because of the widespread standardized usage of these systems. The "Melissa" virus crippled numerous corporations' email servers, prompting many companies to completely shut down their systems until a remedy was found³⁶.

Another problem with COTS implementation, as seen during the YORKTOWN "Smart Ship" experiment, is software integration problems. These applications pulled off the shelf are not necessarily intended to work with each other. When complete systems

are engineered through the normal software life-cycle, interfaces are designed and proper interactions can be planned. When software is taken as-is off the shelf, system designers must accept the limitations of the software as designed for commercial applications (as opposed to specifically designed for military uses) and attempt to make the integration work. The "Smart Ship" trial run exposed potential problems from following this process.

In addition to the issues described here, Major Dale Long, *Chief, Information Management Branch, United States Strategic Command*, predicts the death of COTS in the DoD. There used to be a software-producing industry specific to military applications running in parallel to the commercial industry. The military-industry produced software to the more-exacting military specifications. However, that industry became less efficient as producers rushed their products to market, since the companies who manage to get their products to market first typically make more money than those that deploy later, despite bugs and security holes typically found in the earlier, rushed products. As the military became a smaller part of the software market, it has become more economical for companies to produce software for the public rather than for the military. Thus, the products now available are built more for profitability than for invulnerability to attack. These policies will have to change in order to allow for the higher levels of security and more crucial specifications of the military.³⁷

D. WHAT IS A SOFTWARE ENGINEER? HOW CAN THEY HELP?

Software engineering is not strictly about computer programming. If that were the case, then the Navy wouldn't need to train its personnel specifically for this task. It could simply go out and hire recent college graduates with significant programming experience. Instead, the Navy needs to produce software engineers – personnel who understand and can apply the use of sound engineering principles to economically develop software that is secure, reliable, and flexible. In addition, the software product should be maintainable (due to the traditionally high cost of maintenance and support) and it must actually work on the hardware available. The possible consequences of having software failures during wartime require having an extremely high-level of system

reliability – satisfaction with a system would be extremely low if it crashed due to a software failure while a missile was inbound.

Software engineers are the people trained to translate technical aspects into terms that can be understood by decision-making authorities. Also, these specially-trained engineers can represent government interests in technical discussion and negotiations, and improve overall software development by understanding all facets of the development process.

The DoD's history of dismal failures in its software projects includes projects completed well over-budget, systems failed to be delivered on time, and delivered systems that failed to provide all of the promised functionality. Software engineering helps to preclude these problems to some degree by using the fundamental and sound principles of engineering. Realizing that it is significantly more expensive to fix an error the later in the software development process that it is found and corrected, software system design should be organized and engineered in a very strategic manner. A long, detailed requirements analysis phase helps to ensure that the customer has strong input into what is delivered, and also gives the software producer the ability to clarify questionable design issues.

While requirements change over time during the development process, this "requirements creep" is a good example of how the software engineering process helps to minimize the effects. The creation of small prototypes of reduced functionality that allow the user to see specific parts of what is to be the final delivered system, allows both developer and client to resolve confusing and conflicting development issues.

When software projects are contracted out, the senior-level Navy leadership that supervises these projects need to be able to determine when the contractor is not giving them straight answers, when the promised system is not feasible, or when timelines are not reasonably achievable. Those acquisition professionals protecting the Navy's interests need to foresee and eliminate future problems by having the ability to communicate with the contractors on the same technical level.

Successful software engineers will be able to achieve information superiority for warfighters, improve effectiveness of DoD systems, and increase software project success

rates by decreasing the number of projects that do not provide a final product, are late in delivery, or are less complete than required.

Additionally, there is a great and growing need within the DoD for a higher-level software engineer with Ph.D.-level leadership to direct software development, design, evolution, reuse, and management projects. These leaders would use their knowledge to forecast future needs and procure the programs for future software efforts. These personnel would need to understand the concepts and needs of the Navy on a much higher level than that discussed previously. Visioneering future projects like "CommandPost of the Future" often require fundamental research, and the DoD currently lacks the requisite leadership to direct these projects to fruition. Other DoD leadership issues that could be addressed by these doctorate level engineers include: definition of more effective information technology and information assurance policies, assessment and development of effective software policies for the DoD, and formulation of technological visions and objectives. Additionally, the Navy needs high-level personnel to direct the Smart Ship/Smart Carrier/Smart Gator initiatives discussed earlier in the chapter.

E. POSSIBLE SOLUTIONS

While it is pretty clear from the previous discussion that a need for software engineers in the Navy's future exists, there are numerous different options for creating the assets to address that need. Several available options to provide the required engineers are discussed now.

1. Contracting Civilian Sector Experts and Thinkers

One possible method for dealing with the problem is to use civilian personnel. The DoD and the Navy could contract out all services dealing with software, including the planning and design of future systems. This has the potential to be a cost-effective solution, since there are many people in the commercial sector who have the ability to do the type of work the Navy needs and require no further education to do so.

However, there are numerous issues that simultaneously make this a questionable solution. With the very strong current job market (especially in high-tech fields), the outside contractors would be able to command significant salaries, which may make the cost prohibitive after all. Additionally, while active-duty officers are around for a known period of time, civilian personnel need have no loyalty to the job. If they get a better paycheck or find a more satisfying job elsewhere, they can leave a contracting agency without its personnel, dooming the contract to failure due to delays for re-training new personnel. Also, since many DoD projects require security clearances for the personnel working on them, further delays and difficulties with personnel changes can be expected.

Plus, contracting work outside of the Navy's internal assets puts the Navy at the mercy of the contractors for delivery. While a contractor may not really have the Navy's best interest in mind during a project, "in house" personnel like active-duty officers would more likely be truly interested in the actual needs and requirements of the Navy.

2. Educating Naval Officers in Software Engineering

Software producers sometimes criticize the field of computer science as geared toward theoretical studies and focusing on the modeling of problems as opposed to actual integration of the theory for operational use. Software engineering pertains more to the actual process of software production and system integration. Software engineers use sound engineering principles to economically develop software that is reliable, flexible, maintainable, and that works efficiently on real machines.

A software engineering curriculum would build upon a student's scientific knowledge and teach principles and methods of software development and process management. A curriculum should include in-depth coverage of requirements engineering, software architecture, design automation, development methods, and management processes for software development.

Training Naval officers to become software engineers is not an easy task. Time spent earning a graduate degree is time that officers are away from the tasks that need to be performed in the Fleet. Additionally, beyond the time investment, there is a significant monetary investment in educating officers. Yet, having an educated officer

corps can reap many benefits for the service. These officers would be better prepared to face the systems and software issues that will arise in the technology-dependant future, including the planning and acquisition phases of system development.

Also, officers educated in software engineering would be better equipped to handle real-time system failures than those without such technical expertise. Unfortunately, it is more likely than not that systems onboard Naval assets will undergo a significant system failure at some point. Having officers with the ability to recover from such a situation would be crucial to the ship, sub, aircraft, or other command struck by such a failure.

a. Software Engineering at a Civilian University

There are many excellent software engineering postgraduate programs at universities throughout the country that could potentially fill the Navy's need. Amongst these universities, *Stanford*, *Georgia Tech*, and *University of Southern California* have well-known strong software engineering programs. Additionally, the *Software Engineering Institute at Carnegie Mellon University*, overseen by Dr. Delores Etter, the *Deputy Under Secretary of Defense for Science and Technology*, offers a degree in Software Management. *Carnegie Mellon* also has a "partnership" program that offers internet-based instruction and graduates students with certificates vice degrees, yet it focuses mainly on undergraduate-level courses.

In the fall of 1998, *Stanford University* became the first major research university in the U.S. to offer a master's degree online. The first degree offered was a program in electrical engineering, and consisted of the same course material as given to Stanford students in residence.³⁸ However, at least two reports have warned colleges to "temper their zeal for the rapidly growing on-line education industry, arguing that effectiveness and impact are unclear"³⁹, at least somewhat questioning the adequacy of a web-based degree program.

Certainly, one possible solution to the Navy's software engineering need is to send active-duty officers to one of the universities mentioned or another university

with a quality software engineering program to obtain a software engineering degree and then put that officer to work helping with the Navy's problems.

b. Software Engineering at NPS

The Naval Postgraduate School is the standard school for most postgraduate education curricula that the Navy offers its active-duty personnel. Barring any significant reasons to fund a curriculum elsewhere, NPS is an excellent long-standing educational option for the Navy. Specifically, the *Chief of Naval Operations'* instruction on Graduate Education (OPNAVINST 1520.23B) has an enclosure entitled "Criteria for Selecting Civilian Institutions" which states:

Current guidance from Congress and the DoD mandates the full utilization of DoD sponsored schools (NAVPGSCOL, Defense Intelligence College, and the Air Force Institute of Technology). In some instances where an appropriate curriculum is not available to meet a valid subspecialty requirement, the use of a civilian university is necessary.

Thus, if NPS has a valid software engineering program available, theoretically that program should be utilized prior to engaging a civilian institution to fulfill the Navy's software needs. Specific benefits of both the school and its software engineering programs will be discussed in Chapter IV, along with reasons (beyond the CNO's instruction quoted above) why this is a better option than sending a student to a civilian university.

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III. GRADUATE EDUCATION IN THE NAVY

A. THE IMPORTANCE OF GRADUATE EDUCATION

Graduate education is an important tool for the United States Navy. It is a vital method for educating the future leaders of the service, giving them the skills they will need to lead effectively in the next century. At the same time, it is a reward to the officers for their time in the service, and for their commitment to remain in the service of their country. This retention tool helps keep the best officers in the service by offering them an opportunity to complete their graduate degrees and become more marketable for the careers they will move on to once their military careers are completed.

In fact, the *Chief of Naval Operations* recently wrote a very telling "Vision Statement"¹ on education for Naval officers. It includes numerous quotes that highlight the importance of graduate education in the Navy's future. A copy of the statement follows as Figure 1 (the special punctuation in the text is as written by the CNO, and was not made by the author of this thesis). In the statement, the CNO remarks that to ensure we are prepared to operate in an increasingly sophisticated technological environment, "the Navy must revitalize our investment in officer education." Additionally, experience and formal education are vital to giving officers the "ability to deal with the unknown and uncertain" that arise due to the "revolution in military affairs, driven in large part by the evolution in information technology". He concludes that education is a "critical factor in maintaining the ability to accomplish our primary mission" and that "each career unrestricted line officer will be afforded the opportunity to obtain a relevant graduate degree". Clearly, the CNO realizes the importance of advanced education to the quality of the people who will lead the Navy into the future.

VISION STATEMENT FOR NAVY OFFICER EDUCATION

The 21st Century will present many challenges and opportunities to our Navy. As the nation's principal forward-deployed force, we will continue to be called upon first and often, and meeting our commitments will require us to operate in an increasingly sophisticated technological environment. To ensure that we are fully prepared to carry out this critical role, maintaining the great legacy left by those who have served before us, the Navy must revitalize our investment in officer education.

As has been true in the past, the success of the 21st Century Navy will be totally dependent on the quality of its people -- on their knowledge, skills and ability to lead motivated teams to accomplish challenging and often dangerous missions. Adapting to change has always been inherent in the life of a Navy officer, but flexibility and creativity are more important than ever as today's fast pace and rapid increase in technological sophistication define our times. We are in the midst of a revolution in military affairs, driven in large part by the evolution in information technology. Navy officers must be educated to deal with emerging challenges and opportunities. Training can prepare them for the known challenges, but it is experience and formal education that provide and enhance their ability to deal with the unknown and the uncertain.

Education is crucially important for our future leaders. Navy officers must be committed to life-long learning, and the Navy must do its part to ensure they have the opportunities for advanced education. I fully recognize the operational demands and pressures we place upon our officers, but we must ensure that we are properly preparing them for the future even as they are meeting the myriad challenges of today. Education must not be seen as a diversion from our primary mission, but rather as a critical factor in maintaining our ability to accomplish our primary mission. All Commanding Officers and other senior leaders must make education a priority in the development of our officer corps.

My vision is simple: each career unrestricted line officer will be afforded the opportunity to attain both a relevant graduate degree and appropriate Professional Military Education. I have directed my Director of Naval Training and Chief of Naval Personnel to make this vision a reality by 2001.

J. L. Johnson
Chief of Naval Operations

Figure 1. CNO's Vision Statement for Navy Officer Education

B. GRADUATE EDUCATION BASICS

The Navy graduate education system is a complicated process that requires the balancing of many factors due to limited resources. Time spent at graduate school is time officers must spend away from the operational fleet, which is where commanders would prefer to keep their best and brightest officers. Yet the skills required by many billets need to be learned somewhere, and in many cases the best way to learn these skills is by earning a graduate degree which has been designed to fulfill special knowledge requirements.

As stated by the *Department of Defense* in its directive on postgraduate education, the official purposes of the graduate education program for military officers are twofold. First, to raise the level of individual military officer professionalism and technical competence in order for those officers to more effectively perform their required duties and responsibilities. Additionally, graduate education provides developmental incentives for officers with high ability, dedication, and the capacity for professional growth to remain in the Service.²

The following sections highlight some of the important concepts within the Navy's graduate education system. These concepts are introduced here and will be referenced in the subsequent chapters on the Software Engineering programs at NPS and the newly-proposed Software Engineering curriculum as specific benefits, desired goals, and required changes are discussed.

1. The *Officer Subspecialty System* and Subspecialty Codes

The *Officer Subspecialty System* is the primary method used by the Navy to define the graduate education requirements for the Navy³. This is accomplished by coordinating specific skill requirements related to a job with specific job skills available within the Naval officer corps. Curricula are reviewed and validated on a biennial basis to ensure that the Navy's graduate education programs continue to provide the skills required in the Fleet.

Primary areas of expertise are assigned to officers via a designator code. This designator code describes an officer's main warfare specialty and separates the officer corps into separately managed communities. For example, a Surface Warfare Officer has a designator of 1110, a Submarine Officer has a designator of 1120, and a Naval Pilot has a designator of 1310. Each community has a separate and distinct set of career paths applicable solely to officers with that primary designator. The managers of each community ensure that the community's officers meet the requirements needed to advance along the designated career path. Many billets in the Navy may be filled only by officers from a designated community; clearly, it doesn't make sense to put an Intelligence Officer into a billet as the Aviation Safety Officer for a squadron. That position would be filled by an officer from one of the aviation communities.

Specific billets may require additional qualifications beyond the warfare designator to perform the assigned functions of that position. These additional skill sets are defined as subspecialties. Subspecialties define at a more precise level the skills required to adequately perform in a given position. For example, some billets on a ship could require any LCDR (O-4) who is a Surface Warfare Officer. Another position on the same ship may require a Surface Warfare Officer LCDR, but it must be one who has earned a Master's degree in Mechanical Engineering. The distinction is made via the required subspecialty code for the second billet being more restrictive than that of the first billet.⁴

While a specialized postgraduate degree is the most common method for achieving a subspecialty code, other methods of qualification are permissible. The subspecialty needs for each billet come from a determination of the minimum education or training level deemed essential for performance of the job. Thus depending on the specifics of the position, the actual subspecialty requirement may be filled by postgraduate education, undergraduate education majors, specialized functional training, or significant experience.⁵

Subspecialty codes under the current system consists of five alphanumeric characters. This code has four digits followed by a letter. The first four digits separate the specific subspecialties into specialized areas of focus as defined by the subspecialty

Specific Criteria Statements. The trailing letter in the subspecialty code indicates the level of education, training, or experience in the subspecialty. The two figures on the following pages show the different possible numerals and letters that make up the subspecialty codes. Figure 2 lists the different subspecialty fields and their numeric codes and Figure 3 shows the various levels of qualification within the subspecialty and their corresponding letters. These figures are taken from the electronic version of the *Officer Subspecialty System Handbook*, and are copies of Tables 6 and 8, respectively.

2. The Use of Subspecialty Codes in Officer Placement

The *Bureau of Naval Personnel* (BUPERS) in Millington, Tennessee, is the command responsible for assigning officers to billets. When an officer is preparing to transfer to a new command, the officer contacts his or her detailee. The detailee is the person at BUPERS who works directly with the officer to match the officer's desires along with the needs of the Navy to find an acceptable next position to follow along the officer's career path. Similarly, each command receiving new personnel is represented by a placement officer. The placement officer ensures that only qualified officers are proposed to fill open positions so that the command can continue to complete its mission.

For example, billets for the officers who supervise operations of the nuclear reactors aboard nuclear-powered ships or submarines can only be filled by those personnel who have completed the requisite training and are thus qualified to perform in that capacity. Similarly, there are jobs in the Fleet that require personnel to have specific skills that are obtained via graduate education.

The subspecialty codes are used to match officers who have earned specific subspecialties to the billets that require their skills. In the placement system used by detailers and placement officers, any subspecialty requirements required by a billet are listed. This allows the detailee to determine if a proposed officer has the necessary skills to perform that job. Additionally, once an officer is proposed to a new command by the detailee, that command's placement officer can find the subspecialty codes earned by

**EDUCATION/TRAINING/EXPERIENCE FIELDS
(3RD AND 4TH CHARACTERS)**

XX10 - PUBLIC AFFAIRS[F]	XX49 - OPERATIONAL OCEANOGRAPHY
XX11 - ENGLISH	XX50 - NAVAL SYS ENG (GEN) [A]
XX12 - HISTORY	XX51 - NAVAL CONSTRUCTION & ENG
XX16 - JOINT INTELLIGENCE	XX52 - NUCLEAR ENGINEERING
XX17 - NAVAL TECH INTELLIGENCE	XX53 - NUC PROPULSION PLANT OPS[F]
XX18 - REGIONAL INTELLIGENCE	XX54 - NAVAL/MECHANICAL ENG
XX19 - OPERATIONAL INTELLIGENCE	XX55 - ELECTRONIC ENGINEERING
XX20 - GEN POLITICAL SCIENCE	XX56 - ~~UNDERWATER ACOUSTICS~~ [D]
XX21 - MID EAST/AFRICA/SO. ASIA	XX60 - WEAPONS ENG (GENERAL) [A]
XX22 - FAR EAST/PACIFIC	XX61 - ~~WEAPONS SYSTEMS ENG~~ [D]
XX23 - WESTERN HEMISPHERE	XX62 - CHEMISTRY
XX24 - EUROPE	XX63 - ~~WEAP SYS SCI (PHYSICS)~~ [D]
XX25 - ~~INTERNAT'L NEGOTIATIONS~~ [D]	XX66 - COMBAT SYSTEM SCI & TEC
XX26 - ~~STRATEGIC PLANNING (GEN)~~ [D]	XX67 - ~~NUC PHYS (WEAP & EFFECTS)~~ [D]
XX27 - ~~STRATEGIC PLANNING (NUC)~~ [D]	XX68 - STRATEGIC WEAPONS (FBM)[F]
XX28 - STRATEGIC PLANNING	XX69 - STRATEGIC NAV (FBM)[F]
XX29 - SPEC. OPER/LOW INT.CONFLICT	XX70 - AERO SYS ENG (GEN) [A]
XX30 - MANAGEMENT (GENERAL) [A]	XX71 - AERO ENGINEERING
XX31 - FINANCIAL MANAGEMENT	XX72 - AVIONICS
XX32 - MATERIAL LOGISTICS SUP MGMT	XX73 - FLIGHT PERF/TEST PILOT[F]
XX33 - MNPWR, PERS & TRNG ANALYSIS	XX75 - SPACE SYSTEMS (GEN) [A]
XX35 - TRANSPORTATION MANAGEMENT	XX76 - SPACE SYSTEMS OPERATIONS
XX37 - EDUCATION & TRNG MGMT	XX77 - SPACE SYSTEMS ENGINEERING
XX40 - ~~APPLIED LOGIC (GENERAL)~~ [D]	XX80 - ~~COMMUNICATIONS (GEN)~~ [D]
XX41 - APPLIED MATHEMATICS	XX81 - ~~COMMUNICATIONS ENG~~ [D]
XX42 - OPERATIONS ANALYSIS	XX82 - ~~COMM SYS TECH~~ [D]
XX43 - OPERATIONAL LOGISTICS	XX89 - INFORMATION MANAGEMENT
XX44 - ANTISUBMARINE WARFARE	XX90 - ~~COMPUTER TECH (GEN)~~ [D]
XX45 - COMMAND & CONTROL [C]	XX91 - COMPUTER TECHNOLOGY - SCI
XX46 - ELECTRONIC WARFARE [C]	XX95 - ~~COMPUTER TECH - SYS MGMT~~ [D]
XX47 - METEOROLOGY & OCEANOGRAPHY [B]	0000 - ANY DISCIPLINE
XX48 - METEOROLOGY [B]	

[A] - BILLET CODES ONLY

[B] - ASSIGNED TO 1800 DESIGNATOR

[C] - 2 TOURS REQUIRED FOR EXPERIENCE CODE

[D] - ~~DELETED~~

[E] NEW CODES

[F] BILLETS CAN BE
F&G CODED

Figure 2. Subspecialty Fields⁶

LEVELS OF EXPERIENCE, EDUCATION AND TRAINING

SUBSPECIALTY CODE SUFFIX (5TH ALPHABETIC CHARACTER)

- B - VALIDATED REQUIREMENT FOR MASTER'S OR HIGHER LEVEL OF EDUCATION BUT SECOND PRIORITY TO P, Q, M, N, C, OR D-CODED BILLETS; USED WHEN SUBSPECIALTY CODE COMPENSATION HAS NOT BEEN IDENTIFIED. APPLIES ONLY TO BILLETS.
- C - PHD LEVEL OF EDUCATION - PROVEN SUBSPECIALIST
- D - PHD LEVEL OF EDUCATION
- E - BACCALAUREATE LEVEL IN A FIELD APPLICABLE TO THE SUBSPECIALTY. ASSIGNED TO BILLETS IN UNIQUE AREAS THAT NEED SPECIFIC BACKGROUND TO PERFORM BILLET OBJECTIVES.
- F - MASTER'S DEGREE NOT FULLY MEETING NAVY CRITERIA OR GRADUATE EDUCATION AT LESS THAN MASTER'S LEVEL - PROVEN SUBSPECIALIST
- G - MASTER'S DEGREE NOT FULLY MEETING NAVY CRITERIA OR GRADUATE EDUCATION AT LESS THAN MASTER'S LEVEL
- H - INDICATES A POSITION FOR WHICH THE ASSIGNMENT OF AN OFFICER WITH A MASTER'S LEVEL EDUCATION IS DESIRABLE BUT NOT REQUIRED AFLOAT STAFF ONLY
- M - POST-MASTER'S GRADUATE DEGREE LEVEL - PROVEN SUBSPECIALIST
- N - POST-MASTER'S GRADUATE DEGREE LEVEL OF EDUCATION
- P - MASTER'S LEVEL OF EDUCATION
- Q - MASTER'S LEVEL OF EDUCATION - PROVEN SUBSPECIALIST
- R - SIGNIFICANT EXPERIENCE - PROVEN SUBSPECIALIST
- S - SIGNIFICANT EXPERIENCE
- T - DENOTES TRAINING BILLET WHICH QUALIFIES INCUMBENT FOR AN S-CODE

Figure 3. Subspecialty Letter Codes⁷

that officer, and thus can determine if the officer successfully meets the skill requirements for the position.

In a perfect Navy, there would be a sufficient number of officers with the necessary skills such that an officer could be declined, without question, if the required subspecialty had not been previously earned. This may have been the case prior to the massive drawdown of the Navy in the 1990's. Unfortunately, the current situation in the military is restricted by economic and political realities which limit the size of the military force and also the ability of its officers to take time away from operational tours to complete the requirements to earn subspecialty codes (usually via postgraduate education).

Under these constraints, the placement officer must determine if an officer who does not have the desired subspecialty code can still perform acceptably. For example, an officer who has earned a 0043S code (denoting significant experience in the Operational Logistics field) is not the best solution for a position that requires a 0043P code (earned by completing a postgraduate educational program in Operational Logistics). Nonetheless, having the officer with the S-code would likely be preferable to leaving the position unfilled because no officer with the required P-code is available.

As described here, subspecialty codes are associated with both officers and billets. These codes play a crucial role in ensuring the right people get into the right jobs, helping ensure the Navy can complete its various missions.

3. Graduate Education's Role in Subspecialty Codes

Several years ago, the CNO released a Graduate Education Statement⁸ describing the honor in being selected for graduate education, along with praise for the programs available at NPS. The statement included the following section regarding the utility of subspecialty disciplines in the future of the Navy:

Students will expand their breadth of knowledge in a particular discipline and reinvigorate their ability to successfully analyze and solve the complex challenges we face. These important skills will help guide our Navy into the 21st century through fresh thinking and innovation.

a. *Funded Options - NPS & CIVINS*

The manner in which the Navy addresses the long-range skill requirements of the subspecialty codes is by encouraging its officers to obtain postgraduate degrees. There are several different options available for officers to accomplish this task. The first and most popular method is to spend a shore tour earning a degree at the Naval Postgraduate School in Monterey, CA. When Naval officers are assigned to NPS as students, their full-time job is to earn a Master's degree by completing an assigned curriculum and earning the related subspecialty P-code. In order to earn a P-code, the officer must complete all the Educational Skill Requirements (ESR's) required by the subspecialty. These ESR's are military specific requirements above and beyond the minimum requirements for the postgraduate degree alone.

A second method requires spending a shore tour at one of the universities contracted by the Navy and to earn a Master's degree from that institution. This program is known as the *Civilian Institutions* (CIVINS) program and is available for specific curricula not taught at NPS. These curricula are seen as relevant to the Navy, but they may not be cost effective to develop such programs at NPS. For example, there are officers at law school via the CIVINS program. This is because: (1) no law program exists at NPS; (2) there are already established law programs throughout the country; and (3) it is not really feasible to develop a law program at NPS due to the relatively small need. There is a definite need for Naval lawyers; however, there are not enough students to justify the overhead and additional costs of establishing a law program on-site at NPS.⁹

The curricula developed through the CIVINS program satisfy the educational requirements for their related subspecialties, and the officers who complete these programs earn P-codes, just like those who complete graduate degree programs at NPS.

b. *Unfunded Education*

A third method for an officer to complete a degree is to do so during his or her own free time while performing another full-time duty for the Navy. This option is called *Off-Duty Voluntary Education* and is often used by officers who wish to complete a postgraduate degree but are unable to do so via NPS or the CIVINS program. This may

be due to not being able to secure time away from operational tours, or that there was no available quota [quotas will be discussed later in this chapter] for the desired curriculum at NPS. Another reason could be the lack of the requisite academic background and thus not meeting the minimum Academic Profile Code (APC) requirements for the desired curriculum at NPS.

Typically, the degrees earned off-duty are completed without any interaction with the Navy, and thus it is very unlikely that the officer would qualify for a P-code following graduation. This is because while degree requirements would be met, the military specific ESR's are unlikely to have been completed. However, following graduation, an officer can apply for a subspecialty code based on the degree earned. The most likely subspecialty awarded would be a G-code signifying a "Master's degree not fully meeting the Navy criteria". While not as desirable as an officer holding a P-code in the same subspecialty field, a command's placement officer might accept an officer with a related G-code as having most of the requisite knowledge base.

4. Coded Billets

The lists of all billets that are specifically coded for each subspecialty are promulgated monthly by "OP-114". Actually, OP-114 is an old name for the department. Through various reorganizations at the *Bureau of Naval Personnel*, OP-114 became PERS-213, and is now known as N13, *Military Personnel Policy and Career Progression*. The list is automatically generated and is the responsibility of N131, *Officer Plans and Career Management*.¹⁰

This document consists of hundreds of pages, as there are over 6000 subspecialty-coded billets in the Navy¹¹. A few sample matches between billets and their required subspecialties are listed here to provide a small array of examples. In order to teach Computer Science at the United States Naval Academy, an officer must have a 0091P code, which is earned by completing the Computer Science program at the Naval Postgraduate School. In order to work on the staff of the *Commander In Chief, U.S. Pacific Command* (USCINCPAC) as a Planning Officer, an officer must have completed the National Security Affairs program specializing in the Far East and Pacific program (and earned a 0022P subspecialty code in the process). Similarly, only an officer who

has completed the Aeronautical Engineering curriculum at the Naval Postgraduate School and has earned a 0071P code is qualified to become the Aviation Maintenance Engineer for Fighter Class aircraft at *Commander, Naval Air Force, U.S. Atlantic Fleet* (COMNAVAIRLANT).

The current list of all the coded-billets in the Navy which can be filled by an officer who has earned a Computer Technology - Science 0091 subspecialty is included as Appendix E. The example used in the previous section referring to the Computer Science instructor at the Naval Academy can be seen on the first page of this list ten lines down as the billet entitled "INST ACAD/ INSTR COMP". The list for the 0091 subspecialty codes is included as an appendix, since this is the subspecialty Computer Science students at the NPS currently receive upon program completion. These are the students most likely to have relevant software engineering exposure. In the following chapter, the Software Engineering programs currently at NPS are discussed, along with some significant problems with the current subspecialty system.

5. "Payback", Obligated Service, Utilization, and Fills

Any U.S. Navy student who completes a fully-funded graduate education program at the Naval Postgraduate School is supposed to move on to fill one of the specially-coded billets upon graduating. This is referred to as completing a "payback" tour and is the Navy's attempt to properly utilize the skills officers learn during their graduate education.

In its section on "Utilization", the *Chief of Naval Operations'* Instruction on Graduate Education (OPNAVINST 1520.23B) states that "Officers who have received Navy funded graduate education will serve one tour in a validated subspecialty position as soon as possible but not later than the second tour following graduation." The instruction additionally states that such "officers will serve in as many positions in related subspecialty billets as Navy requirements and career development permit."

While the CNO's desire to get graduated students into applicable billets as soon as possible is an excellent plan in theory, it is not completely implementable in practice. Not every officer has a career path that facilitates the transfer into one of the billets that corresponds to the educated specialty. In addition, the possibility exists that no billets

utilizing the subspecialty are available at the specific time the officer is due to rotate to the initial tour of duty following the postgraduate education tour. To allow for such instances, the Navy (and *Department of Defense* in general) use the two-tour window when calculating the utilization statistic used to track the performance of the detailers and placement officers in putting the right people in the right jobs.

Any officer receiving fully-funded graduate education, whether it is at NPS or via the CIVINS program, agrees to a period of obligated service as part of the acceptance of orders to that tour. A graduate student obligates to continue on active duty for a period equivalent to three times the amount of time spent in school for the first year, and incurs a one-for-one period of obligation thereafter.¹² For example, with a 24-month curriculum, such as the current Computer Science curriculum or the Combat Systems/Software Engineering curriculum proposed in this thesis, a student incurs an additional service obligation of forty-eight months. The Navy should be able to get at least two full tours out of an officer during those four years. This is the rationalization for the CNO's utilization policy requiring a "payback" tour with the first two tours of duty after graduation. Within the officer's additional period of obligated service, the Navy should see some return on its investment by placing the officer in at least one tour utilizing the subspecialty just earned by that officer.

While an officer only needs to work in a job that requires the P-code in either of the first two tours following graduation, and despite the allowance for various difficulties in scheduling officers into billets that appropriately use their skills and other abnormalities in an officer's career path, the actual utilization levels are somewhat weak. Based on the latest statistics available, overall utilization (ignoring the two-tour guideline) is nearly 83%, although by the DoD definition requiring payback within two tours, utilization is less than 76%¹³. Officers who have not utilized their subspecialties, but are not out of the two-tour window are excluded from these calculations. Since these officers number nearly half of those with P-codes, these utilization statistics may be deceptively high compared with reality.

Specific utilization calculations as they apply to the Computer Science 0091P code subspecialty will be addressed later in the thesis.

Another way to measure proper utilization of the skills learned via graduate education is very similar to utilization. "Fills" (or the Fill Report) measure how well qualified the personnel filling subspecialty-coded billets are. This report compares the subspecialty qualifications of the personnel in these jobs to the subspecialty requirements of the billets. According to the statistics received from the previous Assistant Director of Programs at NPS, the direct match of all subspecialty-coded billets is just above 45%¹⁴. This means that more than half of the subspecialty-coded billets are being filled by personnel who do not have the "required" qualifications for those positions.

As an amplification to this "match" statistic, the Navy calculates a second fill statistic counting personnel with "related" subspecialty codes as matching the subspecialty requirements of the billet. Thus, the "direct and related match" statistic would be higher than the "direct match" statistic if any of the personnel in the billets who do not have the appropriate P-code have a code that is "related" to the required P-code. For example, for billets requiring the Computer Technology - Science 0091P code, an officer with a 0055S code (Electronics Systems Engineering) or an officer with a 0089S code (Information Technology Management) would get credit in the "related match" statistic.¹⁵ When counting the direct and related matching subspecialty codes, the overall fill rate increases to over 55%.¹⁶ As with utilization, the fill rates for 0091P coded billets will be discussed later in the thesis.

6. Long-Range Planning with the GERB via the *Quota Plan*

The Navy's path for graduate education is set by the *Graduate Education Review Board* (GERB). This group meets semi-annually, and consists of representatives from the program sponsors responsible for curriculum direction and the funding needed for school overhead (faculty, lab support, thesis travel costs, etc.), and resource sponsors who fund the student *endstrength* (available funding for sending officers to school, including student salaries), along with standing invitations for members from the Naval Postgraduate School, and the Naval War College. The GERB balances the available endstrength and the perceived subspecialty needs of the Navy to develop the plan for the number and make-up of students attending fully-funded postgraduate education.

Another vital piece of the graduate education puzzle is the *Postgraduate Education Quota Model*. The model is run annually to establish the following fiscal year's graduate education student input requirements. The computer model takes into account all the subspecialty-coded billet requirements as well as the current inventory of officers with subspecialty designations, and returns the number of student quotas required for each subspecialty for the coming fiscal year. In addition to separating the officer quotas by curriculum, the model determines what the specific requirements are for each officer community within each curriculum. For example, a number of Surface Warfare Officers and a number of Aviators are needed in the Fleet with the specific skill background associated with some curricula, but perhaps no Fleet Support Officers or Supply Officers with that educational background and subspecialty are needed. Thus, no officers from those last two communities would be slated for those curricula during the quota designation process.

The model also accounts for the grade of officers needed based on years of completed service. Additionally, there are several other factors affecting the officer inventory that are handled by the simulation model. Attrition of officers from the service, officer availability and rotation into new billets all factor into what the following year's requirements would be. Below in Figure 4 is a summary of the inputs, outputs, and relevant factors used by the model.¹⁷

The overall goal of the *Quota Model* is to achieve a steady state for all curricula in order to make the most efficient use of P-coded officers and eliminate large fluctuations in student input¹⁸. This has been an elusive goal with the continually shrinking military and the resulting quota levels that have dropped significantly in recent years. Accordingly, the population of students at NPS has decreased in recent history as well.

The *Quota Model* is developed (or theoretically should be) to fill the curricula for which the corresponding P-codes are most needed in the time frame following graduation of those students. Essentially, the *Quota Model* is forecasting needs several years ahead to prevent a shortage of officers trained with any specific P-code by placing students into the appropriate curricula to produce those officers who can move on to fill all necessary jobs.

COMPUTER SIMULATION MODEL USED FOR COMPUTING POSTGRADUATE EDUCATION QUOTAS

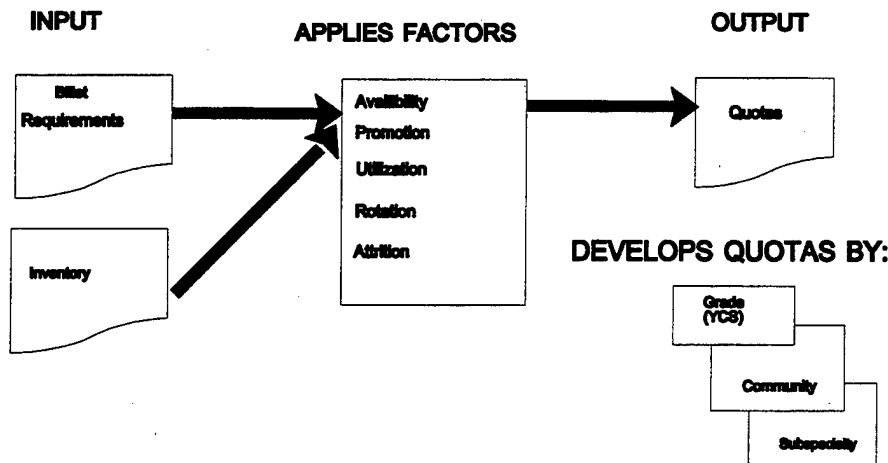


Figure 4. Postgraduate Education Quota Model

The model assumes that all quotas generated will be filled and that the coded officers will be utilized to the maximum extent possible. As noted previously in the section on utilization, this is not the actual observed reality. Additionally, the designated quotas are rarely if ever completely filled. A concept associated with the *Quota Model* is the idea of quota fill percentages. While the quota model is developed to fully meet the Navy's subspecialty skill requirements, the quotas delivered by the model are subsequently cut for many reasons, including fiscal limitations. Due to the manpower reduction strategies of the military drawdown, the general manning philosophy is to expect 80% of the budgeted manning level. With this in mind, one should expect fill levels of the quotas to be around 80%. Some curricula meet the 80% fill expectation, but many other curricula do not reach this level. They are various reasons why some curricula do not even reach the expected fill level, some of which will be discussed later in this section. In reality though, the Navy has done a pretty good job meeting its overall

quota goals. In FY98, the fill level was over 88%, as only 60 of the 512 quotas went unfilled¹⁹.

The model as developed by the computer simulation must be revised by hand to correct for any events or situations that defy the model's assumptions. As it is very difficult to create an accurate simulation for model events occurring several years in the future, some tweaking of the model results is always required.

Each year after the computer simulation model has been run, the GERB meets for the *Quota Plan Conference*. The "Quota Conference" is a very complicated process involving much haggling over quotas. At the conference, the participants adjust the quotas to account for additional long-range goals for Navy postgraduate education not factored in during the computer simulation of the model. Other adjustments are made based on the imperfect assumptions of the model or fiscal issues. The goal of the conference is to "fine-tune" the *Quota Model* and present an acceptable *Quota Plan* for final approval.

After the draft revisions to the *Quota Model* figures are determined by the conference members, the revised draft *Quota Plan* is sent to *Military Personnel Policy and Career Progression* (N13) and *Director of Naval Training* (N7) for further revision and concurrence before signature and approval by the *Chief of Naval Personnel* (N1). Invariably, the model is changed again and again as various lobbying efforts meet with differing levels of success. Due to the large funding issues, politics can play a significant and influential role in what the final *Quota Plan* actually looks like.

Once a *Quota Plan* is finally approved and signed by the *Chief of Naval Personnel*, the officer detailers at BUPERS and the Graduate Education Placement Officer work throughout the year to fill those quotas with students who want to complete a postgraduate education. The detailers and the Graduate Education Placement Officer work with the prospective students to match curricula with student interest to the available quotas. This can be an extremely complicated process for numerous reasons.

Some examples of considerations that need to be met to match an officer and a curriculum include: (1) the prospective student officer needs to be at the "right" time in his or her career to go to NPS to get a graduate education. There may not be available time in an officer's career path to spend two years away from the operational fleet, thus

the officer may not be able to attend NPS; (2) the officer's designator (warfare specialty) must match the *Quota Plan* for the desired curriculum. If the officer is a Surface Warfare Officer who wants to study Financial Management, but there are no quotas for SWO's to study Financial Management, the officer will not be able to attend NPS within that curriculum; (3) the officer must be departing a command and be ready to report to NPS at a time that coincides with one of the course inputs for the curriculum. For fiscal reasons, most curricula at NPS have cut back to two or even only one input per year. If the curriculum only accepts new students in June, an officer due to change commands in December is not a satisfactory student candidate for that curriculum.

Another potential setback for certain students looking for graduate education is the direction ordered by the *Chief of Naval Operations Executive Panel* to select only the "best and brightest" officers for funded education opportunities²⁰. In order to ensure that the future leaders of the service will be broadly educated despite a limited amount of funding to provide such education, only the top performers with the highest potential should be afforded that opportunity. Thus, clearly not all officers can qualify for fully-funded graduate education.

Another consideration is that a student must have the appropriate academic background to qualify for the curriculum desired. For example, it is unlikely that a student who did poorly as an undergraduate history major would be able to handle the difficult postgraduate curriculum of Operations Analysis. Prior to a student's acceptance at NPS, the NPS Admissions Officer works with the Graduate Education Placement Officer to ensure that all prospective students have Academic Profile Codes that qualify them for the curricula they are slated to study.

But perhaps the most important difficulty in the process of matching a prospective student to a curriculum is finding an available curriculum that the student has a desire to study. Students may base their preferences on many factors, including natural aptitude, discipline of their undergraduate degree, perceived difficulty of the postgraduate curriculum, and marketability of the degree to the civilian world in the future. Part of the difficulty lies in the unavailability of quotas, since many of the popular curricula fill up quickly.

C. THE NEW NAVY SUBSPECIALTY SYSTEM

A slight complication to the current state of the subspecialty system is the fact that the CNO directed the *Chief of Naval Personnel* (N1) to reengineer the subspecialty system in order to streamline processes, improve system manageability, and provide better access to users of the system. It is believed these goals are crucial to the expansion of postgraduate educational opportunity for the Navy's officer corps.²¹

The *Student Requirements Task Group* (SRTG) was tasked to review the current subspecialty system and provide the CNO with a better version. The original goal was to have the new system in place along with the delivery of the *FY00 Quota Plan* in May 1999. However, the approval has been delayed numerous times in traditional Navy fashion, and the current intention is to have the new *Navy Subspecialty System* approved by October 1999. Following final approval, the Major Manpower Claimants will have up to 580 days to fully implement the changes.²² Nonetheless, major improvements in the system are expected, including a web-based system for coding billets, which will speed up the process considerably. Additionally, the system will have metrics built into it automatically, so utilization and fill rates will be accessible in a much shorter time than they are currently available.

The new *Navy Subspecialty System* will be discussed in more detail in Chapter V as it specifically applies to the new curriculum proposed in this thesis.

¹ Johnson, J.L., "Vision Statement for Navy Officer Education".

[<http://intra.nps.navy.mil/newIntra/cnovision.html>]. 07 June 1999.

² Department of Defense DIRECTIVE 1322.10, Subject: Policy on Graduate Education for Military Officers, p. 1, 31 August 1990.

³ Bureau of Naval Personnel, Officer Subspecialty Management and Graduate Education Branch, *Officer Subspecialty System Handbook*, p. I-2.

⁴ Willson, J.L., N131 Memorandum to Distribution, Subject: PROPOSED SUBSPECIALTY SYSTEM, 02 December 1998.

⁵ Chief of Naval Operations Instruction, OPNAVINST 1000.16J, Subject: MANUAL OF NAVY TOTAL FORCE MANPOWER POLICIES AND PROCEDURES, p. 6-8 (of Enclosure 1), 06 January 1998.

⁶ *Officer Subspecialty System Handbook*, electronic version, p. 25, received via email from Vicki Poindexter, N131E1, Bureau of Naval Personnel, to author, "RE: Off Subspec Handbk request", 01 September 1999.

⁷ *Officer Subspecialty System Handbook*, electronic version, p. 29, received via email from Vicki Poindexter, N131E1, Bureau of Naval Personnel, to author, "RE: Off Subspec Handbk request", 01 September 1999.

⁸ Johnson, J.L., "CNO Graduate Education Statement", *Naval Postgraduate School Catalog*, Academic Year 1997, p. 6.

⁹ Chief of Naval Operations Instruction, OPNAVINST 1532.23B, Subject: GRADUATE EDUCATION, enclosure 3, 01 October 1991.

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- ¹⁰ Telephone conversation between Jeff Joynt, Lieutenant, USN, Graduate Education Placement Officer, Bureau of Naval Personnel, and the author, 02 September 1999.
- ¹¹ *Naval Postgraduate School Catalog*, Academic Year 1999, p. 18.
- ¹² OPNAVINST 1520.23B, p.2.
- ¹³ Poindexter, Vicki, "Utilization Report for June 1999", received via email from Jeff Joynt, Lieutenant, USN, Graduate Education Placement Officer, Bureau of Naval Personnel, to the author, "FW: SEMI-ANNUAL REPORT OF", 02 September 1999.
- ¹⁴ "FILL REPORT" received from Pernell Jordan, Lieutenant Commander, USN, Assistant Director of Programs, Naval Postgraduate School, 25 June 1999.
- ¹⁵ Subspecialty detailing/utilization matrix received from Pernell Jordan, Lieutenant Commander, USN, Assistant Director of Programs, Naval Postgraduate School, 25 June 1999.
- ¹⁶ "FILL REPORT" received from Pernell Jordan, Lieutenant Commander, USN, Assistant Director of Programs, Naval Postgraduate School, 25 June 1999.
- ¹⁷ *Officer Subspecialty System Handbook*, electronic version, p. 66, received via email from Vicki Poindexter, N131E1, Bureau of Naval Personnel, to author, "RE: Off Subspec Handbk request", 01 September 1999.
- ¹⁸ Ibid.
- ¹⁹ Belcher, Brian, "Advanced Education Update (DRAFT)", brief for Graduate Education Review Board. [<http://web.nps.navy.mil/gerb/aded/sld002.htm>]. 30 March 1999.
- ²⁰ Belcher, Brian, "Advanced Education Update (DRAFT)", brief for Graduate Education Review Board. [<http://web.nps.navy.mil/gerb/aded/sld005.htm>]. 30 March 1999.
- ²¹ Willson, J.L., N131 Memorandum to Distribution, Subject: PROPOSED SUBSPECIALTY SYSTEM, 02 December 1998.
- ²² Meeting with Michael McMaster, Commander, USN, Assistant Director of Programs, Naval Postgraduate School, and the author, 19 August 1999.

IV. SOFTWARE ENGINEERING AT NPS

“Graduate education will continue to play a critical role in the career long development of Navy officers, producing warriors who are highly advanced scientifically and technologically, with a network-centric view across systems and platforms and well-developed problem solving skills.”

Navy Distributed Learning Planning Strategy of 04 December 1998

A. OVERVIEW

With a background understanding of the Navy’s graduate education system, it is now time to return to the problem highlighted in Chapter II. There exists a definite need for engineers trained to handle large-scale software systems in the future, including design and maintenance. Several potential solutions to address this need were presented after the general statement of the problem.

While each of the potential solutions has its own merit, there are numerous benefits in using a curriculum at the Naval Postgraduate School, as opposed to one of the other choices. Discussed here are benefits of the using NPS as the source of instruction, followed by a discussion of some strengths and advantages specific to the Software Engineering Department at NPS.

B. THE BENEFITS OF NPS

“The NPS exists for the sole purpose of increasing the combat effectiveness of the Navy and Marine Corps. It accomplishes this by providing post-baccalaureate degree and nondegree programs in a variety of sub-specialty areas not available through other educational institutions. The NPS also supports DoN through continuing programs of naval and maritime research and through the maintenance of an expert faculty capable of working in, or as advisors to, operational commands, laboratories, systems commands, and headquarters activities of the Navy and Marine Corps.”

“Rationale for NPS” from SECNAV INSTRUCTION 1524.2A
(Policies Concerning the Naval Postgraduate School)

1. General Benefits of a Curriculum at NPS

Providing advanced professional studies for military officers and defense officials from all U.S. military services (as well as from other nations) in order to increase their combat effectiveness by supporting the unique needs and interests of the *Department of Defense* is the mission of the Naval Postgraduate School¹. NPS' ability to develop and offer unique curricula that tailor subjects to the needs of the military make it the premier institution for Naval postgraduate education.

a. Military Atmosphere

One of the biggest benefits of schooling at the Naval Postgraduate School is so obvious that it is easy to overlook. NPS is the major military postgraduate institution in the United States. It is this military aspect that makes the school such a good place for a Naval officer to obtain a postgraduate education. Military relevance is all around at NPS. Many courses are designed exclusively around military topics. There is a constant military presence around the students, including students from all U.S. military services as well officers from many foreign countries, along with the school's curricular officers and other staff, and the military faculty who interact with the students on a daily basis. The interactions with officers from the other military services and from other countries enrich the learning experience at NPS. The professional dialogue achieved by being surrounded by fellow military officer students with different backgrounds, yet similar interests, is particularly beneficial to the efforts of cooperation to solve military problems.

Additionally, this military atmosphere offers the students guidance that would not be as easily accessible at another institution. An officer is easily able to receive career guidance face-to-face from senior officers on campus, rather than from a distance. The lines of contact from the student through the chain-of-command to thesis sponsors are much more accessible through the existing structure at NPS. Additionally, the Superintendent of the Naval Postgraduate School has a guest lecture series that allows students to hear directly from senior-level officials who impart military relevant thoughts, ideas, and information to the student body. Another example of improved quality-of-life

is that students have much better access to their personnel representatives while studying at NPS, as opposed to studying at a civilian university.

The military setting also allows for much more military-relevant research. This is important to students, because each graduate student is supposed to complete a military-relevant thesis as the capstone for their coursework. It should be significantly easier to complete such a thesis at a location with labs specifically designed for military research. A specific advantage of this sort is that a student has the opportunity to perform classified research at the Naval Postgraduate School, which would probably not be possible at another university. There is a definite value-added both to the military services and to the postgraduate experience by the student and faculty research performed on DoD-relevant issues.

b. Curricula and Accreditation

Curricula at NPS are designed with the help of the Flag officer curriculum sponsors. This ensures that the curricula at NPS are more relevant to an officer's career and to the needs of the Navy than curricula offered elsewhere. While some curricula at NPS are offered in similar formats at other universities, some of NPS' curricula are so militarily unique that the coursework is not available elsewhere. There also is a strong argument that much of the research completed at NPS could not realistically be done anywhere else.

While the curricula are developed with the sponsors to highlight the military issues in order to prepare officers for future assignments, the graduate degrees earned are awarded based on the same academic standards found at other accredited institutions. In addition to their uniqueness and specific military relevance, curricula at NPS are strengthened by the school's accreditation by the *Accrediting Commission for Senior Colleges and Universities of the Western Association of Schools and Colleges*. The WASC accreditation board recently finished its lengthy review of the school and its programs and renewed the school's WASC accreditation until its next comprehensive visit in the Spring of 2009².

Every class on campus is taught directly by one of the prestigious faculty members, who have direct experience with and understand the military importance of the

programs found at the Naval Postgraduate School. The school's faculty has a Ph.D. level of over 99%, from a wide variety of educational institutions across the country and across the world. Most classes have an average of less than 17 students per section and due to this small student-to-faculty ratio, the level of interaction between students and faculty is very high.³

c. Cost Issues

The NPS academic calendar is designed specifically to accommodate the professional needs of the student population. The academic year is longer and contains a higher course load in order to increase the productivity of the officer students.

A significant concern for the Navy in choosing between options for providing graduate education to its officers is cost. The *Chief of Naval Operations' Director, Assessment Division* (N81) performed a study in Academic Year 1993 and published a report dated 29 March 1993. The report notes that while it does cost more to send a student to NPS than to an average civilian institution, there are significant advantages in doing so. The higher cost at NPS is attributed to the facts that NPS has a 100% graduate student body (as opposed to most civilian institutions that have only a minority of graduate students), with graduate education costing two to three times more than undergraduate education.⁴ Due to the extended academic year, there is a much lower cost per student class hour for an NPS education than at an average civilian university. This is due to the facts that NPS students go to school more weeks during the year, and also that they have more contact hours per week. Based on total DoN investment costs, a program at NPS is 16% less expensive than an equivalent class hour program in a civilian institution.⁵ The conclusions that can be drawn from the study are that NPS provides more class hours for a given budget and NPS requires a lower budget for a given standardized graduate curriculum. Additionally, due to the faster paced academic schedule with the significantly higher number of contact hours, NPS reduces the time to complete a given curriculum.

d. Promotion Opportunities

The overall benefit of a graduate education is not overlooked by officer promotion selection boards either. For Fiscal Year 1998, the rates of officers "in-zone" selected for promotion to O-4 (Lieutenant Commander), O-5 (Commander), and O-6 (Captain) were all higher for those with graduate degrees than those who had no graduate education. In fact, for the promotions to O-4, 82% of those with graduate degrees from NPS were selected for promotion, compared to only 61% of those who had no graduate education. This is a significant statistic because the majority of Naval officers who graduate from NPS are O-3's soon to be in-zone for selection to O-4. Another telling statistic is that more than 70% of the Navy's Flag officers and almost 80% of the O-6's have graduate education experience.⁶

Additionally, a postgraduate educational tour at NPS offers students an opportunity to work on their Joint Professional Military Education (JPME) credits. These are very important milestones for promotion in the future, as a plan exists to make JPME credits a requirement for promotion to O-6. If an officer does not earn these credits at NPS, they will have to be earned either on the officer's own time, or via a special tour to the Naval War College. Since officers' career paths are cramped without any extra tour requirements, the opportunity to complete this milestone while concurrently earning a degree at NPS is another significant benefit. It might be possible to complete the credits via correspondence while enrolled at a civilian institution, however NPS' infrastructure certainly eases the burden on the participating students.

2. Benefits Specific to the Software Engineering Department at NPS

Some members within the Software Engineering Group at NPS belong to NPS' larger Computer Science Department. The Computer Science Department's missions are to enhance the warfighting capability of the United States by providing DoD-relevant graduate education in Computer Science, and to push the bounds of Computer Science research in directions that will most benefit the DoN, DoD, and the United States.⁷ The Software Engineering part of that department holds similar goals more specific to fields of software education, development, and maintenance. The Software Engineering programs at NPS focus more on the technical engineering aspects (including software

automation) as compared to the software management issues as taught at the *Software Engineering Institute*. The programs at NPS are intended to give their students the life-long capability to apply basic software engineering principles to the creative solution of complex problems.

a. Department Credentials

There are many reasons why a Software Engineering curriculum at NPS would be a good solution to the software engineering needs described earlier in Chapter II. The programs already in place within the department have set a good precedent. In fact, the editor of *Journal of Systems and Software* magazine rated the NPS Software Engineering Department as the #3 Software Engineering department in the world, while rating the department #1 in universities. Rated #1 and #2 overall in the world were AT&T Bell Labs and IBM T. J. Watson Research Institute, respectively.⁸

The success of the department at NPS is due to its commitment to preparing the technological leaders of tomorrow's forces, and being the leader in software engineering education and research supporting the DoD. The department created the first Software Engineering Ph.D. program in the country in order to develop DoD software practitioners with the skills and knowledge necessary to perform state-of-the-art research on large and complex software system development and evolution, including the oversight of other software professionals. The department is responsible for the invention of the *Computer-Aided Prototyping System* (CAPS) and other software engineering technologies, to be described shortly.

b. Special Programs

In addition to strong ratings, the department has a very strong faculty that stays current in the software engineering field. In fact, the faculty not only stays on the leading edge of the field, but it keeps the rest of the world on the forefront as well, with its annual open-invitation *Software Technology Review and Update for Technical Personnel* seminars. For the next seminar, lecturers include faculty from various departments at NPS, as well as a Ph.D. from *Integrated Computer Engineering* who has also lectured to Software Engineering students at NPS. A sample list of topics from the

five-day seminar includes: Economics of the Information Age, Network-Centric Computing, Risk Assessment and Management, Requirements Engineering, Decision Support Systems, Maintenance of Large Software Systems, and Software Engineering and Management.⁹

The Software Engineering Group has made a great deal of use of the distance-learning technology that is enjoying a boom in collegiate education throughout the nation. The Navy in general has shown an increased interest in distributed learning, encompassing both distance-learning via video-teleconferencing (VTC) technologies, as well as internet-based instruction. These flexible solutions to educational problems are an excellent fit to the special needs of Naval officers. Expansion of these programs is currently occurring both at NPS and at the Naval War College.¹⁰ RADM Chaplin, the Superintendent of the Naval Postgraduate School, was very pleased to meet a group of Software Engineering Ph.D. students from distance-learning sites, saying that the program and its extensive use of VTC technology was on the "leading edge of education" and was "carrying the light and water" to the Fleet for the future. Additionally, he was very interested in using the lessons learned by the Software Engineering Department to help improve the new ISO (Information Systems and Operations) curriculum developed by the school.¹¹

c. Faculty

The faculty holds quite a distinction on the academic side as well. There are three Fellows of the Institute for Electrical and Electronics Engineers (IEEE) within the twenty faculty members currently in the Software Engineering Group. Additional professors in the Group who are not from the Software Engineering Department proper, come from the Operations Research, Information Technology Management, Computer Science, C4I, and Mathematics departments at NPS. There are also two National Research Council Fellows within the Software Engineering Group.

The chair of the Software Engineering department, Professor Luqi, was named as a Fellow of IEEE earlier this year. She won the National Science Foundation Engineering Initiation Award in 1988, the Presidential Young Investigator Award in 1990, and an IEEE Technical Achievement Award in 1997. These awards all came for

significant achievement in moving the field of software engineering forward into the future. Professor Luqi has also been nominated to be the Editor-in-Chief of the *IEEE Transactions on Software Engineering*, a worldwide premier software engineering journal, and has been an Associate Editor for six software journals and magazines. In addition to Professor Luqi, the department's co-chair, Professor Valdis Berzins was named as a Senior Member of IEEE in May 1996.

A list of the entire faculty associated with the Software Engineering Group at NPS, including their degree credentials and specific research interests is available via the Software Engineering Group's website. The address to reach the faculty list is: <http://www.cs.nps.navy.mil/~se/personnel.html>

d. Students

The on-campus Computer Science graduates from the Software Engineering department have demonstrated the value of having a high-quality faculty to assist with their learning. Since 1988, ten students have graduated with distinction, and five have won the prestigious *Grace Murray Hopper Award* for Outstanding Achievement in Computer Science. One graduate won the *Navy League Award* for Highest Academic Achievement at NPS. Additionally, the department's students have performed ground-breaking research for the services as described next.

e. Research

The research performed both by faculty and students is another strong positive for the Naval Postgraduate School and its Software Engineering Department. The goals of software engineering research at NPS include the development and utilization of software tools, systematic methods, and theoretical foundations to make easier use of programming languages; enabling the development of higher quality software that more closely matches user needs, is simpler and easier to understand, is more reliable, and easier to modify; and the advancement of the state of computer-aided automation of software development, making software creation less labor intensive, more flexible, and with fewer errors.

To assist with the research efforts, there are several labs on campus at NPS dedicated to providing state-of-the-art educational environments for graphics-based software development automation. The Automated Software Engineering Lab is located in Spanagel Hall, room 531, and the CAPS and Software Engineering Lab is located in Spanagel Hall, room 506E. Efforts currently being performed in these labs includes work on rapid prototyping, specification languages and computer-aided software system design, software verification and testing, software safety, and computer-aided instruction.

The DoD-specific research performed within the department has included almost four million dollars in Research and Development support with approximately 100 theses completed. There are too many examples of outstanding research to detail them all here, but several projects can serve as key examples of the work done within the department. Topics addressed in the research have included network-centric computing, and agile and dependable software. Additionally, students in residence at NPS have worked on thesis topics including a technology assessment for Damage Control in the Carrier Integrated Digital Environment (CIDE), automation of the Army's Integrated Combat Service Support System (ICS3) fuel system, various Army medical applications for the National Institutes of Health (NIH), collaborative engineering projects with NASA, and work on an Unmanned Ship for the Navy. Figure 5 below lists several sample thesis titles completed by distance-learning Master's of Science in Software Engineering students at SPAWAR during their MSSE curriculum.

- "Real-Time, Remotely Controlled, Unmanned, Surface Combatant (RT-RCUSC) using the Internet" by Floyd Bailey and Carl Robbins.
- "Autonomous agents for digital network maximization" by Mike Dabose.
- "SPAWAR Year 2000 assessment phase case study" by Kevin O'Leary.
- "Development of an internet intrusion prevention tool" by Doug Anunciado.
- "Re-engineering of a mission critical satellite communications component TD-1271B/U" by Joe Hirschfelder and Larry Nixon.

Figure 5. Sample Theses Completed by Software Engineering Students¹²

Research topics currently being addressed include projects on automation for software engineering and scalable system integration, networking issues for maximizing bandwidth utilization, security architectures, and automatic generation of Java programs for networks with connection code to linked network servers.

f. CAPS

The keystone research project in the Software Engineering Department has been the *Computer Aided Prototyping System* (CAPS). Originally based on several different research papers on software development by Dr. Luqi, CAPS has grown into a significant platform tool for use by other research projects. The concepts involved (rapid prototyping and software automation) are key to the efficient and effective creation of maintainable large-scale software systems.

CAPS is a significant project, because it helps reduce software costs while speeding up the prototyping and evolution cycle. Throughout its history, CAPS research has been funded by many military commands and government agencies, including the *Office of Naval Research* (ONR), *National Science Foundation* (NSF), *Naval Sea Systems Command* (NAVSEA), the *Army Research Office* (ARO), the *Army Research Lab* (ARL), the *Joint Ada Office*, and the *Defense Advanced Research Project Agency* (DARPA). Ongoing projects include improving the transformation of prototype into final code, automation of the management of reusable software, and the improvement of interoperability technologies.

An example of a recent thesis project that utilized the CAPS technology was the re-engineering of the Army's legacy JANUS system¹³. This thesis was completed by former NPS Army students Major Julian Williams and Captain Michael Saluto under the tutelage of NPS staff members Professor Valdis Berzins and Professor Man-Tak Shing. The project concerned a legacy system that was no longer viable due to its inability to evolve over time. Decades of advances in technology moved the battlefield simulation beyond what the JANUS system could handle. The team re-worked the system using object-oriented design methodologies, and demonstrated a system that could be effectively implemented into service by the Army. This effort saved

the Army a large amount of money, and provided practical experience for two graduate students who are now utilizing that knowledge for the benefit of the U.S. military.

Other successes demonstrations of CAPS' abilities include: a generic C3I station, Missile Defense, Army Tactical Missile System (ATACMS), and a SIDS (Sudden Infant Death Syndrome) Wireless Acoustic Monitor (SWAM).

C. EXISTING SOFTWARE ENGINEERING PROGRAMS AT NPS

Based on the conclusion drawn previously by the author that the best solution to address the Navy's software engineering need is via a curriculum at the Naval Postgraduate School, it is prudent to look at the programs currently offered at the school to determine if any of those programs provide an adequate solution.

Currently, the Software Engineering Group at the Naval Postgraduate School operates on several different fronts to provide education in the field of software engineering to a wide variety of government and military personnel. The various educational programs serviced by the department are described in detail now.

1. The Computer Science Curriculum

Presently, approximately forty U.S. military students are sent to the Naval Postgraduate School annually to study computer science in the fully-funded graduate education program. With students continually arriving and graduating, NPS averages a population of over one hundred Computer Science students at any given time.¹⁴ Students in the Computer Science curriculum come from all of the U.S. services, with a number of international students from other countries and several DoD civilians augmenting the population as well. There are quotas for approximately seven-to-ten Navy students each year to be ordered into the Computer Science curriculum¹⁵.

These students enter the school for an eight-quarter (24-month) curriculum. Depending on their prior academic and operational background, they may be placed in an additional "refresher" quarter prior to the start of the actual curriculum, to help them prepare for the depth and complexity of the upcoming coursework. This concept of a refresher is common with the more difficult engineering curricula at the school, although fiscal concerns have begun limiting the extra time in-residence offered to the students for

preparation. The Engineering Science coursework (as the “refresher” is officially entitled) is designed to improve the Academic Profile Codes of students who do not qualify for direct entry into one of the engineering curricula or to refresh a student’s scholastics and basic engineering skills, as it may have been a lengthy period of time since the student completed undergraduate schooling.¹⁶

The general degree requirements for all Master’s degree programs at NPS as listed in the *Naval Postgraduate School Academic Council Policy Manual* are as follows¹⁷:

- Successful completion of a curriculum approved by the Academic Council as meriting the degree
- 32 hours of graduate level courses, of which 20 hours must be earned in residence
- a thesis or its equivalent
- a 3.0 or higher GQPR
- either a 2.75 or higher TQPR, or a 2.5 or higher CQPR

A Quality Point Rating (QPR) is calculated by averaging a student’s course grades after weighting each grade based on the number of quarter-hours credit that are received for the course. Specific calculations are given in the *NPS Academic Council Policy Manual* and NPS Catalog. The GQPR (Graduate Quality Point Rating) averages only the graduate level courses (3000 and 4000 level courses), the TQPR (Total Quality Point Rating) averages all classes (including 1000 and 2000 level courses), and the CQPR (Curriculum Quality Point Rating) averages all classes within the student’s designated curriculum only.

The following additional requirements are placed on students wishing to complete a program earning a Master’s of Science in Computer Science and can be found within the Computer Science Department’s website at:
<http://www.cs.nps.navy.mil/curricula/acas/programs/NonCS.html>¹⁸:

- At least 40 quarter hours of graduate-level work, of which at least 12 quarter hours must be at the 4000 level
- Completion of an approved sequence of courses constituting specialization in an area of Computer Science
- Completion of an acceptable thesis in addition to the 40 quarter hours of course work

a. All Computer Science Students

In addition to the requirements listed above, students receiving a fully-funded computer science education at the Naval Postgraduate School must fulfill the Educational Skill Requirements (ESR's) required to earn the Navy's 0091P code subspecialty for Computer Technology – Science. In addition to completing a specialization track, all Computer Science students at the school must study a broad range of computer science topics in order to cover all of the ESR's and earn the P-code. The complete Computer Science curriculum checklist contains this list of all "core" computer science classes that must be completed in addition to the specialization tracks. That checklist¹⁹ (minus the parts relating to the specialization track course requirements) is included as Appendix F for reference. All students who complete the Computer Science curriculum receive the degree Master's of Science in Computer Science.

A quick review of the classes required by the Computer Science graduation checklist indicates that the P-code/ESR requirements are much stricter than the broad degree requirements of the Academic Council. This is an example of why a standard curriculum in Computer Science at a typical civilian university may not meet the standards required to earn the corresponding P-code, as discussed in Chapter III.

It is possible for a student to complete the less-stringent requirements and receive the Computer Science degree without completing the more extensive P-code requirements. However, this option is not allowed for full-time students who are at the school for the express purpose of completing the degree along with the P-code requirements. Although students in other services and international students do not technically earn the P-code (it is solely a Navy designation), they are nonetheless subject to the same general class requirements as the full-time Navy students, promoting uniformity in knowledge and curriculum.

The additional ESR course requirements benefit the Computer Science students by exposing them to a wide variety of Computer Science-related topics that are not directly covered in their major field of specialization. This is beneficial for all students, especially in that each student is required to take a course in Software Methodology (CS3460). This pre-cursor to software engineering is at least an introduction to the field. Since every student must take this introductory course, all

students graduating from the Naval Postgraduate School with a degree in Computer Science have had some exposure to software engineering, which is at least a small benefit. The requirement for each student to take the Software Methodology course covers the ESR requiring that all students graduating from the Computer Science curriculum possess skills and competencies in software engineering. The ESR specifically relating to software engineering²⁰ states that:

The officer must have a thorough knowledge of software engineering to include:

- a. An understanding of the software development process, including specification of requirements, design, implementation, testing, maintenance, and process metrics;
- b. The ability to plan and implement a major programming project and develop the appropriate documentation, and;
- c. The ability to incorporate and enforce modern software engineering techniques in system design, and use modern tools to assure quality and short delivery times.

b. The Software Engineering Specialization Track

The second additional requirement listed earlier specific to Computer Science students is to complete a specialization track as part of their coursework. Specialization tracks within the Computer Science program are: the Computer Graphics & Visual Simulation track, the Computer Networks track, the Computer Security track, the Computer Systems & Architectures track, the Database & Knowledge Engineering track, the Software Engineering track, and the ISSO (Information Sciences, Systems, and Operations) track. A student chooses his or her specific track to be completed early on during the eight quarters of study in-residence at NPS. Selections are based on the student's personal interests and research opportunities available.

Historically, less than twenty percent of the Computer Science students have completed the Software Engineering track²¹ and received a more significant exposure to the software engineering field than the average Computer Science student. Students completing the track have been from the U.S. Navy, U.S. Army, U.S. Marine Corps, as well as international military students studying at NPS. Also, several DoD civilians have completed the Software Engineering track for the Computer Science degree while studying in-residence at NPS.

This Software Engineering track is currently the most-utilized software engineering educational option offered by the school to active-duty service members. In order to complete the track, a student must complete at least five graduate-level Software Engineering courses from the selection of courses available within the track. The course requirements to complete the track (in addition to the core course requirements for the MSCS degree) are shown below in Figure 6, as taken from the Computer Science graduation checklist found on the Computer Science Department's web site at <http://www.cs.nps.navy.mil/curricula/acas/programs/Checklist.html>. The one course required in the track, Software Engineering (CS4500), builds the foundation for all of the Software Engineering coursework, and is the prerequisite for the rest of the additional course options within the track.

5. Track Requirements:

Software Engineering Track

___ CS4500 Software Engineering (3-1)

Select at least four of

___ CS4150 Programming Tools and Environments (4-1)

___ CS4510 Computer-Aided Prototyping (3-0)

___ CS4520 Advanced Software Engineering (3-0)

___ CS4530 Software Research and Development (3-0)

___ CS4540 Software Testing (3-1)

___ CS4560 Software Evolution (3-0)

___ CS4570 Software Reuse (3-0)

___ CS4580 Design of Embedded Real-Time Systems (3-0)

___ CS4590 Software Architecture (3-1)

___ CS4591 Requirements Engineering (3-1)

___ CS4592 Software Risk Assessment (3-1)

___ CS4593 Advanced Logic & Algebra for Software R&D (3-1)

___ CS4594 Formal Models for Software Automation (3-1)

___ CS4595 Lightweight Inference Techniques (3-1)

___ CS4596 Algorithm Design and Analysis in Software Engineering (3-1)

___ CS4597 Robust Generation of Control Software (3-1)

___ CS4598 Software Merging and Slicing Techniques (3-1)

___ CS4599 Automated Software / Hardware Integration (3-1)

Figure 6. Track Requirements for Computer Science Curriculum's Software Engineering Specialization Track²²

2. MSSE Program

In 1995, the Software Engineering Department at the Naval Postgraduate School saw the opportunity to expand the horizon of programs it offered, and developed a program to offer a Master's of Science in Software Engineering with a distance-learning option. This program was approved by the *Academic Council* in the Fall of 1996²³ and has been offered continually since its inception. The students in this program do not complete the more general science-oriented Computer Science degree as taken by the students in residence at NPS, but rather a more-specialized program focusing on the engineering side of computing, specifically in the software engineering discipline. The degree granted by the *NPS Academic Council* to the students completing this program is a Master's of Science in Software Engineering.

The MSSE degree can be completed by a student on either a part-time or a full-time basis. Typical course progressions for completion of each method are shown below in Figures 7 and 8.

Quarter	Two courses for a part-time student	
1	CS3460	Software Methodology
	IS4300	Software Engineering and Management
2	CS4500	Software Engineering
	CS4560	Software Evolution
3	CS4520	Advanced Software Engineering
	IS3171	Economic Evolution of Info Systems II
4	CS4510	Computer-Aided Prototyping
	CS4580	Design of Embedded Real-Time Systems
5	CS3502	Computer Communication and Networks
	CS4540	Software Testing
6	CS4570	Software Reuse
	CS4530	Software Research and Development in DoD
7	CS0810	Thesis Research
	CS0810	Thesis Research
8	CS0810	Thesis Research
	CS0810	Thesis Research

Figure 7. Class Schedule for the Part-Time MSSE Distance Learning Program

The MSSE was originally intended for DoD civilian software practitioners with previous computer science or engineering experience. The software engineering coursework covers all aspects of software development and the skills needed to efficiently and reliably plan and create large-scale software systems using the best available tools. The coursework is designed to enable the software practitioners to immediately apply what they learn to their jobs, while bridging the gap between short-term training options and long-term education. The typical student would complete the program in a period of two years on a part-time basis while continuing to work full-time. The requirements for the MSSE degree as approved by the *Academic Council*²⁴ are:

- Completion of a total of 12 graduate-level Software Engineering courses
- Completion of an acceptable thesis in addition to the required course work

Quarter	Four courses for full-time student	
1	CS3460	Software Methodology
	IS3171	Economic Evolution of Info Systems II
	CS3502	Computer Communication and Networks
	IS4300	Software Engineering and Management
2	CS4500	Software Engineering
	CS4540	Software Testing
	CS4560	Software Evolution
	CS4580	Design of Embedded Real-Time Systems
3	CS4520	Advanced Software Engineering
	CS4570	Software Reuse
	CS0810	Thesis Research
	CS0810	Thesis Research
4	CS4510	Computer-Aided Prototyping
	CS4530	Software Research and Development in DoD
	CS0810	Thesis Research
	CS0810	Thesis Research

Figure 8. Class Schedule for the Full-Time MSSE Distance Learning Program

The courses for the MSSE program have been taught at NPS to students in-residence in conjunction with the Computer Science curriculum, and simultaneously televised to the distant locations. To facilitate thesis completion, students studying at the

remote sites occasionally come to NPS to confer with their thesis advisors, or the advisors sometimes go to the remote sites.

To the present time, the MSSE program has been offered via distance-learning only, and no full-time student in-residence at the Naval Postgraduate School has participated in the program. Thus, all MSSE degrees awarded by the Naval Postgraduate School have been to students who have studied at remote sites. Due to the rules restricting the educational services of the Naval Postgraduate School to military personnel or certain DoD civilians, most of the students who have completed this program have been DoD civilians working at various agencies with special software needs. These personnel have completed the program on a part-time basis in their spare time.

The commands that can support their personnel by offering them the opportunity to professionally improve themselves through this degree program receive many benefits for their investment. The participating commands end up with more knowledgeable, better software engineers at the end, plus they often benefit from the research of the students' theses. Job-related Master's theses that can be conducted at the sponsoring agency are encouraged. This makes it easier for the students to complete both their jobs and their theses, and also helps their supporting commands, essentially having research performed for little or no cost. If the commands were to contract that research to other outside software engineers, the monetary cost would be much higher.

There were twenty-seven students in the initial MSSE class started at the *Naval Command, Control and Ocean Surveillance Center* (NCCOSC) RDT&E Division, also known as NRaD, in San Diego, California. That class began its curriculum in the first quarter of Academic Year 1996. After the two-year curriculum was complete, twenty-three of the students had successfully completed the coursework and their theses, and have graduated with Master's of Science in Software Engineering degrees.

Successive class enrollments continued. In Academic Year 1998, twenty-five additional students from SPAWAR (NRaD had become a division of SPAWAR) enrolled in the program. These students have completed the coursework, are currently working on their theses, and should be graduating in the near future. In Academic Year 1999, fifteen

students from the *U.S. Army Tank Command* (TACOM) in Warren, Michigan, enrolled in the curriculum and are currently finishing their fourth quarter in the program.

As Academic Year 2000 starts in October 1999, the excitement about the program continues to grow. In addition to another twenty new enrollees from SPAWAR in San Diego, several additional commands are joining the program. Fort Belvoir, an Army base in Virginia, will have three students commencing on their MSSE degrees. Three or four personnel at the *Naval Surface Warfare Center* (NSWC) at Port Hueneme, California will be taking software engineering courses via distance-learning from NPS as well. There are also active-duty Naval officers in both Pearl Harbor, Hawaii and in Norfolk, Virginia who are trying to organize this distance-learning opportunity.²⁵

Additionally, there will be two students working on the MSSE program in-residence for the first time. One student will be working at a San Francisco-area base and will commute to Monterey to take courses part-time. The second student will be a first in that she is going to be the first full-time MSSE student ever in the program, intending to complete the degree within a year.

Attached in Appendix G is the "MSSE Handbook". This document covers all relevant information regarding all of the Master's programs in Software Engineering available through the Naval Postgraduate School. It is used as a recruiting tool, as well as an informational reference for any parties interested in the programs.

3. Ph.D. Program

Another program in software engineering education offered through the Naval Postgraduate School is the Doctor of Philosophy in Software Engineering. This very important program, the first of its kind in the country²⁶, was approved by the NPS Academic Council in 1998²⁷. The Naval Postgraduate School was the first to promote the idea of educating personnel to be on the cutting edge of research and subsequently earning a Ph.D. in Software Engineering. Recently, all of the 20 students who started the Ph.D. program in October 1998 traveled to NPS in order to take their Written Qualifying Examinations, and met with the Superintendent of the Naval Postgraduate School. During the meeting, the student facilitator for the Ph.D. candidates at TACOM described

the program and the research being performed as “critical to the Army”²⁸. There are approximately 20 additional students starting the Ph.D. program in October 1999.

This new curriculum is intended to provide senior leadership within the DoD to make futuristic visions possible, and addresses the problem that the DoD lacks the Ph.D.-level leadership to direct visioneering projects which require significant amounts of fundamental state-of-the-art research to make the projects a reality. The ability to intelligently manage the research of software practitioners is necessary to bring these large and complex software systems to fruition.

a. Path to Ph.D. Candidacy and Graduation

The path for completing the Ph.D. is long and complicated. The curriculum requires an approximately three-year effort for completion. Each student forms a dissertation committee shortly after admission into the Ph.D. program. This committee oversees the student’s program completion, including coursework and research. The students spend approximately a year taking coursework and preparing for the Written Qualifying Examination, which tests the students’ analytical abilities in the foundations of their research areas, and their abilities to solve problems in those areas.

The students must also complete “Minor” requirements to ensure a breadth of academic exposure. This is a set of three graduate-level courses that form a coherent topic of study separate from the student’s Software Engineering major concentration.

Within two years of successful completion of the Written Qualifying Examination (however, usually performed within a year), a Ph.D. student must complete the Oral Qualifying Examination. All coursework must be completed prior to taking the oral exam. As with the written exam, a maximum of two attempts at the Oral Qualifying Examination is allowed. The Oral Qualifying Exam is given by the student’s Dissertation Committee after acceptance of the student’s dissertation proposal. The Dissertation Committee must make a unanimous decision in order to pass the student.

If the student passes the Oral Qualifying Examination, he or she can petition the *Academic Council* for “advancement to candidacy for the doctorate”. At least six months after passing the oral exam, and following completion of the dissertation, a final oral dissertation defense is the last step to qualify for the Ph.D. degree.

Details for the general requirements of NPS Ph.D. programs can be found in the *Academic Council Policy Manual*, section 5.4. For the Software Engineering Ph.D. program, the requirement that students spend one year in residence at NPS has been modified by the *Academic Council*. To facilitate the distance-learning aspect of this particular program, this requirement was reduced to only twelve weeks for the Software Engineering Ph.D. program.²⁹ This requirement is usually completed by holding on-campus seminars in the weeks preceding the Written Qualifying Examination and the Oral Qualifying Examination to help the students prepare for those qualification requirements.

The details on the Ph.D. program listed in this section were just a brief summary of the program. Attached in Appendix H is the complete documentation on the program available from the Software Engineering Group, including detailed requirements and sample forms used at different milestones on the path to completion of the doctorate degree.

b. Current Status of the Ph.D. Program

When the Academic Council approved the Ph.D. program in 1998, twenty students entered the program, including eight at SPAWAR and twelve at TACOM. After a year of instruction, the students took their Written Qualifying Exams at NPS in June 1999. Seventeen of the twenty students passed their exams and are continuing on in the program. The three exam failures intend to re-take the qualifying exam within six months. As they continue through the rest of the requirements, the first Software Engineering Ph.D. graduates are scheduled to complete their dissertations and final defenses and to receive their degrees in 2001.

4. Certificates Program

One of the options not currently in practice, but being considered by the department is the institution of a Certificates Program. There is an active proposal being developed at NPS to award "Certificates in Software Engineering" to show progress by students unable to devote the time or energy to a full degree program. According to the proposal³⁰, there are three distinct levels that comprise the Certificates Program. A

student would earn a Level 1 Certificate with the completion of four courses, with eight courses required for the Level 2 Certificate and twelve for the Level 3 Certificate. Since all courses taken while enrolled in a certificate program would be counted towards the completion of the MSSE degree, a student who enrolled and completed a Level 3 Certificate program would only need to complete a thesis in order to earn the Master's degree.

The requirements for approval of the current proposal are being investigated, and it is hoped that the Certificates Program will be established and become operational during Academic Year 2000.

5. Short Courses

An additional method the Software Engineering Department offers to further software engineering education within *Department of Defense* agencies is called "Short Courses". These consist of short high-intensity seminars to help software professionals gain or maintain proficiency. These intense, compacted courses may be a week or even two weeks long. These are non-degree granting programs, but are very useful for educating personnel in only a short period of time, when more involved training is not feasible. The short courses may be used to initiate personnel in basic software engineering courses, or to teach high-level concepts to experienced professionals. These courses can be given via distance-learning like the current MSSE programs, or an NPS staff instructor can travel to the remote site and give the course on location.

Another logistical option for a short course is to have the personnel to be instructed come to NPS for the training. An example of this method of delivery for the training is the *Software Technology Review and Update for Technical Personnel* described towards the beginning of the chapter.

The idea of short courses were pitched to numerous DoD agencies during a Software Engineering delegation trip to the East Coast in April 1999. Several agencies were intrigued with the short course program, including the *National Security Agency* and *Defense Information Systems Agency*. U.S. Army personnel at the *Army Personnel Command* (PERSCOM) in Arlington, Virginia, also expressed significant interest in the

short course format due to its high desire for any plan to train its personnel in a short period of time.

D. ASSESSMENT OF THE PROGRAMS CURRENTLY AT NPS

While each of the programs detailed above has its advantages, and all the programs are increasing the level of knowledge in the software engineering field with the *Department of Defense*, only the Computer Science specialization track is currently a significant offering for active-duty Naval officers.

1. MSSE Program

While it is possible to attempt to complete the MSSE program via distance-learning program at a command that has the appropriate facilities available, it is extremely difficult for active-duty officers. Most officer tours are two to three years in length and in order to complete the degree via a part-time program, the timing would have to be extremely fortunate for that officer. Additionally, with the decreasing size of the Navy, officers are often very highly tasked, and usually do not have the large amount of spare time required to complete such a program. There is currently no subspecialty code nor graduate education quotas for a full-time MSSE program at NPS.

2. Short Courses and Certificate Program

The Certificates Program (if approved and instituted) or short courses would definitely be options for officers to get the software engineering knowledge that the Fleet needs. However, if a given officer does not belong to a command that participates in the distance-learning program, or is willing to send that officer to NPS for a short course, this will not be a viable solution either. With the number of commands currently participating in the various programs at NPS being very limited (yet growing!), there are very few officers currently reached by these opportunities.

3. The Ph.D. Program

The Ph.D. program is actually a great opportunity to produce talented, high-level engineers who could use their deep research knowledge and the in-depth software

engineering and management skills to lead the future large-scale DoD software projects. This need for a small number of high-ranking personnel within the Navy having significant in-depth software engineering backgrounds will become vital in the future. These personnel would be responsible for long-range planning and design of very important software systems.

However, there are several problems that exist in trying to qualify active-duty officers to fill those positions. It is very difficult for officers to spend three years in a tour away from their operational specialty, thus a three-year tour to earn a Ph.D. degree would be a "hard sell" to the Navy. Additionally, by the time an officer would get to the point where he or she would have enough experience to earn a Ph.D., the officer would likely be close to retirement, and a three-year educational tour (and the resulting five years of obligated service) might not make much sense. Additionally, Naval officers in full-time study at NPS receive unobserved *Fitness Reports*, meaning that their professional performance is not rated against their peers. Such a long period without an observed FITREP could be very damaging to an officer's career. In fact, this issue is currently being studied to determine if these non-observed performance reports are hurting current graduate student officers.

The Ph.D. degree in Software Engineering has a lot to offer the Navy, but its need is limited. It is not the right solution to all of the Navy's software engineering need. This option would make sense for a small number of specialized officers whose special career paths allow for pay raises and unlimited time in service without the need for promotion to higher military rank, similar to those in the medical corps.

4. The Computer Science/Software Engineering Track

So if the Computer Science program offering the Software Engineering track is the main option for active-duty Naval officers, the real question is: does it fill the Navy's needs?

As stated in the program description, all Computer Science graduates receive some exposure to software engineering. A handful of students receive a more significant software engineering background by completing the Software Engineering track. Unfortunately, this does not meet all of the Navy's needs, especially with the growing

reliance on computer technology, and the increase in the number of engineers the Navy will need in the future. With only a small number of Naval officers ordered into the Computer Science curriculum each year (and only a fraction of those completing the Software Engineering track), there are not enough experienced engineers produced to address all of the Navy's needs. In addition to the shortage of personnel with the requisite knowledge being produced at the school, there are other concerns.

a. Subspecialty Utilization

Many of the officer graduates from NPS are not properly "utilized" as defined by the DoD instruction on graduate education. According to that source, an officer's subspecialty is considered "utilized" if the officer serves in a billet that directly requires the skills of the subspecialty during either of the first two tours after completing the graduate education.

There are two different statistics to note concerning this utilization. One measures whether the officers' subspecialties are utilized during the designated window. The other statistics measures how qualified the personnel being sent to the coded billets are for those jobs.

The utilization statistic determines if officers are using their subspecialties after graduation. For the Computer Science 0091P code, 78% of the officers utilized their subspecialty within the DoD mandated two-tour window. Additionally, a significant number of those who did not utilize the subspecialty within the window did so after they were beyond the window. Thus, the overall utilization of the 0091 subspecialty is just shy of 89%³¹. Of course, those who utilized the subspecialty over four years after they completed their degrees probably needed some refreshing to remember the skills they had learned, however the level of overall eventual utilization is good.

On the other hand, the fill statistic tells a different story. For the 0091P coded billets, the direct subspecialty match is approximately 23.5%, with the "direct and related match" raising the percentage only up to less than 28%.³² This juxtaposition between the utilization and fill rate illustrates the need for an expansion of the officers earning this P-code. If nearly every officer earning the P-code is utilizing it, but over three-quarters of the subspecialty-coded billets are being held by personnel who do not

have the appropriate P-code, then there are far too few officers qualified with this subspecialty.

b. Problems with the 0091P Code

In addition to the fact that not all Computer Science graduates with the 0091P subspecialty code are adequately utilized (and that there aren't nearly enough of them anyway), there is another problem regarding the subspecialty code. While there are numerous billets for those completing the Computer Science program and earning a 0091P code, this system does not take into account the specialization track completed by the student. For example, an officer who completed the Computer Security track and one who completed the Database and Knowledge Engineering track are equivalent in this system. The same is true for the students who complete the Software Engineering specialization track. Despite the wide range of true skill sets, all students who complete the Computer Science curriculum are essentially equivalent as far as their subspecialty codes are concerned.

This makes it impossible to fit an officer who has specific training in the development, evolution, and maintenance of large-scale software systems from being placed into a job that requires those skills. Additionally, such a billet is just as likely to be filled by a Computer Science graduate who completed the Computer Networks track because that graduate would have the same exact P-code as one who specialized in Software Engineering.

The Computer Science curriculum is a decent opportunity to educate officers on the complex field of software engineering. However, the problem of proper utilization of the learned knowledge following graduation exists due to the Navy's system of treating all 0091P code designations as equivalent.

E. THE NEXT STEP TOWARDS RESOLUTION

Since none of the existing programs at NPS fill the need sufficiently, it is time to develop a new program that will address the software engineering need. There needs to be a program in-residence at NPS that offers a Master's of Science in Software

Engineering with a more rigorous software engineering coursework requirement than those programs that currently exist for active-duty Naval officers.

Investigations into the development of a program led to the conclusion that by combining a Software Engineering coursework core within the existing Combat Systems curriculum at the school, support could be acquired and the program could be created and implemented. In addition to the program development, there is an obvious desire to refine the coding of billets, and to create a separate P-code that identifies those who complete a program in Software Engineering, as opposed to those who complete the significantly different Computer Science program.

The background and subsequent development of such a curriculum is the deliverable focus of this thesis. Details of the curriculum's development are presented in the following chapter, along with a discussion addressing the P-code utilization issues.

¹ Superintendent, Naval Postgraduate School Instruction, NAVPGSCOLINST 1550.1A, Subject: Guidelines for Conducting Curricular Reviews, p. 1, 20 November 1996.

² WASC Commission letter to Superintendent, Naval Postgraduate School, 06 July 1999. [<http://intra.nps.navy.mil/wasc/wascReport.html>].

³ Gates, Bill, "The Cost of Education at NPS: A Comparative Analysis" brief. [<http://intra.nps.navy.mil/admin/cost/sld025.htm>]. 16 November 1998.

⁴ Gates, Bill, "The Cost of Education at NPS: A Comparative Analysis" brief. [<http://intra.nps.navy.mil/admin/cost/sld004.htm>]. 16 November 1998.

⁵ "NPS Costs" Point Paper, 16 June 1995.

⁶ Belcher, Brian, "Advanced Education Update (DRAFT)", brief for Graduate Education Review Board. [<http://web.nps.navy.mil/gerb/aded/sld022.htm>, <http://web.nps.navy.mil/gerb/aded/sld023.htm>, <http://web.nps.navy.mil/gerb/aded/sld024.htm> and <http://web.nps.navy.mil/gerb/aded/sld026.htm>]. 30 March 1999.

⁷ Naval Postgraduate School Computer Science Department brief, 25 May 1997.

⁸ Glass, Robert L., "An Assessment of Systems and Software Engineering Scholars and Institutions", *Journal of Systems and Software*, p. 63, 1994.

⁹ Naval Postgraduate School Software Engineering Department, brochure for "Software Technology Review and Update for Technical Personnel".

¹⁰ Belcher, Brian, "Advanced Education Update (DRAFT)", brief for Graduate Education Review Board. [<http://web.nps.navy.mil/gerb/aded/sld003.htm>]. 30 March 1999.

¹¹ Meeting between Robert C. Chaplin, Rear Admiral, USN, Superintendent, Naval Postgraduate School, and the Software Engineering Group (including the author) and Ph.D. students, 10 June 1999.

¹² Naval Postgraduate School Software Engineering Department, "NPS MSSE Thesis Completed" memo.

¹³ Williams, J.R., and Saluto, M.J., *Re-engineering and Prototyping a Legacy Software System - JANUS Version 6.X*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1999.

¹⁴ Meeting between Mark Polnaszek, Commander, USN, Combat Systems Curricular Officer, Naval Postgraduate School, and the author, 07 September 1999.

¹⁵ Knox, Bryant and Belcher, Brian, Postgraduate Education Quota Plans for Fiscal Years 1998, 1999, and 2000, received via email from Jeff Joynt, Lieutenant, USN, Graduate Education Placement Officer, Bureau of Naval Personnel, to the author, "FW: FY 98 Grad Ed Quota Plan (N1-approved)", "FW: FY99 Grad Ed Quota Plan", and "FW:", 15 September 1999.

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- ¹⁶ *Naval Postgraduate School Catalog*, Academic Year 1999, p. 26.
- ¹⁷ Naval Postgraduate School Academic Council, *The Academic Council Policy Manual*, p. 22, 28 July 1995.
- ¹⁸ Naval Postgraduate School Department of Computer Science, "Computer Science MS Degree Requirements". [<http://www.cs.nps.navy.mil/curricula/acas/programs/NonCS.html>]. May 1998.
- ¹⁹ Naval Postgraduate School Department of Computer Science, "Checklist for MSCS Degree". [<http://www.cs.nps.navy.mil/curricula/acas/programs/Checklist.html>]. 05 March 1999.
- ²⁰ *Naval Postgraduate School Catalog*, Academic Year 1999, p. 55.
- ²¹ Naval Postgraduate School's Registrar's Database, statistics covering Academic Years 1994-1999, received from Lisa Quidileg, Office of the Registrar, Naval Postgraduate School, 15 September 1999.
- ²² Naval Postgraduate School Department of Computer Science, "Checklist for MSCS Degree". [<http://www.cs.nps.navy.mil/curricula/acas/programs/Checklist.html>]. 05 March 1999.
- ²³ Balesteri, Angela, Naval Postgraduate School, "Minutes of the Academic Council Meeting of 16 October 1996."
- ²⁴ *Naval Postgraduate School Catalog*, Academic Year 1999, p. 48.
- ²⁵ Interview between Man-Tak Shing, Professor of Software Engineering, Naval Postgraduate School, and the author, 03 September 1999.
- ²⁶ Naval Postgraduate School Software Engineering Department, Software Engineering Ph.D. Program Announcement, 17 August 1998.
- ²⁷ Balesteri, Angela, Naval Postgraduate School, "Minutes of the Academic Council Meeting of 22 July 1998."
- ²⁸ Meeting with Chaplin, R.C., 10 June 1999.
- ²⁹ Balesteri, Angela, Naval Postgraduate School, "Minutes of the Academic Council Meeting of 16 June 1999."
- ³⁰ Naval Postgraduate School Software Engineering Department, "Degree Options at NPS" memo, 29 July 1999.
- ³¹ Poindexter, Vicki, "Utilization Report for June 1999", received via email from Jeff Joynt, Lieutenant, USN, Graduate Education Placement Officer, Bureau of Naval Personnel, to the author, "FW: SEMI-ANNUAL REPORT OF", 02 September 1999.
- ³² "FILL REPORT" received from Pernell Jordan, Lieutenant Commander, USN, Assistant Director of Programs, Naval Postgraduate School, 25 June 1999.

V. THE COMBAT SYSTEMS/SOFTWARE ENGINEERING PROGRAM

A. BACKGROUND/GOALS

Combat Systems education is by its very nature of great importance to the Navy. As such, the Combat Systems curricula comprise a significant program at the Naval Postgraduate School. Within its wide-ranging realm, there are numerous different aspects of combat systems which are all very important, yet differ significantly. The Combat Systems program at the school has diversified over time to encompass these different aspects. This is similar in many respects to the various specification tracks that present options to students studying for a Computer Science degree, as discussed in Chapter IV.

For example, a student entering NPS to study Combat Systems has the option to specialize in guns, missiles, acoustics, or various other options. These different tracks all have the same basic Combat Systems course framework, but each separate track has different specialization coursework requirements. Some of the different tracks result in the student earning identical Master's degrees, while other tracks earn students different degrees. Sample disciplines in which Master's of Science degrees can be earned by students studying the Combat Systems curriculum include: Applied Physics, Physics, Computer Science, Engineering Acoustics, Electrical Engineering, Mechanical Engineering, and Aeronautical Engineering.

The immediate development goal of this thesis was to combine a stripped-down Software Engineering curriculum into the Combat Systems framework to become an additional track option for Combat Systems students. This would allow for the integration of software with the tactics used by officers in the Fleet. According to Commander Mark Polnaszek, the then-Combat Systems Curricular Officer, this plan looked to be a very successful match for several reasons. Similar to the way a Computer Science student can choose a specific specialization track based on personal preference, a Combat Systems student can choose which track to complete from the several options available. The specific track to be completed by any Combat Systems student is chosen by that student in concert with counseling from the curricular officer.

CDR Polnaszek felt that student interest in a track from which they would earn a Master's of Science in Software Engineering would be high, based on the after-service marketability of the degree. In addition, he felt the Aviation community was interested in developing an officer base with the Software Engineering subspecialty. He reasoned that this interest by the Aviation community would help make up for some of the difficulty in filling the available quotas within the Combat Systems curriculum.¹

The *Quota Plan* produced at the *FY98 Quota Conference* designated a total of forty quotas for the Combat Systems curriculum. Disappointingly, only twenty-eight of the forty quotas had been filled however. This is ten percent lower than the 80% fill rate to be expected normally (and far below the Navy's achieved percentage of 88% for FY98). As the resident expert in all Combat Systems curriculum issues, CDR Polnaszek believed part of the reason that not all of the quotas were being filled was because there were not enough students willing to take on the challenging physics-based Combat Systems curriculum. However, he also believed that if the students could graduate from the Combat Systems curriculum with a Software Engineering degree, there would be greater interest. Consequently, the detailers at BUPERS would be able to get more officers into NPS for the Combat Systems curriculum. The increased marketability of a student who has earned a Software Engineering degree for a post-Navy career would provide a greater interest factor for prospective students, despite the curriculum's difficulty. So if the program could be approved, a potential student base to join into the curriculum existed. Additionally, the Combat Systems fill percentages would rise correspondingly.²

The goal of the newly matched curricula is to use the software engineering coursework to familiarize students with all aspects of software development from requirements analysis and design through implementation, debugging, delivery, and follow-on maintenance. These aspects will be combined with the physics and systems engineering coursework that allows students to put these newly-learned abilities into practice. Additionally, this coordination of software engineering theory placed into practice with real combat systems will provide the students and faculty with significant project ideas for useful thesis research.

Specific skills desired in a software engineering graduate include the ability to use the best available tools to properly design, engineer, and create large-scale software systems in the most efficient and reliable manner. These skills address the Navy's needs described earlier, and are an invaluable asset for military officers responsible for software systems in practice. For example, the acquisition or development of new systems, and the maintenance of existing systems, are all tasks that can be significantly improved with the use of educated software engineers.

B. DEVELOPMENT OF THE PROGRAM

1. Involvement of the Author

Prior to the involvement of the author in this project, the Software Engineering Department at the Naval Postgraduate School had previously worked on the problem, attempting to make progress towards fulfilling the Navy's software engineering educational needs. A course plan for a singular software engineering curriculum had been developed by the Department Chair, Professor Luqi. This outline of courses included planned course material and the Educational Skill Requirements to define the P-code requirements. The implementation of this curriculum is still a follow-on goal for the department, being worked in parallel with the effort that has successfully implemented the Combat Systems/Software Engineering curriculum. The goal to implement a solely software engineering curriculum seems attainable once the Combat Systems/Software Engineering combined curriculum proposed here proves its utility, along with continuing Flag-level support for the program. Attached in Appendix I is a Program Objective Memorandum (POM) used by the Software Engineering Group to try to obtain funding support to continue the development of the department, including lab support and research funding.

The Software Engineering Department had a planned curriculum, but it had not created the proper contacts to make all of the required events occur. Someone was needed to help bridge the gap between the academic program and the needs and procedures of the Navy. The author entered the situation as a Naval Officer working on the staff at the Naval Postgraduate School. While not very knowledgeable about the

"Programs" side of the postgraduate education process, the author was able to learn about the steps required to move the program forward towards approval. By determining specifics about the *Officer Subspecialty System*, along with the "Quota" and "Fill" concepts, the author helped facilitate to get the right people talking to each other, and rapid progress was made to make the final goal a reality.

2. The Plan for Approval

When the Software Engineering Department was looking to advance the state of software engineering education in the Navy, the Computer Science Curricular Officer was consulted as the most logical point-of-contact. With his assistance, it was determined that support existed within the Naval leadership structure to integrate a software engineering education within the existing framework of the Combat Systems curriculum. Thus, this would be the "foot in the door" towards the goal of achieving a separate subspecialty which focused mainly on Software Engineering, and not merely incorporating it into the Combat Systems curriculum.

To rectify the problem of students transferring to billets not utilizing their new knowledge and new degree, that problem needed to be confronted from several directions simultaneously to achieve a solution meeting the needs of all entities concerned.

First, the overall program needed to suit the Navy's needs. Clearly, the need to develop a software engineering knowledge base within the Navy's ranks exists, as detailed earlier in Chapter II. The possible difficulty lies in convincing the "right" people that the need exists. All postgraduate education programs at the NPS are funded via Flag officer-level sponsorship. Any new program would also need to have Flag-level sponsorship to provide funding. This funding is required to provide the necessary support for instruction (i.e., labor cost of the faculty), research labs for graduate work, and the costs of student endstrength. This is a major task now facing the effort to create a Software Engineering curriculum on its own. However, as a track within the Combat Systems curriculum, this requirement is eased to convincing the existing Combat Systems curriculum Flag sponsor to include the Software Engineering track. Based on known previous support, this approval (as described shortly) worked in conjunction with the "Navy need" requirement and was arrived at via normal channels.

Any changes to the officer supply chain funneling students into the curriculum and the demand chain for proper utilization of the graduates would also need to be approved. These changes are found within the framework of the Navy's method for handling skill requirements for each billet and the associated postgraduate education required – the *Officer Subspecialty System*. Fortunately, the points of contact within the approving chain-of-command are in close contact with the Flag sponsors, so the real task at hand was to get everyone involved onboard with the changes together at once.

The new curriculum would also have to be interesting and worthwhile to prospective students, enticing them to participate and choose the Software Engineering track option from within the larger Combat Systems curriculum. As described in the background, the person most knowledgeable about the Combat Systems curriculum, CDR Polnaszek, believed that the promise of a Software Engineering Master's degree would provide the requisite interest.

Finally, the program would also need to meet the academic rigors required by the *NPS Academic Council* to grant the degree Master's of Science in Software Engineering. The fulfillment of this need will be discussed in the section regarding approval by the *Academic Council* later in the chapter.

3. Development of a Course Matrix

Using the known needs as a starting point and incorporating the natural fit between the Software Engineering and Combat Systems curriculum based on the known Flag-level support, the Software Engineering Department Chair (Dr. Luqi) and the Combat Systems Curricular Officer (CDR Polnaszek) met to design a program. CDR Polnaszek was very experienced at developing course matrices for various tracks, and together the two developed a coursework plan. The course matrix for the new combined Software Engineering/Combat Systems curriculum resulting from those efforts is enclosed as Appendix A. It is this curriculum matrix that is proposed here as a first-level solution to address the software engineering need in the Navy.

In fact, there are two separate course matrices included in Appendix A. This is because Combat Systems is one of the curricula at the school that continues to have two student inputs during the year. This means that one group of officers is ordered in to NPS

to commence studying the Combat Systems curriculum in July, and another group is ordered in to start in January of the following year. Since several of the courses are only offered once a year due to the relatively small number of students taking the class, the matrices for the two different groups are slightly different. The matrices contain the same requisite courses, but the students take the classes at slightly different points during their tour at NPS. This method of scheduling gives all the Combat Systems/Software Engineering students going through the program the same instruction, and also helps combat a problem concerning having a minimum number of students per course by combining the sections. This issue presents a potential (although unlikely) problem for this proposed curriculum and is discussed in the last section of this chapter.

The coursework is divided into three major course fields. The basic Combat Systems courses in physics and mathematics are necessary as the prerequisites for the Systems Engineering coursework. These are the courses that give students the general knowledge to understand the higher level courses which focus on overall combat systems, including weapons and sensor physics. The courses that make up this group are listed below in Figure 9.

MA1995	MATH METHODS I (5-0)
MA1996	MATH METHODS II (5-0)
PH1121	MECHANICS I (4-2)
PH1322	E&M I (4-2)
PH1623	MODERN PHYSICS I (4-2)
PH2151	MECHANICS II (4-1)
PH2351	E&M II (4-1)
PH3292	PHYSICAL OPTICS (4-2)
PH3352	E&M III (4-0)
PH3652	MODERN PHYSICS II (4-1)
PH3991	THEORETICAL PHYSICS (4-0)

Figure 9. Math and Physics Course Prerequisites

Meanwhile, the Software Engineering courses teach the students a general software engineering knowledge base which they will put to practical use during the Systems Engineering coursework. The Software Engineering courses required to complete this curriculum are listed below in Figure 10.

CS3460	SOFTWARE METHODOLOGY (3-1)
CS4500	SOFTWARE ENGINEERING (3-1)
CS4510	COMPUTER-AIDED PROTOTYPING (3-0)
CS4520	ADVANCED SOFTWARE ENGINEERING (3-0)
CS4530	SOFTWARE ENGINEERING RESEARCH IN THE DoD (3-0)
CS4540	SOFTWARE TESTING (3-1)
CS4570	SOFTWARE REUSE (3-0)
CS4580	DESIGN OF EMBEDDED REAL-TIME SYSTEMS (3-0)
CS4591	REQUIREMENTS ENGINEERING (3-1)

Figure 10. Software Engineering Course Requirements

Systems Engineering courses are the backbone of all Combat Systems curricula. This culmination of software education with the actual Fleet systems found in the Systems Engineering coursework is the climax of overall combat systems comprehension. The integration of the Systems Engineering courses with the Software Engineering classes enables the students to put their newly-acquired software engineering knowledge into practical use by engineering real systems. The Systems Engineering courses required by this program are listed below in Figure 11.

The Systems Engineering courses are also good breeding ground for providing the student with significant military-relevant research topics, which can be addressed much more closely in the required thesis project, the capstone of most master's degree programs at NPS. A thesis requires the graduate to demonstrate the ability to conduct independent research and analysis in the areas of Combat Systems and Software Engineering. The thesis demands the student show proficiency in presenting the results both in writing by means of the written thesis and also orally via a command-oriented

SE2013	ANALOG TECHNIQUES AND COMMS (4-3)
SE2014	DIGITAL TECHNIQUES (4-3)
SE3015	AUTONOMOUS COMBAT SYSTEMS DESIGN (3-4)
SE3172	PHYSICS OF WEAPONS SYSTEMS (4-2)
SE3400	PHYSICS OF SONAR SYSTEMS (4-2)
SE4050	PHYSICS OF E&M SENSORS (4-2)
SE4860	ADVANCED WEAPONS CONCEPTS (4-1)

Figure 11. Systems Engineering Course Requirements

briefing appropriate to the curriculum. To assist with the major time requirements involved with the completion of a thesis, the students are allotted four "thesis research slots" in the curriculum matrix. This is a standard allowance for the students at NPS who are required to complete a thesis as part of their degree requirements³.

In addition to the coursework described above, there is a *Secretary of the Navy* requirement for maritime strategy theory that applies to all fully-funded Naval personnel during their studies at NPS. SECNAVINST 1524.2A states general program guidance for educational programs at NPS including that they must be "uniformly excellent". One of the ways programs at NPS must meet the needs of military services is to provide officer students with "the latest technological knowledge relevant to their future duty assignments as well as an appreciation of the fundamentals of the maritime strategy and concepts of naval warfare."⁴ As a result of the *Academic Council* meeting in September 1989, this guidance turned into a long-standing requirement for all U.S. military personnel studying at the school to take a course in maritime strategy from the National Security Affairs department⁵. Recently, school policy changed the course requirement from the NS3252 course to a course taught by Naval War College staff. For the students who complete the track proposed in this thesis, the SECNAV requirement would be completed in the first quarter with the Naval War College course "Strategy and Policy: The American Experience" (NW3230).

The course requirements were developed around the standard Combat Systems course framework. All of the basic courses, as well as the Systems Engineering courses are found in the standard Combat Systems track. The specialization with the Software Engineering courses meets the general requirements of the Combat Systems curriculum, and also meet the degree requirements for the Master's of Science in Software Engineering as approved by the *Academic Council* in 1996. As highlighted in Chapter IV, the degree requirements under that program require twelve graduate level Software Engineering courses. A careful review of the course requirements detailed above shows that there are only nine "Computer Science" Software Engineering courses. However, the Software Engineering Department routinely crosses department lines to meet the requirement for twelve Software Engineering courses. For example, in the distance-learning Software Engineering program, there are several courses in the Information Systems Department that are used to fulfill the requirement. Similarly, three of the Systems Engineering courses within this proposed curriculum are counted as Software Engineering graduate-level courses for the requirement. These are Physics of Sonar Systems (SE3400), Physics of Weapons Systems (SE4050), and Advanced Weapons Concepts (SE4860). The justification is that the students will be able to use the software engineering knowledge learned in other "Computer Science" Software Engineering courses and apply that to the combat systems in the Systems Engineering coursework. Thus, the software engineering is embedded in those courses, and they can apply towards the twelve-course requirement.

Course descriptions for each of the required courses within the matrix are included in Appendix B. The majority of these course descriptions are found in the NPS Catalog, however the Naval War College course is new to NPS, and has not been updated into the catalog yet. That description will be added into the next revision of the catalog.

The additional software engineering courses listed in the course descriptions on the department's web page are other software engineering courses that Software Engineering students are able to take as electives to further enrich their software engineering knowledge. Many of these courses are taken by the students in the MSSE and Ph.D. course sequences offered by distance-learning and described in Chapter IV in the discussions of the various software engineering programs currently offered at NPS.

The course descriptions describe in detail the subjects and goals of each specific class. As a whole, the curriculum is designed to achieve the goals of creating software engineers who understand the entire software development process and can use their engineering knowledge to effectively manage and design the development of large-scale systems.

While the course matrix displayed in Appendix A may at first appear entirely rigid, that is not necessarily the case. It is true that there is no room for a student to take any elective courses with the matrix exactly as it is written. However, it is entirely possible for a student to open up course slots by validating courses with work done previously. Students with significant undergraduate experience in math, physics, computer science, or software engineering may very well be able to validate a number of these courses. In addition, since several of the courses found in the matrix are offered via distance-learning, it would be possible for a student to complete courses prior to arrival at NPS by taking courses while still physically located at a previous command. This would open the schedule a bit and allow the student to take electives, or possibly even shorten the overall length of the curriculum, reducing the student's required time in residence at NPS to finish the curriculum.

The combination of the Software Engineering courses with the Combat Systems and Systems Engineering curricula allows the officers to hone their skills on real projects as they learn, giving them practical experience they will need to perform while in the Fleet. The Combat Systems basic math and physics coursework fulfills the prerequisites for the later Systems Engineering courses. In conjunction with the Software Engineering courses, the Systems Engineering courses allow the students to apply their software development skills on systems that really matter. This combination forces students to understand the needs of the combat systems the Fleet uses everyday, offering the opportunity to test the students' capabilities as software engineers.

4. Supporting Documentation

Each curriculum at NPS has an entry in the Naval Postgraduate School Catalog. This document is available in a printed version which is revised annually, and is also

available online. Enclosed in Appendix C are the portions of the new catalog entry for the Combat Systems curriculum that applies to the new Software Engineering track⁶.

In addition to the catalog entry, Appendix C also contains the Educational Skill Requirements (ESR's) for the Combat Systems curriculum, also known as curriculum 533 at the Naval Postgraduate School⁷. Any program that completes one of the tracks in the Combat Systems curriculum must fulfill all the ESR's of the Combat Systems program. Thus, these ESR's would apply to this new Combat Systems/Software Engineering track as well. The curriculum developed and described here meets these ESR's.

In a different section of the Naval Postgraduate School Catalog, there is a detailed listing of the various Software Engineering programs available at NPS. There is an additional entry in the latest revision of this Software Engineering section adding the newly-developed Combat Systems/Software Engineering track. This entry for the catalog is enclosed in Appendix D to this thesis⁸. Part of this entry refers to the Software Engineering curriculum 369. This is the program with the ESR's specific to the non-resident Master's program currently offered via distance-learning. If the separate software engineering curriculum is approved and Flag-sponsored for active-duty Naval officers, this is the curriculum and the ESR's that will apply to those students. The ESR's for the Software Engineering curriculum 369 are also enclosed in Appendix D⁹.

C. APPROVAL OF THE PROGRAM

1. Flag Sponsorship for the Curriculum

With a developed course curriculum in hand, the next step was to sell the program to the people who could put the program in practice. The first part of the approval process was to gain the support of high-level policy-makers in Washington DC. This was taken via a two-pronged attack. First, the Combat Systems Curricular Officer (CDR Polnaszek) briefed the new program to the Combat Systems Flag sponsor, Rear Admiral Mike Mathis. The second part of the attack to convince policy-makers of the need for personnel with software engineering skills that could be developed via this graduate-level curriculum. To make this argument, the author organized a trip for several faculty and

students from the Software Engineering Group to travel to Washington DC to make office calls upon those important personnel.

This trip would certainly have been an uphill battle if the group were to pitch the program to a hostile audience. Fortunately however, the process was more like “preaching to the converted” rather than fighting an enemy. This was the situation because many of the issues described in Chapter II had already been foreseen by those looking towards the Navy’s future. Due to the profound problems experienced historically in the Navy’s software projects, the Software Engineering Group had a great number of allies hoping to ensure that the proper knowledge base could be developed.

For example, Rear Admiral Kathleen Paige, the Deputy Program Executive Officer for Theater Surface Combatants (PEO TSC), was very much in favor of advancing the software knowledge of the Fleet, as she stated in an email reply to the Software Engineering department chair, Professor Luqi, shown below in Figures 12a and 12b.

The delegation from the Software Education Group met with RADM Paige during their support-gathering trip to Washington DC. One of the points RADM Paige made clear in the meeting was that she was specifically not interested in particular programming languages, but rather in the engineering process used to achieve a final successful software project.¹⁰ This is exactly the type of attitude held within NPS’ Software Engineering Department.

RADM Paige’s continuing goal for a new Software Engineering subspecialty was:

to ensure that all combat and weapon systems engineers have some exposure to SW [software] engineering disciplines, with a particular focus on large-scale complex, real-time systems. Such systems have their own development practices, issues, and perspectives which differ from the more familiar (and “traditional”) information-based ADP-style systems. Unless this culture is understood by practicing engineers, they are not likely to be as effective as they need to be.¹¹

Additionally, several other high-level officers within the NAVSEA hierarchy had positive impressions of the program and were inclined to increase funding for additional software engineering education.

From: Paige Kathleen K Radm NSSC <PaigeKK@NAVSEA.NAVY.MIL>
To: "Bail William G. CONT NSSC" <BailWG@NAVSEA.NAVY.MIL>,
"luqi@cs.nps.navy.mil" <luqi@cs.nps.navy.mil>
Subject: RE: Sponsorship of Software Engineering Subspecialty
Date: Mon, 11 Jan 1999 12:49:35 -0500

Bill & Luqi, Concur. We need officers who can deal w/ "smartship" like technology; also, who understand the particular complexity of large-scale, real time weapon & combat system computer programs, and the disciplines necessary to manage & monitor the development of those types of systems.

NSWC Dahlgren & Dam Neck are also great sources of expertise, as is NUWC, Newport. I've asked Bill Bail to be the PEO lead on this.

WR/Kate Paige

-----Original Message-----

From: Bail William G. CONT NSSC
Sent: Monday, January 11, 1999 12:02 PM
To: 'luqi@cs.nps.navy.mil'
Subject: RE: Sponsorship of Software Engineering Subspecialty

Dear Luqi,

Thanks for the information. I provided a copy of your last e-mail to RADM Paige to keep her up to date. I believe that she is interested in our providing technical assistance to help review your products and keep it rolling along towards acceptance. Your justification is quite convincing and hits some important points.

Thanks again!

Bill Bail

-----Original Message-----

From: luqi [mailto:luqi@cs.nps.navy.mil]
Sent: Sunday, January 03, 1999 7:22 PM
To: BailWG@navsea.navy.mil
Cc: boger@cs.nps.navy.mil
Subject: Sponsorship of Software Engineering Subspecialty

Dear Bill Bail -

The Software Engineering faculty at NPS has developed an extensive SE course curriculum and degree program, and would like to create a new Naval Subspecialty based on this curriculum. We would very much appreciate your support in this matter.

This is a mildly confusing process due to the current status of the Naval Subspecialty System (NSS); however, much work has already been completed in the process, and we would like to continue working towards the approval and implementation of the subspecialty. The new subspecialty system is supposed to be completely implemented by May 1999 for the FY00 Quota Plan (as set by N1B, the Subspecialty Review Task Group chair), and we are tailoring the Software Engineering subspecialty to be active at that time as well. The subspecialty package is being finalized and will be forwarded to the CNO (N7) for final approval shortly.

(continued)

Figure 12a. E-mails between NPS and NAVSEA

It would greatly bolster our case to have NSWC onboard prior to the final submission. In the matrix for all NPS curricula (a table of numeric codes) we suggest a Software Engineering subspecialty code of 5801. We argue that the subspecialty described certainly belongs with the Engineering 5000 group. The Occupational Core requirements of the Engineering and Technology 5000 section are directly relevant to the duties of a Software Engineer. A complete set of Educational Skill Requirements (ESR's) has already been developed by the Software Engineering group and approved by the Naval Postgraduate School Academic Council. These are also being forwarded to N7 for approval along with the subspecialty application. We would like to request NSWC to be the Subject Matter Experts (SME's) to sponsor our SE curriculum.

Justification for the new subspecialty:

The need for software engineers in the Navy is pretty clear. Perhaps a more accurate term would be software systems engineers. One primary example of the need is from the test run of the "Smart Ship" USS Yorktown, which had to be towed back into port following problems with the computers onboard. The personnel onboard were not software engineers, and were unable to deal with the software problems that occurred during the test run. We have seen time and again that we have catastrophic failures when personnel not adequately trained for the job they are trying to perform. As we move to a Navy with higher and higher levels of dependence on computer technology, and lower and lower levels of manning, it is clear that those we retain NEED to be trained to deal with this technology.

The Software Engineering program at NPS is designed to do exactly that:

to give junior officers returning to the Fleet the necessary tools to deal with the technology. These officers are also the ones that will be specifying or creating the software to power these future systems. It is imperative that this process be completed in the most intelligent manner possible. The Software Engineering graduates from NPS have extensive training in the software development process. They learn techniques for developing requirements and producing reliable software that can be evolved, integrated and tested effectively. For any standard software system, between fifty and eighty percent of the overall cost comes from maintenance of the software through the life of the system. By using the proper techniques to create the software to run our naval systems, we can lower this cost. Systems can be created that are more robust and easier to maintain, even with the inevitable loss of "corporate knowledge" experienced during turnover and rotation.

The current Plan of Action to get the Software Engineering subspecialty approved follows the path described here:

- * Secure NSWC's support as the Subject Matter Experts (SME's).
- * Send subspecialty package to CNO (N7) for final approval.
- * Request TYCOM to determine billets for re-coding with the new Software Engineering Subspecialty.
- * Following approval of re-coded billets, have detailers assign Software Engineering graduates into these billets.
- * Have the graduate education placement officer budget the new subspecialty into future quota plans.

To this end we would like to meet with you to discuss any concerns or questions you have and work to win your support for developing the subspecialty.

Best regards!

-Luqi

Figure 12b. E-mails between NPS and NAVSEA (continued)

CDR Polnaszek's brief to the RADM Mathis was a success. RADM Mathis understood the need for the program and agreed that the program should be included within the programs offered in the Combat Systems curriculum.¹²

2. Supply and Demand Chains

The Flag-sponsorship success highlights an advantage for the initial inclusion of the Software Engineering coursework within the Combat Systems curriculum. As an established curriculum already in place, the Combat Systems curriculum is already represented in the *Officer Subspecialty System* and the *Quota Plan*. Thus, a student supply chain already exists.

To establish a solely software engineering curriculum, this student supply base will need to be created from scratch, which is always difficult for new curricula. To establish the full-time curriculum based only on the Software Engineering coursework, the program would need a new subspecialty in order to get the curriculum entered onto the *Quota Plan*, from which it could then derive a student base.

However, the Software Engineering track in the Combat Systems curriculum does not have this problem. Since students are already ordered into the Combat Systems curriculum on a regular basis, an available student supply chain exists and does not need to be created solely for this track. Any interested Combat Systems students can study the Software Engineering track once they arrive at NPS.

The demand chain corresponding to the postgraduate student output will be utilized via a new subspecialty. This was addressed during the delegation trip to Washington DC, and will be fleshed out in much greater detail now.

3. The Navy Subspecialty System

As described in Chapter III, the demand for Navy student graduates with specific skills is handled by the *Officer Subspecialty System* and its subspecialty coding of billets in the Fleet. Naval officers who complete graduate education at the Naval Postgraduate School receive a P-code designating the specialization of their education. The code is valuable because it allows Navy detailers (the personnel who make job assignments) to match specific skill requirements to the positions that require those skills.

For the purposes of developing the new Software Engineering program, it is logical to determine which billets out in the Fleet require the special skills of a software engineer. This will also indicate the number of software engineers the Navy needs on a continual steady-state basis. However, there are currently no billets designated for software engineers, because billets are not coded for a subspecialty that does not exist.

So the next part of the process to ensure any software engineers are properly slated to jobs that meet their skill sets is to get a software engineering subspecialty approved within the *Officer Subspecialty System*. Unfortunately, it is usually a long drawn-out and fairly complicated process to obtain the approval of a new subspecialty code. In fact, under normal circumstances, it requires the approval of the *Director of Naval Training* (N7) for any proposed new subspecialty, increase in curriculum length, or increase in the number of subspecialty-coded billets.¹³

However, when the effort to create the new Software Engineering curriculum was undertaken, the *Officer Subspecialty System* was in the process of revision. The revisions were being studied and accomplished by a special *Student Requirements Task Group*, as ordered by the *Chief of Naval Operations*. With the system undergoing a complete overhaul, numerous additions and deletions of subspecialties were occurring.

a. *The Engineering Duty Officer Connection*

With this knowledge in hand, a case was made to Commander Tom McCoy, the head Engineering Duty (ED) Officer at NPS that the new Software Engineering curriculum was needed¹⁴. It was known that the ED community was very interested in the software engineering capabilities because some officers working at NAVSEA in Washington DC had indicated as much.

Additionally, the ED community is responsible for the major engineering efforts in the Navy, including many of the facets of program acquisition. This is one of the key areas where having personnel who are educated in the ways of software engineering can have a profound impact. Dealing with outside software development contractors, and determining if the contractor is being honest and straight-forward with the government is an important skill. It is very difficult for someone who does not have the knowledge to understand if things are going according to plan or as promised, or if

the contractor is actually promising a product that cannot be delivered on time and within budget.

The Software Engineering department prompted CDR McCoy for a determination of how best to proceed to bring the program to fruition. Since the ED's were interested in the addition of a software engineering subspecialty, he put the group in touch with Patsy Morgan, the head of Plans and Policies for the ED community. Ms. Morgan is responsible for managing the detailers and all the billets for the ED community. She knows all the senior ED's (LCDR and above) by reputation, and by name, and knows many by face as well. She manages the coding of billets for many of the Engineering P-codes, and is the primary consultant for the Mechanical Engineering, Electrical Engineering, Computer Science, and Combat Systems curricula at NPS. Ms. Morgan wields considerable influence among the Flag officers of both the ED and the Unrestricted Line communities. Essentially, she is known as the "lynchpin" for all things in the ED community.¹⁵

b. Creation of a New Subspecialty

During the Software Engineering group's trip to Washington DC, a presentation was made to Ms. Morgan by the author along with a senior member of the department. Due to her important role in determining the career paths for ED's, Patsy was a member of the *Student Requirements Task Group* re-working the *Officer Subspecialty System*. As a result of the presentation to Patsy and with the support from higher members in the ED community, Patsy successfully lobbied for a new subspecialty within the Combat Systems subspecialty group. This change was incorporated into the new *Navy Subspecialty System* and is now an official subspecialty code in the Navy's postgraduate education system¹⁶.

There are five Subspecialty Major Areas in the new subspecialty system, including Policy, Strategy & Intelligence, Resource Management and Analysis, Applied Disciplines, Engineering and Technology, and Operations. All subspecialties fall into one of the Subspecialty Major Areas. The new Combat Systems/Software Design subspecialty is located within the "Engineering and Technology" area. The entire matrix

for all the subspecialties within this area is shown here as Figure 13. The new subspecialty was given the P-code of 5707, and is found near the bottom of the matrix.

The subspecialty code created designates NAVSEA as the subspecialty sponsor, which is the Flag sponsor for all the Combat Systems curricula. NAVSEA is also the sponsor for all engineering curricula. Thus, the effort to obtain separate sponsorship for the singularly Software Engineering curriculum also is proceeding through the NAVSEA chain-of-command.

Additionally, the subspecialty designation specifies SPAWAR as the Subject Matter Expert (SME). This means that the *Space and Naval Warfare Command*, actually SPAWARSYSCOM but SPAWAR for short, would assist with the curriculum development and maintenance. The SME is also responsible for establishing, maintaining, and approving the skill requirements for the curricula, and also for reviewing and endorsing billet coding requests.¹⁷ In addition to adding the new P-code subspecialty to the system, Patsy Morgan started the process of identifying the specific billets in the Fleet which require the skills of the new P-code¹⁸. Once this process is completed, there will be the opportunity to properly utilize the software engineers produced via this new curriculum. Thus, the demand chain for the engineers produced by the program has been created, with further development currently underway.

With billets using the subspecialty properly identified and coded, the Navy will then be able to track officer subspecialty utilization. With the software engineers getting a more precise subspecialty code as compared to the 0091P code received via the Computer Science curriculum in the previous *Officer Subspecialty System*, hopefully a better, more accurate utilization of skills will be possible.

4. The NPS Academic Council

With a program developed and approved by the requisite personnel in Washington DC, the next step to place the program in practice was to ensure the program satisfied the requirements of the *Naval Postgraduate School Academic Council*. This step was crucial to ensure that any students who completed the program would graduate

Engineering and Technology										
1st Digit	2 nd Digit	3rd Digit	4th Digit	Definition 1st Digit	Definition 2nd Digit	Definition 3rd Digit	Definition 4th Digit	Subspecialty Sponsor	Subject Matter Expert	Old Code
5	0	0	0	Engineering and Technology						50/60
5	1	0	0	Engineering and Technology	Construction			NAVSEA	NAVSEA	51
5	1	0	1	Engineering and Technology	Construction		Naval	NAVSEA	NAVSEA	51
5	2	0	0	Engineering and Technology	Nuclear			NAVSEA	NAVSEA	52
5	2	0	1	Engineering and Technology	Nuclear		Naval	NAVSEA	NAVSEA	52
5	2	0	2	Engineering and Technology	Nuclear		Reactors	NAVSEA	NAVSEA-08	52
5	2	0	3	Engineering and Technology	Nuclear		Propulsion Systems	NAVSEA	N87	53
5	3	0	0	Engineering and Technology	Electrical/Electronic Systems			NAVSEA	NAVSEA	55
5	3	0	1	Engineering and Technology	Electrical/Electronic Systems		Electrical Systems	NAVSEA	NAVSEA	55
5	3	0	2	Engineering and Technology	Electrical/Electronic Systems		Communications	NAVSEA	SPAWAR	55
5	3	0	3	Engineering and Technology	Electrical/Electronic Systems		Electro-magnetic	NAVSEA	SPAWAR	55
5	3	0	4	Engineering and Technology	Electrical/Electronic Systems		GUIDANCE/NAV	NAVSEA	SPAWAR	55
5	3	0	5	Engineering and Technology	Electrical/Electronic Systems		Electromag Sys	NAVSEA	SPAWAR	55
5	3	0	6	Engineering and Technology	Electrical/Electronic Systems		DSP	NAVSEA	SPAWAR	55
5	3	0	7	Engineering and Technology	Electrical/Electronic Systems		Electronic Systems	NAVSEA	SPAWAR	55
5	3	0	8	Engineering and Technology	Electrical/Electronic Systems		Total Ship	NAVSEA	NAVSEA	55
5	3	0	9	Engineering and Technology	Electrical/Electronic Systems		Computer Science	NAVSEA	SPAWAR	91
5	4	0	0	Engineering and Technology	Aeronautical			NAVSEA	NAVAIR	70
5	4	0	1	Engineering and Technology	Aeronautical		Avionics	NAVSEA	NAVAIR	72
5	4	0	2	Engineering and Technology	Aeronautical		Aerospace	NAVSEA	NAVAIR	71
5	4	0	3	Engineering and Technology	Aeronautical		Test Pilot	NAVSEA	NAVAIR	73
5	5	0	0	Engineering and Technology	Space Systems			NAVSEA	SPAWAR	75/77
5	6	0	0	Engineering and Technology	Naval Mechanical			NAVSEA	NAVSEA	54
5	6	0	1	Engineering and Technology	Naval Mechanical		Naval	NAVSEA	NAVSEA	54
5	6	0	2	Engineering and Technology	Naval Mechanical		Mechanical	NAVSEA	NAVSEA	54
5	6	0	3	Engineering and Technology	Naval Mechanical		Total Ship	NAVSEA	NAVSEA	54
5	6	0	4	Engineering and Technology	Naval Mechanical		Weapons	NAVSEA	SSP	63/68/69
5	7	0	0	Engineering and Technology	Combat Systems					
5	7	0	1	Engineering and Technology	Combat Systems		Sensors	NAVSEA	NAVSEA	60/61/68/69
5	7	0	2	Engineering and Technology	Combat Systems		Weapons	NAVSEA	NAVSEA	60/61/68/70
5	7	0	3	Engineering and Technology	Combat Systems		Physics	NAVSEA	NAVSEA	60/61/68/71
5	7	0	4	Engineering and Technology	Combat Systems		Acoustics	NAVSEA	NAVSEA	60/61/68/72
5	7	0	5	Engineering and Technology	Combat Systems		Total Ship	NAVSEA	NAVSEA	60/61/68/73
5	7	0	6	Engineering and Technology	Combat Systems		Missiles	NAVSEA	SSP	60/61/68/74
5	7	0	7	Engineering and Technology	Combat Systems		Software Design	NAVSEA	SPAWAR	60/61/68/74
5	7	0	8	Engineering and Technology	Combat Systems		Robotics	NAVSEA	SPAWAR	60/61/68/75

Figure 13. Engineering and Technology Subspecialty Matrix¹⁶

and receive a Master's of Science in Software Engineering as planned (in addition to the newly created P-code subspecialty earned by completing the associated Combat Systems ESR's).

Initially, it appeared as though the program would need to be explicitly presented to the *Academic Council* for approval, which would likely be another long and arduous process. However, a different conclusion was reached during a meeting between the acting Mechanical Engineering Department Chairman (Dr. Matthew Kelleher), a one-time member of the *Academic Council*, the new Combat Systems Curricular Officer (CDR McCoy), and the author¹⁹. Dr. Kelleher determined that the program as described was not a new program requiring the *Academic Council's* specific approval. This is due to the fact that the program meets all requirements of the MSSE program previously approved by the *Academic Council*, and currently offered as the distance-learning program.

It was the interpretation of Dr. Kelleher that while the *Academic Council* is required to approve all degree programs, it is the responsibility of the curricular officer to implement those degree programs. The *Academic Council* has no concern with the P-code or subspecialty requirements, as those are Navy concerns, not academic concerns. Since the program proposed in this thesis meets the requirements of an approved degree program, any student completing the proposed program would be eligible for the MSSE degree. Therefore, it is the responsibility of the curricular officer to ensure that the program completed by students fulfills the requirements of the subspecialty.

At this point, the program's status was determined to be approved because it satisfies the degree requirements for the *Academic Council* and it meets the needs of the Software Engineering subspecialty. Thus, graduates finish the program with both the Software Engineering graduate degree and the subspecialty code, qualifying them for jobs that require such knowledge, as determined by the coding procedure begun by Patsy Morgan following the addition of the subspecialty code to the subspecialty matrix.

D. IMPLEMENTING THE NEW CURRICULUM

With the final step of approval confirmed, efforts commenced to begin utilizing the program by enrolling students in the program and aligning their coursework with the

newly-developed class matrix. A new class of Combat Systems students began their first quarter in early July 1999 along with the other students commencing their postgraduate education in NPS' Summer Quarter of 1999. Despite the variety of the various track opportunities available to combat systems graduate students, the first quarter is uniform for all of them. During the first quarter, students attend seminars that describe the various tracks of coursework. These seminars, along with counseling and guidance from the Combat Systems Curricular Officer, assist the students in determining which track to branch into during their second quarter. This second quarter for the class that recently began in the summer will commence in late September 1999.

There will be students from this class of new Combat Systems students who will enter the Software Engineering track, graduate with a MSSE degree, and earn the Combat Systems/Software Design 5707P subspecialty code. Having completed all steps described, the Software Engineering/Combat Systems curriculum and specialty are a reality. Assuming these personnel and their special knowledge are utilized in appropriate billets following their graduation, this effort will have a profound impact on the software systems in the Navy's future. Current software systems will be dealt with more effectively, and quality maintainable, evolvable, and more cost effective systems will be developed in the future, due to the upgrading of the Navy's trained and educated software engineers.

1. One Potential Problem With Program Implementation

There is a potential problem with actual implementation of the curriculum as time goes by. This is as a result of a Naval Postgraduate School policy that has created ongoing problems for several curricula. Currently, each section of each class offered during a given quarter must have five students registered for the class. If less than four students are registered, the faculty instructor receives no financial compensation for teaching the course. If four students are registered, the instructor receives reduced pay, but gets no credit for teaching the course. Thus, faculty have no incentive to teach a course with fewer than five students. This policy was created by the Provost/Academic Dean and the Director of Academic Planning for several reasons. One reason is that the lower bound is a deterrent for instructors to take on as little work as possible via a minimal number of

students. A second reason is to encourage faculty to teach a course less frequently, resulting in a better turnout rather than offering a course every quarter to only a few students.²⁰

On the other side of the argument, there has been a decline in number of enrolled students due to the military drawdown. Additionally, curriculum populations have thinned the existing student base due to the creation of new curricula and the addition of new tracks to existing programs.

Fortunately for the curriculum posed here, this appears to be an unlikely hurdle to have to face, although it is a possibility. The math and physics prerequisite courses are requirements for all of the Combat Systems students, and the Systems Engineering courses are taken by a significant number of the Combat Systems students in any of the other tracks as well. Thus, these courses are subject to the entirety of the Combat Systems curriculum students, which should easily number five per class at any given time.

The Software Engineering courses offered at NPS are often very close to the minimum limit of five students per class, as many of the students taking these classes are the distance-learning non-resident students who do not count towards the minimum count. However, due to the fact that many of the courses are taken by Computer Science students, especially (but not exclusively) those who complete the Software Engineering specialization track, generally there should be an adequate number of students to fulfill the minimum requirement for each class. Additionally, as originally discussed during the description of the curriculum, the scheduling of groups from both of the year's Combat Systems student inputs combines all the students, and thus a minimum of five students should normally be available.

If any course were to be cancelled, an alternative plan would need to be developed to ensure that the curricular program could still be completed by any students effected by the cancellation. This would likely be the responsibility of the Combat Systems Curricular Officer in conjunction with the Department Chair for the cancelled class.

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- ¹ Meeting between Mark Polnaszek, Commander, USN, Combat Systems Curricular Officer, Naval Postgraduate School, Luqi, Software Engineering Chairman, Naval Postgraduate School, and the author, 17 March 1999.
- ² Ibid.
- ³ Interview between Michael McMaster, Assistant Director of Programs, Naval Postgraduate School, and the author, 16 September 1999.
- ⁴ Secretary of the Navy Instruction, SECNAVINST 1524.2A, Subject: POLICIES CONCERNING THE NAVAL POSTGRADUATE SCHOOL, p. 2, 04 April 1989.
- ⁵ Telephone conversation between Mitch Brown, Professor, Naval War College, and the author, 01 September 1999.
- ⁶ NPS Catalog entry for Combat Systems received via email from Tom McCoy, Commander, USN, Combat Systems Curricular Officer, Naval Postgraduate School, to author, "RE: Additional File Request", 01 September 1999.
- ⁷ "EDUCATIONAL SKILL REQUIREMENTS COMBAT SYSTEMS SCIENCES AND TECHNOLOGY CURRICULUM (533)". *Naval Postgraduate School Catalog*, Academic Year 1999, pp. 44-45.
- ⁸ Naval Postgraduate School Software Engineering Department, entry for NPS Catalog, 06 July 1999.
- ⁹ "Computer ESR's", *Naval Postgraduate School Catalog*. [<http://web.nps.navy.mil/~ofcinst/esr369.htm>]. September 1999.
- ¹⁰ Meeting between Kathleen Paige, Rear Admiral, USN, Deputy Program Executive Officer – Theater Surface Combatants, and Software Engineering Group delegation (including the author), 09 April 1999.
- ¹¹ Email from Bill Bail, Systems Engineering, Naval Sea Systems Command, to Luqi, Software Engineering Chairman, Naval Postgraduate School, "RE: Sponsorship of Software Engineering Subspecialty", 11 March 1999.
- ¹² Meeting between Mark Polnaszek, Commander, USN, Combat Systems Curricular Officer, Naval Postgraduate School, and the author, 21 April 1999.
- ¹³ Tracey, P.A., Chief of Naval Operations Memorandum Serial N731/7U637356 to Distribution, Subject: OFFICER GRADUATE EDUCATION REQUIREMENTS, 20 October 1997.
- ¹⁴ Meeting between Tom McCoy, Commander, USN, Mechanical Engineering Curricular Officer, Naval Postgraduate School, and Software Engineering Group (including the author), 05 January 1999.
- ¹⁵ Email from Tom McCoy, Commander, USN, Mechanical Engineering Curricular Officer, Naval Postgraduate School, to author, "RE: Meeting with Professor Luqi", 31 December 1999.
- ¹⁶ Email from Tom McCoy, Commander, USN, Mechanical Engineering Curricular Officer, Naval Postgraduate School, to Luqi, Software Engineering Chairman, Naval Postgraduate School, and the author, "Software Engineering Track", 03 February 1999.
- ¹⁷ Willson, J.L., N131 Memorandum to Distribution, Subject: PROPOSED SUBSPECIALTY SYSTEM, 02 December 1998.
- ¹⁸ Email from Tom McCoy, Commander, USN, Mechanical Engineering Curricular Officer, Naval Postgraduate School, to Luqi, Software Engineering Chairman, Naval Postgraduate School, and the author, "Software Engineering Track", 03 February 1999.
- ¹⁹ Email from Pernell Jordan, Lieutenant Commander, USN, Assistant Director of Programs, Naval Postgraduate School, to author, "FW: Changes to the SUBSPEC system", 28 April 1999.
- ²⁰ Meeting between Dr. Matthew Kelleher, Acting Mechanical Engineering Chairman, Naval Postgraduate School, Tom McCoy, Commander, USN, Combat Systems Curricular Officer, and the author, 12 July 1999.
- ²⁰ Telephone conversation between Pat Paulson, Naval Postgraduate School Academic Services Manager for the Provost and Academic Dean, and the author, 03 September 1999.

VI. CONCLUSIONS AND FUTURE WORK

A. CONCLUSIONS AND CURRENT STATUS

As society and warfare become increasingly complicated, computer technology has become the essential tool to process excessive information loads, providing unmatched accuracy in an enormous multitude of processes. As situations continue to increase in complexity, computers will be necessary to do the processes no human could ever possibly perform.

The use of computer technology as a highly effective tool is ever increasing in our modern world, and the warfare arena is no different. Manning issues due to budget concerns require a smaller military workforce, but theater conflicts are growing more complex in scope. Computers can be used as powerful tools to aid the warrior's ability to fight a war despite an onslaught of information.

It is indeed fortunate that all of the emerging technologies are creating great warfighting opportunities. It gives those who successfully integrate technological capabilities into their operations a significant advantage over those who cannot do so. The inability to efficiently conquer the technology of the information warfare age will lead to a significant hindrance in military capabilities.

Among the many military services, there is a recognized need for this progression of technology and its implications on the strategy of warfare. With theater operations becoming so complicated that every possible advantage must be exploited, commanders have come to rely on computers as valuable information-processing, decision-making assets.

Information must be processed quickly and properly to be effective. The decisions made or recommended by the technology must be correct. They must be based on accurate principles. Flawed reasoning and flawed technology can have very high costs and impose very severe negative (including fatal) effects in the military field. The systems upon which the military comes to depend must be developed using strict engineering disciplines.

The Navy's push toward IT-21 and network-centric warfare requires information-intensive systems of unprecedented reliability, capability, performance, and scale. The

advances in software engineering technology continue to grow at an ever increasing rate. Software systems developed or acquired must be interoperable and employ information assurance. Personnel ensuring the completion of these tasks need to become "smart buyers" with respect to software systems. Additionally, operational commands need officers with software expertise to recover from possible failures in their information-intensive systems.

The goal of this thesis was to develop a program that would help to ensure that the future needs for software engineers in the Navy would be adequately addressed. Engineers who can develop and maintain systems to ensure that future warriors can safely depend on the technology at their fingertips can be educated via a curriculum at the Naval Postgraduate School. These same NPS graduates would also have the ability to assume leadership roles in charting the technological specifications for future systems.

This thesis advanced the realization of the need in the United States Navy for structured, organized software engineering education. Efforts by the Software Engineering Department staff and faculty, the Computer Science Department, various NPS curricular officers, and the author, have prompted changes to be made which will ensure the Navy is better prepared in the future to handle its software engineering concerns.

The solution presented here was the development of a curriculum that combined the established Combat Systems framework with a specialization in Software Engineering. Approval was obtained at each requisite level, and a Combat Systems/Software Engineering subspecialty code has been added to the table of subspecialties in the new *Navy Subspecialty System*. As a result of this inclusion, graduates from the program should be better utilized in follow-on billets within the Navy. The specialization track has been added into the Combat Systems curriculum, and the NPS Catalog has been updated to reflect this new program.

Students have received orders to attend the school to study the Combat Systems curriculum and are currently progressing towards completion of the Software Engineering track. Additionally, students previously in other tracks within the Combat Systems curriculum have changed their specialization and begun their studies in the Software Engineering track as an alternative. These students will be the first group of

active-duty Naval officers to graduate from the Naval Postgraduate School with Master's degrees in Software Engineering. (There is currently one active-duty officer at a remote command who has completed the coursework for an MSSE degree via distance-learning. Upon completion of his thesis, he will be the initial active-duty MSSE graduate from NPS.)

With the completed education of Naval policy-makers in Washington DC concerning the need for Software Engineering education within the active-duty ranks, the development of a program addressing that need, the approval of that newly-developed program, and the implementation of the approved program, the effort undertaken in the thesis should be viewed as successful.

B. FUTURE WORK

Despite the progress made over the past year, the integration of Software Engineering education at the Naval Postgraduate School into the future plans for the Navy is incomplete. The largest project remaining is the expansion of the program in the establishment and acceptance of a singular Software Engineering curriculum.

While the current successes in improving the state of Software Engineering education in the Navy will undoubtedly make a difference in the future, not all of the Navy's software engineering needs will be met by the addition of a handful of students each year from within the Combat Systems curriculum. A greater number of qualified engineers with specific in-depth knowledge will be needed to fill all of the requirements of a future Navy which will become more dependent on computer technology than ever before.

A sample curriculum with a much wider range and depth of software engineering topics has been assembled, but the perceived need for it remains to be sold to the officials who have backed the initial software engineering curriculum proposed within this thesis. Perhaps after the success of this program, it will be much easier to argue that the full solution does indeed meet the true needs of the Navy.

In addition to the expansion of education, it is also vital that the results of the new Combat Systems/Software Engineering program be tracked. At some point a few years in the future, the utilization numbers for the software engineers produced at NPS should

be examined to determine if an improvement has been made following the program's implementation. After the new *Navy Subspecialty System* comes online (currently scheduled for October 1999), it will take time (possibly up to 18 months) for the *Major Manpower Claimants* who drive the system to fully implement the changes. The author recommends that the statistics be reviewed after several years, to ensure that the desired effect is being achieved. That is to say, software engineers produced at the Naval Postgraduate School transfer into billets that can fully utilize their skills.

Additionally, similar conclusions about the effects of the educational process can be drawn based on the results of future software projects undertaken by the service. If graduating officers move into positions where they can affect the overall software acquisition or development process, a future reduction in the number of failed, delayed, or over-budget projects would be a positive indicator of a successful educational program.

Finally, it could be worthwhile to investigate the possibility of establishing a long-term career path for software engineers in the Navy. Part of the concern with establishing an extensive Software Engineering program with long-term experts is the lack of a viable career path for promotion and retention within the Naval structure. Recognizing the need to build a sense of identity and highlight the importance of Naval officers with experience and training within information systems technology, the *Commander-in-Chief of the U.S. Pacific Fleet* (CINCPACFLT) recently released a Naval message¹ calling for a dedicated cadre of officers with subspecialties centered on information technology, along with supporting viable sea/shore rotations and career continuity. This recognition of the need to develop officers competent with the latest computer technology opens the possibility for developing a career path for software specialists. If a career path was developed to make earning a Ph.D. in Software Engineering a realistic possibility, the Navy should step up its efforts to produce these Ph.D.'s at NPS. This would provide an outstanding source of very knowledgeable high-level engineers who could lead the future major software projects in the DoD.

C. WORKING WITH OTHER SERVICES AND AGENCIES

This thesis focused on one specific aspect of the need for software engineering education in the future – the need of the United States Navy to produce engineers adept at handling the large-scale software systems found in the military. This focus was made based on the author's Naval background, along with some knowledge of the Navy's *Officer Subspecialty System*. Yet, the need for software engineers is universal in all branches of the military. For example, the Army has tanks and other weapons driven by software. The Air Force, like the Navy, has warplanes that use high-tech avionics. These large-scale projects are also greatly aided by the utilization of engineers specifically trained in this discipline.

As discussed previously, there are students from all services in attendance at the Naval Postgraduate School, and in fact all the major services (Navy, Army, Air Force, Marines) currently have students enrolled in the Computer Science curriculum. Many of the successful Software Engineering track students within the Computer Science curriculum have come from services other than the Navy.

As with the Navy however, for each service there is a gap between the engineers being trained to understand the principles of software engineering and the very real need for future implementation skills related to large-scale software systems.

The Navy need has been addressed on at least an initial level via the program proposed here, with the Naval officers completing the requirements of the new Combat Systems/Software Engineering subspecialty. Since the *Department of Defense Directive on the Policy on Graduate Education for Military Officers* (DoD Directive 1322.10) specifies that each Military Service shall: "Specifically identify all military officer duty-assignment positions requiring their incumbents to possess a graduate degree", certainly the other services must have a plan to address their graduate educational needs, but those exact methods are not known to the author. Additional work could be performed to determine if other potential students for the Software Engineering program at NPS could be recruited from the other services.

Meanwhile to address these needs outside of recruiting additional students to study in-residence at NPS, the Software Engineering Department has been working to find additional ways to expand the educational opportunities available to the services. It

is this effort that is responsible for the recent expansion of the student base in the distance-learning program as mentioned earlier. However, other opportunities exist within the *Department of Defense* to further the knowledge of software engineering.

During a trip to the *Army Personnel Command* in Arlington, Virginia, the Army was interested in several aspects of the Software Engineering coursework available from the department at NPS. For example, they were particularly interested in any program that their officers could complete in a single year², as opposed to most curricula at NPS that are two years in length, including the standard Computer Science curriculum. While those students who are not computer experts typically need two years to complete a degree, it is possible to develop a plan for experienced computer scientists to complete the degree requirements in a four-quarter period. The full-time one-year MSSE program currently taught by distance-learning is exactly such a program.

Additionally, the DoD civilian Master's of Science in Software Engineering programs at various military commands helps to support the other services. Investigations into the expansion of these programs to new sites are on-going and could increase the knowledge assets onboard military and government installations across the country. Since it is easier for these students to complete their Master's theses on topics which are directly related to their jobs at their sponsoring agencies, those agencies and services benefit not only from more experienced and knowledgeable engineers, but also from the completion of research projects at minimal costs. This holds a potential for huge savings when compared to contracting out the research to an outside company, both in the costs of the research and in the time which would be needed to bring the outside company up to speed on the project before they could even begin the research.

Discussions about the expansion of the distance-learning program have taken place between the Software Engineering Department and Marvin Langston, a previous *Department of the Navy Chief Information Officer* (DONCIO). Approximately a dozen additional distance-learning sites have been proposed in the on-going talks. Some of the locations where negotiations for a distance-learning program in software engineering are on-going include: Fort Monmouth, the *Office of the Secretary of Defense* (OSD), the *U.S. Army Training Command* at Fort Monroe, Red River, Fort Gordon, Fort Huachuca, the *Naval Undersea Warfare Center* (NUWC), the *Naval Air Warfare Center* (NAWC) at

China Lake, and the *NASA White Sands Test Facility*. Additionally, the Pentagon³ and the D151 Training Department at the *Defense Information Systems Agency* (DISA) in Arlington, Virginia⁴, have contacted the Software Engineering Department at NPS to inquire about the availability of course offerings via video tele-conferencing (VTC). Whether any or all of these sites will take advantage of the opportunity to hold software engineering refresher short courses or to establish a distance-learning degree program akin to those at SPAWAR, TACOM, and the newly established programs at Fort Belvoir and NSWC is unknown.

¹ CINCPACFLT PEARL HARBOR, Naval Message, Subject: Information Technology Officer Community, 291816Z JUL 99.

² Meeting between personnel from *Army Personnel Command*, Arlington, Virginia, and Software Engineering Group delegation (including the author), 07 April 1999.

³ Email from Melissa Hicks, Office of the Director of Information Systems for Command, Control, Communications, and Computers, Headquarters, Department of the Army, Washington, DC, to Luqi, Software Engineering Chairman, Naval Postgraduate School, "RE: SE Master degree program announcement", 09 June 1999.

⁴ Email from James Jeffries, Defense Information Systems Agency, D151 Training, Arlington, Virginia, to Luqi, Software Engineering Chairman, Naval Postgraduate School, "SE Master Degree Program Announcement", 09 June 1999.

APPENDIX A. COURSE MATRICES FOR THE COMBAT SYSTEMS/SOFTWARE ENGINEERING TRACK

Included here are two matrices containing the required coursework in the new Software Engineering track within the Combat Systems curriculum. These matrices cover the two separate student inputs during the year for the Combat Systems curriculum.

The first matrix contains the typical course of study for the students who enter the Combat Systems curriculum in July. This is the course matrix being used by the students who have already begun completion of this track.

The second matrix is for the students who arrive at NPS and begin classes in January. This matrix is similar to the first matrix, except that the actual sequencing of several of the courses is different to facilitate course scheduling concerns. The exact same courses are taken by all the students, regardless of the entry date to the curriculum.

Combat Systems curriculum -- Software Engineering track (MSSE degree)

JULY start date

QTR	Four courses for full-time students			
1	PH1121 Mechanics I (4-2)	MA1995 Math Methods I (5-0)	MA1996 Math Methods I (5-0)	NW3230 Strategy and Policy (4-0)
2	PH1322 E&M I (4-2)	PH2151 Mechanics II (4-1)	PH3991 Theoretical Physics (4-0)	CS3460 Software Methodology (3-1)
3	PH1623 Modern Physics I (4-2)	PH2351 E&M II (4-1)	SE2013 Analog Techniques and Communications (4-3)	CS4500 Software Engineering (3-1)
4	PH3352 E&M III (4-0)	PH3652 Modern Physics II (4-1)	SE2014 Digital Techniques (4-3)	CS4520 Advance Software Engineering (3-0)
5	PH3292 Physical Optics (4-2)	SE3015 Autonomous Combat Systems Design (3-4)	CS4510 Computer-Aided Prototyping (3-0)	CS4530 Software Engineering Research in the DoD (3-0)
6	Thesis	SE3172 Physics of Weapon Systems (4-2)	CS4540 Software Testing (3-1)	CS4580 Design of Embedded Real-Time Systems (3-0)
7	Thesis	SE3400 Physics of Sonar Systems (4-2)	CS4570 Software Reuse (3-0)	CS4591 Requirements Engineering (3-1)
8	Thesis	Thesis	SE4050 Physics of E&M Sensors (4-2)	SE4860 Advanced Weapons Concepts (4-1)

Combat Systems curriculum -- Software Engineering track (MSSE degree)

JANUARY start date

QTR	Four courses for full-time students			
1	PH1121 Mechanics I (4-2)	MA1995 Math Methods I (5-0)	MA1996 Math Methods I (5-0)	NW3230 Strategy and Policy (4-0)
2	PH1322 E&M I (4-2)	PH2151 Mechanics II (4-1)	PH3991 Theoretical Physics (4-0)	CS3460 Software Methodology (3-1)
3	PH1623 Modern Physics I (4-2)	PH2351 E&M II (4-1)	SE2013 Analog Techniques and Communications (4-3)	CS4500 Software Engineering (3-1)
4	PH3652 Modern Physics II (4-1)	PH3352 E&M III (4-0)	SE2014 Digital Techniques (4-3)	CS4540 Software Testing (3-1)
5	PH3292 Physical Optics (4-2)	SE3400 Physics of Sonar Systems (4-2)	CS4570 Software Reuse (3-0)	CS4591 Requirements Engineering (3-1)
6	Thesis	Thesis	SE3172 Physics of Weapon Systems (4-2)	CS4520 Advance Software Engineering (3-0)
7	Thesis	SE3015 Autonomous Combat Systems Design (3-4)	CS4510 Computer-Aided Prototyping (3-0)	CS4530 Software Engineering Research in the DoD (3-0)
8	Thesis	SE4050 Physics of E&M Sensors (4-2)	SE4860 Advanced Weapons Concepts (4-1)	CS4580 Design of Embedded Real-Time Systems (3-0)

APPENDIX B. COURSE DESCRIPTIONS

Listed below are the course descriptions for all the courses found in the proposed Combat Systems/Software Engineering program, as described in the text of Chapter IV. These descriptions were taken from the online NPS Catalog found via the NPS Office of Instruction pages at <http://web.nps.navy.mil/~ofcinst>

The one exception is the description for the mandatory Naval War College course, which is not listed in the current online NPS Catalog due to its recent addition to the list of courses available through the school. The description listed here for the "Strategy and Policy" course was obtained from the developers of the course at the Naval War College via a 28 July 1999 email from Professor Doug Smith at the NWC to Commander Michael McMaster, the Assistant Director of Programs at NPS. This course description will be included in the next version of the Naval Postgraduate School Catalog.

Much greater detail on all the Software Engineering courses, including the electives not listed as requirements for this curriculum, is available for viewing online at the web site containing all pertinent information on the Software Engineering Department: <http://www.cs.nps.navy.mil/~se/> Available there are expanded entries containing the courses' catalog descriptions, prerequisites, textbooks used, academic objectives, summaries of course content, skills learned, and applicable ESR's.

The descriptions that follows are not the complete list of all courses available from these departments, but only those used in this specific curriculum. A complete list of all courses is available online via the above listed NPS Office of Instruction web page.

MATHEMATICS COURSE DESCRIPTIONS

MA1995 MATHEMATICS FOR SCIENTISTS AND ENGINEERS I (5 - 0).

This course is taken concurrently with MA1996 (5 - 0). Descriptions of all topics in both courses are provided in this course description but half of these topics are taught in MA1996 (5 - 0). Precalculus review, complex numbers and algebra, complex plane, DeMoivre's Theorem, matrix algebra, LU decomposition, Cramer's rule, eigenvalues and eigenvectors. Limits and rates of change, derivatives, rules of differentiation, extreme values, indefinite integrals, vectors in the plane, definite integrals, applications and modeling physical problems, special functions, vectors in space, partial derivatives multiple integrals, integration in vector fields, extreme values, power series, first and second-order ordinary differential equations with applications. This course was designed for the METOC and Combat Systems curricula. PREREQUISITE: Precalculus mathematics.

MA1996 MATHEMATICS FOR SCIENTISTS AND ENGINEERS II (5 - 0).

This course is taken concurrently with MA1995 (5 - 0). Descriptions of topics in this course are given in the course description for MA1995 (5 - 0). This course was designed for the METOC and Combat Systems curricula. PREREQUISITE: Precalculus mathematics.

PHYSICS/SYSTEMS ENGINEERING COURSE DESCRIPTIONS

PH1121 PHYSICS I (4 - 2).

Particle kinematics, Newton's laws of motion, particle dynamics, work and energy, conservation of energy and momentum, systems of particles, rotational kinematics and dynamics including torque and angular momentum, gravitation, stress and strain in materials, simple harmonic motion, fluids. Laboratory exercises. PREREQUISITE: A course in calculus or concurrent registration in a calculus course and approval of the instructor.

PH1322 PHYSICS II (4 - 2).

Electric charge, Coulomb's Law, electric field, Gauss' Law, electrical potential and energy, current and resistance, EMF, capacitors and dielectrics, magnetic field, Faraday's Law, Ampere's law, Maxwell's equations, wave motion. Laboratory exercises. PREREQUISITE: PH1121 or approval of the instructor.

PH1623 PHYSICS III (4 - 2).

Geometrical and physical optics, thermodynamics and kinetic theory, sound, atoms and molecules, modern physics. Laboratory exercises. PREREQUISITES: PH1322 or approval of the instructor.

PH2151 PARTICLE MECHANICS (4 - 1).

After a review of the fundamental concepts of kinematics and dynamics, this course concentrates on those two areas of dynamics of simple bodies which are most relevant to applications in Combat Systems: vibrations and projectile motion. Topics include: damped and driven oscillations, projectile motion with atmospheric friction, satellite orbits, and rotating coordinate systems. PREREQUISITES: PH1121 or equivalent; MA2121 or equivalent course in ordinary differential equations (may be taken concurrently).

PH2351 ELECTROMAGNETISM (4 - 1).

Electrostatic fields in vacuum and dielectrics, electrostatic energy and capacitors. The magnetic field of steady currents, Biot-Savart and Ampere's Laws, vector potential, magnetic properties of matter. Faraday's Law. Magnetic energy. Maxwell's Equations. Gauge transformations. The electromagnetic wave equation and plane waves. PREREQUISITES: PH1322 or equivalent, a course on multivariable calculus and a course on differential equations.

PH3292 APPLIED OPTICS (4 - 2).

An intermediate-level course in optics. Review of basic optical concepts: reflection, refraction, imaging systems, interference, polarization. Matrix methods of ray tracing and matrix-based analysis of optical systems. Introduction to aberrations. Birefringence, circular and elliptical polarization, optical activity, electro-optical modulators. Multiple-beam interference. Huygens-Fresnel principle, Fraunhofer diffraction, Fresnel diffraction. Introduction to Fourier optics. Basic coherence theory and its applications. PREREQUISITES: PH1623 and PH3352, or equivalents.

PH3352 ELECTROMAGNETIC WAVES AND RADIATION (4 - 0).

Propagation of uniform plane waves in free space, in dielectric media, in conducting media (with emphasis on sea water), and in the ionosphere. Reflection and refraction. Radiation and antennas. Principles of radar. Rectangular waveguides. PREREQUISITE: PH2351.

PH3652 QUANTUM MECHANICS (4 - 1).

This course covers the fundamentals of quantum mechanics that are required for applications in combat systems technology. Wave-particle duality and the Schrodinger equation, bound states, scattering by simple barriers, WKB approximation, expectation values and operators, rotationally invariant potentials, hydrogen atom, quantum theory of angular momentum, spin, identical particles, Pauli exclusion principle, perturbation theory. PREREQUISITES: PH1623, PH3152, PH3991.

PH3991 THEORETICAL PHYSICS (4 - 0).

Discussion of heat flow, electromagnetic waves, elastic waves, and quantum mechanical waves; applications of orthogonal functions to electromagnetic multi poles, angular momentum in quantum mechanics, and to normal modes in acoustic and electromagnetic systems. PREREQUISITE: Basic physics, multivariable calculus, vector analysis, Fourier series, complex numbers, and ordinary differential equations.

SE2013 INTRODUCTORY APPLIED PHYSICS LABORATORY (4 - 3).

This course is an introduction to basic electronic test instrumentation and basic passive and active circuit components, with emphasis on extensive, practical hands-on exposure to laboratory hardware and devices. Included are the measurement and signal processing of analog signals and analog sensors/transducers as well as applied Fourier analysis and transfer functions. Operational amplifiers are introduced as building blocks of analog systems. Negative feedback amplifiers and op-amp applications are covered as well as positive feedback and oscillators. Some background in laboratory instrumentation and simple DC and AC circuit elements is assumed. PREREQUISITES: College-level basic physics and mathematics, plus simple electrical circuits (e.g. PH1322).

SE2014 INTERMEDIATE APPLIED PHYSICS LABORATORY (4 - 3).

This course is a continuation of the instrumentation and signal processing topics begun in SE2013. Included are controllable oscillators and RF modulation/demodulation techniques. Basic electrical noise sources and active filters are covered. The basics of elementary digital logic gates and ICs are covered, as well as an overview of some relevant microcomputer topics, such as digital encoding schemes, analog and digital interfacing, and serial communications and networking. At the discretion of the instructor, a hands-on class project, incorporating the course material, may be assigned. Typical projects are: in-air sonar systems, radio receivers and transmitters, and opto-electronic communications links.

SE3015 ADVANCED APPLIED PHYSICS LABORATORY (3 - 4).

Students are expected to integrate the material that they learned in the previous two courses (SE2013 and SE2014), along with some additional basic material on embedded microprocessors. A working introduction to control systems theory is provided and incorporated into an autonomous weapon system or "robot". With the exception of the formal material on control systems, the entire course is devoted to the project, with students split into competing teams, each developing independent hardware and software. At the end of the quarter, each team's system competes against the others' systems in a comprehensive contest that tests the students' assimilation of both the formal and the practical aspects of analog and digital instrumentation, sensor interfacing and system control. PREREQUISITES: SE2911 or other C/C++ programming course, plus SE2013 and SE2014.

SE3172 PHYSICS OF WEAPONS SYSTEMS: FLUID DYNAMICS OF WEAPONS, SHOCK WAVES, EXPLOSIONS (4 - 2).

This course provides the basic physical principles applicable to air-borne and water-borne missiles, as well as the fluid dynamics of shocks and explosions. Topics include: Elements of thermodynamics, ideal fluid flow, elementary viscous flows, similitude and scaling laws, laminar and turbulent boundary layers, underwater vehicles, classical airfoil theory, supersonic flow, drag and lift of supersonic airfoils with applications to missiles, fluid dynamics of combustion, underwater explosions. PREREQUISITES: PH2151 and PH3991.

SE3400 SURVEY OF UNDERWATER ACOUSTICS (4 - 2).

The physics of the generation, propagation, and detection of sound in the ocean. Topics include the acoustic wave equation and its limitations in fluids; plane, cylindrical, and spherical waves; the ray approximation; reflection of plane waves from plane boundaries; radiation of sound from circular piston, continuous line source, and linear array; speed of sound and absorption in the ocean; active and passive sonar equations; transmission-loss and detection-threshold models; normal mode propagation in the ocean; the parabolic equation approximation. Laboratory experiments include surface interference, noise analysis, normal modes, and acoustic waveguides. PREREQUISITES: PH2151 and PH3991.

SE4050 PHYSICS OF ELECTROMAGNETIC SENSOR SYSTEMS (4 - 2).

Introduction to the physics of active and passive electromagnetic detection systems. Basic radiometry. Introduction to radar: ranging, pulse rate and range ambiguity, Doppler measurements radar equation, target cross-sections, antenna beam patterns and phased arrays. Optoelectronic displays: CRTs, LEDs, LCDs, plasma displays. Introduction to lasers: transitions, population inversion, gain, resonators, longitudinal and transverse resonator modes, Q-switching, mode-locking, laser applications. Photodetection basics: noise and its characterization, photovoltaic, photoconductive and photoemissive detectors, image intensifiers, CCDs. Introduction to optical fibers and their applications. PREREQUISITES: PH3292, PH3352 and PH4653, or equivalents.

SE4860 ADVANCED WEAPON CONCEPTS (4 - 1).

This course serves as a final synthesis course in the Combat Systems Science and Technology Curriculum 533. It brings together many elements of the curriculum in a comprehensive overview of the components and underlying technologies of modern missile delivered warheads. After an introduction to modern high explosives and determination of velocities of explosively driven metal, a description of principles and design considerations for all types of modern warheads is given. This is followed by an analysis of the effects of the various warhead mechanisms on targets. The second half of the course is dedicated to a comprehensive overview of modern missile elements and their technologies. The course concludes with a summary of the tactical missile development process. PREREQUISITES: The course requires good comprehension of all aspects of mechanics (e.g. PH3152), electromagnetism (e.g. PH3352), modern optics (e.g. PH3292) and some fluid dynamics (e.g. SE3172).

SOFTWARE ENGINEERING COURSE DESCRIPTIONS

CS3460 SOFTWARE METHODOLOGY (3 - 1).

Introduction to the software life cycle. Methods for requirements definition, design, and testing of software. Basic concepts of software engineering, including stepwise refinement, decomposition, information hiding, debugging, and testing. PREREQUISITES: CS2972 and CS3300.

CS4500 SOFTWARE ENGINEERING (3 - 1).

The techniques for the specification, design, testing, maintenance and management of large software systems. Specific topics include software life cycle planning, cost estimation, requirements definition and specification, design, testing and verification, maintenance and reusability. The laboratory sessions will discuss special topics.

PREREQUISITE: CS3460 or consent of instructor.

CS4510 COMPUTER-AIDED PROTOTYPING (3 - 0).

This course covers the concept and application of computer-aided prototyping to the development and acquisition of DoD software systems. Specific topics include the prototyping software life cycle, system models, design methods, automatic code generation, prototyping languages and tools, and their unique systematic system construction methods for increasing productivity, reliability and portability of software development in comparison with other development methods. PREREQUISITE: CS4500 or consent of instructor.

CS4520 ADVANCED SOFTWARE ENGINEERING (3 - 0).

This course is a sequel to CS4500. The methods for specifying, designing, and verifying software systems are covered in depth, with emphasis on automatable techniques and their mathematical basis. The techniques are applied to construct and check Ada programs using a formal specification language. The course concludes with a summary of current research areas in software engineering. PREREQUISITE: CS4500 or consent of instructor.

CS4530 SOFTWARE RESEARCH AND DEVELOPMENT IN DOD (3 - 0).

This course builds on the material covered in CS4500. Fundamental principles of computer system/network security and distributed computing are covered along with advanced methods, techniques and standards aimed at improving the development and acquisition of DoD software systems. Specific topics include: the application of software engineering principles for designing large, secure, embedded real-time computer systems; the application of software engineering principles for the design of distributed systems; automated tools for the specification, design and generation of code for applications; and existing emerging DoD standards for software development, security and acquisition. PREREQUISITE: CS4500 or consent of instructor.

CS4540 SOFTWARE TESTING (3 - 1).

This course covers the theory and practice of testing computer software with the intent of preventing, finding and eliminating bugs in software. Planning and executing software tests are covered, including requirements-based testing, and advanced testing techniques. These topics are discussed in the context of a realistic development environment, illustrated using a variety of software testing tools. PREREQUISITE: CS4500 or consent of instructor.

CS4570 SOFTWARE REUSE (3 - 0).

This course covers the concepts, methods, techniques and tools for systematic reuse of software components and systems. Specific topics include design and re-engineering for reuse, mechanisms for enhancing reuse, domain specific reuse and software architectures, reuse of requirements models, specifications and designs, tools for reuse, software library organization, and methods for component search. PREREQUISITE: CS4500 or consent of instructor.

CS4580 DESIGN OF EMBEDDED REAL-TIME SYSTEMS (3 - 0).

This course covers the concepts, methods, techniques and tools for supporting the design of embedded real-time systems. Specific topics include real-time systems and concurrency models, object-oriented methods for real-time system design, real-time scheduling, and Ada 95 support for concurrent and real-time systems. PREREQUISITE: CS4500 or consent of instructor.

CS4591 REQUIREMENTS ENGINEERING (3 - 1).

This is an in-depth treatment of requirements engineering concepts, methods, and tools. The role of requirements engineering within software engineering is explored as well as consistency, cost-benefit analysis, resolving multiple viewpoints, dependency tracing, and automated decision support. Topics are reinforced with examples from DoD applications. Prototyping is introduced as a means of assessing requirements early in the design process. PREREQUISITE: CS4500 or consent of instructor.

NAVAL WAR COLLEGE COURSE DESCRIPTION

NW3230 STRATEGY AND POLICY: THE AMERICAN EXPERIENCE (4 - 0).

This course is a tailored version of the Strategy and Policy (S&P) course taught at the Naval War College in Newport, RI. It has been revised to focus on the critique of strategies and their utility in achieving a nation's policy objectives. The course utilizes case studies derived from the American experience. This course is mandatory for all DoN students, and it will be taught by NWC faculty during the normal academic day. (This course replaces the previously mandatory course NS3252 Maritime Strategy).

APPENDIX C. NPS CATALOG ENTRY FOR THE COMBAT SYSTEMS CURRICULUM

Enclosed here is the revised entry for the Combat Systems curriculum for the next version of the NPS Catalog, as updated by the Combat Systems Curricular Office. Due to the size of the Combat Systems curriculum with its various track options, the entire catalog entry has not been included, but instead only the parts of the entry relevant to the new Software Engineering track option.

The Educational Skill Requirements are the same for all tracks in the Combat Systems curriculum (curriculum 533), and they are included here as well. These ESR's describe the desired educational goals for the curriculum's graduates. The ESR's were taken from the 1999 printed version of the NPS Catalog.

The XX66P code mentioned as the Combat Systems subspecialty is the code currently earned under the old *Officer Subspecialty System*. Under the new *Navy Subspecialty System*, there are actually nine different Combat Systems P-codes. Of the codes in the new system, one is a generic Combat Systems P-code, and the other eight are specific to the specialization track completed along with the P-code requirements. The matrix containing all of the Engineering and Technology (5XXX level) subspecialties in the new subspecialty system includes all nine of the Combat Systems subspecialties and was presented as Figure 13 in Chapter V.

COMBAT SYSTEMS PROGRAMS

Curricular Officer:

William T. McCoy

CDR, USN

Engineering & Technology, Code 34

The Mechanical Engineering Building

Building 245, Room 115

(831) 656-2033, DSN 878-2033

e-mail: wtmccoy@nps.navy.mil

<http://web.nps.navy.mil/~code34>

COMBAT SYSTEMS SCIENCES AND TECHNOLOGY

CURRICULUM 533

Physics Web Page: <http://www.physics.nps.navy.mil>

This program is designed to meet the needs of the military services for an officer having a broad-based advanced technical education applicable to combat systems design, development, test and evaluation, acquisition, operation, and support- Included in the core are courses on electromagnetic radiation, signal processing, optoelectronics, servo and computer control systems, explosives and warheads, fluid dynamics of weapons, combat simulation, quantum devices, detection and engagement elements, combat systems integration, and computing resources for advanced combat systems. Additionally, the officer will take a sequence of four or more courses in one of the following concentration areas: electromagnetic sensors systems, weapons and effects, underwater acoustic systems, tactical missile systems, total ships systems engineering, software engineering, or an engineering area related to combat systems. The officer will also conduct thesis research on a military relevant technical problem.

REQUIREMENTS FOR ENTRY

A baccalaureate degree with mathematics through differential and integral calculus and a calculus-based basic physics sequence are required for direct input. Courses in the physical sciences and engineering are highly desirable. An APC of 334 is required.

COMBAT SYSTEMS SCIENCES AND TECHNOLOGY SUBSPECIALTY

Completion of this curriculum qualifies an officer as a **Combat Systems Sciences and Technology Sub-specialist** with a subspecialty code of XX66P. The curriculum sponsor is the Naval Sea Systems Command.

Typical Jobs in this Subspecialty:

NTDS-CIC:FLTCOMBDSSA, San Diego, CA

Weapons Instructor: Naval Academy, Annapolis, MD

Testing Officer: COMOPTEVFOR; Defense Nuclear Agency (DNA)

Research Associate: Lawrence Livermore Laboratory: Los Alamos National Laboratory, Naval Research Laboratory

Physics Instructor: Naval Academy, Annapolis, MD

Electro-Optics Project Officer: Naval Ocean Systems Center, San Diego CA

Project Management: NAVSEASYS COM, SPAWAR SYSCOM

Physicist: Defense Nuclear Agency (DNA) Tactical Nuclear Weapons/Plans: CINCLANT, DNA, Los Alamos

Training Officer: PDW-1 24 (Undersea Surveillance)

Strategic Systems Project Officer: Director of SSPO

ENTRY DATES

Combat Systems Sciences and Technology is an eight-quarter course of study with entry dates in January and July. If further information is needed, contact the Academic Associate or Curricular Officer for this curriculum. Other entry dates are possible by special arrangement with the curricular officer.

Curriculum 533

Academic Associate:

James V. Sanders, Associate Professor

Code PH/Sd, Spanagel Hall, Room 200A

(831) 656-3884/2116, DSN 875-3884/2116

e-mail: jsanders@nps.navy.mil

DEGREE

Students, depending on background, may earn a Master of Science in Physics, Applied Physics, Computer Science, Engineering Acoustics, or one of the engineering disciplines.

**TYPICAL COURSE OF STUDY
APPLIED PHYSICS OPTION**

Quarter 1

MA1995	(5-0)	Mathematics for Scientists and Engineers I
MA1996	(5-0)	Mathematics for Scientists and Engineers II
NW3230	(4-0)	Strategy and Policy: The American Experience
PH1121	(4-2)	Mechanics

Quarter 2

PH1322	(4-2)	E&M
PH2151	(4-1)	Particle Mechanics
PH3991	(4-0)	Theoretical Physics
SE2911	(4-3)	Combat Systems Simulation *

Quarter 3

PH1623	(4-2)	Optics, Thermo and Modern Physics
PH3152	(4-0)	Mechanics of Physical Systems
PH2351	(4-1)	Electromagnetism
5E2013	(4-3)	Analog and Communications Techniques *

Quarter 4

PH3352	(4-0)	Electromagnetic Waves and Radiation
PH3652	(4-1)	Quantum Mechanics *
SE3172	(4-1)	Physics of Weapon Systems*
SE2014	(4-3)	Digital Techniques

Quarter 5

		Concentration Course
PH3292	(4-2)	Applied Optics
PH4653	(4-0)	Condensed Matter *
SE3015	(4-3)	Autonomous Combat System Design *
SE2020	(1-0)	Combat Systems Requirements and Design

Quarter 6

		Concentration Course
		Concentration Course
SE4050	(4-2)	Physics of E&M Sensor Systems *
XX0810	(0-8)	Thesis Research

Quarter 7

SE3400	(4-2)	Physics of Sonar Systems*
		Concentration Course
XX0810	(0-8)	Thesis Research
XX0810	(0-8)	Thesis Research

Quarter 8

SE4021	(4-0)	Combat Systems Project Integration *
SE4022	(3-0)	Combat Systems Capstone *
SE4860	(4-0)	Advanced Weapons Concepts *
XX0810	(0-8)	Thesis Research

*In development

Concentration Areas:

NOTE: Final approval of an individual student's degree rests with the Chairman of the cognizant department.

(A) MS Applied Physics:

(B) MS Physics:

(C) MS Computer Science:

(D) MS Engineering Acoustics:

(E) MS Electrical Engineering:

(F) MS Mechanical Engineering

(G) MS Aeronautical Engineering

(H) MS Software Engineering

CS3460 Software Methodology
CS4500 Software Engineering
CS4510 Computer-Aided Prototyping
CS4520 Advanced Software Engineering
CS4530 Software Research and Development in DoD
CS4540 Software Testing
CS4570 Software Reuse
CS4580 Development of Embedded Real Time Systems
CS4591 Requirements Engineering

EDUCATIONAL SKILL REQUIREMENTS
COMBAT SYSTEMS SCIENCES AND TECHNOLOGY
CURRICULUM (533)
Subspecialty Code XX66P

- 1. MATHEMATICS, SCIENCE, AND ENGINEERING FUNDAMENTALS:** A solid foundation in mathematics, physics, and engineering to support the theoretical and experimental aspects of the technical courses in the curriculum.
- 2. SCIENTIFIC AND ENGINEERING PRINCIPLES** necessary to understand the elements of combat systems:
 - a. Acoustic and electromagnetic propagation; physics of solid-state, electro-optic, and quantum devices; principles of radar and sonar systems; and signal analysis and decision theory.
 - b. Communication systems, fiber optics, integration of computing resources in advanced systems, advanced distributed computing concepts, and automatic control systems.
 - c. Fluid dynamics of subsonic and supersonic weapons, warheads and their effects (nuclear and conventional), counter measures and deception techniques.
 - d. Combat systems simulation and testing including sufficient probability and statistics theory to appreciate the limits of simulation.
- 3. COMBAT SYSTEMS ENGINEERING:** An understanding of the principles of design, development, improvement, and logistics engineering, including the importance of technical and economic trade-offs.
- 4. MATERIALS SCIENCE:** Familiarity of the concepts of materials science sufficient for an understanding of the mechanical, electrical, and thermal properties of materials.
- 5. JOINT AND MARITIME STRATEGIC PLANNING:** American and world military history and joint and maritime planning including the origins and evolution of national and allied strategy; current American and allied military strategies which address the entire spectrum of conflict; the U.S. maritime component of national military strategy; the organizational structure of the U.S. defense establishment; the role of the commanders of unified and specified commands in strategic planning, the process of strategic planning; joint and service doctrine, and the roles and missions of each in meeting national strategy.
- 6. GRADUATE CONCENTRATION:** A concentration of several graduate-level courses in a technical field within the general area of combat systems. The knowledge required for an approved concentration is:
 - A. ELECTROMAGNETIC SYSTEMS**
 - 1) Statistical physics.
 - 2) Electromagnetics propagation in homogeneous and random media.
 - 3) Sensors for detecting electromagnetic radiations.
 - 4) Concepts of target surveillance, acquisition, and engagement.
 - B. CONVENTIONAL WEAPONS, DIRECTED ENERGY WEAPONS, AND WEAPONS OF MASS DESTRUCTION AND THEIR EFFECTS**
 - 1) Physics of High velocity Impact phenomena in Solids.
 - 2) Weapons Lethality and Survivability.
 - 3) Nuclear and other weapons of mass destruction and their effects.
 - 4) Physics of Directed Energy Weapons.

C. UNDERWATER ACOUSTIC SYSTEMS

- 1) Acoustical theories, mechanical vibration, wave propagation in the ocean; scattering, fluctuations and boundary interactions; transducer theory and design; and array theory.
- 2) Active and passive acoustic signal processing including adaptive techniques.
- 3) Acoustic influences of oceanographic phenomena including boundary characteristics, ambient noise, sound speed profiles, fronts, and eddies.

D. ENGINEERING DISCIPLINE

A series of at least six graduate-level courses in an area related to combat systems in the disciplines of either Electrical Engineering, Mechanical Engineering, Aeronautical Engineering, Software Engineering, Computer Science, Total Ship System Engineering or Physics. This series must be approved by the Curricular Officer.

- 7. THESIS:** Ability to recognize scientific and engineering advancements of potential value to the Navy, formulate a research problem, perform the necessary research, and report the results.

Curriculum Sponsor and ESR Approval Authority

Commander, Naval Sea Systems Command

APPENDIX D. NPS CATALOG ENTRY FOR SOFTWARE ENGINEERING PROGRAMS

The development of the new Software Engineering track within the Combat Systems curriculum required the change in the Combat Systems catalog entry as seen in Appendix C. In addition to the update to that entry, the Software Engineering catalog entries have been updated to include the new program amongst the number of different Software Engineering programs available through the school. As opposed to Appendix C, where only the material relevant to the new Software Engineering track was included, the entirety of the new Software Engineering catalog entry is presented here based on the relevance of all the Software Engineering programs to this thesis.

Also included in the appendix is the list of Educational Skill Requirements for the Software Engineering curriculum (curriculum 369) as taken from the NPS Catalog. These ESR's describe the desired educational goals for the curriculum's graduates.

THE SOFTWARE ENGINEERING CURRICULUM 369/533

Modern software engineering encompasses all aspects of large scale software development and acquisition, from requirements and design to reliability assessment, maintenance, system integration, and reengineering. The phrase software engineering was coined in 1968 as a sort of rallying cry when NATO convened a workshop by that name to assess the state and prospects of software production. Since that time, software development has slowly emerged from ad hoc practice into an engineering discipline that is based on scientific knowledge from computer science and other disciplines. While computer science provides good models and theories to analyze problems and synthesize solutions, it fails to package and integrate the results for operational use, leading to the criticism sometimes made by software producers that computer science is irrelevant to practical software.

The software engineering curriculum was designed to address this problem. It builds upon the students' scientific knowledge in computer science from their undergraduate education and the insight into software problems from work experience. The curriculum introduces students to a set of engineering practices that enable ordinary practitioners to create sophisticated software systems that work. It teaches students the principles and methods of software development and process management. The curriculum provides in-depth coverage of requirements engineering, software architecture, design automation, development methods, and management processes for software development.

The program offers both M.S. and Ph.D. degrees in Software Engineering. The MSSE program comes with a 1-year full-time option and a 2-year part-time distance learning option. Students not enrolled in the MSSE degree program may also enroll in individual courses and receive NPS credit upon successful course completion.

MASTER OF SCIENCE IN SOFTWARE ENGINEERING, NON P-CODE PROGRAM (369)

REQUIREMENTS FOR ENTRY

An accredited Bachelor's degree in computer science, computer engineering, or related field, with above-average grades in mathematics, resulting in an APC of at least 325, and at least two years of software development or maintenance experience is required for entry.

ENTRY DATE

The MSSE is a four-quarter curriculum with entry dates in October. If further information is needed, contact the Curricular Officer or the Academic Associate (Point of Contact) for this curriculum.

DEGREE

Requirements for the degree Master of Science in Software Engineering are met as a milestone en route to satisfying the Educational Skill Requirements of the curricular program.

TYPICAL COURSE OF STUDY FOR FULL-TIME MSSE PROGRAM

Quarter 1

CS3460	(3-1) Software Methodology
CS4540	(3-0) Software Testing
CS4580	(3-0) Design of Embedded Real-Time Systems
IS4300	(3-2) Software Engineering and Management

Quarter 2

CS4500 (3-1) Software Engineering
CS4570 (3-0) Software Reuse
CS4591 (3-1) Requirements Engineering
CS0810 (0-8) Thesis Research

Quarter 3

CS3502 (4-0) Computer Communications and Networks
CS4520 (3-0) Advanced Software Engineering
IS3171 (4-1) Economic Evaluation of Information Systems II
CS0810 (0-8) Thesis Research

Quarter 4

CS4510 (3-0) Computer-Aided Prototyping
CS4530 (3-0) Software Research and Development in DoD
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

TYPICAL COURSE OF STUDY FOR THE PART-TIME MSSE DISTANCE LEARNING PROGRAM**Quarter 1**

CS3460 (3-1) Software Methodology
IS4300 (3-2) Software Engineering and Management

Quarter 2

CS4500 (3-1) Software Engineering
CS4560 (3-0) Software Evolution

Quarter 3

CS4520 (3-0) Advanced Software Engineering
IS3171 (4-1) Economic Evaluation of Information Systems II

Quarter 4

CS4510 (3-0) Computer-Aided Prototyping
CS4530 (3-0) Software Research and Development in DoD

Quarter 5

CS4540 (3-0) Software Testing
CS4580 (3-0) Design of Embedded Real-Time Systems

Quarter 6

CS4570 (3-0) Software Reuse
CS0810 (0-8) Thesis Research

Quarter 7

CS3502 (4-0) Computer Communications and Networks
CS0810 (0-8) Thesis Research

Quarter 8

CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

COMBAT SYSTEMS SUBSPECIALTY, MASTER OF SCIENCE IN SOFTWARE ENGINEERING (533)

This is a systems engineering program with an emphasis on computer-based systems and DoD applications. This program is designed to meet Navy needs that go beyond software to treat whole system issues.

REQUIREMENTS FOR ENTRY

A baccalaureate degree with mathematics through differential and integral calculus and a calculus-based basic physics sequence are required for direct input. Courses in the physical sciences and engineering are highly desirable. Officers not having the required qualifications for direct input enter the program indirectly through the Engineering Science (460) Curriculum. An APC of 323 is required.

ENTRY DATE

The Combat Systems subspecialty MSSE is an eight-quarter curriculum with entry dates in July and January. If further information is needed, contact the Curricular Officer or the Academic Associate for this curriculum (533).

DEGREE

Requirements for the degree Master of Science in Software Engineering are met as a milestone en route to satisfying the Educational Skill Requirements of the curricular program.

TYPICAL COURSE OF STUDY

Quarter 1

PH1121	(4-2)	Mechanics I
MA1995	(5-0)	Math Methods I
MA1996	(5-0)	Math Methods II
NW3230	(4-0)	Strategy and Policy: The American Experience

Quarter 2

PH1322	(4-2)	E&M I
PH2151	(4-2)	Mechanics II
PH3991	(4-0)	Theoretical Physics
CS3460	(3-1)	Software Methodology

Quarter 3

PH1623	(4-2)	Modern Physics I
PH2351	(4-1)	E&M II
SE2013	(4-2)	Analog Techniques and Communications
CS4500	(3-1)	Software Engineering

Quarter 4

PH3352	(4-0)	E&M III
PH3652	(4-1)	Modern Physics II
SE2014	(3-4)	Digital Techniques
CS4520	(3-0)	Advanced Software Engineering

Quarter 5

PH3292	(4-2)	Physical Optics
SE3015	(3-4)	Autonomous Combat Systems Design
CS4510	(3-0)	Computer-Aided Prototyping
CS4530	(3-0)	Software Research and Development in DoD

Quarter 6

SE3172	(4-1)	Physics of Weapons Systems
CS4540	(3-1)	Software Testing
CS4580	(3-0)	Design of Embedded Real-Time Systems
CS0810	(0-8)	Thesis Research

Quarter 7

SE3400	(3-4)	Physics of Sonar Systems
CS4570	(3-0)	Software Reuse
CS4591	(3-1)	Requirements Engineering
CS0810	(0-8)	Thesis Research

Quarter 8

SE4050	(4-2)	Physics of E&M Sensors
SE4860	(4-0)	Advanced Weapons Concepts
CS0810	(0-8)	Thesis Research
CS0810	(0-8)	Thesis Research

DOCTOR OF PHILOSOPHY IN SOFTWARE ENGINEERING, NON P-CODE PROGRAM (369)**REQUIREMENTS FOR ENTRY**

An applicant should have a Master's Degree in Software Engineering (MSSE) or a related field. Applicants not meeting this requirement are encouraged to apply to the Master's program. Ph.D. applicants should have above-average grades in a typical Master's degree program and demonstrate the ability to think creatively and work independently. Other evidence of research or academic ability, such as work experience or publications, is also taken into consideration when evaluating applicants.

ENTRY DATE

Admitted Ph.D. students may begin in any quarter, but it is recommended that the student start in either the Fall Quarter (beginning in October) or the Spring Quarter (beginning in April) due to the requirements and timing of the Written Qualifying Examination. If further information is needed, contact the Curricular Officer or Academic Associate (Point of Contact) for this curriculum.

DEGREE

The Ph.D. program in Software Engineering is designed for DoD software practitioners who want to acquire the skill and knowledge to perform state-of-the-art research on issues related to the development and evolution of large complex software systems, and to intelligently manage the research of other software practitioners. It offers the software professionals a unique program of study and advances software engineering principles and technology vital to DoD researchers and program managers. Students typically take three years to complete the doctoral program.

The first milestone in the Ph.D. program is the Written Qualifying Examination. This provides early feedback to students and faculty so that a course of study that leads to the successful completion of all the requirements can be determined.

TYPICAL COURSE OF STUDY

Ph.D. students are expected to complete the following steps:

1. Form a Dissertation Committee,
2. Pass the Written Qualifying Examination,
3. Fulfill Minor Requirements,
4. Pass the Oral Qualifying Examination,
5. Pass the Final Dissertation Examination,
6. Complete the Dissertation.

Students are expected to complete steps 1 and 2 by the fourth quarter of doctoral study, complete step 3 and 4 by the sixth quarter, and complete steps 5 and 6 by the twelfth quarter.

Additional information is available on the Software Engineering web page <http://www.cs.nps.navy.mil/~se/phd.html>.

Curriculum 369

Academic Associate: N/A

Curriculum 533

Academic Associate:

James V. Sanders, Associate Professor
Code PH/Sd, Spanagel Hall, Room 200A
(831) 656-3884/2116, DSN 878-3884/2116

For more information on Curriculum 369, please contact any of the following:

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EDUCATIONAL SKILL REQUIREMENTS

SOFTWARE ENGINEERING

CURRICULUM (369)

All officers with advanced degree education in Software Engineering must possess skills and competencies in software design, development processes, and related software technology applicable to large-scale military systems. The skills and competencies are detailed below.

1. SOFTWARE DESIGN

The officer must have a thorough knowledge of software system design to include:

- a. System analysis and design theory encompassing the basics of requirements engineering and specification, system modeling and software architecture and its application to automation of military processes;
- b. An understanding of the design issues related to digital data processing, interfacing to hardware systems, real-time command and control, distributed computation, and end-to-end systems integration. An understanding of the design issues related to software system interoperability, system reengineering, design rationales, system architecture, and software reuse;
- c. The ability to design systems that are readily adaptable to changing military needs;
- d. An understanding of system reliability issues and quality assurance methods for achieving high software reliability; and
- e. The ability to understand, diagnose and recover from software failures.

2. DEVELOPMENT PROCESSES

The officer must have a thorough knowledge of software development processes to include:

- a. An understanding of the software development process, including requirements determination, feasibility assessment, design, configuration management, implementation, quality assurance, and system evolution;
- b. The ability to perform feasibility assessments of complex computer-based systems via prototyping, simulation, and static analysis;
- c. The ability to plan, evaluate, and manage major software projects, choose appropriate design automation tools and develop appropriate documentation; and
- d. The ability to assess software development risks and improve software development processes to reduce costs and produce more reliable systems.
- e. An understanding of the development process issues related to improving maintainability and upgradeability of software in integrated systems.

3. SOFTWARE TECHNOLOGY

The officer must have a thorough knowledge of software technology that includes:

- a. Methods for efficiently representing data and techniques for efficiently operating upon data structures;
- b. The structure, control, and design of software systems involving multiprocessing, distributed processing and network-centric computing;
- c. Representations and automatable methods for design and analysis of software systems;
- d. Tools and techniques for simulation and modeling of systems; and
- e. Engineering automation capabilities for design and assessment of software systems, program generation, and computer aided software design tools.

4. PROBLEM SOLVING AND MILITARY APPLICABILITY

The officer shall possess skills that enable a realistic perspective on problem solving and provide an appreciation of the difficulty and power of applying theory to military concerns such as information warfare and command and control. This includes:

- a. Completing a significant project applying software engineering skills to Navy and/or DoD relevant problems;
- b. Exercising skills in problem formulation, criteria specification, analysis, design, and evaluation of results as they relate to military requirements; and
- c. Clearly communicating the results of a project orally and in writing.

5. JOINT AND MARITIME STRATEGIC PLANNING

The officer will have a graduate level understanding of strategy, especially maritime strategy, naval doctrine, and the effect of technical developments on warfare. The officer must become familiar with the following subjects for the United States, its allies, and opponents: The roles and missions of military services, policy-making processes regarding the armed forces, history of joint and general staffs, joint planning for acquisition and operations, and current issues in defense reform and reorganization.

APPENDIX E. SAMPLE 0091 SUBSPECIALTY-CODED BILLETS

The next three pages contain the billets in the Navy currently coded for the 0091 subspecialty, Computer Technology - Science. The list of billets is distributed monthly by OP-114 (now N13 due to various reorganizations) at BUPERS, and this particular list was run at the end of July 1999, and received at NPS in August 1999. The list of 0091 codes is given to show examples of potential billets where graduates would currently utilize their learned skills, as there are no billets specifically coded for the new 5707 Combat Systems/Software Design P-code yet. The closest match is the 0091P code currently earned by Computer Science graduates along with their Master's degree upon graduation from NPS. These students do receive at least some Software Engineering education, and possibly a significant amount depending on their specialization tracks.

Re-coding of billets for the P-codes in the new *Navy Subspecialty System* is underway at this time. There will undoubtedly be a transition period required as the new system is put into operation, and the subspecialty codes change from the 00XX codes to the new system where codes are separated by major field of concentration into 1XXX, 2XXX, 3XXX, 4XXX, 5XXX, and 6XXX codes.

Explanations of a few of the various important fields in the list to help readability are:

Column	Title	Description
3	AUIC	Number used to identify the command (Activity's Unit Identification Code)
4	ACTIVITY NAME	Name of the command where the billet exists
5	BSC	Number identifying the actual billet at the command (Billet Sequence Code)
6	BILLET TITLE	Job title for the coded position
9	CODE PRI	Subspecialty code required by the billet

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MMC BIN	AUIC	ACTIVITY NAME	BSC	BILLET TITLE	EFF DATE	SUBSPEC SEC	CODE PRI	DESIG PRI	NOBC	AQD	BA	FYC	FY1	FY2
11	0000463	00011 OPNAV	COMPUTER TECHNOLOGY - SCIENCE	60940 COMH PLN&OPS/N631D ASST		0076S	0091B	14401	9515	AGN	1	1		1
19	0003277	00032 PEOCMANDUAV PAX RV		04270 DPJ BUS ADMIN/HD P IMAG			0091P	1110H	2164	AAN		1		1
19	0003274	00032 PEOCMANDUAV PAX RV		81150 MGR DPJ FE/DIR AFLOAT PR		0072S	0091P	1510H	2163	AAC	1	1		1
19	0003339	00032 PEOCMANDUAV PAX RV		82240 DPJ SUP/ADV SYSTEMS ENGI			0091P	11401	2170	AAN	1	1		1
11	0003611	00038 USCINCPAC		14300 SIGINT TECH 212/04ARCH			0091P	16101	9720	JD1	1	1		1
69	0005490	00069 COMNAVSECGRU FT MEAD		06350 98 CMU SYS ANAL/ADPROJ			0091P	1610J	9735		1	1		1
02	0006431	00087 USSPACECOM		63220 ADV SATCOM 6320/02 TEC			0091Q	10001	9060	JD1	1	1		1
11	0007775	00161 NAVAL ACADEMY ANNAPO		41200 SCH ADMIN/ASSOC DIR COMP			0091Q	1000H	3283		1	1		1
11	0007776	00161 NAVAL ACADEMY ANNAPO		41210 INST ACAD/INSTR COMP			0091P	10001	3251		1	1		1
11	0007777	00161 NAVAL ACADEMY ANNAPO		41220 INST ACAD/INSTR COMP			0091P	1000J	3251		1	1		1
11	0007781	00161 NAVAL ACADEMY ANNAPO		41240 INST ACAD/INSTR COMP			0091P	10001	3251		1	1		1
11	0007456	00161 NAVAL ACADEMY ANNAPO		60090 ADP SYS DIR/COMP SYS DEP			0091P	17001	9705		1	1		1
70	0025619	03363 CV		63 KITTY HAWK 30260 NTDS-CIC			0091S	1322J	9217	LF7	1	1		1
70	0025783	03364 CV		64 CONSTELLAT 30200 NTDS-CIC			0091S	1322J	9217	DGO	1	1		1
70	0025795	03364 CV		64 CONSTELLAT 30210 NTDS-CIC			0091S	1322J	9217	DGO	1	1		1
60	0026379	03367 CV		67 JOHN F KEN 30260 NTDS-CIC			0091S	1322J	9217		1	1		1
70	0026553	03368 CVN		68 NIMITZ 30048 NTDS-CIC			0091S	1322J	9217		1	1		1
60	0026737	03369 CVN		69 EISENHOWER 30240 NTDS-CIC			0091S	1322J	9217	LF7	1	1		1
60	0036290	21247 CVN		71 T ROOSEVELT 30240 NTDS-CIC			0091S	1160L	9745	VX1	1	1		1
60	0056437	21281 CG		47 TICONDEROG 02150 ADP SYS MNT			0091S	1160L	9745		1	1		1
70	0056475	21295 CG		49 VINCENNES 02150 ADP SYS MNT			0091S	1160L	9745		1	1		1
60	0056822	21344 CG		50 VALLEY FOR 02150 ADP SYS MNT			0091S	1160L	9745		1	1		1
70	0056861	21345 CG		51 THOMAS S G 02150 ADP SYS MNT			0091S	1160L	9745		1	1		1
70	0056900	21346 CG		52 BUNKER HIL 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0057051	21387 CG		53 MOBILE BAY 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
60	0057090	21388 CG		54 ANTIETAM 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
60	0057130	21389 CG		55 LEYTE GULF 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0057352	21412 CVN		56 SAN JACINT 02180 ADP SYS MNT			0091S	1322J	9217	VX1	1	1		1
70	0057622	21428 CG		73 GEORGE WAS 02820 NTDS-CIC			0091S	1160L	9745		1	1		1
60	0057662	21429 CG		57 LAKE CHAMP 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0057861	21447 CG		58 PHILIPPINE 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
60	0057901	21449 CG		59 PRINCETON 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0057941	21450 CG		60 NORMANDY 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0057981	21451 CG		61 MONTEREY 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0058572	21623 CG		62 CHANCELLOR 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
60	0058612	21624 CG		63 COMPENS 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
70	0058652	21625 CG		64 GETTYSBURG 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0058761	21656 CG		65 CHOSIN 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
70	0058801	21657 CG		66 HUE CITY 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0058841	21658 CG		67 SHILOH 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0058975	21684 CG		68 ANZIO 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0059739	21827 CG		69 VICKSBURG 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0059779	21828 CG		70 LAKE ERIE 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
60	0059819	21829 CG		71 CAPE ST GE 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
70	0059859	21830 CG		72 VELLA GULF 02180 ADP SYS MNT			0091S	1160L	9745	VX1	1	1		1
39	0080306	3019A SPAVARSYSCOM CINC IN		73 PORT ROYAL 02180 ADP SYS MNT			0091S	1160L	9745		1	1		1
				33050 ELX P&P DIR/REQUIREMENTS			0091P	1110H	5913	AAN	1	1		1

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MNC BIN	AUIC	ACTIVITY NAME	BSC	BILLET TITLE	EFF DATE	SUBSPEC SEC	CODE PRI	DESIG NOBC	AQD	BA	FYC	FY1	FY2
39	0080356	3020A SPAWARSSCOM CINC IN	72140	DPJ SUP/REQUIREMENTS SPE			0091P	14401 2170	AAN	1	1	1	1
39	0080310	3021A SPAWARSSCOM CINC IN	33020	ELX REQ/REQUIREMENTS			0091P	14401 5917	AAN	1	1	1	1
12	0001551	30320 DON INPO NETWORK PRO	10200	ADP SYS DIR/DEP DIR SAM		0055S	0091B	1440H 5917	AAN	1	1	1	1
12	2787702	30320 DON INPO NETWORK PRO	70020	ADP SYS DIR/OPERATIONS F		0055S	0091Q	1700H 9705	ASN	1	1	1	1
39	0077810	30968 JSIMS DET FORT MONRO	71005	DPJ SUP/ASST PROJ MGR/OP			0091B	1050H 2170	ASN	1	1	1	1
39	0071943	35333 SPAWAR SPACE TECH PG	40210	DPJ SUP/CDP SYS ACQ MGR/			0091P	1510J 2170	AAN	1	1	1	1
39	2878879	35333 SPAWAR SPACE TECH PG	42190	SPACE ACQ/COMPUTER SYSTE		0089S	0091B	1610J 2192	ARN	1	1	1	1
24	0080194	35366 NAVSEASCOM PMS WAS	43035	MAJ PJ MGR FE/430DE - HD			0091Q	1110H 2163	AAN	1	1	1	1
24	0100741	35366 NAVSEASCOM PMS WAS	43040	TRADEV PC/308(-)430 JSMI			0091P	1440H 5761	AAN	1	1	1	1
11	0074812	39211 USACOM ISSG	02230	CH GCCS OP 20/01L			0091P	1700J 9705	JD1	1	1	1	1
11	0074814	39211 USACOM ISSG	02250	PROJ OFF 10/04L			0091S	1000K 9735	JD1	1	1	1	1
11	0074822	39211 USACOM ISSG	04010	CH INFO ASSUR 40/008			0091P	1700J 9715	JD1	1	1	1	1
39	2053674	39698 JOINT SIMULATION SYS	00200	ELX RSCH ADMIN/PROJ MGR-			0091B	1440H 5980	ASN	1	1	1	1
69	0125724	39754 NAVSECGRUACT FT MEAD	50105	59 NSG SPEC OPS/ FOR			0091S	1610J 9860	ASN	1	1	1	1
69	0065902	39888 FIMC NORFOLK/CSS	58005	STAF RED1 TAC/ADP/ FOR			0091P	1610J 9073	ASN	1	1	1	1
69	0087303	39889 FIMC NORFOLK/ECCM	50005	DSUP COOR NSG/C2 PROT			0091P	1610J 9850	ASN	1	1	1	1
11	0077388	42091 PG SCH PROFESSIONAL	32020	SCH ADMIN/ASST CURR			0091B	1000J 3283	ASN	1	1	1	1
11	0077422	42091 PG SCH PROFESSIONAL	76030	INST TECH/INST COMP SCI			0091D	1000J 3250	ASN	1	1	1	1
11	0077425	42091 PG SCH PROFESSIONAL	76060	INST TECH/INST COMP SCI			0091P	1000J 3250	ASN	1	1	1	1
19	0079765	42191 NASC/AIR 4.0 ENGINEE	41550	A/C ELX DIR/FE-18 SSE (S/		0072S	0091P	1510H 2170	ASN	1	1	1	1
19	0079766	42191 NASC/AIR 4.0 ENGINEE	41550	A/C ELX DIR/FE-18 SSE (S/			0091P	1510J 5961	ASN	1	1	1	1
19	0079767	42191 NASC/AIR 4.0 ENGINEE	41750	A/S ELX DIR/P-3C UD 111			0091P	1300J 5961	ASN	1	1	1	1
39	0080477	42200 SPAWARSSCOM PROJ MG	36020	MAJ PJ MGR SEL/DEPUTY			0091B	1610G 2161	AAC	1	1	1	1
39	0080309	42200 SPAWARSSCOM PROJ MG	33030	MGR DPJ FE/PJ MGR SPEC			0091B	1050H 2163	AAN	1	1	1	1
39	0080339	42200 SPAWARSSCOM PROJ MG	33060	DPJ SUP/APM FOR SENS OPE			0091B	1440J 2170	AAN	1	1	1	1
39	0080304	42200 SPAWARSSCOM PROJ MG	70080	ELX REQ/RSCH/INFOSEC OFFI			0091P	1440H 5917	AAN	1	1	1	1
39	0080348	42200 SPAWARSSCOM PROJ MG	70090	DPJ SUP/PROJECT OFFI			0091B	1000J 2170	AAN	1	1	1	1
39	0080406	42200 SPAWARSSCOM PROJ MG	71120	DPJ SUP/JMCIS AFLOAT PRO			0091B	1110H 2170	AAN	1	1	1	1
39	0080479	42200 SPAWARSSCOM PROJ MG	81015	MGR DPJ FE/HD DEV AND SY			0091P	1440J 2163	AAN	1	1	1	1
02	0132444	43442 ROCLANT	01230	ASST OPS OFF RC-1004			0091S	1700J 9590	ASN	1	1	1	1
69	0067634	43456 NAVSECGRUACT KUNIA H	35005	52 ADP SYS SPEC/HD AIS			0091P	1610J 9781	ASN	1	1	1	1
39	0085012	44633 SPAWAR INTEL TNG SPT	71060	DPJ SUP/CRYPTOLOGIC/DATA			0091B	1610J 2170	AAN	1	1	1	1
02	0085297	44839 PEP USA-MILITARY ACA	40400	ASST PROF COMP SCI			0091P	1000J 3255	ASN	1	1	1	1
69	0087211	45082 NAVSECGRUACT SAN DIE	56005	DS NSG SURF/CRG			0091P	1610J 9851	ASN	1	1	1	1
43	0076555	46280 DISA D6 JNTINTEROP E	10520	C31 ENG JEXIB 020			0091P	1440H 9710	ASN	1	1	1	1
43	0134958	46280 DISA D6 JNTINTEROP E	11630	CMPTTR SYS JEXIF 020			0091S	1700J 9735	ASN	1	1	1	1
69	0092060	46439 NAVINFOWARACT/PG11	20010	XO SHR ACT			0091P	1610H 9436	ASN	1	1	1	1
69	0092072	46439 NAVINFOWARACT/PG11	58430	CLASSICOWL OPS/COMP			0091P	1610J 9865	ASN	1	1	1	1
69	0092067	46439 NAVINFOWARACT/PG11	58440	ADP SYS DIR/PROJECT MGR			0091P	1610J 9705	ASN	1	1	1	1
69	0092068	46439 NAVINFOWARACT/PG11	58445	ADP PGM/COMP SYS MGR			0091P	1610J 9710	ASN	1	1	1	1
69	0161948	46828 NAVSECGRUACT PENSACO	35010	52 ADP SYS DIR/IW DEPT H			0091P	1610J 9705	ASN	1	1	1	1
69	0093080	46828 NAVSECGRUACT PENSACO	55045	42 CMPU SYS ANAL/AIS MAI			0091P	1610J 9735	ASN	1	1	1	1
69	0093081	46828 NAVSECGRUACT PENSACO	55055	42 ADP PGM OFFICER/INFO			0091P	1610J 9710	ASN	1	1	1	1
69	0142995	46828 NAVSECGRUACT PENSACO	56105	66 NSG OPS/FOR DTY 10 CT			0091P	1610J 9815	ASN	1	1	1	1
02	0094889	47072 USSPACECOM COS GDIP	23220	NAVAL ANAL 2332F/01			0091S	1630J 9680	VX2	1	1	1	1
75	0094993	47081 US TRANSPORTATION CO	63110	CH PGM MGMT BR 652/			0091P	1000H 9060	JD1	1	1	1	1
75	0094989	47081 US TRANSPORTATION CO	63120	CHS STF OFF 002/04			0091R	1700J 9060	JD1	1	1	1	1
75	0094987	47081 US TRANSPORTATION CO	93130	SFTWARE SYS ENG 931/			0091R	1000J 9060	JD1	1	1	1	1
75	0094951	47081 US TRANSPORTATION CO	93230	CHS SYS TESTING 661			0091R	1700J 9085	JD1	1	1	1	1
45	0096093	47656 NSA/CSS COMSEC FT ME	00130	ADP SYS SEC/CMPU SCI			0091P	1610J 9781	ASN	1	1	1	1

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MMC BIN	AUIC	ACTIVITY NAME	BSC	BILLET TITLE	EFF DATE	SUBSPEC SEC	CODE PRI	DESIG PRI	AQD	BA	FYC	FY1	FY2
45	0096096	47656 NSA/CSS COMSEC FT ME	00175	COMM SEC			0091P	1610H 9517	JD1	1	1	1	1
45	0096113	47656 NSA/CSS COMSEC FT ME	00450	ADP SYS SEC/CMPU SCI/CH1			0091P	1610H 9517	JD1	1	1	1	1
45	0096117	47656 NSA/CSS COMSEC FT ME	00485	ADP SYS SEC/CMPU SCI/V24			0091P	1000I 9781		1	1	1	1
45	0096151	47656 NSA/CSS COMSEC FT ME	00920	ADP SYS SEC/CMPU SCI			0091P	1700I 9781		1	1	1	1
24	2794675	47869 PEO (TAD) DET HUNTSV	00200	ENG LIAISON/TECH DIR/ADD			0091P	1610J 9781		1	1	1	1
29	0097230	48137 PEO(1) PAX RIVER	10520	MAJ PJ MGR SEL/ MPM E-2/			0091P	1440H 7910	ASN	1	1	1	1
24	0097583	48159 PEO TAD/SURFACE COMB	02950	DPJ SUP/400B34 COMP & DI			0091P	1300G 2161	ASN	1	1	1	1
19	0154168	48402 NAVAIRSYSCOM NAS JPO	00210	DEP DPJ MGR/JPO/JPLALS			0091P	1440H 2170	ASN	1	1	1	1
45	0098104	48451 NSA/CSS DCP FT MEADE	00125	ELXEQ RSCH/CMPU SCI			0091P	1510H 2162	AAC	1	1	1	1
69	0005537	49606 NAVINFOWARACT FTND/C	57415	58 CLASSIC OWL OPS/ PROJ			0091P	1610H 5917		1	1	1	1
60	2964576	55722 F1WC NORFOLK VA	00760	ELINT TCU/RED TEAM			0091P	1610I 9865		1	1	1	1
60	2964584	55722 F1WC NORFOLK VA	00880	NSG OPS/IW-D-OPS		0089S	0091P	1610J 9840	B13	1	1	1	1
60	0109886	55722 F1WC NORFOLK VA	00890	STF OPS&PLN/PROJECTS		0089S	0091P	1610J 9815	B13	1	1	1	1
60	2964598	55722 F1WC NORFOLK VA	01220	INFO P&R NSG/NAVCIIRT		0089S	0091S	1700J 9065	B13	1	1	1	1
11	0111521	57023 COM OP TEST AND EVAL	61010	OP T&E/NAVIGATION SYSTEM		0089S	0091P	1610J 2181		1	1	1	1
11	0111514	57023 COM OP TEST AND EVAL	62010	OP T&E/HD TAC DATA SYSTEM			0091S	1110J 2181	ATN	1	1	1	1
11	0111515	57023 COM OP TEST AND EVAL	65020	OP T&E/COMBAT DIR SYSTEM			0091P	1300H 2181		1	1	1	1
24	0127590	63273 NAVSURFWARACT PHD DE	66005	ADP PGM/SYS ENG OFF			0091S	1110I 9710		1	1	1	1
69	0129229	63891 NAVSECGRUACT NORTHWE	53110	42 HDEF ANAL/CS OFFI			0091P	1610J 9835		1	1	1	1
69	0129349	63913 NAVSECGRUACT ROTA SP	50025	36 INFO P&R NSG			0091S	1610K 9825		1	1	1	1
02	0132892	64591 US STRATCOM	16140	STRAT CON OFF 532/04			0091S	1050I 9085	JD1	1	1	1	1
02	0132949	64591 US STRATCOM	20350	SYS SUPP OFF 6110/03			0091S	1700I 9720		1	1	1	1
02	0132951	64591 US STRATCOM	20490	NAV C3 SYS 6110/100FF			0091S	1050I 9720	JD1	1	1	1	1
02	0133406	64771 HQ AF SOUTH	09150	ANAL/PGMR CSM003		0033S	0091S	1110I 9715	JD1	1	1	1	1
11	0133850	65146 OPNAV SUPPACT WASH DC	10850	CMPU SYS ANAL/N161F PROG			0091S	1000I 9735		1	1	1	1
42	0134792	65460 DTRA FCOSWA/KIRTLAND	75210	DSWA ADP 6300/30 C03			0091P	1700I 9710		1	1	1	1
43	0087648	65462 DISA HQ WASHINGTON D	00540	ADP PLNS D217 040			0091S	1700J 9720		1	1	1	1
43	0134986	65462 DISA HQ WASHINGTON D	00750	ADP SYS STF D231 050 OFF			0091Q	1700I 9710	JD1	1	1	1	1
43	0134984	65462 DISA HQ WASHINGTON D	00760	ADP SYS STF D231 060 OFF			0091P	1700I 9735	JD1	1	1	1	1
43	0134991	65462 DISA HQ WASHINGTON D	01020	ADP SYS STF D261 020			0091S	1700J 9740		1	1	1	1
43	0134978	65462 DISA HQ WASHINGTON D	02430	C41 SYS ARCH D52/030		0089S	0091S	1700J 9735		1	1	1	1
43	0134977	65474 DISA W. HEMISPHERE	13330	AIS SCTY WEY1 0300FF			0091S	1700J 9735		1	1	1	1
29	0135361	65487 JNT STF JNT CHIEF	05210	CHIEF JSIRMO CB52			0091P	1110G 9705	JD1	1	1	1	1
29	0135451	65487 JNT STF JNT CHIEF	63120	CH CAP ANALYSIS CON JD20			0091Q	1050H 9085	JD1	1	1	1	1
29	0135457	65487 JNT STF JNT CHIEF	63600	CH STUDIES/ANALYSIS JD10			0091Q	1000G 9705	JD1	1	1	1	1
29	0135459	65487 JNT STF JNT CHIEF	63650	ADP SYS ANL JD10			0091Q	1700H 9735	JD1	1	1	1	1
29	0135461	65487 JNT STF JNT CHIEF	63700	SP ASST CINC LIAISONJB40			0091Q	1310H 9085	JD1	1	1	1	1
39	0138940	66001 SPAWARSYSCEN S DIEGO	04400	ELXEQ RSCH/PRJ OFF ARTIF			0091Q	1050I 5917	VX3	1	1	1	1
39	0126693	66001 SPAWARSYSCEN S DIEGO	40090	CMPU SYS ANAL/PROJECT OF			0091S	1322J 9735	DL3	1	1	1	1
02	0142489	66597 JNT COMMAND & CONTR	06130	CMPTR SYS 6002/003L			0091P	1700J 9735	B12	1	1	1	1

134 136 135 134

B	12	12	12	12
P	55	55	54	54
Q	10	10	10	10
S	53	54	54	54
D	1	1	1	1
R	3	3	3	3

APPENDIX F. COMPUTER SCIENCE GRADUATION CHECKLIST

This appendix contains highlights of the graduation checklist for Computer Science graduates at the Naval Postgraduate School. The version of the checklist available online at <http://www.cs.nps.navy.mil/curricula/acas/programs/Checklist.html> is the original and official version of the checklist.

The checklist displayed here is a version of the original edited by the author to remove lengthy items not relevant to the discussion in this thesis. Some of these deleted items include: signature blocks, course requirements for international military students, acquisition course requirements for Marine Corps students, and the details of each of the specialization tracks. The course requirements for the Software Engineering specialization track were included in Chapter IV in the section on the Software Engineering track in the Computer Science curriculum.

The checklist illustrates several of the considerations discussed in the text of the thesis. For example, the checklist lists that Software Methodology (CS3460) is a core course required to be completed by all Computer Science graduates. Additionally, the *Secretary of the Navy* requirement that all NPS programs must provide officers “an appreciation of the fundamentals of the maritime strategy and concepts of naval warfare” is represented by the listing of NS3252 as a requirement for all U.S. Military students. Due to a recent change in school policy, this requirement will be filled with the NW3230 course discussed during the description of the newly-developed curriculum. The official Computer Science checklist will need to be updated to accurately reflect this change.

Naval Postgraduate School
Department of Computer Science
Checklist for MSCS Degree
(Revised: March 5, 1999)

Student name: _____
Month/year enrolled: _____
CS Track Completed: _____

1. Masters Thesis:

Title: _____

Advisor(s): _____
Second Reader: _____
Presentation date: _____ **Where:** _____

2. Core Courses:

All of the following courses must be completed or validated.

- ___ MA3025 Logic and Discrete Mathematics (5-1)
- ___ MA3030 Introduction to Combinatorics and Applications (4-1)
- ___ CS3010 Computer Architecture and Operating Systems (4-0)
- ___ CS3200 Computer Architecture (3-2)
- ___ CS3310 Artificial Intelligence (4-1)
- ___ CS3320 Database Systems (3-1)
- ___ CS3450 Operating Systems (3-2)
- ___ CS3460 Software Methodology (3-1)
- ___ CS3502 Computer communications and Networks (4-0)
- ___ CS3600 Introduction to Computer Security (3-2)
- ___ CS3601 Theory of Formal Languages and Automata (4-0)
- ___ CS3650 Design and Analysis of Algorithms (4-0)
- ___ CS4202 Computer Graphics (3-2)
- or ___ CS4203 Interactive Computation Systems (3-2)
- ___ CS4900 Research Seminar in Computer Science (0-2)
- ___ CS4905 Research Seminar II in Computer Science (0-2)

Complete one of the following three course sequences:

- ___ CS2970 Fundamental Object-Oriented Programming in ADA (4-2)
- ___ CS3970 Data Structures & Intermediate Object-Oriented Programming in ADA (4-2)
- ___ CS3771 C++ as a Second Language (4-2)
- or ___ CS3773 JAVA as a Second Language (4-2)
- or
- ___ CS2971 Fundamental Object-Oriented Programming in C++ (4-2)
- ___ CS3971 Data Structures and Intermediate Object-Oriented Programming in C++ (4-2)
- ___ CS3770 ADA as a Second Language
- or ___ CS3773 JAVA as a Second Language (4-2)

or

- ☐ CS2973 Fundamental Object-Oriented Programming in JAVA (4-2)
- ☐ CS3973 Data Structures & Intermediate Object-Oriented Programming in JAVA (4-2)
- ☐ CS3770 ADA as a Second Language
- or ☐ CS3771 C++ as a Second Language (4-2)

3. U.S. Military Requirements:

- ☐ NS3252 Joint and Maritime Strategy (U.S. Military) (4-0)
- ☐ CS2970 Introduction to Object-Oriented Programming with ADA (4-2)
- or ☐ CS3770 ADA as a Second Language (4-2)

APPENDIX G. THE MSSE HANDBOOK

Appended here is the handbook regarding all Master's programs at NPS in the Software Engineering Department. This handbook is used as a recruiting and informational tool by the department, and is sent to any parties inquiring about the programs available at NPS.

The information in this appendix was verified accurate with the most current revision of the handbook dated 23 September 1999.

SOFTWARE ENGINEERING MASTER'S PROGRAM HANDBOOK

1. INTRODUCTION

- 1.1 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, FULL-TIME OPTION (369)
- 1.2 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, PART-TIME DISTANCE LEARNING OPTION (369)
- 1.3 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, COMBAT SYSTEMS SUBSPECIALTY OPTION (533)
- 1.4 MASTER OF SCIENCE IN COMPUTER SCIENCE, COMPUTER SCIENCE SUBSPECIALTY OPTION (368)

2. TYPICAL COURSE OF STUDY

- 2.1 THE FULL-TIME MSSE PROGRAM (369)
- 2.2 THE PART-TIME DISTANCE LEARNING MSSE PROGRAM (369)
- 2.3 THE COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)
- 2.4 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM (368)

3. ENTRY REQUIREMENTS

- 3.1 THE MSSE PROGRAM (369)
- 3.2 THE COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)
- 3.3 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM (368)

4. ADMISSION PROCEDURE

5. DEGREE REQUIREMENTS

- 5.1 THE MSSE PROGRAM (369)
- 5.2 THE COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)
- 5.3 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM (368)

6. VTC EQUIPMENT SPECIFICATIONS

7. THESIS GUIDELINES

8. THE THESIS PROCESS

APPENDIX A. COURSE DESCRIPTIONS

1. INTRODUCTION

The Software Engineering program at the U.S. Naval Postgraduate School provides military and government graduate students with an opportunity to learn all aspects of software development and the skills needed to efficiently and reliably plan and create large-scale software systems using the best available tools. These skills are essential for officers and civilians responsible for acquisition, development or maintenance of military software.

The program includes in-residence and distance learning M.S. and Ph.D. degree programs, certificate programs, short courses, and laboratory support. The Ph.D. program is the first-ever doctoral program in Software Engineering. Both the M.S. and Ph.D. degree programs may be completed either on campus by students carrying a full-time course load, or part-time through the distance learning option.

1.1 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, FULL-TIME OPTION (369)

The MSSE offers a four-quarter full-time curriculum with entry dates in October.

For more information, visit our web-site at <http://cs.nps.navy.mil/~se> or email your inquiries to se@cs.nps.navy.mil, or contact the Curricular Officer, CDR Mark Polnaszek, at mpolnaszek@nps.navy.mil

Application information for the M.S. degree in Software Engineering can be found at: <http://cs.nps.navy.mil/~se/master.html>

1.2 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, PART-TIME DISTANCE LEARNING OPTION (369)

The MSSE program is offered with a two-year part-time distance learning option with entry dates in October.

For more information, visit our web-site at <http://cs.nps.navy.mil/~se> or email your inquiries to se@cs.nps.navy.mil, or contact the Curricular Officer, CDR Mark Polnaszek, at mpolnaszek@nps.navy.mil

Application information for the M.S. degree in Software Engineering can be found at: <http://cs.nps.navy.mil/~se/master.html>

1.3 MASTER OF SCIENCE IN SOFTWARE ENGINEERING, COMBAT SYSTEMS SUBSPECIALTY OPTION (533)

This is a systems engineering program with an emphasis on computer-based systems and DoD applications. This program is designed to meet Navy needs that go beyond software to treat whole system issues.

The Combat Systems subspecialty MSSE is an eight-quarter curriculum with entry dates in April and October. If further information is needed, contact the Curricular Officer or the Academic Associate for this curriculum (533).

1.4 MASTER OF SCIENCE IN COMPUTER SCIENCE, COMPUTER SCIENCE SUBSPECIALTY OPTION
(368)

The Computer Science curriculum is designed to provide the officer with the technical knowledge and skills necessary to specify, evaluate and manage computer system design; to provide technical guidance in applications ranging from data processing to tactical embedded systems; to educate the officer in the analysis and design methodologies appropriate for hardware, software and firmware; and to provide the officer with practical experience in applying modern computer equipment and research techniques to solve military problems.

The purposes of the Software Engineering Track are to provide knowledge of all aspects of software development and to develop skills needed to efficiently and reliably implement military systems and application software using the best available tools and techniques.

The MSCS is an eight-quarter course of study with entry dates in April and October. Those requiring the six or twelve week refresher will begin study prior to those entry dates. If further information is needed, contact the Academic Associate or Curricular Officer for this curriculum (368).

2. TYPICAL COURSE OF STUDY

2.1 THE FULL-TIME MSSE PROGRAM (369)

Quarter 1 (Fall)

CS3460 (3-1) Software Methodology
CS4540 (3-0) Software Testing
CS4580 (3-0) Design of Embedded Real-Time Systems¹
IS4300 (3-2) Software Engineering and Management

Quarter 2 (Winter)

CS4500 (3-1) Software Engineering
CS4560 (3-0) Software Evolution²
CS4570 (3-0) Software Reuse
CS0810 (0-8) Thesis Research

Quarter 3 (Spring)

CS4520 (3-0) Advanced Software Engineering
CS3502 (4-0) Computer Communications and Networks
IS3171 (4-1) Economic Evaluation of Information Systems II
CS0810 (0-8) Thesis Research

Quarter 4 (Summer)

CS4510 (3-0) Computer-Aided Prototyping
CS4530 (3-1) Software Research and Development in DoD³
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

¹ Not offered in October 2000. Students should take CS4592 instead.

² To be replaced by CS4591 starting January 2001.

³ Not offered in July 2000. Students should take CS4580 instead.

2.2 THE PART-TIME DISTANCE LEARNING MSSE PROGRAM (369)

Quarter 1 (Fall)

CS3460 (3-1) Software Methodology
IS4300 (3-2) Software Engineering and Management

Quarter 2 (Winter)

CS4500 (3-1) Software Engineering
CS4560 (3-0) Software Evolution¹

Quarter 3 (Spring)

CS4520 (3-0) Advanced Software Engineering
IS3171 (4-1) Economic Evaluation of Information Systems II

Quarter 4 (Summer)

CS4510 (3-0) Computer-Aided Prototyping
CS4530 (3-1) Software Research and Development in DoD²

Quarter 5 (Fall)

CS4540 (3-0) Software Testing
CS4580 (3-0) Design of Embedded Real-Time Systems³

Quarter 6 (Winter)

CS4570 (3-0) Software Reuse
CS0810 (0-8) Thesis Research

Quarter 7 (Spring)

CS3502 (4-0) Computer Communications and Networks
CS0810 (0-8) Thesis Research

Quarter 8 (Summer)

CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

¹ To be replaced by CS4591 starting January 2001.

² Not offered in July 2000. Students should take CS4580 instead.

³ Not offered in October 2000. Students should take CS4592 instead.

2.3 THE COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)

A. Entry Date in January

Quarter 1 (Winter)

PH1121 (4-2) Mechanics I
MA1995 (5-0) Math Methods I
MA1996 (5-0) Math Methods II
NW3230 (4-0) Strategy and Policy: The American Experience

Quarter 2 (Spring)

PH1322 (4-2) E&M I
PH2151 (4-1) Mechanics II
PH3991 (4-0) Theoretical Physics
CS3460 (3-1) Software Methodology

Quarter 3 (Summer)

PH1623 (4-2) Modern Physics I
PH2351 (4-1) E&M II
SE2013 (4-3) Analog Techniques and Communications
CS4500 (3-1) Software Engineering

Quarter 4 (Fall)

PH3352 (4-0) E&M III
PH3652 (4-1) Modern Physics II
SE2014 (4-3) Digital Techniques
CS4540 (3-1) Software Testing

Quarter 5 (Winter)

PH3292 (4-2) Physical Optics
SE3400 (4-2) Physics of Sonar Systems
CS4570 (3-0) Software Reuse
CS4591 (3-1) Requirements Engineering

Quarter 6 (Spring)

SE3172 (4-2) Physics of Weapons Systems
CS4520 (3-0) Advanced Software Engineering
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

Quarter 7 (Summer)

SE3015 (3-4) Autonomous Combat Systems Design
CS4510 (3-0) Computer Aided Prototyping
CS4530 (3-0) Software Research and Development in DoD¹
CS0810 (0-8) Thesis Research

Quarter 8 (Fall)

SE4050 (4-2) Physics of E&M Sensors
SE4860 (4-1) Advanced Weapons Concepts
CS4580 (3-0) Design of Embedded Real-Time Systems²
CS0810 (0-8) Thesis Research

¹ Not offered in July 2000. Students should take CS4580 instead.

² Not offered in October 2000. Students should take CS4592 instead.

B. Entry Date in July

Quarter 1 (Summer)

PH1121 (4-2) Mechanics I
MA1995 (5-0) Math Methods I
MA1996 (5-0) Math Methods II
NW3230 (4-0) Strategy and Policy: The American Experience

Quarter 2 (Fall)

PH1322 (4-2) E&M I
PH2151 (4-1) Mechanics II
PH3991 (4-0) Theoretical Physics
CS3460 (3-1) Software Methodology

Quarter 3 (Winter)

PH1623 (4-2) Modern Physics I
PH2351 (4-1) E&M II
SE2013 (4-3) Analog Techniques and Communications
CS4500 (3-1) Software Engineering

Quarter 4 (Spring)

PH3352 (4-0) E&M III
PH3652 (4-1) Modern Physics II
SE2014 (4-3) Digital Techniques
CS4520 (3-0) Advanced Software Engineering

Quarter 5 (Summer)

PH3292 (4-2) Physical Optics
SE3015 (3-4) Autonomous Combat Systems Design
CS4510 (3-0) Computer Aided Prototyping
CS4530 (3-0) Software Research and Development in DoD¹

Quarter 6 (Fall)

SE3172 (4-2) Physics of Weapons Systems
CS4540 (3-1) Software Testing
CS4580 (3-0) Design of Embedded Real-Time Systems²
CS0810 (0-8) Thesis Research

Quarter 7 (Winter)

SE3400 (4-2) Physics of Sonar Systems
CS4570 (3-0) Software Reuse
CS4591 (3-1) Requirements Engineering
CS0810 (0-8) Thesis Research

Quarter 8 (Spring)

SE4050 (4-2) Physics of E&M Sensors
SE4860 (4-1) Advanced Weapons Concepts
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

¹ Not offered in July 2000. Students should take CS4580 instead.

² Not offered in October 2000. Students should take CS4592 instead.

2.4 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM (368)

A. Entry Date in Fall

Quarter 1 (Fall)

CS2973 (4-2) Fundamental OOP in Java
CS3010 (4-0) Computer Systems Principles
MA3025 (5-1) Logic and Discrete Mathematics
NW3230 (4-0) Strategy and Policy: The American Experience
CS4900 (0-2) Research Seminar in Computer Science

Quarter 2 (Winter)

CS3973 (4-2) Data Structures and Intermediate OOP in Java
CS3200 (3-2) Computer Architecture
CS3320 (3-1) Database Systems
CS3650 (4-0) Design and Analysis of Algorithms
CS4900 (0-2) Research Seminar in Computer Science

Quarter 3 (Spring)

CS3460 (3-1) Software Methodology
CS3770 (4-0) Ada as a Second Language
CS3502 (4-0) Computer Communications and Networks
CS3310 (4-0) Artificial Intelligence

Quarter 4 (Summer)

CS4500 (3-1) Software Engineering *
CS4510 (3-0) Computer-Aided Prototyping *
CS4530 (3-0) Software R&D in DoD¹ *
CS3450 (3-2) Operating Systems

Quarter 5 (Fall)

CS4540 (3-1) Software Testing *
CS4580 (3-0) Design of Embedded Real-Time Systems² *
----- (4-0) Track Elective
----- (4-0) Track Elective

Quarter 6 (Winter)

CS4570 (3-0) Software Reuse *
CS4591 (3-1) Requirements Engineering³ *
CS4203 (3-2) Interactive Computation Systems
CS0810 (0-8) Thesis Research

Quarter 7 (Spring)

----- (4-0) Track Elective
CS4520 (3-0) Advanced Software Engineering *
CS3600 (3-2) Introduction to Computer Security
CS0810 (0-8) Thesis Research

Quarter 8 (Summer)

----- (4-0) Track Elective
----- (4-0) Track Elective
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

* Track requirements = CS4500 + 4 other Software Engineering courses.

¹ Not offered in July 2000. Students should take CS4580 instead.

² Not offered in October 2000. Students should take CS4592 instead.

³ Not offered in January 2000. Students should take CS4560 instead.

B. Entry Date in Spring

Quarter 1 (Spring)

CS2973 (4-2) Fundamental OOP in Java
CS3010 (4-0) Computer Systems Principles
MA3025 (5-1) Logic and Discrete Mathematics
NW3230 (4-0) Strategy and Policy: The American Experience
CS4900 (0-2) Research Seminar in Computer Science

Quarter 2 (Summer)

CS3973 (4-2) Data Structures and Intermediate OOP in Java
CS3200 (3-2) Computer Architecture
CS3320 (3-1) Database Systems
CS3650 (4-0) Design and Analysis of Algorithms
CS4900 (0-2) Research Seminar in Computer Science

Quarter 3 (Fall)

CS3460 (3-1) Software Methodology
CS3770 (4-0) Ada as a Second Language
CS3502 (4-0) Computer Communications and Networks
CS3310 (4-0) Artificial Intelligence

Quarter 4 (Winter)

CS4500 (3-1) Software Engineering *
CS4570 (3-0) Software Reuse *
CS4591 (3-1) Requirements Engineering¹ *
CS3450 (3-2) Operating Systems

Quarter 5 (Spring)

CS4520 (3-0) Advanced Software Engineering *
----- (4-0) Track Elective
----- (4-0) Track Elective
----- (4-0) Track Elective

Quarter 6 (Summer)

CS4510 (3-0) Computer-Aided Prototyping *
CS4530 (3-0) Software R&D in DoD² *
CS4203 (3-2) Interactive Computation Systems
CS0810 (0-8) Thesis Research

Quarter 7 (Fall)

CS4580 (3-0) Design of Embedded Real-Time Systems³ *
CS4540 (3-1) Software Testing *
CS3600 (3-2) Introduction to Computer Security
CS0810 (0-8) Thesis Research

Quarter 8 (Winter)

----- (4-0) Track Elective
----- (4-0) Track Elective
CS0810 (0-8) Thesis Research
CS0810 (0-8) Thesis Research

* Track requirements = CS4500 + 4 other Software Engineering courses.

¹ Not offered in January 2000. Students should take CS4560 instead.

² Not offered in July 2000. Students should take CS4580 instead.

³ Not offered in October 2000. Students should take CS4592 instead.

3. REQUIREMENTS FOR ENTRY

3.1 THE MSSE PROGRAM (369)

Any military or civilian personnel sponsored by the US Government, holding an accredited Bachelor's degree in computer science, computer engineering, or related field, with above-average grades in mathematics, resulting in an APC of at least 325, and at least two years of software development or maintenance experience is eligible to apply.

Application information for the M.S. degree in Software Engineering can be found at: <http://www.cs.nps.navy.mil/~se/degrees.html>

3.2 THE COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)

A baccalaureate degree with mathematics through differential and integral calculus and a calculus-based basic physics sequence are required for direct input. Courses in the physical sciences and engineering are highly desirable. Officers not having the required qualifications for direct input enter the program indirectly through the Engineering Science (460) Curriculum. An APC of 323 is required.

3.3 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM (368)

A baccalaureate degree, or the equivalent, with above-average grades in mathematics, (including differential and integral calculus) resulting in an APC of at least 325 is required for direct entry. Undergraduate degrees in applied science or engineering are highly desirable. Students lacking these prerequisites may be acceptable for the program, through a six or twelve week refresher, providing their undergraduate records and/or other indicators of success, such as the GRE (Graduate Record Examination), indicate an ability to work in quantitative subjects. While previous academic or practical experience in computer science is certainly helpful and can enhance the applicant's potential for admission, such experience is not a prerequisite.

4. ADMISSION PROCEDURES

The point of contact for requests for Naval Postgraduate School catalogs and admission to all degree programs is:

Director of Admissions
Code 01B3, Naval Postgraduate School,
589 Dyer Rd., RM 103C
Monterey, CA 93943-5100

Telephone (831) 656-3093, DSN 878-3093
FAX (831) 656-2891

5. DEGREE REQUIREMENTS

5.1 THE MSSE PROGRAM (369)

Students enrolled in the Software Engineering curriculum must successfully complete the 12 quarter-length Software Engineering courses. Completion of a master's thesis is required.

5.2 COMBAT SYSTEMS SUBSPECIALTY MSSE PROGRAM (533)

Students enrolled in the Combat Systems Subspecialty Software Engineering curriculum must successfully complete the 12 quarter-length Software Engineering courses. Completion of a master's thesis is required.

5.3 THE COMPUTER SCIENCE SUBSPECIALTY MSCS PROGRAM

Students enrolled in the MSCS/Software Engineering track must successfully complete the 17 general Computer Science courses plus 5 advanced Software Engineering courses. Completion of research leading to a master's thesis is required.

6. VTC EQUIPMENT SPECIFICATIONS

Students participate in the Distance Learning Program via our PictureTel 4000 Video Teleconferencing Systems using Integrated Services Digital Network, Basic Rate Interface (ISDN BRI) lines. This setup allows two-way, interactive audio and video between distant sites and an NPS classroom. The students' site must have a standards-based (H.320-compatible system) connection to a dial-up network (FTS2000).

Commercial networks may be used when FTS2000 is not available. NPS uses AT&T Accunet for commercial calls. NPS is currently establishing a program to lease VTC equipment to sites to provide the highest degree of compatibility and fidelity that the technology offers.

7. THESIS GUIDELINES

The Master's thesis is the capstone achievement of the student's academic endeavor at NPS. A challenging research thesis, requiring students to apply their focused graduate education, is one of the most effective methods for both solving Fleet/Joint force problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

A Software Engineering thesis should either demonstrate the use of Software Engineering principles and techniques in solving existing software problems, or develop new theory, models, methods, or tools for building/maintaining software systems. A thesis must have some kind of scientific contribution, not just manufacturing of a lot of source code. This is why students must specify their expected scientific contributions in their thesis proposal.

It is very important for a student to pick the right project and define the scope of the thesis work. The student's thesis advisor will help him/her define the scope of the thesis work and identify its scientific contributions.

Additionally, the thesis advisor will:

- help a student to lay out a schedule of milestones.
- suggest initial references to read and people to contact.
- meet with the student regularly to monitor progress and provide consultation and direction.
- review and critique the thesis outline.
- review and critique the work, offer suggestions for necessary revisions, and check for accuracy and completeness.

The thesis advisor can help with topics in one of the following two ways:

- (1) The advisor has a list of thesis topics in mind. He/she already knows how much work each topic is involved and what the scientific contributions are. A student simply has to follow the direction of his/her advisor to complete the thesis work.
- (2) A student has a project from work, and he/she finds it beneficial to use results of the project to write the thesis.

If a student chooses option 2, then the thesis advisor will have to spend time to understand the project in order to help the student define the scope of the thesis and identify its scientific contributions. In many cases, the advisor may have to suggest work in addition to that done in the project to generate enough scientific contribution from the thesis work. Depending on the labor involved, the advisor may need reimbursable research funding support to allow him/her to work on the project.

8. THE THESIS PROCESS

An on-line thesis handbook is available at:

<http://vislab-www.nps.navy.mil/~code36/THESISGUIDE.html>

8.1 THESIS PROPOSAL

The thesis proposal is the key document in preparing for the thesis process. It performs several important functions in the process of communicating thesis activities. The proposal focuses the research effort for the student. It requires the student to develop a specific research question and subsidiary research questions, and to identify the methodologies to be employed in the research and the particular scope and limitations of the thesis work; it forces the student to give serious thought to the items that might become major problems later on. For a proposal example, refer to:

<http://vislab-www.nps.navy.mil/~code36/THESISGUIDE.html#proposalexample> and
<http://vislab-www.nps.navy.mil/~code36/THESISGUIDE.html#appendixA>

8.2 STEPS FOR COMPLETING THE THESIS PROPOSALS

A. ON-CAMPUS STUDENTS

- (i) Submit drafts of the thesis proposal to the advisor(s) and second reader (if applicable) for review.
- (ii) Ask the advisor(s), second reader (if applicable), and the CS Chairman to sign the final thesis proposal.
- (iii) Submit the signed proposal to Curricular Officer.

B. DISTANCE LEARNING STUDENTS

- (i) Send drafts of the thesis proposal to the advisor(s) and second reader (if applicable) for review.
- (ii) If the thesis involves co-advisor or second reader at a remote site, ask them to sign the final thesis proposal.
- (iii) Send the final thesis proposal to the advisor(s) and second reader (if applicable) at NPS for signature.
- (iv) Ask the advisor to forward the signed thesis proposal to the Software Engineering program coordinator.
- (v) The Software Engineering program coordinator will obtain the signature of the Chairman and then forward the proposal to the Curricular Officer for signature and filing.

8.3 THESIS FORMAT APPROVAL

When determining format in terms of pagination, titles, headers, etc., follow the guidelines in the NPS Thesis Preparation Manual. The most current edition of this manual is available from the Thesis Processor.

Ms. Sandra Day, Code 92/Sd
Research Office
Naval Postgraduate School
589 Dyer Road
Room 270A
Monterey, CA 93943-5131

DSN:878-2762, 831-656-2762

The Thesis Processor will become very important to the student as the student prepares the final draft of the thesis. She will provide the student formatting information and other such information needed to get the thesis published.

The student should send the Thesis Processor a copy of their thesis for format check as soon as a complete draft of the thesis is completed. This can be done while waiting for comments from advisors and second readers.

8.4 FINAL THESIS SUBMISSION

(A) ON-CAMPUS STUDENTS

- (i) The student notifies the curricular office by the first Friday of the quarter that he/she plans to graduate.
- (ii) The thesis is signed by the advisor(s), second reader, and the CS Chairman.
- (iii) Submit thesis to the Thesis Processor.

(B) DISTANCE LEARNING STUDENTS

- (i) The student notifies the Software Engineering program coordinator by the first Friday of the quarter that he/she plans to graduate that quarter. The Software Engineering program coordinator will forward the request to the school (Academic Council, Graduation coordinator, etc.) via the curricular office.
- (ii) If the thesis involves co-advisor or second reader at a remote site, ask them to sign the thesis.
- (iii) Send three copies of the thesis, together with the thesis classification form, thesis advisor information sheet and a floppy disk containing an on-line copy of the special abstract to the advisor at NPS for signature.
- (iv) Ask the advisor to forward the signed thesis, floppy disks, etc. to the Software Engineering program coordinator.
- (v) The Software Engineering program coordinator will obtain the signature of the Chairman and then forward the thesis to the Thesis Processor.
- (vi) The Software Engineering program coordinator will notify the student via email once the thesis has been accepted by the Thesis Processor.

Appendix A. COURSE DESCRIPTIONS

CS3460 SOFTWARE METHODOLOGY (3-0).

Introduction to the software life cycle. Methods for requirements definition, design, and testing of software. Basic concepts of software engineering, including stepwise refinement, decomposition, information hiding, debugging, and testing.

Highlight:

Provide hands-on experience in applying the modern software engineering principles to analysis, design and develop DoD software systems.

Text:

"Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design" by Craig Larman, Prentice Hall, ISBN 0-13-748880-7

"The Mythical Man-Month (Anniversary Ed.)" by Frederick Brooks, Jr., Addison Wesley, ISBN 0-201-83595-9

CS3502 COMPUTER COMMUNICATIONS AND NETWORKS (4-0).

An introduction to the structure and architecture of computer networks. The physical, data link and network layers of the ISO model are covered, as well as some aspects of the higher layers. Several important communication protocols are studied, including the currently used models for their specifications and analysis. Local Area Networks, such as Ethernet and Token Ring, are also covered. Term papers and/or projects are an important aspect of this course.

Highlight:

Provide basic knowledge essential to DoD networks.

Text:

"Data and Computer Communications (6th Ed.)" by William Stallings, Prentice Hall, ISBN: 0-13-084370-9

CS4500 SOFTWARE ENGINEERING (3-1).

The techniques for the specification, design, testing, maintenance and management of large software systems. Specific topics include software life cycle planning, cost estimation, requirements definition and specification, design, testing and verification, maintenance and reusability. The laboratory sessions will discuss special topics. PREREQUISITE: CS3460 or consent of instructor.

Highlight:

Teach students the concepts for formalized software development and techniques to develop software systems that meet user needs.

Text:

"Software Engineering with Abstractions" by V. Berzins and Luqi, Addison-Wesley, ISBN: 0-201-08004-4.

CS4510 COMPUTER AIDED PROTOTYPING (3-0).

This course covers the concept and application of computer-aided prototyping to the development and acquisition of DoD software systems. Specific topics include the prototyping software life cycle, system models, design methods, automatic code generation, prototyping languages and tools, and their unique systematic system construction methods for increasing productivity, reliability and portability of software development in comparison with other development methods. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Emphasis on the use of computer-aided prototyping methods and tools to support software development and acquisition.

Text:

Lecture notes and selected paper from research literature.

CS4520 ADVANCED SOFTWARE ENGINEERING (3-0).

This course is a sequel to CS4500. The methods for specifying, designing, and verifying software systems are covered in depth, with emphasis on automatable techniques and their mathematical basis. The techniques are applied to construct and check Ada programs using a formal specification language. The course concludes with a summary of current research areas in software engineering. PREREQUISITE: CS4500 or consent of instructor.

Highlight:

Teach students the principles and technology to construct tools for automated software synthesis and analysis.

Text:

"Software Engineering with Abstractions" by V. Berzins and Luigi, Addison-Wesley, ISBN: 0-201-08004-4.

Selected papers from research literature.

CS4530 SOFTWARE ENGINEERING RESEARCH AND DEVELOPMENT IN DoD (3-1).

This course builds on the material covered in CS4500. Fundamental principles of computer system / network security and distributed computing are covered along with advanced methods, techniques and standards aimed at improving the development and acquisition of DoD software systems. Specific topics include: the application of software engineering principles for designing large, secure, embedded real-time computer systems; the application of software engineering principles for the design of distributed systems; automated tools for the specification, design and generation of code for applications; and existing emerging DoD standards for software development, security and acquisition. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Address DoD's needs to develop secure and reliable embedded real-time systems and large distributed systems.

Text:

Recent articles selected from conference proceedings and journals.

CS4540 SOFTWARE TESTING (3-1).

This course covers the theory and practice of testing computer software with the intent of preventing, finding and eliminating bugs in software. Planning and executing software tests are covered, including requirements-based testing, and advanced testing techniques. These topics are discussed in the context of a realistic development environment, illustrated using a variety of software testing tools. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Teach students on the proper use of software testing to improve the software quality.

Text:

"Testing Computer Software (2nd edition)" by Cem Kaner, Jack Falk and Hung Quoc Nguyen, Van Nostrand Reinhold, 1993, ISBN 0-442-01361-2.

CS4560 SOFTWARE EVOLUTION (3-0).

This course covers the concepts, methods, techniques and tools for supporting the evolution and maintenance of software systems. Specific topics include the use of formal specifications to support software evolution, design databases, configuration management, software change merging, and software re-engineering. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Emphasis on the application of modern software engineering principles to control and realize the evolution of software systems.

Text:

Lecture notes and selected paper from research literature.

CS4570 SOFTWARE REUSE (3-0).

This course covers the concepts, methods, techniques and tools for systematic reuse of software components and systems. Specific topics include design and re-engineering for reuse, mechanisms for enhancing reuse, domain specific reuse and software architectures, reuse of requirements models, specifications and designs, tools for reuse, software library organization, and methods for component search. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Emphasis on methods and tools for computer-aided software reuse.

Text:

Lecture notes and selected paper from research literature.

CS4580 DESIGN OF EMBEDDED REAL-TIME SYSTEMS (3-0).

This course covers the concepts, methods, techniques and tools for supporting the design of embedded real-time systems. Specific topics include real-time systems and concurrency models, object-oriented methods for real-time system design, real-time scheduling, and Ada 95 support for concurrent and real-time systems. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Emphasis on practical approaches to design and develop DoD warfighter systems.

Text:

"Real-Time UML - Developing Efficient Objects for Embedded Systems" by Bruce Douglass, Addison Wesley, ISBN: 0-201-32579-9

CS4591 REQUIREMENTS ENGINEERING (3-1).

This is an in-depth treatment of requirements engineering concepts, methods, and tools. The role of requirements engineering within software engineering is explored as well as consistency, cost-benefit analysis, resolving multiple viewpoints, dependency tracing, and automated decision support. Topics are reinforced with examples from DoD applications. Prototyping is introduced as a means of assessing requirements early in the design process. PREREQUISITE: CS4500 (may be taken concurrently) or consent of instructor.

Highlight:

Emphasis on the formal modeling of requirements for DoD applications.

Text:

"Software Requirements: Objects, Functions and States (Second Edition)" by Alan M. Davis, Prentice Hall, March 1993, ISBN 0-13-805763-X.

Papers and supplementary material from research literature.

IS3171 ECONOMIC EVALUATION OF INFORMATION SYSTEMS II (4-0).

This course provides class participants with concepts and techniques derived from applied managerial economics to various aspects of information technology and information technology management. Each class will typically begin with a brief formal presentation of course materials. Every class participant should endeavor to contribute to class discussion. You are encouraged to relate your own experience which may have involved I.T. In addition to providing a unique perspective on a particular subject, audience participation helps the instructor better interact with his class and trigger interests from class participants.

Highlight:

Emphasis on economic issues in the deployment of I.T. in the DoD and well as in the civilian world.

Text:

"Cost-Benefit Analysis for Information Technology" by William J. Haga and Robert G. Lang, Naval Postgraduate School, 1998.

"Information Rules: A Strategic Guide to the Network Economy" by Carl Shapiro and Hal R. Varian, Harvard Business School Press, November 1998.

"MCS2: Software for the Soldier" by Harvey Simon, John F. Kennedy School of Government, Harvard University. Last Modified Jan 14, 1998.

"Microsoft Does Not Have Monopoly Power Over the PC Operating System", Schmalensee Testimony given on behalf of Microsoft in Washington, D.C., Jan. 11, 1999, Available from <http://www.microsoft.com/>

"Bad News for Trees", The Economist, 19 December 1998.

"Big Friendly Giant", The Economist, 30 January 1999.

"A New but Risky Sort of War - The 21st-Century Army", The Economist, 2 January 1999.

IS4300 SOFTWARE ENGINEERING AND MANAGEMENT (4-0).

This course educates students in areas of concern to the Department of Defense in the fields of software project management and software engineering. Management steps are presented in the same sequential order as encountered on systems developments, in order to provide a roadmap and process that the student can implement for the management of software projects. Practical issues including those involving personnel management, risk management, requirements volatility, and budget uncertainties are examined. In addition, software management issues are connected to issues associated with DoD software standards, systems engineering, and software engineering. DoD software standards, systems engineering, and software engineering are reviewed and key problem areas related to the management of software systems are discussed.

Highlight:

Teach students to monitor and manage the development of DoD software systems.

Text:

"Microsoft Corporation: Office Business Unit" by Marco Iansiti and Geoffrey Gill, Harvard Business School, Product Number 691033, Publication Date: 5/31/94.

APPENDIX H. THE SOFTWARE ENGINEERING PH.D. PROGRAM AT NPS

Chapter IV summarizes the procedures and requirements of the Software Engineering Ph.D. Program at NPS. This appendix contains the complete documentation from the Software Engineering Group (soon to be available online!) regarding the program, including background information, complete degree requirements, procedures to be followed, and sample forms to be filled out at the various steps of degree completion.

Ph.D. in Software Engineering

Introduction

Requirements for entry

Application procedure

Sample application letter

Sequence of events leading to a Ph.D.

Degree requirements

Form a dissertation committee

Role of Ph.D. Committee

Role of Dissertation Committee

Role of Advisor

Sample Appointment of Dissertation Committee memorandum

Written Qualifying Examination

Fulfilling the minor requirements

Dissertation proposal

Advancement to candidacy

Oral Qualifying Examination

Sample Oral Qualifying Examination memorandum

Sample Advancement to Candidacy memorandum

Dissertation

Final Oral Examination (Dissertation Defense)

Sample Dissertation Defense memorandum

Sample Results of Dissertation Defense memorandum

Introduction

The Ph.D. program in Software Engineering is specifically designed for DoD software practitioners who want to acquire the skill and knowledge to perform state-of-the art research on issues related to the development and evolution of large complex software systems, and to intelligently manage the research of other software practitioners. It offers the software professionals a unique program of study and advances software engineering principles and technology vital to DoD researchers and program managers. Delivery will be by distance learning as well as on campus.

There are institutional rules on all the Ph.D. programs at the Naval Postgraduate School (see Academic Council Policy Manual, Section 5.4). The rules described here supplement, but do not supplant, the institutional rules.

Excerpt from Academic Council Policy Manual (as of September 1999)

The degree Doctor of Philosophy is awarded as a result of meritorious and scholarly achievements in a particular field of study which has been approved by the Academic Council as within the purview of the Naval Postgraduate School. A candidate must exhibit faithful and scholarly application to all prescribed courses of study, achieve a high level of achievement, and establish an ability for original investigation leading to the advancement of fundamental knowledge.

Any program leading to the degree Doctor of Philosophy requires the equivalent of at least three academic years of study beyond the baccalaureate level, with at least one academic year[†] (or its equivalent) being spent in residence at the Naval Postgraduate School.

[†] Equivalent Software Engineering Distance Learning Residency Requirement (as of June 1999)

Distance learning students can satisfy residency requirements by:

- (1) Take a minimum of three graduate level Software Engineering seminars (approx. 20-40 hours of study time per week) either on campus or via distance learning;
- (2) Register for a minimum of 8 units of thesis research each quarter when not taking NPS distance learning courses;
- (3) Participate in a two-week on-campus orientation and intensive study retreat prior to taking the written qualifying examination;
- (4) Conduct a two-week on-campus directed study prior to taking the oral qualifying examination;
- (5) After advancement to candidacy, spend the equivalent of at least one week each quarter on campus conducting thesis research.
- (6) The time spent satisfying each of the above requirements must be disjoint.

[†] An equivalent distance learning residency requirement has been established by the Software Engineering Group as approved by the Academic Council on 26 June 1999.

Requirements for Entry

U.S. military officers, foreign military officers, U.S. Government civilians and employees of foreign governments may apply. An applicant should have a Master's Degree in Software Engineering, Computer Science, or in a closely related field. Generally, an acceptable Ph.D. applicant must have above-average grades in a typical Master's degree program. The Ph.D. Program Committee will also take other evidence of research or academic ability into account in making a recommendation as to whether to admit an applicant.

Application Procedure

Applicants must follow the standard procedures of their sponsoring organization in applying to a graduate education program, see Academic Council Policy Manual, Section 4.4. Applicants should have the sponsoring organization forward their letter of application to:

Director of Admissions (Code 01B3)
Naval Postgraduate School
589 Dyer Rd., RM 103C
Monterey, CA 93943-5100

Telephone (831) 656-3093, DSN 878-3093
FAX (831) 656-2891, DSN 878-2891

The application should include:

- certified transcripts of all courses taken at the university level, including both undergraduate and graduate courses
- results of a recent GRE general test if the prospective student is not currently at the Naval Postgraduate School
- scores on the TOEFL examination if the prospective student is a foreign student who is not a native speaker of English

If available, the following should be included:

- any material demonstrating ability to perform research, such as Master's theses and research papers
- reference letters only if the writer can report direct knowledge of the candidate's technical and research abilities

The Ph.D. Program Committee evaluates each applicant to gauge the minimum amount of time the applicant will need to complete the program (normal time is three years). The Software Engineering Group may impose the condition that the applicant obtain authorization for at least four years to complete the Ph.D. Admitted Ph.D. students may begin in any quarter, but it is recommended that the student start in the Fall Quarter (beginning in October) due to the requirements and timing of the Written Qualifying Examination.

Applicants are cautioned that admission to the Ph.D. program does not guarantee successful completion of the program. It is significantly more difficult to assess the qualifications of a student for a Ph.D. admission than for other degrees. This is because the research work required for the Ph.D. requires significant creativity and independence. Past experience suggests that not all of the students admitted will successfully complete the program. The purpose of the Written Qualifying Examination is to give students early warning if they are likely to have trouble in our Ph.D. program. For self-assessment, prospective applicants can obtain copies of previous examinations together with solutions by contacting the Software Engineering Ph.D. Program Committee at the Naval Postgraduate School.

[Click **here** and type return address]

September 27, 1999

Director of Admissions (Code 01B3)
Naval Postgraduate School
589 Dyer Rd., RM 103C
Monterey, CA 93943-5100

To Director of Admissions:

Please accept my application to the Ph.D. Program in Software Engineering at the Naval Postgraduate School. I have enclosed the following application materials:

Certified transcripts from [Enter Academic Institution here]

Certified transcripts from [Enter Academic Institution here]

Results from a recent GRE general test

Master's Thesis entitled [Enter thesis title here]

Research paper entitled [Enter paper title here]

Reference letter from [Enter name of reference here]

Thank you for your consideration.

Sincerely,

[Click **here** and type your name]

[Click **here** and type job title]

Sequence of Events Leading to a Ph.D. in Software Engineering

A general outline for a student's progression through the Ph.D. program follows:

1. The student applies for admission to the Software Engineering Ph.D. program through the Dean of Admissions. Upon satisfactory review of the package by the Chair of the Software Engineering Ph.D. Committee and the Software Engineering Curricular Officer, the student is admitted to the program.
2. The Software Engineering Ph.D. committee nominates, for approval by the Academic Council, a dissertation committee, which henceforth bears the responsibility for the study program, and for general guidance in the research program. Until the dissertation committee is named, the Software Engineering Ph.D. committee has the responsibility to oversee the student's study program. Upon successful completion of the study program, any minor, language, or computing requirements, passage of the written and oral qualifying examinations, and approval of a dissertation topic, the student becomes eligible for advancement to candidacy. The departmental Ph.D. committee then recommends that the Academic Council advance the student to candidacy for the doctorate.
3. The Software Engineering study program must include a minor.
4. When the student's study program is essentially complete, the Software Engineering Ph.D. committee, or the faculty it designates on its behalf, administers a written qualifying examination.
5. When the student has successfully passed the written qualifying examination and the dissertation proposal has been submitted to the dissertation committee, the Software Engineering Ph.D. committee, or the faculty it designates on its behalf, administers an oral qualifying examination. All minor departmental requirements must be satisfied prior to taking the oral qualifying examination.
6. The departmental Ph.D. committee names a member of the dissertation committee to be dissertation supervisor, and certifies to the Academic Council that the individual so named is qualified under the guidelines of this Policy Manual.
7. When the candidate's investigations are complete and the dissertation has been submitted, the dissertation committee administers a final oral dissertation defense.
8. After the unanimous recommendation of the dissertation committee, the Academic Council makes the final decision to recommend a candidate for the award of the Ph.D. degree.

Degree Requirements

The students must complete the following steps, which are detailed in the corresponding sections.

1. Satisfy the residency requirement
2. The following two requirements can be satisfied in any order, but they must be completed before step 3.
 - a) Form a Dissertation Committee
 - b) Pass the Written Qualifying Examination
3. Complete a Minor course of study
4. Advancement to Candidacy
 - a) Dissertation proposal must be approved by the Dissertation Committee
 - b) Pass the Oral Qualifying Examination
5. Pass the Final Oral Examination
6. Submit Approved Dissertation

Ph.D. Committee, Dissertation Committee, and the Thesis Advisor

From the Academic Council Policy Manual (as of September 1999)

The departmental Ph.D. committee nominates a dissertation committee, to be approved by the Academic Council. One member of this committee is identified as the dissertation supervisor, and the departmental Ph.D. committee must certify to the Academic Council that the individual so named is qualified under the requirements of this Policy Manual. The student, in conjunction with the dissertation supervisor, identifies a dissertation topic, which must be approved by the dissertation committee. The departmental Ph.D. committee also designates the member of the dissertation committee who shall serve as dissertation committee chair, if that person is to be different from the dissertation supervisor.

Departmental Ph.D. Committee

From the Academic Council Policy Manual (as of September 1999)

Each Department offering a Ph.D. degree must have a standing Ph.D. committee. It shall be the responsibility of the departmental Ph.D. committee to oversee the Ph.D. program for the Department.

Among the duties of the departmental Ph.D. committee are the following:

1. Ensuring that the Ph.D. program designed for each student conforms to the minimum requirements imposed by the Academic Council in the Academic Council Policy Manual.
2. Determining any standing requirements, beyond those of the Academic Council, that must be fulfilled by all Ph.D. students in the Department.
3. Nominating, for approval by the Academic Council, the members of each Ph.D. student's dissertation committee, the dissertation supervisor, and certifying to the Council that the dissertation supervisor is qualified to hold that position.
4. Overseeing the administration of the written and oral qualifying examinations for each Ph.D. student, and insuring that the nature of those examinations conforms to the requirements of the Academic Council Policy Manual.
5. Requesting that the Academic Council advance a student to candidacy for the Ph.D. degree upon approval of a dissertation committee, dissertation topic, and successful completion of all screening, minor, language, computing, and qualifying requirements and exams.

Prior to the naming of a dissertation committee and a dissertation supervisor, the departmental Ph.D. committee has the responsibility of supervising the student's program of study. After the naming of the dissertation committee and dissertation supervisor, the departmental Ph.D. committee retains the responsibility of overseeing the activities of dissertation supervisor and the dissertation committee, maintaining quality control of the departmental Ph.D. program.

The Dissertation Supervisor

Software Engineering Policy

The Software Engineering Ph.D. Committee oversees the formation of the Dissertation Committee. Faculty without any prior experience advising Ph.D. students in Software Engineering or a closely related field must petition the Ph.D. Committee for permission to supervise a Ph.D. student. The petition must be in writing and should include a curricula vita and any other material validating the faculty member's academic qualifications.

From the Academic Council Policy Manual (as of September 1999)

The dissertation supervisor has the responsibility to supervise the student's program of study in accordance with the requirements of the major Department and Academic Council.

The dissertation supervisor should have the following qualifications:

- a doctorate in the his/her field of specialty;
- experience in thesis advising;
- activity and productivity in research, as evidenced by recent publications of his or her research in
- recognized journals, or a broad reputation as a productive researcher in his or her field of specialty.
- Other evidence may be considered which is pertinent to demonstrating research activity or productivity.

The Dissertation Committee

Excerpt from the Academic Council Policy Manual (as of September 1999)

The candidate's dissertation committee, once established, is responsible for supervising the candidate's completion of his/her degree, including completion of course of study, dissertation research, and production of the dissertation document. The dissertation committee is nominated by the departmental Ph.D. committee, and will consist of five or more members, at least one of whom shall be from outside the major Department. One member of this committee may be from another university or appropriate institution. At least four members must have earned the doctorate. The departmental Ph.D. committee shall designate one or more members of the dissertation committee to be the dissertation supervisor(s).

Forming a Dissertation Committee

The student must form a Dissertation Committee to oversee his or her program as soon as possible after admission to the Ph.D. program. The Dissertation Committee is responsible for supervising the candidate's completion of the degree, including completion of a course of study, dissertation research, and production of the dissertation document. The Dissertation Committee

also administers and determines the results of the Oral Qualifying Examination and the Final Dissertation Defense. Once a Dissertation Committee is formed, the Ph.D. Program Committee nominates the Dissertation Committee for approval by the Academic Council.

One of the members of the Committee from the Software Engineering Group must be designated as the Dissertation Supervisor, and will be the student's primary technical contact; the Dissertation Supervisor must be knowledgeable about the proposed research area for the dissertation and should have prior personal experience on Dissertation committees. The student must therefore choose the general research area for the dissertation prior to forming the Dissertation Committee.

Each Dissertation Committee must have a Chairman, who can be the same as the Dissertation Supervisor. The Dissertation Committee must contain at least three members of the Software Engineering Group faculty.

At the time of approval of the Dissertation Committee, the student must also formulate a Study Plan that includes a list of courses to be validated and a timetable of when he or she expects to pass the various milestones of his/her Ph.D. program. The Study Plan should be developed in consultation with the proposed Dissertation Supervisor. The Dissertation Committee members must agree that the Study Plan is acceptable when agreeing to serve on the Committee.

NAVAL POSTGRADUATE SCHOOL
Software Engineering
Monterey, California 93943

<DATE>

MEMORANDUM

From: Chair, Ph.D. Program Committee, Software Engineering

To: Academic Council

Subject: APPOINTMENT OF DISSERTATION COMMITTEE

1. <NAME> was accepted into the Software Engineering Ph.D. program on <DATE>.
2. The Software Engineering Ph.D. Program Committee requests the following dissertation committee be formed to guide their research.

<COMMITTEE MEMBERS and their FIELDS OF EXPERTISE>

3. <NAME> will conduct his research in the area of <AREA OF RESEARCH>.
4. To allow <NAME> to more effectively organize a program of study, action on this request is requested at the earliest convenience of the Council.

<Name>

<Title>

Chair, Ph.D. Program Committee

cc: <Ph.D. Candidate>
<Committee Members>

Written Qualifying Examination

The purpose of the Written Qualifying Examination is to check each student's analytical abilities in the foundations of software engineering, their proposed research area, and solving problems in that area. These abilities are crucial for success in Ph.D. dissertation work.

Students typically complete the doctoral qualifying examination within one year of entering the Ph.D. program. There are two possible outcomes of the Written Qualifying Examination: Passed and Failed. If the student fails the first Written Qualifying Examination, the Software Engineering Ph.D. Program Committee may grant the privilege of a second examination opportunity. If granted, the second examination must be within 6 months of the first, and only two opportunities for passage are allowed (see Academic Council Policy Manual, Section 5.4.8).

Written Qualifying Examination questions will come from at least two subject areas determined by the Software Engineering Ph.D. Program Committee. There must be two faculty members, selected by the Software Engineering Ph.D. Program Committee, for each of the topics chosen for testing. To ensure breadth, a minimum of four faculty (at least two of whom are Software Engineering Group faculty) must be involved in the preparation and grading of the examination. The Written Qualifying Examination will be open notes/book.

Excerpt from the Academic Policy Manual
(as of September 1999)

The exam is the responsibility of the departmental Ph.D. committee, and is administered by this committee or by faculty members whom the departmental Ph.D. committee designates to act on its behalf.

The written exam is administered after the student's program of study is essentially completed.

An up-to-date written statement of the format and procedures of the examination must be filed by each Department with the Academic Council.

Passage of the written qualifying examination requires a unanimous vote of the departmental Ph.D. committee, or those faculty members designated to act on its behalf.

If the student fails the first written qualifying examination, the departmental Ph.D. committee may grant a second examination opportunity to the student. If the privilege of re-examination is granted, the time period within which it must be accomplished is specified by the departmental Ph.D. committee, but it shall not exceed 12 months. Only two opportunities for passage are allowed.

Format of the Written Qualifying Examination

REQUIRED AREAS

Software Engineering Core – Software development process and techniques

- Software life cycle models, software engineering concepts and principles
- Specification and verification of software
 - Modeling, analysis, and assessment
- Design of large software systems
 - Architectures, patterns, and protocols
- Maintenance of large software systems
 - Reengineering, transformations, recovering specs and rationale

Advanced Software Engineering – Software automation

- Reducing coding efforts
 - Program generation, synthesis techniques, static checking
- Computer-aided prototyping
 - Models, languages, methods
- Software reuse
 - Search methods, library organization
- Software evolution
 - Models, automation methods, merging and slicing
- Domain specific
 - Real-time systems

CHOOSE ONE OF THE FOLLOWING

Computer Science

- Mathematical fundamentals
 - Using algebra and set theory for abstract data types
 - The role of logic in specification and verification
- Algorithms and data structures in software engineering
 - Recurrence equations
 - Algorithm design and analysis
 - Complexity and computability
- Compilation technology
 - Scanner/parser generators, attribute grammars
- Artificial Intelligence
- Security

Management and Economics

- Project planning and management
 - Cost estimation, team organization, scheduling, process improvement
- Quality Assurance
 - Risk assessment, reliability models, metrics, testing
- Software economics
 - Productivity, risk assessment, cost/benefit analysis, determining priorities
- Knowledge bases

- Project data bases, knowledge acquisition and representation
- Decision support
 - Models for group decision making
- Fundamentals for modeling
 - Optimization – linear inequalities
 - Applied probability and statistics
 - Differential Equations
 - Simulation

Computer Systems

- Real-time systems
- Networks and distributed systems
- Hardware/software integration
- Interoperability of network based systems
- Computer graphics and interfaces
- Signal processing and embedded control systems

Fulfilling Ph.D. Minor Requirements

Excerpt from Software Engineering Ph.D. Program Description

To satisfy the Ph.D. breadth requirement, students must complete a set of three graduate-level courses that form a coherent topic of study distinct from the student's major concentration, approved by the student's Dissertation Committee. Students may fulfill the minor requirements by taking these courses via distance learning (or in residence). These courses are not restricted to a particular department and may be in the form of directed study, subject to the approval of the student's Dissertation Committee. Completion of the minor requirement is certified by the student's Dissertation Committee.

Academic Council Policy on Course Transfers (as of September 1999)

Appropriate courses taken at another institution with a grade of "B" or better after receipt of a baccalaureate degree may be considered for transfer for credit toward a graduate degree at the Naval Postgraduate School.

Graduate credit for courses completed more than three years prior to entry into residence on campus will not be awarded on the basis of transcripts alone. Credit for such courses can be granted upon successful passage of a departmental examination.

No more than a total of 12 quarter hours of graduate credit may be transferred. Approval of transfer credits shall be given by the Academic Council upon the recommendation of the Department Chair. Transfer credit based on courses completed at another institution shall not be used in computation of quality point rating.

Alternatives

- a) Students transfer credits from a previous M.S. program (see requirements above).
- b) Students take three courses from a local accredited graduate institution and transfer the credits (see requirements above).
- c) Students identify thesis topic and then work with NPS to identify a three course sequence from NPS on campus or via distance learning in a minor area. Distance learning courses are subject to availability. There are several ways to accomplish this:

- 1) Select three courses from an existing area such as:

- Software Engineering Program
- Systems Engineering Program
- Systems Management Program
- Mechanical Engineering Program
- Electrical and Computer Engineering Program

Current distance learning offerings can be found at:

http://web.nps.navy.mil/~ofcinst/dlc_h.htm

- 2) Individual courses can be taken by directed independent study. Independent study must be pursued under the guidance of a specific faculty member. These have to be addressed on a case by case basis and the proposed independent study has to be cleared by the student's Dissertation Committee.

Dissertation Proposal

A dissertation proposal should be submitted to the Dissertation Committee at least one week before the Oral Qualifying Examination. The purpose of the dissertation proposal is to provide the Dissertation Committee with the information needed to determine whether the proposed research topic is suitable for a Ph.D. dissertation. The proposal should describe the student's best current estimate of their research plan. The details in the proposal may be changed later as the research subject is understood in more detail.

Advancement to Candidacy

The following requirements must be satisfied before a student can be advanced to candidacy for the Ph.D. degree:

1. Approval of the dissertation subject
2. Completion of the minor requirements
3. Passing the Written Qualifying Examination
4. Passing the Oral Qualifying Examination

Upon successful completion of the Oral Qualifying Examination, the student must petition the Academic Council for "advancement to candidacy for the doctorate." A memo to the Academic Council must be prepared stating that the requirements for advancement to candidacy have been successfully completed. The Academic Council notifies candidates of advancement to candidacy in writing.

Oral Qualifying Examination

Usually within one year and no more than two years after the successful completion of the Written Qualifying Examination, the student must successfully complete the Oral Qualifying Examination. Any courses in the study plan must be completed before the student can take the Oral Qualifying Examination. The student gets only two chances to pass the Oral Qualifying Examination (see Academic Policy Manual, Section 5.4.9, shown below).

The Oral Qualifying Examination is administered by the student's Dissertation Committee. The Dissertation Committee Chairman schedules the oral portion of the Qualifying Examination and the student submits a dissertation proposal to the Dissertation Committee.

The Dissertation Committee asks any questions that it feels may help decide whether the student has sufficiently broad knowledge of the dissertation topic and sufficient analytic capability to begin full-time Ph.D. research. Time permitting, other faculty members in attendance may also ask questions of the student. The questions may be on any reasonable topic.

When the Dissertation Committee is satisfied that the student has been questioned thoroughly, the student leaves the room, the Dissertation Committee discusses concerns and votes on whether to pass the student; a unanimous vote is required. The final overall decision regarding pass or fail of the entire Qualifying Examination is made by the Dissertation Committee after the oral examination is completed.

The final result of the Written and Oral Qualifying Examinations must be reported to the Curricular Officer for Software Engineering Programs, the Associate Provost for Instruction, and to the Academic Council not later than two weeks after the scheduled date of the oral qualifying examination. Each member of the departmental Ph.D. committee, or those designated on its behalf, shall sign the report.

The Academic Council representative must submit a written report on the oral qualifying examination. The report is sent to the Academic Council to verify that the oral examination was conducted in accordance with the rules of the Academic Council.

Excerpt from the Academic Council Policy Manual Section 5.4.9 (as of September 1999)

The oral qualifying examination may be scheduled only after successful passage of the written qualifying examination and fulfillment of any major and minor field requirements, language requirements, and computer competency requirements.

The oral qualifying examination is the culmination of the course of study. The purpose of the oral qualifying examination is to test basic knowledge and creative ability and to demonstrate the student's capacity to use material from the course of study. The oral qualifying examination shall contain no prepared presentation, its format shall be exclusively question-and-answer.

Passage of the oral qualifying examination requires a unanimous vote of the examiners. All departmental Ph.D. committee members, or those designated on their behalf, must be present during all phases of the oral exam. There must be a minimum of three examiners.

The extent of participation of all parties is determined by the departmental Ph.D. committee, or those designated to act on its behalf. The Academic Council representative must attend all phases of the oral examination, and shall report to the Academic Council that the examination was conducted in accordance with the rules of this Policy Manual. Attendance at the oral qualifying exam is delineated in Table 1.

If the student fails the first oral qualifying examination, the departmental Ph.D. committee may grant a second examination opportunity to the student. If the privilege of re-examination is granted, the time period within which it must be accomplished is specified by the departmental Ph.D. committee, but it shall not exceed 12 months. Only two opportunities for passage are allowed.

CATEGORY	Oral Qualifying Examination
Departmental Ph.D. Committee members or those acting on its behalf	A, B, C, D
Academic Council Representative	A, B, C
Other faculty	A, B
Examinee	A
Students, Staff, and Visitors	A

Table 1: Attendance and Voting Privileges for Oral Qualifying Examinations. A: may attend Interrogation Phase, B: may attend Comment Phase, C: may attend Voting Phase, D: may Vote.

NAVAL POSTGRADUATE SCHOOL
Software Engineering
Monterey, California 93943

<DATE>

MEMORANDUM

From: <NAME> (Chair, Dissertation Committee for <NAME>)
Code <CODE>, Software Engineering Department
Naval Postgraduate School
Monterey, CA 93943

To: Academic Council
Code O1B, Associate Provost for Instruction
Naval Postgraduate School
Monterey, CA 93943

Subject: Ph.D. Oral Qualifying Examination

1. In accordance with Academic Council Policy, the purpose of this memorandum is to inform the Academic Council of the upcoming Ph.D. Oral Qualifying Examination for my Ph.D. Student, <NAME>.
2. I have arranged for <NAME> Ph.D. Oral Qualifying Examination to be held at <DATE/TIME> in <LOCATION>.
3. It is requested that the Academic Council designate a representative to attend.
4. If you have any question, please give me a call at <PHONE>.

<Name>
<Title>

cc: Chair, Ph.D. Program Committee<Name>
 <Committee Members>
 <Ph.D. Candidate>

NAVAL POSTGRADUATE SCHOOL
Software Engineering
Monterey, California 93943

<DATE>

MEMORANDUM

From: Professor <NAME> (Chair, Dissertation Committee for <NAME>)

To: Academic Council, Code O1B

Subject: Ph.D. Oral Qualifying Examination/Advancement to Candidacy

1. Results of Dissertation Committee's Ph.D. Oral Qualifying Examination of <NAME>.

<Name>(Dissertation Supervisor): Pass/Fail _____

<Committee Member>: Pass/Fail _____

<Committee Member>: Pass/Fail _____

<Committee Member>: Pass/Fail _____

<Committee Member>: Pass/Fail _____

2. As dissertation supervisor of <NAME>, I am hereby informing the Academic Council of the unanimous dissertation committee passing of <NAME>'s Ph.D. Oral Qualifying Examination.
3. Having successfully completed all the necessary requirements of Ph.D. Candidacy as outlined by the Academic Council and Department of Software Engineering, I recommend <NAME> to be advanced to candidacy.

<Name>
<Title>
Chair, Dissertation Committee

cc: <Name> (Chairman), Dissertation Committee
<Ph.D. Candidate>

Dissertation Guidelines

Dissertation Topic – Academic Council Policy Manual (as of September 1999)

The distinct requirement of the doctorate is the successful completion of a scholarly investigation leading to the original and significant contribution to knowledge in the candidate's major area of study. The subject of the investigation must be approved by the dissertation committee, and must be submitted to the Council no later than the time of the request for advancement to candidacy.

A minimum of six months must elapse between successful completion of the oral qualifying examination and the defense of the dissertation.

Final Dissertation Guidelines

When the dissertation has been revised and clarified to the satisfaction of each member of the Dissertation Committee, each signs it. The Registrar checks the dissertation format, and finally the Degree Program Chair and Associate Provost for Instruction sign it.

Final Oral Examination

At least six months after passing the Qualifying Examination, when the dissertation research is almost complete, and a draft of the dissertation has been finished and is available, the Final Oral Examination (also known as the dissertation defense) occurs. This examination is administered by the Dissertation Committee and consists of the following:

1. An open (public) presentation of the findings of the research by the candidate, including response to questions from the audience within an allotted time period.
2. A question and comment phase open to all NPS Software Engineering faculty.
3. A closed session involving only the members of the student's Dissertation Committee and the Academic Council Representative. A unanimous vote by the Dissertation Committee is required for a successful outcome.

From the Academic Council Policy Manual (as of September 1999)

Dissertation Defense

When the dissertation research has been completed, the Ph.D. candidate prepares a draft of the dissertation and provides a copy to each member of the dissertation committee for approval. Upon the dissertation committee's unanimous acceptance of the draft as the basis for a dissertation defense, the dissertation committee chair notifies the departmental Ph.D. committee and provides it with a draft of the dissertation. The dissertation committee chair schedules the final dissertation defense. This examination must be scheduled later than one week after the submission of the draft of the dissertation to the departmental Ph.D. committee.

All members of the dissertation committee are required to attend the final defense, and the entire Academic Council is invited to attend. The Academic Council shall designate a representative, who must attend the dissertation defense.

In the final dissertation defense, the candidate presents the dissertation and is subject to such questions as the entire dissertation committee deem appropriate. The extent of participation of all parties is determined by the dissertation committee chair. Attendance at the final dissertation oral examination is delineated in Table 1.

CATEGORY	ORAL FINAL EXAM (Dissertation Defense)
Dissertation Committee	A, B, C, D
Academic Council Representative	A, B, C
Other faculty	A, B
Examinee	A
Students, Staff, and Visitors	A

Table 1: Attendance and Voting Privileges for Dissertation Defenses. Phase A: may attend Interrogation Phase, B: may attend Comment Phase, C: may attend Voting Phase, D: may Vote.

The Academic Council representative must submit a written report on the dissertation defense. The report is sent to the Academic Council to verify that the defense was conducted in accordance with the rules of the Academic Council.

Report of Completion of Dissertation and Successful Defense

The results of the final dissertation defense and completion of the dissertation document are reported to the Academic Council, the report bearing the signatures of all the members of the dissertation committee.

If the candidate is passed, the report shall also include: nomination of the successful candidate for the award of the degree, Doctor of Philosophy.

NAVAL POSTGRADUATE SCHOOL
Software Engineering
Monterey, California 93943

<DATE>

MEMORANDUM

From: Chairman, Doctoral Committee for <NAME>

To: Academic Council

Subject: DISSERTATION DEFENSE FOR <NAME>

1. <NAME> will appear before the Dissertation Committee on <DATE>
at <TIME> in <LOCATION> to defend their doctoral dissertation entitled "<TITLE>".
2. It is requested that the Academic Council designate a representative to attend.

<Name>
Chairman, Doctoral Committee

cc: <Ph.D. Candidate>
Associate Provost for Instruction (Code 01B)
<Committee Members>
Software Engineering Faculty

NAVAL POSTGRADUATE SCHOOL
Software Engineering
Monterey, California 93943

<DATE>

MEMORANDUM

From: <NAME>, Chair, Dissertation Committee

To: Academic Council, Code O1B

Subject: RESULTS OF DISSERTATION DEFENSE

1. <NAME> has successfully completed all the requirements for a Ph.D. in Software Engineering. His dissertation entitled: "<TITLE>" was successfully defended before this committee on <DATE OF DEFENSE>.
2. This committee nominates <NAME> for the degree, Doctor of Philosophy in Software Engineering.

<NAME>
<TITLE>
Chair, Dissertation Committee

<Committee Member>
<Title>

<Committee Member>
<Title>

<Committee Member>
<Title>

<Committee Member>
<Title>

cc: Dissertation Committee
Chair, SE Department
Chair, Ph.D. Committee

APPENDIX I. PROGRAM OBJECTIVE MEMORANDUM

This appendix contains the Program Objective Memorandum (POM) written by the Software Engineering Group at NPS to request financial support for continuing the development and advancement of the Software Engineering Program at NPS. Thus far, the POM has been sent to the Provost of the Naval Postgraduate School, to Dr. Delores Etter, the *Deputy Under Secretary of Defense (Science and Technology)*, and to Mr. Dan Porter, the *Department of the Navy Chief Information Officer (DONCIO)*.

PROGRAM OBJECTIVE MEMORANDUM

In Support of Naval Postgraduate School (NPS) Software Engineering Program In-Residence and Distance-Learning Options, Certificates, Short Courses, and Software Engineering Laboratory

The infusion of technology into systems and software dramatically increases complexity in capability, architecture, implementation, and life cycle support. Without a thorough understanding of the software systems under their command, DoD personnel can not and will not effectively utilize the technology available to them. The field of Software Engineering and in particular the Software Engineering Programs at the Naval Postgraduate School address these issues and this need within DoD.

The Software Engineering Program at the Naval Postgraduate School includes In-Residence and Distance Learning M.S. and Ph.D. Degree Programs, Certificate Programs, Short Courses, and Laboratory Support. The Ph.D. Program is the first-ever doctoral program in Software Engineering. Both the M.S. and Ph.D. Degree Programs may be completed either on campus by students carrying a full-time course load, or part-time through the Distance Learning Program, which focuses on the principles, methods and practices needed by DoD software engineers to build, modify and maintain large complex software systems.

The Masters Program: The M.S. Program provides students with the lifelong capability to apply basic software engineering principles to the creative solution of complex problems. It encourages job-related thesis research that can be conducted at the sponsoring agency, especially in the Distance Learning option. To date, 23 Masters students have graduated from the program. Currently, there are 42 enrolled students, and interest in the program is growing.

The Ph.D. Program: There is a great and growing demand within the *Department of Defense* for Ph.D.-level leadership to direct software development, design, evolution, reuse and management projects. As the only Software Engineering Ph.D. program in the world, NPS' doctoral program offers a unique curriculum to educate and train a new Ph.D.-level leadership within the DoD Labs capable of making the IT21 Vision a reality.

Request for Program Objective Memorandum: To continue the success of the NPS Software Engineering Program and meet our objectives, it is imperative that we receive assistance and support in the following five areas (see attachment for funding numbers):

1. Increase in the number of students
2. Course Development
3. Faculty Development
4. Curriculum Development
5. Lab Support

1. Increase in the Applicant Pool – The DoD Labs, other Government agencies, and the military services need to recognize Software Engineering as *a military necessity* and proportionately increase the priority of and funding for advanced educational programs in this field for their personnel. Our ability to offer both the M.S. and Ph.D. Programs via video tele-conferencing (Distance Learning) to personnel at their work sites enables them immediately apply what they learn on the job and bridges the gap between long-term education and short-term training options.

2. Course Development – Significant new course development has already taken place on paper, but requires additional funding and course content validation by DoD agencies for further development.

3. *Faculty Development* -- Additional support for individual faculty research as well as for the Software Engineering Group as a whole is needed. As the military services, DoD Labs and Government agencies increasingly encourage and fund their personnel to enroll in our M.S. and Ph.D. Programs, our Faculty will benefit both as a Group and individually. Faculty oversee students' thesis research, ensuring that each thesis advances the field and incorporates new developments on the forefront of Software Engineering.

4. *Curriculum Development* -- Additional assistance is needed to keep our curricula at the forefront of the Software Engineering field. This requires a significant effort, as specific curricula are developed for each Distance Learning site. Faculty designated as Distance Learning staff must be specially trained to deliver high-quality courses to both on-site and off-site students. Short courses and certificate programs also require additional development support.

5. *Lab Support* -- The Software Engineering Program requires full-time staff to monitor and assist students in their research and coursework, acquire and maintain current technology, and keep abreast of DoD standards. Additional funding for state-of-the-art equipment and support for these personnel is needed to maintain a cutting-edge Software Engineering Laboratory Program, whose purpose is to support the education and research of both faculty and students.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
8725 John J. Kingman Road, Ste 0944
Fort Belvoir, VA 22060-6218

2. Dudley Knox Library 2
Naval Postgraduate School
411 Dyer Road
Monterey, CA 93943-5101

3. Professor Luqi, Code CS/LQ 1
Naval Postgraduate School
Monterey, CA 93943

4. Dr. Dan Boger 1
Chairman, Computer Science Department, Code CS
Naval Postgraduate School
Monterey, CA 93943

5. Commander Mark Polnaszek 1
Naval Postgraduate School
Computer Science Curricular Officer, Code 32
Monterey, CA 93943

6. Commander Tom McCoy 1
Naval Postgraduate School
Combat Systems Curricular Officer, Code 34
Monterey, CA 93943

7. Commander Valerie Moule' 1
Naval Postgraduate School
Center for Executive Education, Code 01E
Monterey, CA 93943

8. PEO Carriers, NAVSEA 1
Attn: CAPT Tal Manvel, NC3, 8E55
2351 Jefferson Davis Highway
Arlington, VA 22242-5172

9. Bill Bail 1
Naval Sea Systems Command
2351 Jefferson Davis Highway
Arlington, VA 22242-5165

10. Patsy Morgan 1
Naval Sea Systems Command
Code SEA00PZ
2351 Jefferson Davis Highway
Arlington, VA 22242-5160
11. RADM Mike Mathis 1
Naval Sea Systems Command
2351 Jefferson Davis Highway
Arlington, VA 22242-5165
12. RADM Kathleen Paige 1
Naval Sea Systems Command
2351 Jefferson Davis Highway
Arlington, VA 22242-5165
13. LT Michael J. Bok 3
4418 East Barwick Drive
Cave Creek, AZ 85331