

Metrics Thermostat for Strategic Priorities In Military System Acquisition Projects

by

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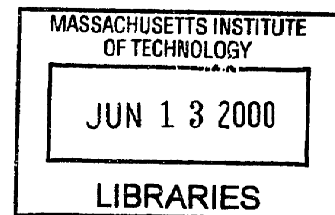
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ABSTRACT

Innovation and rapid fielding ("commercialization") of superior technology has been a key element in the United States military's strategy throughout its history. Maintaining this edge in the current environment of increased rate of technological change but dramatically reduced military procurement budgets will require strategically developing the most cost effective systems and optimizing the productivity of new product development teams. An emerging framework for a "metrics thermostat" based on an agency theory model for selecting and prioritizing metrics for product development teams has shown promising results in two commercial applications.

This study focused on applying this framework to one of the government's largest procurement organizations, the Naval Sea Systems Command (NAVSEA), the Navy Department's central activity for designing, engineering, integrating, building and procuring U.S. naval ships and shipboard weapons and combat systems. A working metrics hierarchy and construct was developed. Desired outcomes or profit analogies were defined to value and differentiate strategic priorities, enabling metrics and covariates. Five strategic priorities aligned with NAVSEA's stated goals were selected for the study and enabling metrics and covariates directly impacting these strategic priorities and desired outcomes were defined. Approximately 50 product/systems were identified and investigated to varying degrees. Significant progress was made toward populating the defined data fields for the selected data points/systems. Preliminary analyses offer hope that the combination of a large data set and broad, robust metrics will reveal meaningful correlations and leverages.

The data sources have been largely identified but substantial data collection remains to be done. As this is completed, comprehensive regression analyses will be performed to determine the relative effectiveness of the strategic priorities and enabling metrics. These results, and corresponding directions to program managers on which strategies and metrics to emphasize and which to de-emphasize, will be validated by NAVSEA experts.

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Chapter 1 - Introduction

How will the United States military take advantage of the dramatic and rapid technological advances in the commercial sector? How will the United States military operate in a prolonged period of reduced budgets? Will it be able to capitalize on what many observers believe is a coming "revolution in military affairs" driven by hyper speed advances in command, control, computers, communications, intelligence, surveillance and reconnaissance (C4ISR)?

1-1 Problem and Motivation

1-1-1 Greater Demand for Innovation

Innovation and rapid fielding ("commercialization") of superior technology has been a key element in the United States military's strategy throughout its history. During the Cold War, technological superiority was considered necessary to offset the much larger forces of the former Soviet Union. Many experts credit the United States "victory" in the Cold War not to successes in battlefield engagements but to generally superior product development, most especially by the military industrial sector. More recently, advanced technology enabled the Defense Department (DoD) to achieve decisive victory with historically low levels of casualties and collateral damage to civilians during the Persian Gulf War.

In this information age, the United States has become more determined than ever that its armed forces have no technological peer. The rapid spread of commercial communications and computer technologies around the world—coupled with the proliferation of weapons of mass destruction—have only increased the stakes in the technological arms race. (Kitfield, 1998) Not only is the battle space threat constantly changing and adapting over time, but national and organizational politics and external and internal strategic priorities are also constantly in flux. This complex and dynamic

environment in which the military operates makes the acquisition of major systems difficult. Even at any one point in time there are numerous competing strategic priorities that must be incorporated into new systems.

1-1-2 Greater Demand for Efficiency

Responding to this environment has required considerable financial expense. The nuclear weapon buildup in addition to conventional armaments cost the United States trillions of dollars over the past few decades. Many argue that much of this money was wasted and could have been converted to other social needs. In 1955 President Eisenhower, the only professional soldier among America's postwar presidents, warned, "The problem in defense spending is to figure how far you should go without destroying from within what you are trying to defend from without." (Downing and Issacs, 1998) Even if one grants that all of the defense systems and operations were absolutely essential, there is widespread belief that the projects and processes were inefficient albeit effective. An Arms Control and Disarmament Agency report found attempts at commercial diversification by U.S. defense companies "a discouraging history of failure." (Augustine, 1997) This is proof, critics might say, that these companies have over-charged the government while the military has mismanaged its acquisition contracts. Thus, throughout the years many have questioned the cost of military systems and called for greater oversight and accountability.

Perhaps partly in response to this as well as the end of the Cold War, military budgets have been reduced dramatically. According to government figures, expenditure on national defense, which peaked as a proportion of gross domestic product during a second world war at nearly 40 percent, ran at over 10 percent to the 1950s, 9 percent in the 1960s, and declined to around 5 percent in the 1970s. It rose again, however in the 1980s to over 6 percent. In real terms it ran at \$400 billion annually, in 1996 dollars during Korea, Vietnam, and in the second half of the 1980s when it contributed to overall budget deficits. (Downing and Issacs, 1998) In the first half of the 1990s the defense budget was slashed by 36%. In the second half of the 1990's, it has grown very slowly from \$254 billion in 1996 to \$272 billion in 2000. Defense *procurement* spending, in particular, has

declined by more than 60 percent in constant dollars since 1989. (Augustine, 1997) As a result, the demands for advanced technology and new military systems as well as the demands for oversight, accountability and affordability are greater than ever today.

1-1-3 Many Strategies but Which Are Working?

This mood is only heightened by the recent but long running prosperity of American companies and the economy as a whole. Few would disagree the commercial sector of the 1980s and 1990s clearly outpaced the military industrial sector in terms of technological innovation, quality initiatives and cost reductions in a wide range of products. Many have demanded that government, including the military, be run more like a business where presumably there is greater accountability for return on investment. Government civilian authorities and military service leaders have responded with a dizzying array of acquisition reform initiatives, strategic priorities, improvement programs and metrics for project managers and their teams to follow in conducting major system acquisitions. However, the displacement in time, place and priorities between system requirement definition, concept development, prototyping and fielding makes it difficult to determine which priorities and initiatives are yielding positive results, which require more attention and which have been overemphasized at the expense of others.

1-2 Potential Solution

Professor John Hauser and others in MIT's Center for Innovative Product Design have been developing an agency theory model for selecting and prioritizing metrics for product development teams. Recent empirical studies of applications in commercial settings have shown promising results. (Hauser, 1999; LaFountain, 1999) In this research we will experiment with applying the theory to the major systems acquisitions in the United States Navy. For instance, how much commercial-off –the-shelf subsystem content in major system acquisitions, specifically naval ships is appropriate given the ultimate objectives of maximizing mission performance and minimizing life cycle cost? Can the

process used to answer this be generalized to make trade-offs between a wide range of competing and evolving strategic priorities and initiatives in major system acquisitions?

The ultimate objective for this work is to develop a practical application of agency theory, a "metrics thermostat." The thermostat would provide the organization management continuous feedback regarding the optimal level of effort to expend on a select few strategic priorities. This dynamic feedback would be a combination of a strategic priority's leverage against the outcome, its influence on other strategic priorities and the effectiveness of incentives for product development teams to act on the strategic priority. One might imagine a dashboard of such thermostats continuously monitoring and guiding management's selection and emphasis of strategic priorities through incentives and rewards. Strategic priority in this context would apply to relatively broad direction given to improve an entire organization or product line as opposed to specific task direction given to a single product development team on a specific project. "Efforts to define useful metrics for the acquisition ... process must focus on measures that give insights into reform effects, not specific acquisition program indicators." (Pinker et al., 1997)

1-3 Overview of Thesis

Chapter 2 provides background on the Navy's major system acquisition - equivalent to a commercial entity's new product development - organization and process. It will also provide context for the current priorities and initiatives within the organization. Finally, it will provide a very brief overview of studies of similar problems in the commercial sector.

Chapter 3 overviews the study methodology and construction of a metrics framework for the Navy's major system acquisition organization. Individual metrics and the rationale for their selection to be used in this study are described.

Chapter 4 discusses the data collection process including difficulties encountered.

Chapter 5 presents the preliminary analyses and results.

Chapter 6 summarizes the progress thus far, presents cursory conclusions and makes recommendations for continuing study.

Chapter 2- Background

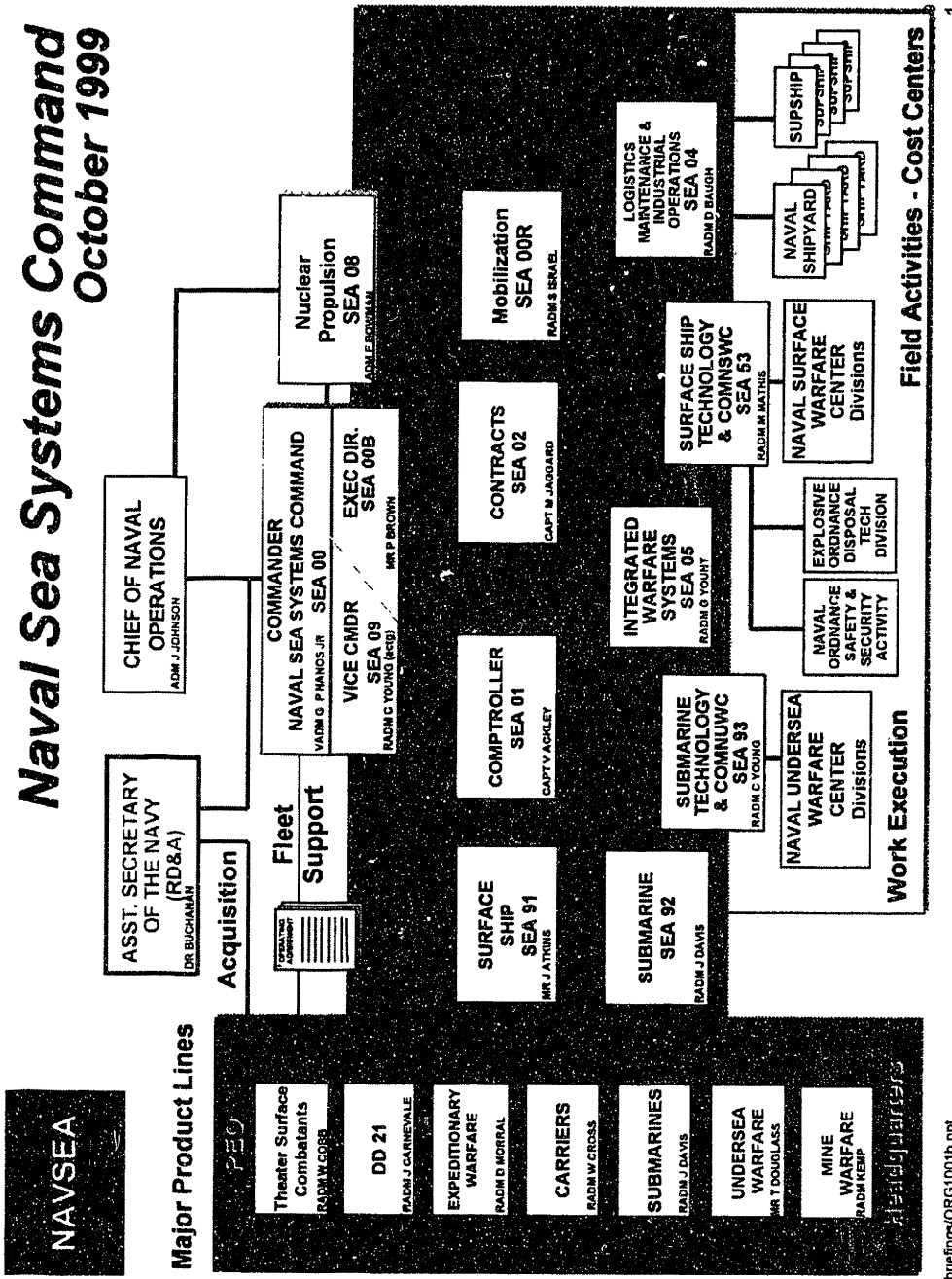
2-1 Naval Ship and Major Combat Systems Acquisition - NAVSEA

This study will focus on one of the government's largest procurement organizations, the Naval Sea Systems Command (NAVSEA).¹ NAVSEA is the Navy Department's central activity for designing, engineering, integrating, building and procuring U.S. naval ships and shipboard weapons and combat systems. Their mission is "to develop, acquire, modernize, and maintain affordable ships, ordnance, and systems that are operationally superior so our sailors and Marines can protect and defend our national interests and, if necessary, fight and win." NAVSEA's responsibilities also include the maintenance, repair, modernization and conversion of in-service ships and their weapons and combat systems. Additionally, it provides technical industrial and logistics support for naval ships, and ensures the proper design and development of the total ship, including contractor furnished shipboard systems. Its fiscal year 2000 budget of approximately \$14 billion and workforce of 50,000 people place it among the nation's largest business enterprises. (NAVSEA (1, 2000)) Figure 1 is NAVSEA's organization chart as of October 1999.

NAVSEA is provided ample guidance for the conduct of its acquisition or "new product development" projects. The Office of Management and Budget's Circular A-109; Major System Acquisitions; April 5, 1976; DoD Directive 5000.1; Defense Acquisition; March 15 1996; (Incorporating Change 1, May 21, 1999); and DoD 5000.2-R; Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information Systems (MAIS) Acquisition Programs; (Includes Change 4); 11 May 1999 specifically outline the acquisition process and the management approaches to be used.

¹ The work is sponsored by the Product Innovation Division of the Office of Naval Research NRL as part of their ongoing sponsorship of the MIT Center for Innovative Product Development.

Figure 1 – NAVSEA Organization Chart



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2-2 Overview of the Acquisition Management Process

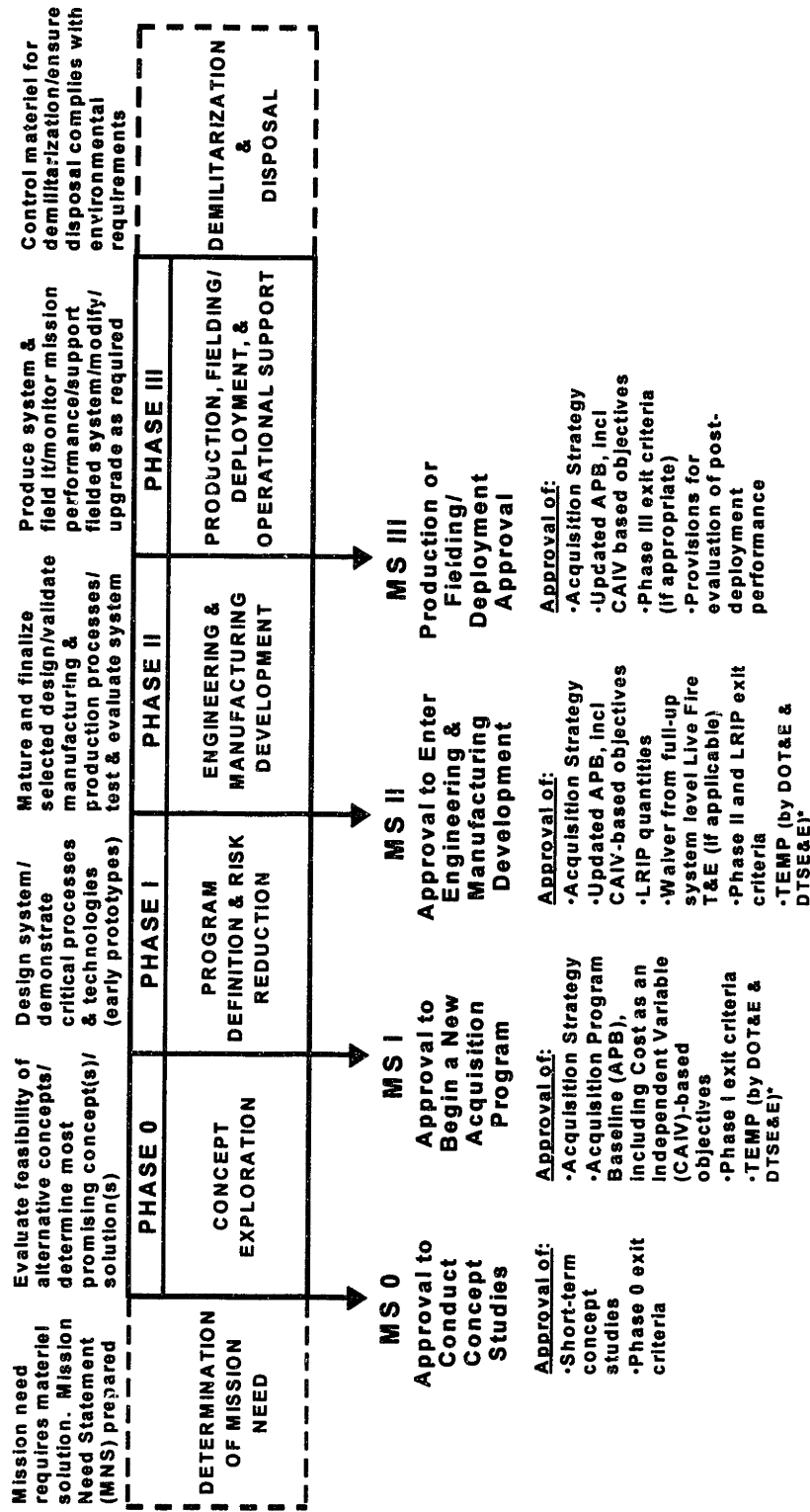
According to DoD 5000.2-R, the acquisition process shall be structured in logical phases separated by major decision points called milestones. The process shall begin with the identification of broadly stated mission needs that cannot be satisfied by non-materiel solutions. Acquisition program stakeholders shall consider the full range of alternatives prior to deciding to initiate a new Major Defense Acquisition Program (MDAP). Threat projections, system performance, unit production cost estimates, life-cycle costs, interoperability, cost-performance-schedule trade-offs, acquisition strategy, affordability constraints, and risk management shall be major considerations at each milestone decision point, including the decision to start a new program.

At program initiation, and after consideration of the views of the Working-Level Integrated Product Team (IPT) and Overarching IPT members, the Project Manager (PM) shall propose, and the Milestone Decision Authority (MDA) shall consider for approval, the appropriate milestones, the level of decision for each milestone, and the documentation needed for each milestone. This proposal shall consider the size, complexity, and risk of the program. The determinations made at program initiation shall be reexamined at each milestone in light of then-current program conditions. Unless tailored by the MDA, the sequence of project phases and milestones through a product/program's entire life cycle are as depicted in figure 2.

This process is not terribly different from those used effectively in many commercial enterprises and product development teams. And, as stated in the introduction, the pressure for efficiency within the DoD acquisition community and the military industrial sector has attracted a great deal of oversight and demand for metrics. In spite of this oversight - some might say in part due to the oversight - military acquisition projects still frequently overrun schedules and budgets and underachieve in terms of performance.

Figure 2 -- NAVSEA "New Product Development" Process (Cochrane, 1998)

Defense Acquisition Milestones & Phases



*OSD T&E Oversight Programs only

Some in the military and in industry argue that many military requirements are fundamentally different from commercial requirements. Not only are there obvious shocks and environmental extremes in the military application not found in the commercial world, but there are significant logistics and risk issues. The military depends on deep “just in case” stock systems. The commercial world is moving to thin “just in time” inventory systems. The risk analysis for military applications is also different. A server system failure that disables some portion of a corporate LAN in an office and idles 30 office workers has far different consequences than a single workstation-controlled weapons system failure that leaves a ship unable to defend itself against a supersonic missile attack.

Still, while the products may be somewhat different and may have to operate in a different environment, many question how significant these differences really are. Commercial products are also subject to severe environments and high expectations by today's consumers. In fact, commercial products have proven to be effective and suitable for many military applications. For instance, 8000 commercial GPS units obtained through an urgent procurement during the 1991 Gulf War proved were so successful, the US Army subsequently documented a requirement for 75,000 more. A slightly modified but non-developmental item procurement following the war provided the Army a product that met or exceeded all of its performance requirements and cost 75% less than its initial estimate. (Defense Standardization Program, 1996)

Similarly, while the business processes may be different, many question how significant these differences really are. Both entities should be interested in the best value proposition that meets their requirements. Consequently, many government leaders have pushed the military acquisition activities - and the services as a whole - to be managed more like commercial enterprises.

2-3 Acquisition Reform

2-3-1 Overview

In response to these problems and to take advantage of lessons learned in private industry, DoD initiated a wide range of objectives, strategies and practices under the umbrella of "Acquisition Reform" in the early 1990s. According to the Navy Acquisition Reform Office's TurboStreamliner web site (2000), "Acquisition Reform is a way of thinking. That thinking is guided by three objectives that shape the products, processes, and practices of Defense Acquisition: better, faster and cheaper. As acquisition reform thinking evolves, the acquisition community will develop new strategies, practices and initiatives." A few of the more than 30 acquisition reform initiatives currently under way are listed below under the three core reform objectives.

- **Better: Improved Products, Processes and Practices.**
 - Streamlining focuses on reducing the cost and length of acquisitions by eliminating unnecessary duplication and burdensome administrative elements.
 - Integrated Product and Process Development (IPPD) and Integrated Product Teams (IPT) initiatives encourage the use of multifunction teams that are committed to delivering a product or service. When the government functional specialist participate with industry on IPPD/IPT efforts, the gains realized in early integration of business, contracting, manufacturing, testing, training and support considerations in the design process will result in fewer changes later in the procurement process.
 - Commercial Products, Processes and Practices allow the government to benefit from the best practices of industry and the testing ground of the commercial marketplace.
 - Past Performance Evaluations of contractors' work on similar procurements with respect to cost, schedule and technical performance will be used in source selection.

- Best Value Contract Awards must be designed into source selection procedures. Offers must be afforded wide latitude in proposing varying technical/cost trade-offs.
 - Risk Management responsibility will be passed onto contractors to accompany their latitude in specification development.
 - Performance Based Acquisition will reduce detailed specifications (military specifications and standards) and foster Open System Architecture.
- **Faster: Reduce Acquisition Response Time.**
 - Information Technology applications will be encouraged to speed up cost, schedule and technical data flow to them from the contractor.
 - Cycle Time Reduction will be encouraged to place new capabilities in the hands of the war fighter quicker and reduce costs.
- **Cheaper: Affordable Ownership**
 - Total Ownership Cost will be used as a criterion in evaluating contractor proposals to ensure that all cost drivers in the programs are controlled.
 - Testing requirements must be illuminated or restated in performance-based terms to reduce unnecessary or redundant testing requirements.

All of these initiatives properly implemented will almost certainly improve the acquisition process. However, they all must compete for resources of the department in the attention of the program offices. Overemphasis of one or more to the detriment of others might sub optimize the desired outcome. We look at a few of these reform initiatives more closely. They have been highlighted as particularly promising for great savings and or offer relatively easy to find metrics/easy to access data.

2-3-2 COTS, CANDI and Commercial Standards

Two initiatives seemed like sure hits for great savings (Behr, 1997):

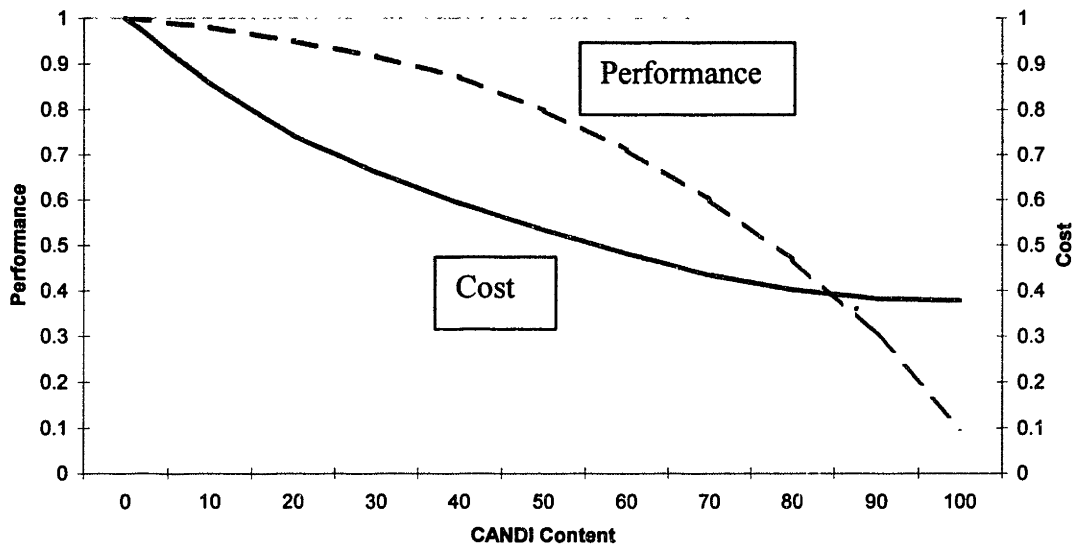
- Greater emphasis on the use or incorporation of Commercial Off-The-Shelf (COTS) systems and components or Non-Developmental Items (NDI). Collectively, these two categories of goods have been dubbed (CANDI). The former group (COTS) refers to equipment or products that are immediately available in stores or catalogs that will meet military requirements. The second group while not immediately available for sale requires no further development and could be produced quickly if a buyer so desired.
- Substitute with commercial standards or simply eliminate every military standard possible.

Logically, one might hypothesize that there is a general optimum mix of commercial and military specific equipment that ought to be incorporated into a naval ship. As CANDI content approaches zero and the ship requires completely unique design and support, cost presumably must rise steeply while performance improves little if at all. As CANDI content moves toward 100%, performance tradeoffs will undoubtedly have to be made and cost savings, particularly support cost savings, will be marginal at best. This is depicted in figure 3. The objective then would be to find the CANDI content for which you can gain maximum benefit from the cost savings without unacceptable performance sacrifices. The data and studies regarding the use of CANDI to achieve “better, faster, cheaper” processes are anecdotal at best and marked with failures as well as success stories. (Forsberg, 1999)

Similarly, it would seem that there is a general optimum mix of commercial and military standards that ought to be incorporated into a naval ship. Clearly, there are many systems or at least subsystems and components, for which commercial standards are adequate. Maintained by industry, professional or standards organizations, commercial standards benefit from extensive market testing and cost the Navy nothing. There are almost certainly some military specific systems for which there are no commercial standards. For these, the Navy may have to develop its own standards and specifications. However,

it must also then bear the cost of maintaining them and being one of the few if not only "companies" using them.

Figure 3 - Performance and Cost vs CANDI Content



2-3-3 Open Systems Architecture for Modernization

DoD's role is shifting from technology producer to technology consumer because of decreased budgets and increasingly fast changing commercially developed technology. A shift to commercial products will also require a new technical approach to systems engineering. An open systems approach must be followed to encourage affordability, accommodate changing technology and promote multiple sources of supply. Modularity should be designed in based on well-defined interfaces to isolate components that are likely to change over time. Proponents assert that this will facilitate relatively low cost and continuous evolutionary upgrade with the technology as well as a large supplier and customer base. (Hanratty and Lightsey, 1999)

2-3-4 IPPD/IPT

IPPD/IPT is a cornerstone principle of acquisition reform. DoD defines IPPD as, "A management process that integrates all activities from product concept through

production/field support, using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives." IPPD evolved from concurrent engineering, and is sometimes called integrated product development (IPD). It is a systems engineering process integrated with sound business practices and common sense decision-making. One of the key tenets of IPPD is that of multidisciplinary teamwork via Integrated Product Teams (IPTs).

IPTs are cross-functional teams that are formed for the specific purpose of delivering a product for an external or internal customer. IPT members should have complementary skills and be committed to a common purpose, performance objectives, and approach for which they hold themselves mutually accountable. IPTs are the means through which IPPD is implemented. (Secretary of Defense, 1995)

2-4 Strategic Planning

The Deputy Secretary Of Defense for Acquisition, Technology and Logistics chartered the Defense Systems Affordability Council (DSAC) to develop and guide the implementation of integrating strategy for achieving affordable defense systems that meet all essential performance requirements. Better, faster, cheaper modernization. The scope of the activities covered by the strategy includes all of the processes required for the development, production, life cycle support, and disposal of defense systems. In this leadership role, the DSAC has enumerated three top-level goals for the department:

- Field high-quality defense products quickly; support them responsively.
- Lower the total ownership costs of defense products.
- Reduce the overhead cost of the acquisition and logistics infrastructure.

"Process change is needed to achieve the objectives for each of these goals. **Metrics and incentives are needed to drive change.** Implementing change and measuring results are the combined responsibility of the office of the Secretary of Defense, the Services, the Joint Staff, the Defense Agencies, and industry." (Gansler, 1999)

The Assistant Secretary of the Navy for Research, Development and Acquisition has issued The Naval Research, Development and Acquisition Team 1999-2004 Strategic Plan. "In keeping with the goals of the National Performance Review and consistent with the Government Performance and Results Act and the Revolution in Business Affairs, ASN (RDA) will strive to develop and procure the weapons systems of tomorrow better, smarter, cheaper and faster. We will carry forth this revolution by expanding acquisition reform beyond procurement into logistics, finance and other key business areas, with the ultimate goal of combating resource shortages through revolutionary business practices. Resource savings may then be applied toward modernization and recapitalization of the Navy-Marine Corps team." Reducing total ownership costs to increase resources available for recapitalization and modernization is the overarching concept for the strategic plan. The plan includes four goals:

- WARFIGHTER - Improve war fighter satisfaction - "Better"
- BUSINESS PROCESSES - Reduce cost and cycle time for delivering equipment and services - "Faster"
- FINANCIAL - Lowering the total ownership costs of equipment and services - "Cheaper"
- PEOPLE - Shape and train and efficient and effective acquisition workforce - "Smarter" (Buchanan, 1999)

In support of the ASN(RDA) 1999 - 2004 Strategic Plan (Warfighter, Business Processes, People and Financial), the Acquisition Reform Office will accomplish the following four specific goals in FY 2000.

Challenge: The demand on internal resources is too high.

Goal: ARO will strive to eliminate report duplication, reduce RDA reporting requirements, and reduce information required in DAES reporting requirements.

Challenge: Weapon system schedules are too long.

Goal: ARO will work with three program offices to implement AR initiatives with a focus on reducing cycle time.

Challenge: Weapons system costs are too high.

Goal: ARO will work with organizations to initiate five implementations of Activity Based Cost Management (ABCM) and incorporate Earned Value Management (EVM) into three contracts.

Regulations, Policies and Statutes Questionnaire

Challenge: There are too many statutes, policies, and regulations.

Goal: ARO will champion the elimination of 15 statutory, regulatory, or policy barriers to the acquisition community performing its work. (US Navy Acquisition Reform Office, 2000)

Amidst this direction from superiors, the NAVSEA commander has outlined 8 strategic goals (priorities) for the organization:

- **People.** Develop and maintain a capable diverse workforce with all members performing to their full potential.
- **Customers and Communication.** Earn the respect and confidence of our customers and communicate effectively.
- **Total Ownership Costs.** Reduce total ownership costs of our products.
- **Safety and Environment.** Take the lead in effectively integrating pollution prevention and safety into the design and life cycle of our ships, systems, and ordnance, into the execution of our processes and into the operation of our facilities.
- **Business Processes.** Explore, identify, and implement best practices in processes in our acquisition business which will result in reduced costs, reduced cycle time, improved quality, and increased productivity.
- **Innovation/Technology Opportunities.** Develop innovative approaches to deploy 21st century technology.
- **Engineering of Systems.** Develop systems is that optimize costs, schedule and performance requirements at both the ship and warfare area levels.

- **Organization.** Create a forward-looking organization that is responsive and efficient. (NAVSEA (2, 2000))

Within these eight priorities, there are numerous sub-strategies, objectives and metrics.

2-5 More Priorities

Customers served by NAVSEA and senior managers within NAVSEA have refined their superiors' initiatives and identified and generated still more priorities and objectives. For instance, NAVSEA's Fleet Maintenance Policy and Process Program has the following goals:

- integrate maintenance requirements across all platforms (in-service and new construction)
- provide a feedback process to continually improve maintenance and lower total ownership costs (POC)
- establish and maintain consistent and standardized maintenance requirements, policies and processes across all maintenance levels.

Within just this program, there are no less than 20 sub-programs and initiatives with their own missions, visions, objectives and metrics. The sub programs include: Surface Ship Effectiveness Review (SURFMER), Engineering for Reduced Maintenance (ERM), Top Management Attention/Top Management Issues (TMA/TMI), Capital Investment for Labor (CIFL), Cumbersome Work Practices (CWP), Maintenance Engineering Technology Team (METT), the Fleet Modernization Program (FMP) and others.

Many of these initiatives have attracted high-level attention and sponsorship. Regarding the Capital Investment for Labor program, Admiral Jay Johnson, Chief of Naval Operations, says, "My ultimate goal is to eliminate unnecessary workload, return discretionary time to commanding officers, and allow our sailors to spend more time at home during the interdeployment training cycle." Honorable Richard Danzig, Secretary of the Navy adds, "I am pressing for us to invest more in treating sailors and Marines as valued professionals, with time to train, equipped with the tools and supplies to do their

jobs in the most efficient way, in decent environments, with enough time to produce work that's worthy of pride -- not just to be playing catch-up. ... why can't we have paint that is more resistant to deterioration and therefore would require less chipping and repainting in the first place? Can't we design ships that have less steel and better corrosion protection, so there's less rust? And why not have watertight doors to advance on World War II technology -- so sailors spend less time maintaining the ship?"

The Top Management Attention / Top Management Issues (TMA/TMI) program also enjoys high-level support. Type Commanders identify systems or equipment for inclusion in the TMA/TMI Program semi-annually through review of Casualty Reports, Technical Ticklers, and 3M data. Systems or equipment that have high numbers of maintenance actions, high repair costs, or excessive down time are identified through this process as having a high impact on Fleet material readiness and maintenance costs. The objective is to identify systems/equipments as candidates for consolidated action to improve performance. Prime candidates are those for which performance improvements can significantly improve fleet readiness. The Type Commander inputs are forwarded to NAVSEA, as the sponsor for TMA/TMI, for action. NAVSEA assigns the identified systems/equipments and technical issues to the responsible NAVSEA, Space and Naval Warfare Systems Center (SPAWAR), Naval Air Systems Command (NAVAIR), Program Executive Office (PEO), or Naval Supply Center (NAVSUP) code for technical review and resolution. Results and progress are monitored with program specific metrics.

2-6 Priorities Change Over Time (Slowly)

Further complicating matters is the fact that the priorities change over time. Management fads, changes in the senior leadership and real lessons learned all contribute to the continually changing landscape of priorities and metrics. At the implementation level, Hauser and Katz (1997) point out, " Once the enterprise is committed to certain metrics, the metrics gain tremendous inertia. Those who know how to maximize (priority or metric) *a*, *b* and *c* fear to change course. It is extremely hard to refocus the enterprise on new goals."

For instance, the TMA/TMI process identified the following three priority shifts corresponding to changes in senior leadership:

- Three years ago - "Reduce Ownership Costs"
- Two years ago - "Boost Readiness and System Availability"
- Today - "Reduced Sailor Workload"

How quickly, precisely and accurately the in-service engineering agents and the new product design agents actually refocused their efforts is unclear. Furthermore, it will likely be just as unclear whether overall improvements next year are due to reducing ownership costs, boosting readiness and system availability, reducing sailor workload or some other priority, initiative or practice instilled in the enterprise through another channel.

2-7 Balanced Scorecard Effort

NAVSEA, DoD and the government as a whole recognize that they have had a problem with multiple priorities and inadequate measures. The Secretary of Defense has already started tracking metrics on the effectiveness of various Acquisition Reform initiatives. (Deputy Under Secretary of Defense for Acquisition Reform, 1999) The project managers and a broad range of support activities are working hard to sift through old and new measures. The general objective is to find metrics that are not only useful for one's own organization but that also automatically roll up to meet customer and or supplier needs. A nested set of "Balanced Scorecards"² is one approach.

² Kaplan and Norton (1996) have introduced the Balanced Scorecard as a "new framework for integrating measures derived from strategy. While retaining financial measures of past performance the Balanced Scorecard introduces the drivers of future financial performance. The drivers, encompassing customer, internal-business-process, and learning and growth perspectives are derived from an explicit and rigorous translation of the organization's strategy into tangible objectives and measures."

NAVSEA is in the process of developing a Balanced Scorecard in an effort to translate strategy to action via key perspectives. According to a January 2000 briefing titled, "Aligning Business Plan Metrics Using a Balanced Scorecard Approach" (NAVSEA 09B, 2000) NAVSEA will use their Balanced Scorecard to:

- Effect Strategic Planning and Deployment
 - Set Direction and Goals
 - Define Progress Measures
 - Prioritize Efforts
 - Ensure Efforts Are Aligned Across the Organization
 - Balanced Financial/Non Financial Measures
 - Tie Budget to Strategy
- Show the Health of the Organization through Key Success Factors
- Focus Attention to the Critical Few
 - Only 4 to 8 Metrics at Each Level

The briefing then emphasizes, "That which gets measured gets done! and Measurement motivates!"

NAVSEA'S strategic plan goals are listed as:

- Increase Customer Satisfaction
- Improve Employee Effectiveness
- Improve How We Work
- Deliver Affordable, Capable Products
- Innovate

NAVSEA intends to use cascading balanced scorecards to align and empower organizations and employees at the department level down to the division level.

One department, the Naval Undersea Warfare Center (NUWC), has already employed this approach for its divisions. (Harrigan, 1999)

However, at the working level in the product development teams (often government – industry IPTs), project managers must use immediately quantifiable surrogate metrics as

the final result, detached from the development team by time and space, will not be evident until the system has served in the field. "It is not easy to decide what these surrogate metrics should be, and it is not always clear how they would contribute to the goal of fielding military systems that are better, faster, and cheaper." (Pinker et al., 1997)

As it stands right now however, there are numerous competing and overlapping priorities and initiatives. There are also multiple definitions for the same metrics. Thus, many managers, engineers and acquisition project team members are simply weary if not suspicious of new initiatives and measurement programs. In fact, it would appear that even the leaders calling for improved metrics and feedback are either tired or unable to keep up with the data flow and associated noise.³ Perhaps not so surprisingly then it is not at all clear that equipment and organization performance metrics are feeding back to the acquisition projects.

Responding to this gap and recognizing the changing priorities of the past ten years, Joseph Cipriano (1999), Executive Director of the Naval Surface Warfare Center Port Hueneme Division has noted, "When the in-service engineers' knowledge of in-service performance is coupled with threat analysis and design simulations is a powerful tool for managing mission effectiveness emerges. The system design agent and in-service engineering agent provide the forge in the chain of accountability for combat systems safety and effectiveness."

Once again, muddled though this may sound, it is not terribly different than the challenges industry has faced and continues to face.

2-8 Overview of "Metrics Thermostat" Research

Recent research done at MIT's Center for Innovative Product Development has illustrated and tested a practical adaptive control method to adjust strategic priorities in the

³ Our offers of assistance - and requests for data - e-mails, phone calls and visits typically received a lukewarm response if any.

commercial development environment. (Hauser, 1999; LaFountain, 1999) Working with two major US corporations, Hauser found product development teams attempting to satisfy numerous metrics that followed in the wake of recent trends in marketing and strategy. However, assuming the firm was already operating efficiently, management and the design team had to make tradeoffs between these subordinate objectives to maximize the superordinate objective of profitability. Xerox emphasized three different strategic priorities over the course of a decade. In the late 1980s and early 1990s, customer satisfaction was a strategic priority. In the mid 1990s, time to market, cycle time and first mover advantage became strategic priorities. In the late 1990s, platform-centric design and platform reuse became strategic priorities. As in NAVSEA's case, much of their work was actually guided by a still lower tier of enabling objectives or metrics. Empirical product development data as well as subsequent performance in the market was collected on numerous recent product launches. Additionally, agency theory, observed practices and design team surveys were used to develop a model that determined the weighted impact of lower level metrics on higher objectives and predicted appropriate tradeoff functions. Combining the data and theory generated confidence in the model and suggested which priorities needed adjustment and in what direction, i.e. reduce emphasis on reuse to improve customer satisfaction and ultimately improve profitability. The corporation's executives subjectively validated the results. They have since refined priorities and realigned incentives for their product development teams.

2-9 Study Scope

This study is a focused demonstration project to apply the metrics thermostat methodology to NAVSEA's major system acquisition (new product development) process. As such, it will not address the entire NAVSEA enterprise and all eight of its objectives. Instead, it will concentrate on a subset of these priorities that directly impact new product development and resonate with many of the other priorities identified above and below the NAVSEA command level. It also will not address the agency issue problems but will attempt to lay the groundwork for future investigations.

Chapter 3 - Methodology

3-1 Overview of Methodology

Steps (1) through (6) are part of this thesis. Steps (6) through (11) will be completed in a thesis by Jeff Moffitt (June 2001).

1. Propose a profit analogy(s) to differentiate strategic priorities and enabling metrics.
2. Simplify the set of priorities. Choose common themes but just a few priorities for which data can be obtained for demonstration purposes.
3. Simplify the problem to combat systems and major hull, mechanical and electrical systems. Ships in total provide too much variation and too few data points to yield significant results.
4. Define the metrics. Use existing NAVSEA definitions as much as possible, but provide consistency across all systems.
5. Collect data on as many major system acquisition projects and products as possible. Select project and products that span the spectrum of enabling metrics and covariates measured.
6. Perform initial regression analyses to determine the correlations between outcomes, strategic priorities, enabling metrics and covariates.
7. Refine metrics definitions and hierarchy.
8. Refine the set of systems to use as data points and complete data collection.
9. Perform final regression analyses.
10. Subjectively validate the results with NAVSEA leadership.
11. Iterate as necessary.

3-2 Selection and Hierarchy of Metrics and Covariates

3-2-1 General

In formulating the framework of metrics for use in this study we talked with executives, managers, acquisition project team members and Fleet support technicians from the following offices: NAVSEA (several divisions and offices), Defense Advanced Research Projects Agency (DARPA), Naval Research Laboratory (NRL), Naval Undersea Warfare

Center (NUWC), Fleet Technical Support Center Atlantic (FTSCLANT), Naval Surface Warfare Center Port Hueneme Division (NSWC PHD) and SPAWARS. We also studied countless DoD, Department of the Navy and NAVSEA web sites; read policy statements and press releases; and reviewed directives and briefing packages. There was no consensus "profit analogy" for NAVSEA. Thus, there were many differing views on what the ultimate desired outcome metric ought to be for NAVSEA and more specifically the program offices charged with major system acquisitions. Similarly, other than the very high-level and relatively vague direction of better, smarter, faster and cheaper, we did not find a concise, cogent set of core strategic priorities for the "new product development teams" within NAVSEA.

3-2-2 Defining the Profit Analogy

Defining a profit analogy is perhaps the most difficult aspect of applying the "metrics thermostat" to NAVSEA or any military/government product development organization. This difficulty alone; however, should not dissuade one from attempting to use proven commercial techniques for motivating an organization to provide the best possible value for its customers. The utility or benefit of military systems is very real but admittedly difficult to measure. Notwithstanding inter-service rivalries, the country's defense needs are served by only one military organization. The problem is further complicated by the relatively specialized nature of each system and the lack of similar systems with which to benchmark. In contrast, one's copying needs are potentially served by a large number of competing suppliers. Assuming customers collectively and accurately discern the best value from amongst competing models, the most profitable (short-term and long-term) manufacturers could be judged the most successful.

In our setting, without the marketplace to synthesize utility and cost into profit, a single measure of success, we must consider system effectiveness and cost separately as outcomes in determining success. We have combined system performance or capability with availability and impact on the ship by weight and volume to determine effectiveness. We have had to non-dimensionalize performance or utility against the few similar systems in the service's inventory or against the stated required level of performance. Given the resulting small range of variance in system performance, volume and weight,

the measure of effectiveness is primarily determined by the systems availability. For cost, we chose to use total ownership cost on an annual per system basis.

As a government agency, the success and sustainability of NAVSEA is also based in part on factors other than just performance and cost of its products. NAVSEA must also support government-wide initiatives that have little to do with its own success.

Complying with regulations requiring a certain proportion of projects and contracts set aside for small businesses, for instance, may not improve product development but may be absolutely necessary for continued funding, read stockholder support. Success in implementing acquisition reforms, reducing sailor workload and other strategic priorities may have inherent value to the organization regardless of their impact on the effectiveness and cost outcomes. Thus, a final superordinate outcome, judged cost-effectiveness, must be subjectively determined by the organization's major stakeholders.

In summary, we will collectively consider all of the following outcomes as our analogy to profit:

- System Effectiveness
- Total Ownership Cost
- Judged Cost-Effectiveness

3-2-3 Defining the Strategic Priorities

Covering all of the stated organization strategic priorities, goals and objectives was unrealistic. We deemed even attempting to cover the NAVSEA Commander's eight strategic goals beyond the scope of this first demonstration study of new product development metrics in the public sector. We needed a smaller set of more clearly defined strategic priorities to build on. The selected strategic priorities had to be specific enough to directly incentivize, or at least influence, the product development teams' behavior and enabling metrics. At the same time, they had to be broad enough to directly impact not just one development team's product but the entire organization's process and product outcomes and superordinate goal. Wanting to go beyond a purely academic

exercise we did not want to arbitrarily select or contrive the strategic priorities ourselves but choose contemporary issues with real data and real interest from the organization.

Fortuitously, although belatedly, we came in contact with the TMA/TMI program office, who were working on a problem somewhat similar to ours. Mr. Ron Jolley and his colleagues at FTSC/LANT have been collecting and analyzing data for the TMA/TMI program for more than four years. TMA/TMI is a process that:

- Uses data from diverse sources to objectively identify critical fleet maintenance issues, which negatively impact material readiness, cost, and/or training.
- Focuses management attention and diverse resources on actions to correct these critical issues.
- Enhances communication among Type Commanders (TYCOMs), NAVSEA Program Offices and other naval support activities.
- Actively monitors corrective actions with useful metrics to determine degree of success.

The program has developed an excellent reputation in the field as well as in NAVSEA headquarters. The fleet and technicians know that a problem system highlighted in the TMA/TMI program will get professional and high-level attention. The NAVSEA leadership trust that the program identifies the fleet's most problematic systems and implements cost-effective solutions, even going so far as to predict and track return on investment. Owing to its effectiveness, the TMA/TMI program has been kept active through several changes in leadership at various levels in NAVSEA and through shifting priorities. The FTSC/LANT staff noted three such shifts in their program priority. Three years ago the focus was "Reduce Ownership Costs." Two years ago the focus was "Boost Readiness and System Availability." Today it is "Reduce Sailor Workload." The TMA/TMI process has proved to be a robust solution adaptable to changing senior leadership goals.

However, it was not clear to the program which of the priorities and corrective actions were most effective. While the current leadership might be attributing the latest in-service system effectiveness and efficiency improvements to their new priorities, the

technicians at the "deck plate" level may still be working according to last year's priorities. Alternatively, perhaps all priorities are getting equal attention, but one or more is having far more impact than the others. The multiple and simultaneous initiatives coupled with the displacement in time and place between corrective actions and outcomes make this difficult to discern without an objective statistical analysis. This is very similar to the Xerox problem addressed by Hauser and LaFountain (1999) in their empirical exploration of metrics for product development teams.

The TMA/TMI priorities are actually focused on solving in-service system and equipment problems. However, the three priorities observed in this program could just as easily apply further upstream to the NAVSEA program offices developing new products to correct shortfalls in the current systems inventory. We found the Naval Surface Warfare Center Port Hueneme Division (NSWC PHD) to be interested in just this. As noted in section 2-7, they have concluded that the in-service engineering agents must become more closely coupled to the system design agents, or in other words, the new product development teams. Like the TMA/TMI program, this organization uses a relatively rigorous approach in their data gathering and metrics reporting. One might even argue that leaders of the TMA/TMI program were actually reacting to in passing on more general priorities of NAVSEA's top leadership. In any case, they provide for interesting, real and, to some degree, competing priorities.

Modernization through open systems architecture and acquisition reform were not explicitly or separately captured in the TMA/TMI or NSWC PHD programs. However, both are such pervasive themes and important issues for current acquisition projects we felt compelled to include them in our set of strategic priorities. Acquisition reform actually includes many elements. For this study we chose to include the cycle time, military standard/specification, CANDI, design process and I PPD/IPT initiatives for consideration.

In summary then, the following five strategic priorities were used in this study:

- Sailor Workload Reduction

- **Readiness and Availability**
- **Affordability and Reduced Ownership Costs**
- **Modernization through Open Systems Architecture**
- **Acquisition Reform.**

Independently, of course these are all worthy objectives. However, they are not independent of each other and in an environment of limited resources all of these priorities must be balanced against each other and a host of others. The real work of implementing these priorities falls to the new product development teams and the in-service engineers. Their capability or leverage against these organization priorities is monitored and motivated with enabling metrics. At the same time, there are other factors impacting organization, the environment in which it operates and the interaction of these two that are beyond the organization's control. Measures of these factors have been termed covariates. While the enabling metrics and covariates usually impact more than one strategic priority, we have linked them directly to the most likely metrics for the purposes of this thesis. If we imagine an office set up for each priority (in fact, we found there are often many such offices), these are the metrics they would be monitoring and aggregating to measure their performance. The actual linkages will be determined by multiple regression analyses after all of the data have been collected. Estimating interactions, positive and negative correlations with other enabling metrics, will be the focus of the total system regression analyses. Based on our set of strategic priorities we have chosen to look at the following enabling metrics and covariates in table 1.

Table 1 – Strategic Priorities and Enabling Metrics and Covariates

STRATEGIC PRIORITIES	ENABLING METRICS AND COVARIATES
Sailor Workload Reduction	Enabling Metrics <ul style="list-style-type: none"> • Operations Manpower • Preventative Maintenance Manpower Covariates <ul style="list-style-type: none"> • Corrective Maintenance Manpower
Readiness and Availability	Enabling Metrics <ul style="list-style-type: none"> • Mean Time to Repair (MTTR) • Criticality Covariates <ul style="list-style-type: none"> • Mean Time Between Failures (MTBF) • Capability of Performance • System Weight • System Volume
Affordability and Reduced Ownership Costs	Enabling Metrics <ul style="list-style-type: none"> • Commonality: Total Installed • Commonality: Number of Ship Classes • Reuse Content Covariates <ul style="list-style-type: none"> • Acquisition Cost • Operations and Maintenance Costs
Modernization through Open Systems Architecture	Enabling Metrics <ul style="list-style-type: none"> • Modularity / Upgradeability • Military Standard/Specification Content
Acquisition Reform	Enabling Metrics <ul style="list-style-type: none"> • COTS Content • Design Process Rigor • IPT Use • Acquisition Process Cycle Time

The enabling metrics and covariates are defined and discussed below in the somewhat arbitrary order of their appearance in the chart above. Many of these definitions were taken in whole or in part from the Safety, Effectiveness, and Affordability Review Guide of the Port Hueneme Division of the Naval Surface Warfare Center (PHD NSWC).

3-2-4 Enabling Metrics

3-2-4-1 Operations Manpower

Description: The number of people spending more than 50 percent of their effort on the system in preparation for or during its normal operations.

Units: Number of people/system

Data Sources: In-Service Engineering Agents, Type Commander

Issues: This “first order” metric does not account for the special training, experience or seniority that may be required. It also does not account for ship to ship or operation to operation tailoring to specific needs done at the local level.

3-2-4-2 Preventative Maintenance Manpower

Description: The number of person hours required per year to complete 100 percent of the required preventative maintenance assuming a normal or average system usage rate.

Units: Number of person hours/system

Data Sources: 3M database, In-service Engineering Agents

Issues: This metric does not account for tailoring to specific needs done at the local level.

3-2-4-3 Mean Time to Repair (MTTR)

Description: The average time elapsed between system failure and restoration to full operational capability, regardless of causes for delays.

Units: Days

Data Sources: OARS, 3M database, CASREP database, In-service Engineering Agents

3-2-4-4 Criticality

The extent to which the system is required to execute the ships' primary missions.

Evaluate according to the following index:

Index Value	Description
1	Not necessary for execution of primary missions.
2	Mission enhancing system. Negligible degradation of primary mission capability without the system.
3	Mission enhancing system. Minor degradation of a primary mission capability without the system.
4	Mission critical system. Major degradation of a primary mission capability without this system.
5	Mission essential system. Complete loss of a primary mission capability without this system.

Units: Nondimensional index, 1 through 5

Data Sources: NAVSEA program office, project management documentation

Issues: The data set that we selected (starting with the TMA/TMI systems) will by definition primarily have values of 4 or 5 for this metric.

3-2-4-5 Commonality: Total Number Installed in the Fleet

Description: The total number of systems installed throughout the fleet.

Units: Nondimensional sum

Data Sources: OARS, 3M database

3-2-4-6 Commonality: Number of Ship Classes on Which Installed

Description: The number of distinct ship classes with one or more of these systems installed as standard equipment.

Units: Nondimensional sum

Data Sources: OARS, 3M database

3-2-4-7 Reuse Content

Description: The proportion of system components or subsystems that were used on earlier models, similar or even on related systems. This is not applicable to simple upgrades of already installed systems.

Units: Percent reuse/system

Data Sources: NAVSEA program office, In-service Engineering Agents

3-2-4-8 Modularity / Upgradeability

Description: The degree to which an open architecture design was used and allows for modular upgrades, "plug and play" improvements in hardware and software. Evaluate according to the following index:

Index Value	Description
1	Extensive use of proprietary hardware and/or software. Upgrade requires renewal of entire system.
2	Moderate use of proprietary hardware and/or software.
3	Limited use of proprietary hardware and/or software. Upgrade possible leaving substantial portion of system intact.
4	Minimal use of proprietary hardware and/or software. Product improvement opportunities throughout life cycle designed into the system.
5	Complete use of open architecture, open standards. Specifically designed to facilitate continuous upgrades throughout life cycle.

Units: Nondimensional index, 1 through 5

Data Sources: NAVSEA program office, project management documentation

3-2-4-9 Military Standard/Specification Content in System Specifications

Description: The proportion of system components or subsystems covered by one or more military standard specifications.

Units: Percent milstd/spec

Data Sources: Program Office, In-service Engineering Agents, RFP Specifications

3-2-4-10 COTS Content

Description: The proportion of system components or subsystems that is commercially available off-the-shelf.

Units: Percent COTS

Data Sources: NAVSEA program office

3-2-4-11 Design Process Rigor

Description: The degree to which the full process for major defense acquisition programs according to instruction 5000.2 was followed and additional design process tools were used. Evaluate according to the following index:

Index Value	Description
1	One or more required milestones were omitted.
2	One or more milestones were deleted by the MDA.
3	Marginal compliance with all milestone and process requirements.
4	Thorough compliance, in letter and spirit, with all milestone and process requirements.
5	Complete compliance with 5000.2 plus use of one or more additional project management tools such as quality functional deployment, virtual prototyping, etc.

Units: Nondimensional index, 1 through 5

Data Sources: NAVSEA program office, project management documentation

Issues: This metric is fairly subjective and dependent on the “quality” of corporate memory and record keeping.

3-2-4-12 IPT Use

Description: The extent to which the IPPD process and IPT's were used. Evaluate according to the following index:

Index Value	Description
1	No use of IPTs or multidisciplinary teams during design process.
2	Minimal use of IPTs or multidisciplinary teams during design process.
3	Limited use of IPTs or multidisciplinary teams during design process. Stakeholder involvement and input actively solicited.
4	Moderate use of IPTs or multidisciplinary teams during design process. Most stakeholders actively involved.
5	Extensive use of IPTs or multidisciplinary teams during design process. All stakeholders actively involved.

Units: Nondimensional index, 1 through 5

Data Sources: NAVSEA program office, project management documentation

Issues: This metric is fairly subjective and dependent on the “quality” of corporate memory and record keeping.

3-2-4-13 Cycle Time

Description: The elapsed time between milestone 0 approval and Initial Operating Capability (IOC) achievement.

Units: Years

Data Sources: NAVSEA program office, project management documentation

3-2-5 Covariates

3-2-5-1 Corrective Maintenance Manpower

Description: The number of person hours per year spent on schedule maintenance of the system.

Units: Person Hours/system

Data Sources: OARS, 3M database, In-service Engineering Agents

3-2-5-2 Mean Time Between Failures (MTBF)

Description: The average energized time between failure events

Units: Days

Data Sources: OARS, 3M database, CASREP database, In-service Engineering Agents

3-2-5-3 Capability of Performance (direct enabling metric for system effectiveness outcome)

Description: The capability to perform a given mission; this metric is a measure of the inherent physical limitations of system within the physics of its mission environment. $P_c = 1 -$ the probability of failure without equipment, computer program, or human error.

Units: Nondimensional index between 0 and 1

Data Sources: NAVSEA program office, In-service Engineering Agents, Type Commander

Issues: Given the criticality of the selected systems, this metric is likely to be very close to 1.0 for all systems.

3-2-5-4 System Volume (direct enabling metric for system effectiveness outcome)

Description: the volume of space required aboard the ship by this system has installed. This volume includes any space surrounding hardware that is reserved for access, operations, cooling, etc. and thus not available for other systems. It also includes all major subsystems more than 50 percent dedicated to support of this system.

Units: Cubic feet/system

Data Sources: NAVSEA program office, In-service Engineering Agents

3-2-5-5 System Weight (direct enabling metric for system effectiveness outcome)

Description: The weight of the system as installed aboard ship including the weight of all major subsystems more than 50 percent dedicated to supporting the system.

Units: Tons/system

Data Sources: NAVSEA program office, In-service Engineering Agents

3-2-5-6 Acquisition Cost

Description: The average total cost to acquire one unit of the system including contract costs and project management costs. Project management costs include project office salaries from milestone 0 to IOC.

Units: Dollars/System

Data Sources: NAVSEA program office

3-2-5-7 Operations and Maintenance Costs

Description: The parts and labor costs per year for operations, PMS and corrective maintenance of the system.

Units: Dollars/system

Data Sources: OARS, 3M database, In-service Engineering Agents

3-2-6 Outcomes

3-2-6-1 Operational Availability (lower level outcome metric)

Description: The likelihood that, when required, a system is operating at a predefined performance level for a sufficient duration of time to accomplish its mission. $A_o = \text{MTBF}/(\text{MTBF}+\text{MTTR})$

Units: Nondimensional index between 0 and 1.

Data Sources: In-service Engineering Agents, TMA/TMI, OARS, CASREP database

3-2-6-2 System Effectiveness

Description: The relative ability of equipment or system to complete its mission.

It is the product of four ratios.

- System capability of performance divided by the mean capability of performance for all similar systems.
- System operational availability divided by the mean operational availability for all similar systems.
- Personnel requirements (sum of operations and preventative and corrective maintenance person hours per hour of system operation) for all similar systems divided by personnel requirements of subject system.
- Mean ship impact (product of volume and weight) for all similar systems divided by ship impact of subject system.

Units: Nondimensional index

Data Sources: In-service Engineering Agents, TMA/TMI, OARS, NAVSEA program office

Issues: NSWC PHD cautions that their experience with similar definitions has shown that is difficult to combine these components in a mathematically sound fashion. They have begun analyzing the components in as quantitative a manner as possible but then assigning a qualitative value for effectiveness (read, yellow, or green) based on an engineering assessment. With our hierarchy and construct, operational availability will be the primary driver for this outcome.

3-2-6-3 Total Ownership Costs

Description: The sum of all costs incurred in all cost categories over a project, product or system's anticipated useful life divided by years of useful life.

Units: Dollars/System

Data Sources: In-service Engineering Agents, TMA/TMI, OARS, NAVSEA program office

Issues: There are numerous definitions for this metric throughout NAVSEA. Including acquisition cost is difficult given the uncertainty of the system service life / period for amortization.

3-2-6-4 Judged Overall Success

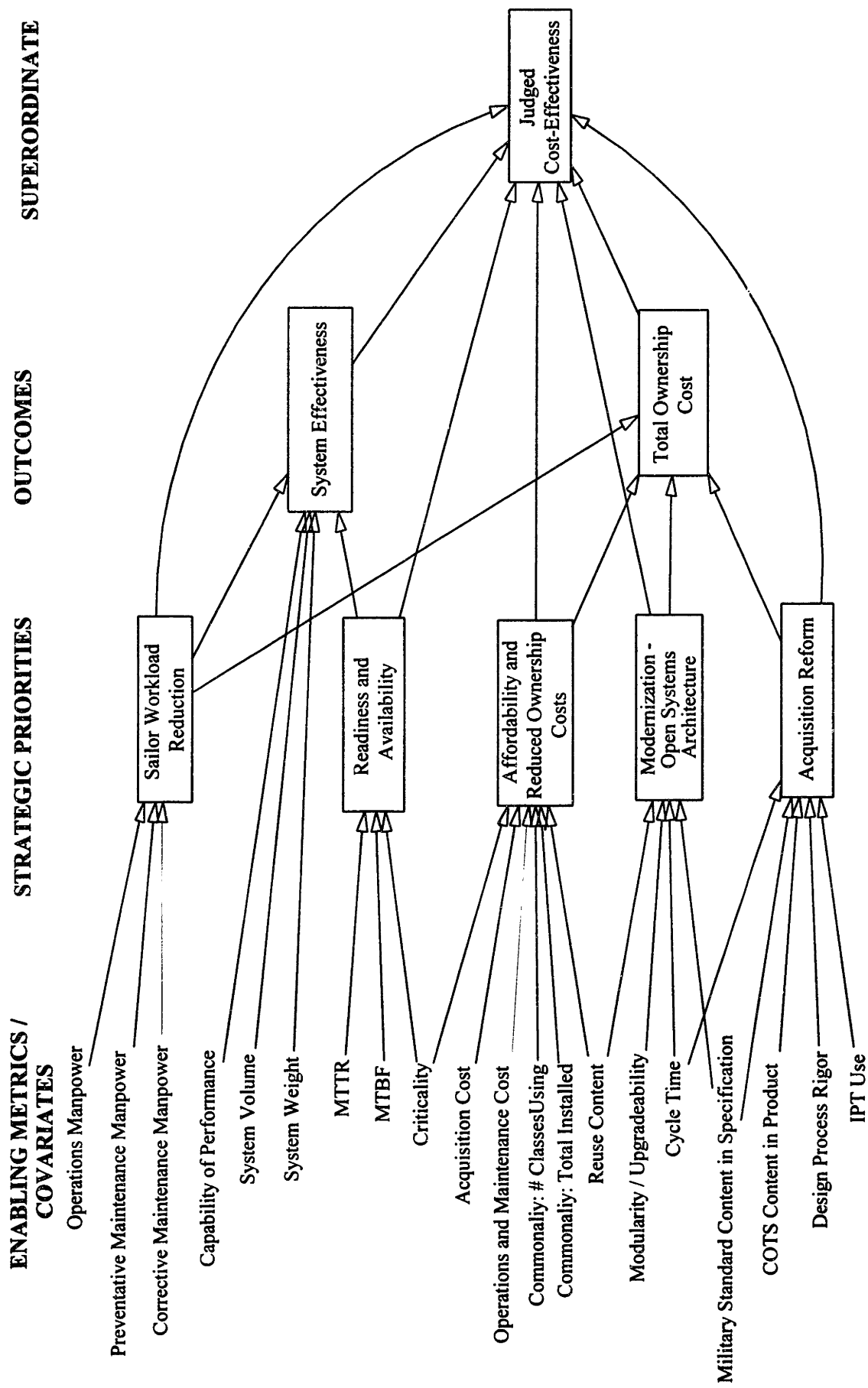
Description: A qualitative measure that is primarily a function of system effectiveness and total ownership cost. However, judged success in meeting objectives of the organization’s strategic priorities should also be considered. 3 experts; 1 each from the NAVSEA program office, the in-service engineering agent and the type commander, will evaluate the system according to the following index:

Index Value	Description
1	Major problems/substantial degradation of mission capability due to shortcomings in capability, availability, workload, cost and or ease of technical refreshment.
2	
3	Minor problems/significant degradation of mission capability due to shortcomings in capability, availability, workload, cost and or ease of technical refreshment.
4	
5	Consistently meets all mission requirements. No problems/ degradation of mission capability due to shortcomings in capability, availability, workload, cost and or ease of technical refreshment.

Units: Nondimensional index between 1 and 5

Data Sources: In-service Engineering Agents, NAVSEA program office, Type Commander

3-2-7 Figure 4 - Summary Visual Representation of Metrics Construct



3-3 Potential Limitations and Weaknesses

Regarding the selection of effective acquisition process metrics, Pinker et al. (1997) warn that combining various metrics into one big picture is difficult because directly computable metrics tend to be limited in scope and specific in nature. "Past efforts to combine metrics numerically have usually failed." They proposed solving this by using Quality Function Deployment (QFD) or Analytical Hierarchy Process (AHP) to engage the relative contribution of the metrics at one level to the metrics at a higher level. "QFD offers interesting opportunities for linking metrics from one level of abstraction to a higher level. The ranking of metrics in the QFD process allows one to select the relatively important metrics. This prioritization could lead to a more efficient strategy for assessing the acquisition process."

The metrics thermostat actually evolved from QFD and AHP. Further, it incorporates a practical application of agency theory. Going beyond simply selecting the relatively important metrics, we intend to use statistical analysis to update (and ultimately seek) the optimal priorities associated with each metric so that overall success is maximized. We will validate our results with experts' judged cost effectiveness as an outcome.

The single biggest weakness of this metrics framework is the possibility that significant organization priorities and metrics have been missed. Without having a NAVSEA command level perspective or critique, we have posited our own subset of strategic priorities and desired outcomes based on published issues being faced at lower levels in the organization. Similarly, we chose lower tier enabling metrics, which were already in use, and for which we hoped data would be readily available. Because of these factors, this work is meant only to be a demonstration as to how the metrics thermostat might work in the military acquisition setting. It should still provide some insight relative to the marginal priorities of the chosen metrics, but it is not meant to definitively address the organization's strategic position and direction.

Another potential limitation, at least in communicating the results, is that the framework will mean different things to different people. There are conflicting definitions and uses for the same metrics throughout NAVSEA. Higher-level metrics, particularly operational availability, effectiveness, and total ownership cost have different definitions in different offices within NAVSEA. Using portions of different definitions and different data sources in the same construct and analysis risks losing something of the original context in which the metric was intended to be used. The underlying agency theory applied at individual operating points attempts to address this on the firm level assuming all people are working at their local efficient frontier.

Shifting priorities over time and over the span of projects mean metrics have shifted function. For instance, programs using Cost As an Independent Variable (CAIV) could turn acquisition cost from a covariate into an enabling metric. Depending on perspective within the organization one could argue acquisition reform and modernization through open architecture are more like high level enabling metrics than stand alone strategic priorities. These issues will be addressed by trying alternative metrics constructs in the regression analyses.

Chapter 4- Data Collection

4-1 Process

The wide variety of specialized organizations and the compartmentalized and stovepiped nature of the NAVSEA organization made data collection a challenge. We wanted to use existing databases and readily available information as much as possible to minimize our impact on the organization and expedite the research. In the end, data was collected in a number of ways and from several sources throughout the NAVSEA organization (and the country).

Selecting systems to use as data points was the first step in the process. We considered everything from entire ships to individual pumps and motors. Major systems were chosen based on their impacts on the ship's mission as a whole as well as the availability of valid data. Effectively, this became an iterative process. The chosen priorities and metrics led us to certain systems, which in turn led us to certain organizations.

Interviews and discussions with these organizations suggested different metrics and systems as better targets for our study. This led us to modify our set of metrics and systems which then led us to different organizations and so on.

We chose the five-year period, January 1994 through December 1998, as the bounds for data collection. Wanting a large number of systems in our data set, we did not restrict ourselves to system introduced during that period. In fact, most of the systems were in service prior to 1994. Given the dramatic reduction in budgets and employees in the 1990s, NAVSEA did not introduce that many new combat systems during the 1994-1998 period. We felt we could still adequately link these systems to sufficient variability in most of the enabling metrics and covariates to make the demonstration meaningful.

4-2 “Data Points” / Candidate Systems

Instead of new copiers or new cars, we based our study on major combat, hull, mechanical and electrical systems. New ships might be more analogous to cars and copiers as the ultimate product of your station but they are not produced in sufficient numbers for our statistical analysis. To enlarge the product and model population, we initially targeted hull, mechanical and electrical (H,M&E) systems but ran into a number of difficulties. Beyond design of interfaces and integration into the larger ship system, H,M&E systems tended to be substantially commercial-off-the-shelf (COTS) and not really NAVSEA products. These items also tended to have a lower criticality and therefore were treated with less rigor by the program offices as well as the in-service engineering agents. This further translated to a sparsity of reliable data.

Combat systems were then made the primary focus due to the greater depth and reliability of the data available. In selecting candidate systems as data points the TMA/TMI program was again a very helpful starting point. In the normal course of their work, they were collecting data on some of the Navy's most interesting systems, combat and H, M&E. They had done much of the difficult work of defining and bounding a system by its primary components and subsystems. The highly integrated nature of the combat systems and the ship surrounding them made this a difficult task. Within several of the Navy databases, this requires identifying and aggregating a combination of Equipment Identification Codes (EICs) and Allowance Parts Lists (APLs). Without years of experience in the Navy logistics world this system can be quite confusing.

We finally settled on 47 data points or systems. These included:

- 7 radars
- 7 sonars
- 6 fire control systems
- 5 missile launchers
- 3 electronic countermeasure systems
- 3 navigation systems

- 4 gas turbines
- 3 air conditioning plants
- 2 diesel engines

4-3 Data Sources

Personal interviews, databases, project documentation and routine reports from all the following organizations were used to collect data:

The Naval Sea Logistics Center (NSLC) is a field activity of the Naval Sea Systems Command Logistics Directorate (SEA 04) and serves as the Naval Sea Technical Agent for developing, maintaining, and assessing life-cycle logistics support policies, procedures, and data systems. Created to be the interface between engineering and logistics, it performs a wide range of logistic support functions. NSLC is the Navy's primary maintenance and logistics database and systems manager.

Open Architecture Retrieval System (OARS), maintained by the NSLC, is a windows-based desktop tool designed to access information from multiple databases regarding equipment operational availability and fleet readiness. It is powerful in terms of the span of databases it can query. However, NSLC's claims that the system is intuitive, flexible, quick and easy to use were not supported by our experience.

Ships Maintenance and Material Management (3-M), maintained by the NSLC, contains preventative and corrective maintenance information for organizational and intermediate levels of maintenance that is essential to achieve maximum equipment operational readiness. The ships 3M system provides all program managers, maintenance activities and engineers with maintenance and material data throughout the life cycle of an equipment. The quality of data in the 3m database is dependent on proper completion of 4790.2K forms by each ship's force.

Casualty Report (CASREP) database, maintained by the NSLC, contains all casualty report information including fleet-wide number of failures, severity of the failures, time between failures, time to repair and causes for delay in repairs. The quality of data in the 3m database is dependent on proper completion of casualty reports by each ship's force. This data may not reflect 100% of all failures.

TMA/TMI is a cooperative effort between the Type Commanders, NAVSEA headquarters and In-service engineering agents to objectively identify critical fleet maintenance issues, which negatively impact material readiness, cost, and/or training. The group focuses management attention and diverse resources on actions to correct these critical issues and actively monitors corrective actions with useful metrics to determine the degree of success. The TMA/TMI analysts have become experts at discerning critical systems and gleaning useful metrics from diverse data sources. Continuously monitoring maintenance activity, parts and labor costs, failures and operational availability for systems in the program. Thus, they were an invaluable resource not just for specific data needs but for process and technique in querying different databases and a list of primary sources for a variety of different data needs.

Type Commander is the operational Navy's expert and advocate for a specific class of ship. Each class has its own type commander responsible for maintaining operations and engineering doctrine and policy and performance standards. They monitor individual ship as well as fleet operational readiness. They are the best source for consolidated end user evaluation of systems and feedback.

FTSCLANT is a field service engineering activity providing direct support to the fleet, type commanders and regional maintenance centers, in matters of technical and logistics services, and meeting with installation, operation, alteration, maintenance, and readiness of shipboard equipment and systems. They do much of the TMA/TMI analysis work and also supply the deckplate expert technicians linking the individual ships with the type commander or in-service engineering agent expertise.

Port Hueneme Division of the Naval Surface Warfare Center (PHD NSWC) designs, develops, tests, and certifies system performance and safety. A system is effective if it is reliable, works when it needs to work, has been fully tested at sea under stressful, threat-like conditions, and sailors are trained to employ and maintain the system. System effectiveness means that the detect, control, and engagement elements of the combat system all work together in an integrated, seamless manner. Finally, a system is effective when the sailor can get help when he or she needs it, anytime of the day, any day of the year, anywhere in the world. PHD NSWC is a key source of expertise and data on radar, fire control and missile systems.

NAVSEA Program Offices are the Navy's nearest equivalent to new product development teams. More and more they are populated with IPTs, but have long depended on multi disciplinary teams to integrate a variety of experts support functions from within the navy and from the commercial sector through contracts. They maintain all project documentation during the concept exploration, program definition and risk reduction, engineering and manufacturing development, and production, fielding, deployment and operational support phases of the acquisition or new product development process.

Space and Naval Warfare Systems Center (SPAWAR) designs, builds, tests, fields, and supports the frontline command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems used today, or planned for the future. They are key sources of data for navigation, communications and electronic warfare systems.

The Naval Undersea Warfare Center (NUWC) is the Navy's full-spectrum research, development, test and evaluation, engineering and fleet support center for submarines, autonomous underwater systems, and offensive and defensive weapons systems associated with undersea warfare.

4-4 Difficulties / Weaknesses

The wide variety but relatively low volume of highly specialized systems typical of the military and present in our sample make comparison and identification of trends difficult. Proving statistical significance requires a sizable sample of similar cases. "Repeatable processes, highly desirable for drawing statistical inferences, are usually unavailable for a weapon system acquisition. Such an acquisition is in most cases a unique event. Moreover, the success or failure of the acquisition is determined in retrospect by how well the weapon system has served the military." (Pinker et al., 1997) Our hope is that by making the sample large enough and metrics robust enough we can discern underlying signals from the expected and necessary noise.

Another problem in the sample is system configuration control. In reality, there are small variations in system design and operation across applications in the fleet. Some of these may be systemic and purposeful depending on the class of vessel and their intended missions. Others may be almost random as the operators on each ship slightly modify the system or their operational procedures to fit local experience and needs. Configurations also change over time as new "versions" and "mods" are retrofit into the fleet. All of these variations are usually small and only incrementally change the general functionality and performance of the system. However, we are not knowledgeable enough on many of the systems to know when the differences have been significant. Again, if we assume everyone is individually operating on their own efficient frontier, these local optimizations will simply map onto the firm's frontier.

Our sample is not random or necessarily representative of typical NAVSEA products. To facilitate quicker data collection a majority of the systems came from the TMA/TMI program. These are by definition the more "troubled" systems. We did our best to mitigate this by adding similar "untroubled" systems to the sample. Ideally, we may want interesting variations in enabling metrics and outcomes more than a statistically correct, population representative sample to provide an adequate feedback signal to the metrics thermostat.

The contraction and reorganization of NAVSEA throughout the 1990s has moved or removed many of the key people in the product development teams and in-service engineering teams. Corporate memory of such metrics as design process rigor for 15-year-old projects was in many cases a bit cloudy. Another result of this is that the remaining people feel as though they are busier than ever and indeed they were difficult to contact.

Chapter 5 – Preliminary Data Analyses / Results

Data collection proved to be quite challenging and we not collected sufficient data to perform interesting regression analyses. There is no shortage of data but it is extremely compartmentalized, sometimes intentionally, often unintentionally. Within each division or database, we were interested in very specific elements and only a small fraction of the whole. Thus, the data gathering process is akin not to searching for a needle in a haystack, but for searching for 2000 needles in 200 haystacks. To date we have populated only 25% of the approximately 2000 data elements (50 systems times 40 data fields) desired.

However, a cursory review and analysis of the data collected thus far demonstrates some degree of face validity and reliability. Some of the early data and simple graphs show clear patterns that make intuitive sense. For instance, in figure 5 we see that corrective maintenance work is inversely related to MTBF. The relatively limited scatter gives us some sense of the data's reliability and the intuitively correct relationship of less maintenance required for systems that fail less frequently gives us some confidence in the face validity. The apparent strength of the relationship also suggests – not surprisingly - that our future regression analyses will likely indicate a significant correlation between MTBF and Sailor Workload Reduction even though our initial construct shows MTBF primarily as an enabling metric for Availability.

Similarly, figure 6 shows a clear relationship, albeit with more scatter, between maintenance costs and system population or commonality. Again, this supports face validity. One-of-a-kind systems or systems produced and operated in very small numbers do not benefit from economies of scale in training, parts procurement and maintainer experience. Design quality, perhaps partially captured in the enabling metric of design rigor, would likely correlate to some of the scatter portrayed. Well-designed systems, even if produced in small numbers should have lower maintenance costs.

Figure 5 - Maintenance Work vs MTBF

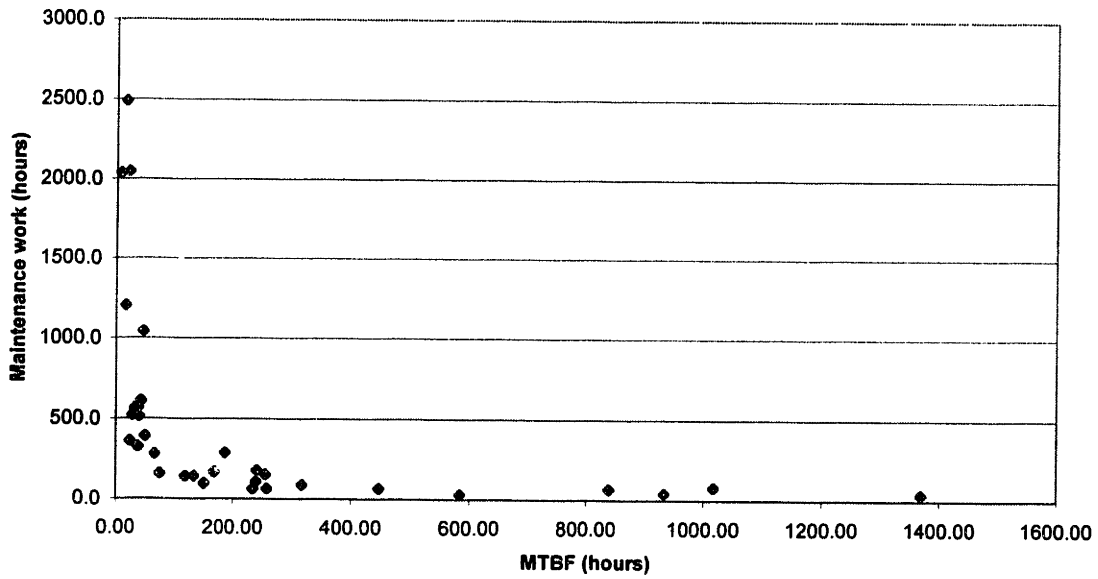
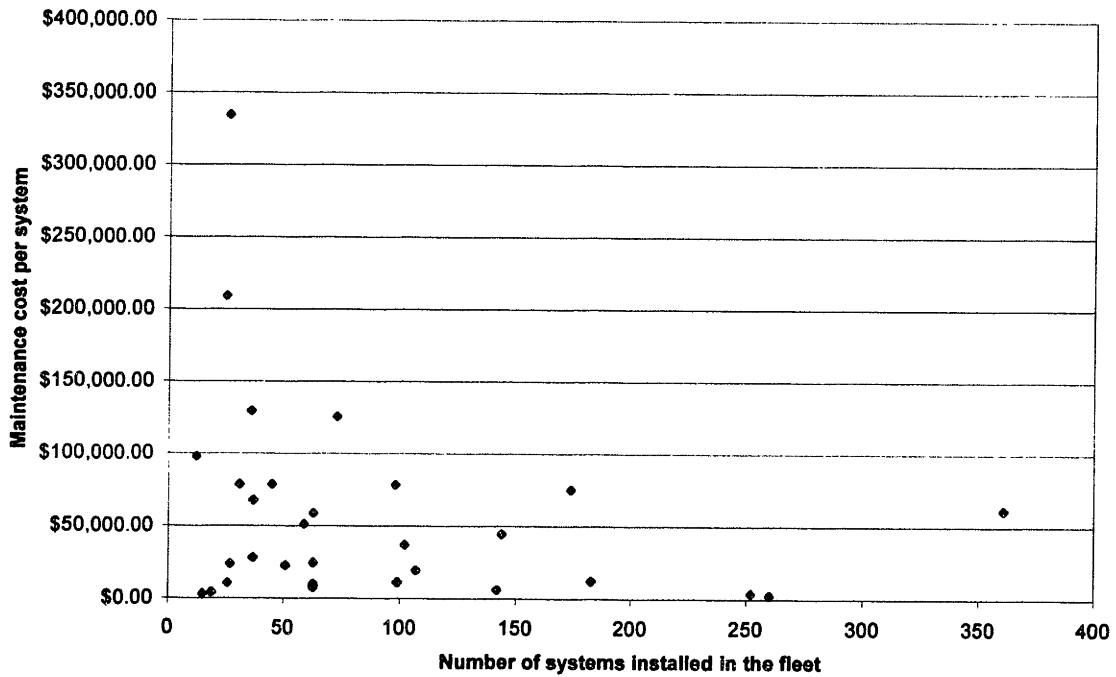


Figure 6 - Maintenance Cost vs Population



Very few products in our data set were introduced during the investigated time period or even during the past decade. The 1990s and 1994 through 1998 in particular were a slow

period for new NAVSEA product introductions due to significant budget cutbacks and extensive downsizing and reorganization. Additionally, NAVSEA's product development cycle time, while reportedly improving, is still much longer than typical commercial enterprises. Thus, significant affects of acquisition reform and the other strategic priorities will diffuse into the service inventory slowly.

Chapter 6 - Conclusions and Recommendations

While we have not yet been successful in collecting enough data to effectively test and demonstrate the metrics thermostat concept, the progress thus far has convinced us of the need to continue. Our accomplishments, conclusions and recommendations are below.

6-1 Accomplishments

Steps 1 through 4 of the methodology outlined in Chapter 3 have been completed. As noted in steps 7 through 11 further iterations and refinement will be required. Still a working metrics hierarchy and construct has been developed.

- Desired outcomes or profit analogies, namely, System Effectiveness, Total Ownership Cost and Judged Cost-Effectiveness, have been defined to value and differentiate strategic priorities, enabling metrics and covariates.
- Five strategic priorities aligned with NAVSEA's stated goals have been selected: Sailor Workload Reduction, Readiness and Availability, Affordability and Reduced Ownership Costs. Modernization Through Open Systems Architecture, and Acquisition Reform.
- Enabling metrics and covariates directly impacting the strategic priorities and desired outcomes have been defined.
- A broad level of product complexity has been selected as a basis for system selection and approximately 50 product/systems have been identified and investigated to varying degrees.

Significant progress has been made toward step 5, actually collecting the defined data fields for the selected data points/systems.

Finally, preliminary work done on step 6 indicates that there are trends and patterns in the data. This provides hope that the combination of a large data set and broad, robust metrics will reveal meaningful correlations and leverages.

6-2 Conclusions

Most of NAVSEA's products have little or no application in the commercial world and fortunately the United States has engaged in few naval conflicts over the past two decades. This lack of combat engagements and other tests in some way analogous to the competitive landscape of the commercial marketplace means that NAVSEA and similar organizations are judged by surrogate metrics. This makes these metrics and their link to in-service performance all the more pertinent. All of the following issues discovered during the course of this research could benefit from a mechanism such as the metrics thermostat:

- The TMA/TMI programs questions regarding which strategies have been most effective in correcting in-service system problems
- PHD NSWC Executive Director's assertion that in-service engineering agents and design agents must become more closely coupled
- The ongoing NAVSEA Balanced Scorecard development effort
- The potentially confusing profusion of priorities and metrics above, below and within NAVSEA.

Beyond this metrics regression analysis and demonstration, the NAVSEA environment also appears to be a rich opportunity to further investigate and apply the agency theory aspects of the metrics thermostat. Beneath and amidst the hail of initiatives and priorities, NAVSEA program offices must translate operational requirements into product specifications and eventually new ships and combat systems. The sheer volume of priorities, initiatives and metrics reduces the impact of any single priority that does get through the *noise*. In our interviews, we frequently found people turned off as soon as we started discussing priorities and metrics. The message was clear. "No thanks, I have too many of those already." Perhaps most telling along this line is what we did not hear. In outlining his strategy for affordability in January 1999 Undersecretary of Defense for Acquisition, Technology and Logistics, Dr. Jacques Gansler, wrote, "his strategy seeks to reaffirm a close partnership across the department to accelerate the process. We are

actively soliciting your help and ideas on changes needed at all levels. (E-mail us at feedback@acq.osd.mil) We have an open door for your ideas and will support you. All of us need to bring about a revolution in the way we do business." We received no response to our e-mails offering assistance through this research. In fairness, we did not communicate a clear sense of how our research would be useful or a request for specific assistance. We now have a clearer sense of the research's utility and specific requests for data.

Fortunately, several of NAVSEA's many priorities are aligned or at least stress similar themes, but there is considerable conflict as well. Those priorities, initiatives, objectives and metrics that rise above the din raise interesting and challenging agency issues:

- War fighter performance demands verse Congressional and White House budget demands
- Department of Defense jointness vs. Navy "competitive advantage"
- Military specifications verse commercial specifications
- Automation verse job security
- Short-term career objectives verse long-term program objectives
- Frequently rotating military personnel verse specialty, career minded civilians
- COTS verse military specialization
- High-tech performance verse robustness
- New product development verse maintenance of current systems

6-3 Recommendations

We must continue tracking down data through the various in-service engineering agents throughout the Navy. They have been very helpful thus far. However, their specialized nature and the variety of systems we are investigating require us to work with many of them in many different offices and locations.

The problems we intend to address, our proposed solution, and our data needs are now much more clear, at least to us. We need to reengage NAVSEA program offices to get

more assistance. We had hoped to have a more conclusive demonstration study to show them but we need a little more interaction to get to a meaningful result. Specifically, we need them to:

- Critique the metrics hierarchy and definitions
- Provide access to their program offices or new product development teams
- Sponsor our efforts to collect data in their subordinate commands around the country

Finally, we need to initiate new contacts with the type commander organization to better get at the voice of the sailor, customer.

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