

**DAHLGREN DIVISION  
NAVAL SURFACE WARFARE CENTER**

Dahlgren, Virginia 22448-5100

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**NSWCDD/TR-08/98**

**COST-EFFECTIVE STRATEGY FOR SURFACE NAVY  
SYSTEMS INTEGRATION AND TEST ENGINEERING**

**BY ANTHONY SCARAMOZZI**

**WARFARE SYSTEMS DEPARTMENT**

**AUGUST 2008**

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## FOREWORD

This document describes the complexity and burgeoning inter- and/or intraconnectivity demands that have imposed an infrastructure within the Naval Warfare Enterprise that includes test and evaluation as a significant aspect of each Navy Combat System Acquisition Program as well as support for deployed units. This paper will provide insight into the current state of the Navy land-based test infrastructure and capability and how it is exploited for large-scale complex system acquisition support. Strategic options for adjustment to optimize the infrastructure, funding paths, process, and organizational alignment and potentially offer a more cost-effective, integrated approach to providing certified Navy warfighting capability are explored.

This document has been reviewed by G. Dale Galyen, Deputy Department Head, Warfare Systems Department.

Approved by:

A handwritten signature in black ink, appearing to read "D. Burnett", with a stylized flourish at the end.

DONALD L. BURNETT, Head  
Warfare Systems Department

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**GLOSSARY**

<b>Acronym</b>	<b>Definition</b>
ASN(RDA)	Assistant Secretary of the Navy (Research, Development, and Acquisition)
COMNAVSEA	Commander, Naval Sea Systems Command
CONUS	Continental United States
GFE	Government-Furnished Equipment
LBTS	Land-Based Test Site
LSI	Large-Scale Integration
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NGS	Next-Generation Simulation
NSWCDD	Naval Surface Warfare Center, Dahlgren Division
NSWCPHD	Naval Surface Warfare Center, Port Hueneme Division
PEO IWS	Program Executive Office Integrated Warfare Systems
PM	Program Manager
SES	Senior Executive Service
SoS	System of Systems
T&E	Test and Evaluation
TC	Technical Capability
TEMP	Test Engineering Management Plan

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## 1.0 SCOPE

### 1.1 Introduction

Key to the success of almost any surface ship combat and/or warfare system acquisition program, test and evaluation (T&E) is a complex process of requirements evaluation, Test Engineering Management Plans (TEMPs) development, testing development, scheduling, execution, analysis, and certification. Each component, element, subsystem, and system within a ship is tested extensively to ensure that the ship's systems meet mission requirements, are safe to operate, and are effective. A building block approach is used by each acquisition program, which tailors the test process to the program budget and direction of each Program Manager (PM). The result is a different test process for almost every program, depending on the requirements, the platform, and which organization leads the test process. This approach allows each acquisition program to develop infrastructure that is finely tuned to the respective program's requirements. However, it can also result in duplicate organizations, infrastructures, and investments that, while creating efficiencies for individual programs, can create unnecessary expenditure of the overall Surface Navy combat system integration and test budget.

Determining T&E cost is a hugely complex issue, and it is worth noting that testing in a land-based test environment can cost eight to ten times less than it costs the Navy to conduct the same test at sea. Empirical data indicates that most relatively complex acquisition programs expend nearly 30 percent of their budgets for integration and test purposes. Thus, presenting options, opportunities, and a strategy for cost-effective Surface Navy combat system integration and testing within recognizably constrained budgets is worth pursuing. The combination of people, processes, and facilities together forms the basic T&E capabilities across the Warfare Centers and test sites for the Naval Sea Systems Command (NAVSEA) and the Assistant Secretary of the Navy (Research, Development, and Acquisition) [ASN(RDA)]. Integration of systems requires unique expertise, and moving from a loose collection of systems engineering and test engineering talent to cohesive activity, alignment, and unity of effort is a real challenge. Shifting from industry leadership to government leadership of large-scale integration and testing is also a difficult transition to make because so much government expertise has shifted to industry due to the approach taken through acquisition reform.

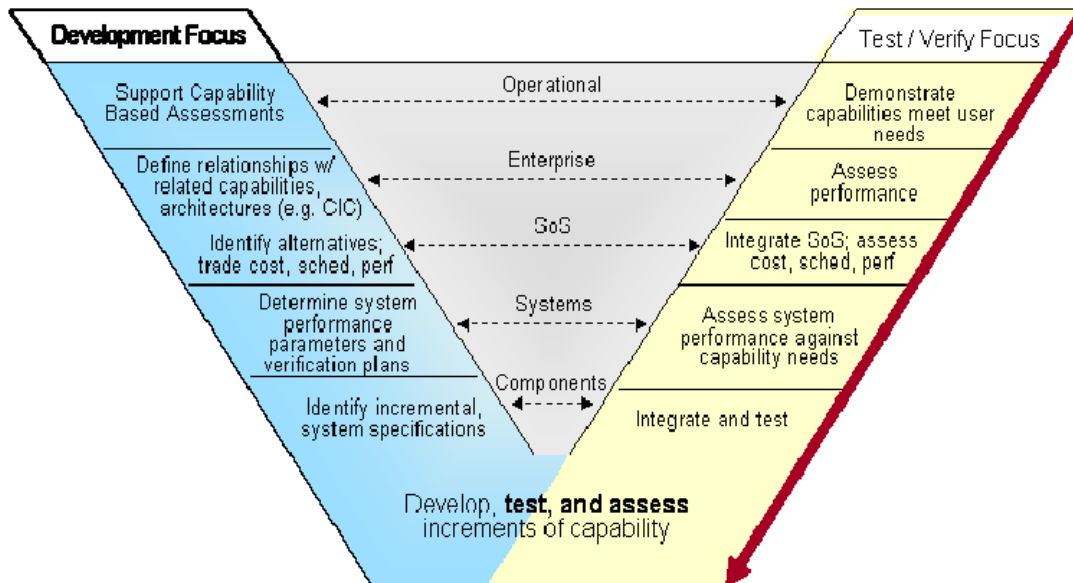
#### *1.1.1 Background*

Following the Reagan era budget plus-ups toward the end of the Cold War, the United States began efforts to claim the new "Peace Dividend." Since 1985, the budgetary high-water mark of the Cold War, funding for defense has declined and the "Peace Dividend" eroded. Since then, with the cost of the Global War on Terror and other budget issues, the test community within the Surface Navy has seen a steady decline in funding and a push for continued cost avoidance by increasing the role of industry in the acquisition, systems integration, and test processes. The Surface Navy test community has struggled to accomplish the necessary task of performance characterization and conduct testing sufficient to provide inputs to the certification process for Surface Navy systems and, more precisely, combat systems, despite this funding decline.

With the looming development of CVN 78, DDG 1000, the Littoral Combat Ship, Amphibious Transport Dock, Aegis Modernization, Aegis Ballistic Missile Defense, and other requirements facing the integration and test community, finding a means to cost-effectively integrate test systems for deployment and mission execution is a critical component of each acquisition program budget.

## 1.2 The Building Blocks

Surface Navy combat systems are complex entities designed and built in stages of increasing complexity and intra/intersystem connectivity, communication, dependency, and operation. The integration and test process applies a similar building block approach, with hardware and software components tested as they are developed. As they are grouped within functions for system performance, they become elements, subsystems, systems, and a system of systems (SoS). For shipboard installation and test, there is a formal seven-stage process as presented in DoD-STD-2106 that reflects a similar building block approach (Reference 1). This approach (albeit in various forms) surfaces at the factory or with the developer, in land-based test sites (LBTSs), and finally aboard ship. Software testing for Navy combat systems holds to a similar disciplined building block approach with tailoring by each organization involved. To some degree, migration has occurred from the waterfall\* model for software systems to a spiral model\*\* for development and deployment (Reference 2). However, the spiral model applies engineering within the spirals, such that the building block approach is nevertheless employed with a characteristic “V” shape (see Figure 1) to the overall process from concept, through development, to deployment.



**Figure 1. Systems Engineering V-Chart**

\* Waterfall model derived from the cascading effect of movement from one phase to the next, where each phase is generally well defined and separate.

\*\* Spiral model combines elements of design and development stages.

The V-Chart, as it is referred to in the systems engineering community, rests upon a foundation of disciplined testing designed to assure expected performance. Most testing stems from the systems engineering discipline and, in fact, many consider it a subspecialty. However, it should be noted that, from the competency perspective, T&E stands shoulder to shoulder with other competencies in the Competency-Aligned Organization and, at NAVSEA, is covered under the cognizance of the same Senior Executive Service (SES) leader as the Systems Engineering Competency.

T&E execution has seven basic steps: (1) identifying system performance expectations and the test requirements, (2) planning, (3) conducting pretest analysis, (4) tailoring the test process, (5) scheduling and executing the test, (6) conducting posttest evaluation (analysis), and (7) reporting. As stated previously, these steps are accomplished according to each program's requirements and are therefore targets of opportunity for competency development; movement toward more common, more useable, and effective tool sets; standardized processes; consistent and persistent teams; and formal (and possibly accredited) test discipline.

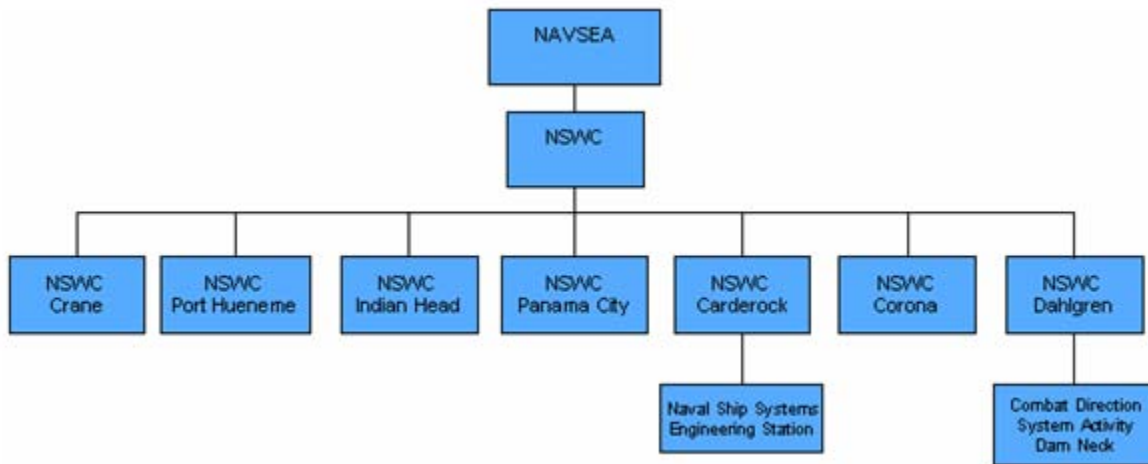
Testing is an essential feedback loop that provides assurance that the system or SoS meets capability expectations and mission requirements. A significant portion of the test process is or can be conducted at LBTS facilities throughout the United States. These sites have grown in size and complexity as situations have merited, as requirements have dictated, and as budgets have allowed.

### **1.3 Current State**

Each LBTS facility was developed to address requirements within a particular domain, area of responsibility, or technical capability (TC). A TC is defined as "representing the blending of intellectual and physical assets provided by a cadre of technical people with knowledge, skill, experience, and requisite facilities and equipment that yield the ability to deliver technical products." (See Reference 3.) For instance, the Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD), lists nine TCs, each of which includes T&E in the title and in the detailed description as well. As it turns out, there is overlap between the NSWC PHD TCs and those of other Warfare Centers (see Figure 2), such as Naval Surface Warfare Center, Dahlgren Division (NSWCDD); but the overlap diminishes with an understanding of each TC's application. Some examples are PH02 Surface Combat Systems In-Service Engineering T&E, and Integrated Logistics Support for NSWC PHD; DD 05 Surface Combat Systems Engineering and Integration Research, Development, Test, and Evaluation for NSWCDD; and DD 35 Integrated Surface Combat Control and Systems Support for Dam Neck.

The essence of the difference in this case is that NSWC PHD leads the at-sea test efforts, while NSWCDD and Dam Neck lead land-based test efforts in their respective domains. As can be seen from the example, some overlap provides a mutually supportive and beneficial aspect embedded in the warfare system TCs. Over time, however, the same apparent overlap has contributed to establishment of infrastructure that, if left to individual PMs to decide, will grow to meet individual program needs but won't necessarily be harnessed collaboratively to meet the requirements of the larger Navy budget constraints. One approach to rectify the drift toward independent, overlapping, and duplicative capabilities is to develop partnerships across the

Warfare Centers that leverage existing Warfare Center strengths rather than developing or creating further duplication.



**Figure 2. Naval Surface Warfare Center Chain/Construct**

## 1.4 Opportunities

There are many significant areas in the Surface Navy combat system test domain that together form targets of opportunity for adjustment to achieve greater collaboration across the Warfare Center and the activities,\* and achieve significant measures of cost avoidance and cost savings\*\* for the Navy. Factors include the following:

1. Surface Navy combat system T&E requirements are significant budget drivers.  
This significant budget driver surfaces for many reasons. Significant among them are the high cost of new facilities to meet new requirements, the inefficiency of distributed investments to achieve similar goals by different programs<sup>†</sup> and sponsors,<sup>‡</sup> and the overlap of government and industry roles and infrastructure that drives investment duplication. An example of infrastructure is the costly development of a simulation/stimulation integration and test environment for each new program.
2. There is currently no mechanism for singular task generation across Warfare Centers to address test requirements.

Due to a number of factors, each Warfare Center is independently funded to accomplish similar tasking across different programs and sponsor requirements. Warfare Centers are working capital fund organizations. In essence, that means that when a requirement exists that a Warfare Center can fulfill and a program or sponsor is willing to fund, the center is paid. That is opposed to mission funding, which refers to being a part of a line item in the President's budget. Other influences include the variation of

\* "Activity" or "activities" sometimes refers to sites that do not fall within the Warfare Center construct.

\*\* "Cost avoidance" is akin to efficiency in that it refers to the ability to do more or the same for less money, while "cost savings" addresses money returned to the sponsor.

† "Programs" in this context refers to acquisition programs such as Aegis or Littoral Combat Ship.

‡ "Sponsors" are organizations such as NAVSEA 05 that have requirements that must be funded to fulfill but do not "own" programs.

technical capability (which incorporates overlap), personal preference or bias, and legitimate program requirements that must be met.

3. There are overlapping site-, Warfare Center-, industry-, and sponsor-supported integration and test efforts and capabilities.

The last target of opportunity for achieving greater efficiencies and effectiveness is that there are duplicative investments across sites, Warfare Centers, industry, and sponsor-supported integration and test efforts and capabilities. This can lead to the instantiation of redundancies geared toward optimizing for legitimate program requirements, such as meeting demand versus capacity realities. This duplication of effort can also be a function of the constructs of the acquisition process that does not easily provide for overarching mechanisms for bigger Navy support structures as opposed to individual program requirements. To achieve cost avoidance and improvement in competency (Reference 4),\* capability (Reference 5),\*\* and effectiveness and instantiating an independent structure for combat systems integration and test requirements, an integrated test approach can be stood up.

## **1.5 Desired (Future) State**

The issue for attempting any alignment of effort across the Warfare Centers is that each center receives funding and direction from a myriad of customers, such as NAVSEA 05 and Program Executive Office Integrated Warfare Systems (PEO IWS), to accomplish similar work. Thus, leadership, cost sharing, and control surface quickly as significant issues to be overcome in any associated alignment strategy. However, a vision can be achieved for unified and aligned efforts (see Figure 3), and the many Warfare Centers can be bent to operate as a singular integration and test enterprise with respect to Surface Navy combat systems. Such a state would account for alignment, from the bottom to the top, of the integration, test, and evaluation processes as illustrated in Figure 4.

### ***1.5.1 Leadership***

In order to achieve the vision of an integrated test approach across the Warfare Centers, we may need to lessen the need for individual program management to control every aspect of the infrastructure and process associated with that program's success; no small matter to consider. It is also important that the Warfare Centers and other integration and test sites operate collaboratively rather than as individual organizations looking out for each program, without consideration for the cost to other programs for individual approaches to the Surface Navy combat system test process. Responsibility could be transferred to the Integrated Test Team leadership for effecting optimum test processes across acquisition programs and for optimizing to achieve maximum cost effectiveness as well. With an eye toward meeting multiple rather than singular stakeholder needs, an integrated test team can provide the linkage between capability, budget, and test requirements, as shown in Figure 5. However, this is a paradigm shift for

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\* The state of having attributes, expertise, and knowledge that are "adequate for the stated purpose" refers to individual competence.

\*\* The cumulative result of people, their individual competences, processes, and facilities leveraged to achieve the desired outcomes.

NAVSEA and ASN(RDA), and a commensurate cultural shift must occur as well, leveraging both top-down and bottom-up leadership to achieve success.

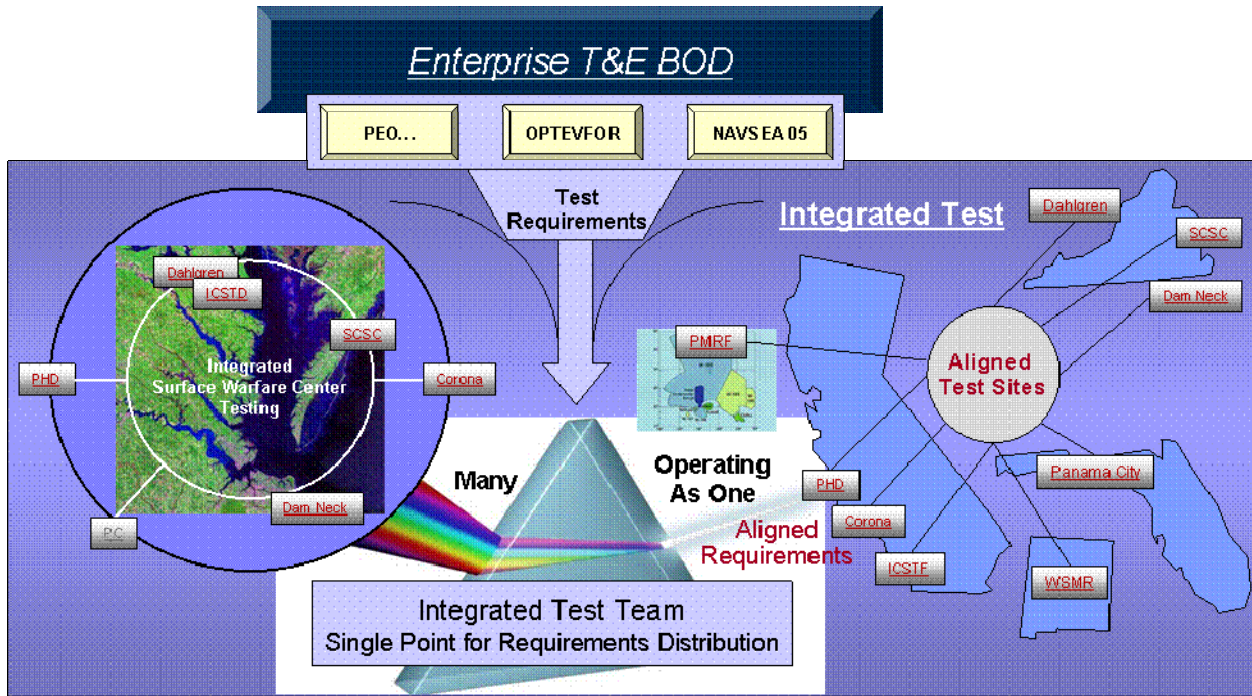


Figure 3. Vision for an Integrated Test Approach

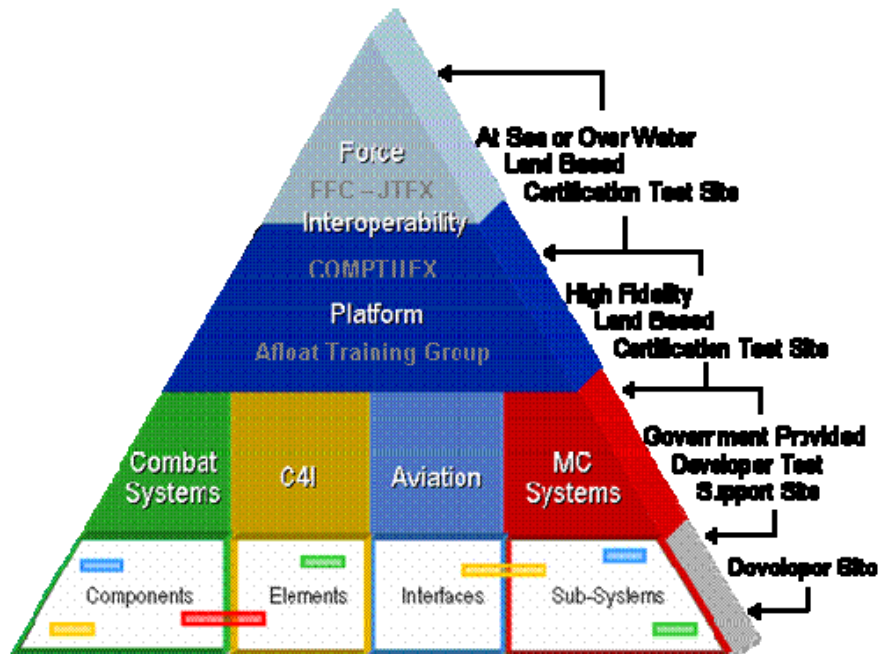
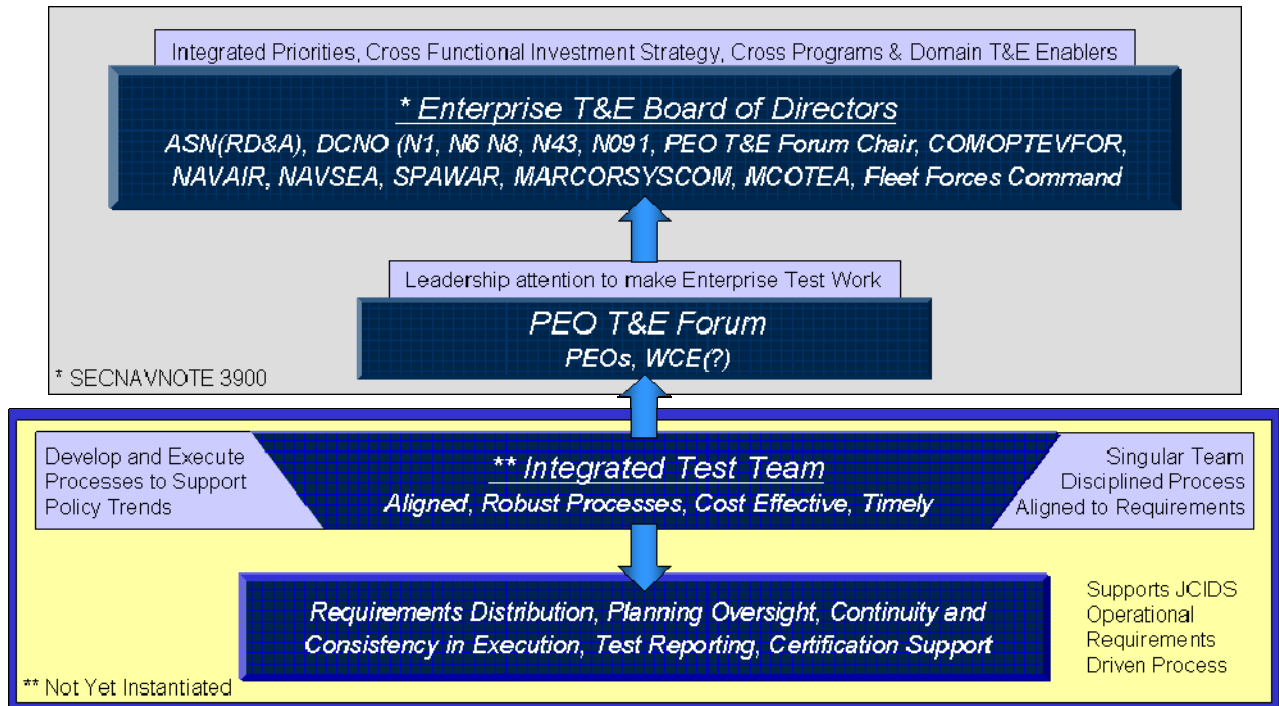


Figure 4. Overall Aligned Test Approach



**Figure 5. Collaborative Leadership Applied to Support the Integrated Test Concept**

**1.5.2 Constraints**

Success may require that individual program sponsors relinquish some measure of control. It also requires sufficient budget; but what constitutes sufficiency? Adaptability to constrained budgets is a fact of life given the level of funding available to support Surface Navy combat system integration and test requirements. Perhaps though there is sufficient budget to accomplish the required tasks. What is lacking is sufficient control over application of that budget to optimize necessary activity. That is, consider whether organizational tasking might enable facility optimization as opposed to programmatic tasking for each program’s integration and test objectives.

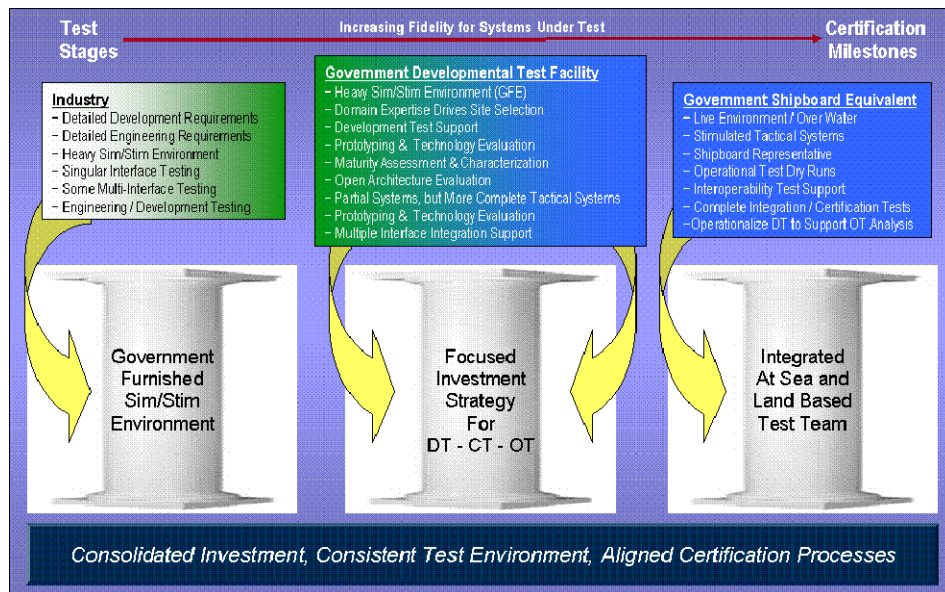
If each program developed its TEMP but leveraged the Integrated Test Team to do so and allocated a sufficient percentage of funding to support the integration and test process, a cross-organization, cross-program, cost-effective test strategy could be developed. Another approach might be to fund testing independent of programs. That is, testing could become a Surface Navy/NAVSEA budget line item. This might prove untenable since each program still requires some level of testing to prove its components or systems meet quality standards and warfighter or end user requirements, at least through the development cycle. However, a single sponsor could accommodate both.

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## 2.0 STRATEGY

### 2.1 Options

One approach to achieving the necessary insight into combat systems performance at reduced cost and overcoming the duplicate investment issue inherent in the overlap of Warfare Center-, industry-, and sponsor-supported T&E efforts and capabilities is to realign and refocus the Surface Navy test community. It is possible that the number of systems fielded at industry and government sites can be reduced by reemphasizing the government role in the certification process. That is, reduce the number of Navy-funded systems at industry sites to that needed for singular interface testing while still providing for industry partners' development laboratory requirements. However, there should then be an integration-focused site that industry can use when system development requires multiple system-level interface testing. This would be the simulation/stimulation-driven environment\* for integration and testing in a controlled environment, using reduced levels of tactical equipment and heavier use of commercial or functional equivalent systems built at significantly lower costs than those of tactical suites. Figure 6 reflects an adjustment in site focus and test approach that can address significant cost avoidance in the integration and test process.



**Figure 6. Aligned Integration and Test Leveraging Government Integration**

Finally, the Navy could build one full-up tactical suite to support final integration and configuration testing. To streamline system integration and startup at the respective sites, the Navy could also provide one simulation/stimulation environment designed to provide all the external interfaces with which a combat system expects to interface, as government-furnished

\* That portion of the test environment that supports controlled testing where live components are not available (simulated) and stimulation that drives the system under test to respond.

equipment (GFE) to industry as well as to each government site. A government-funded simulation/stimulation environment could reduce the cost of building a unique test environment at a site as the suite grows in size and complexity; the net result being deployment of fewer tactical suites, each of which takes a significant portion of a program budget. Compounded with the savings from the government-funded simulation/stimulation environment, this approach can bring about tremendous cost savings.

As an example, a representative GFE environment known as Next-Generation Simulation (NGS) costs about \$300K, where simulation development individually can and has cost millions. One program in execution today estimates dedicating more than 22,000 labor hours to developing a simulation/stimulation capability for just one integration and test requirement interface at the industry development site. Functionally equivalent systems have been utilized at the Surface Combat System Center in Wallops Island, Virginia, which have resulted in excess of \$500K savings per cabinet.

## **2.2 Implementation**

To effect such an aligned approach requires leadership support from the sponsor, Office of the Chief of Naval Operations, from the PEO major PMs, as well as from NAVSEA and ASN(RDA). The Secretary of the Navy; Commander, NAVSEA (COMNAVSEA); and Congress agree that there should be renewed emphasis on government leadership of large-scale integration (LSI) efforts. This approach aligns with that idea, but not all parties agree up and down the chain of command nor does industry relish the loss of such a lucrative and profitable business base.

At a recent all-hands brief, COMNAVSEA presented a chart that illustrated the government infrastructure size that would be leveraged to engineer LSI solutions for the Navy. This infrastructure, the Warfare Center Engineering community, a portion of which is reflected in Figure 2, is second in size only to the largest defense industry conglomerates but operates at significantly less cost than its industry contemporaries. Moving to more government-led integration and test provides significant motivation to effect alignment. However, true success will not occur until the bottom-up approach underway across the Warfare Center construct meets top-down direction from appropriate senior Navy leadership.

## **2.3 Execution**

Several initiatives have been developing momentum to achieve the outcomes projected in an aligned Surface Navy test strategy: moving toward common data analysis tools across Warfare Centers; consolidating test efforts across different levels (subsystem, element, and system) so that less redundant testing is needed; and having NGS development architected to provide all external interfaces required for combat system testing at a reduced cost. At the same time, SES- and Flag-level leadership needs to develop and implement motivational factors to achieve success. Rewarding cost reductions over some significant size while achieving expected results with a percentage of the savings or avoided costs can be a significant motivator across the Navy. Implementing training and education to further acculturate the PM, NAVSEA, and ASN(RDA) work force would help institutionalize the continuous improvement and streamlining vision until

it becomes a natural part of everyday efforts. Aligning required competencies to meet the demand signals expected from such an approach is also a necessary element for success.

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### **3.0 RISK**

#### **3.1 Risk Impact**

Considering both the probability and the impact of risks inherent in developing an overarching, consistent, and program-independent integrated test team approach requires keen insight into the test process. While Naval Air Systems Command (NAVAIR) has had clarity in its T&E structure for some time, the NAVSEA organization is spread out to address testing at a different level of complexity. NAVAIR conducts testing of aircraft, complex units in and of themselves; but the Surface Navy combat system level of complexity, integrating across multiple systems and multiple warfare areas and missions and combining complex capabilities while allowing flexibility and agility of response, has pushed NAVSEA to distribute its test capability by domain rather than function. Migrating to a competency-aligned organization, with a robust and focused test team distributed across the nation while maintaining centralized control, is no easy task.

Risks include growing or favoring one organization over another as leadership shifts; aggregate costs for test capability (people, process, and facilities) become bundled and therefore large enough to draw attention as targets of opportunity for reduction; and an inability to accurately identify the full extent of test costs on a per program or Warfare Center-by-Warfare Center basis occurs. The complexity of shifting from a distributed or federated approach under control of individual programs to a different approach also has risk. The shift alone could cause missed schedules or prove testing inadequate if not appropriately funded, tooled, and given solid leadership. But each of these risks, even with their commensurate impacts, could be overcome given solid leadership and commitment toward such a shift in strategy. It should be noted that the Navy often operates through individual interpretation of a Commander's intent, solid leadership that interprets orders and intentions, and executes on its own at every level. While this can at times be considered strength, in the case of movement toward an integrated test team across distributed Warfare Centers, the individualist approach could well prove catastrophic and has already proven expensive. There are, however, mechanisms for managing these risks.

#### **3.2 Risk Management**

If consensus were developed top down as well as bottom up and a shift to an integrated testing were to be held in abeyance until discordant requests poured in as the concept was advertised, then the risk of splintering as the shift occurs can be diminished. Another approach is strong top-down leadership combined with consensus and bottom-up leadership, which might well prove successful; but leadership at the top changes often. There needs to be some institutionalizing of the integrated test approach, with bridges burned to prevent falling back to how we used to do business; there might then be a greater opportunity to manage the risk. This is true for many of the risks mentioned: an aggregate budget, integrating across multiple programs, even the shift to centralized direction.

Providing customer service agreements that link organizations through tasking and response to sponsors and PMs would help to force collaboration across the construct to greater and greater levels until they operate seamlessly, almost indistinguishable, one from the other, the distinguishing element being primarily domain expertise. Single tasking that includes or even requires multiple organizations to achieve expected outcomes, enforced within funding documents, brings with it the force of a contract. When that occurs, the Warfare Centers may quickly join forces to achieve success.

The potential gain is worth the risks, but prudent selection of both the Enterprise Leadership Group participants at the certification panels and knowledgeable leaders in the test domain from around the country to lead and direct the Integrated Test Team can make the shift to integrated test under centralized leadership of distributed test capabilities a success.

## 4.0 CONCLUSION

### 4.1 Measuring Results

Combat system and platform-level testing costs for the Navy for each ship, system, subsystem, and component are nearly astronomical. To baseline costs using today's approaches and then watch the cost of testing over time as shifts toward an aligned test strategy occur is one measure of effectiveness. The size of the test organization capability (Reference 6),\* the number of resources (people), and the proliferation of common tools used across the Warfare Centers are also measures of effectiveness. Baseline costs can be considered lagging indicators of future activity. Trends seen, as these types of data are captured, can become lead indicators for further success.

### 4.2 Success

Success will be at hand only when an independent but fully integrated team is responsible for distributing test requirements, ascertaining which facilities achieve what capability level and are operating together as a single entity. Success is also dependent on test funding as a single stream managed by a single set of leaders—and on a single team managing, distributing, and reporting test process results that have been system engineered to achieve desired outcomes. When the aligned approach is institutionalized across the Surface Navy test community, then success will have occurred and new problems will take the better part of our attention and our time. Until then, pay now, pay more, and then pay again later.

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\* Capability is defined as processes, people, and facilities needed to effect positive outcomes.

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C	2/0
CD (KOCH, REIDL, MONTIETH, STUTLER, HUMPHREY)	5/0
CDS (DRAKE, GRAY, MADDRY, MURPHY, WRIGHT)	5/0
G	7/0
K	7/0
Q	7/0
W	5/0
W05	10/0
W06	7/0
W10	7/0
W20	7/0
W30	7/0
W40	7/0
W41	1/0
W43	1/0
W50	7/0
W60	7/0
XD	2/0
Z	1/0
Z31 (TECHNICAL LIBRARY)	2/1

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