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COST EFFICIENT RISK MANAGEMENT THROUGH INTEGRATED T&E THROUGHOUT THE SYSTEMS ENGINEERING LIFE-CYCLE

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ABSTRACT

Acquisition programs are becoming increasingly complex, more costly, and more integrated. Test and evaluation (T&E) must stay ahead of this rapid transformation to ensure the right data is provided to the decision makers to ensure the right capability is delivered in an affordable and timely manner to the warfighters

To meet the challenge, T&E must transform into a continuum of integrated objectives interwoven throughout the systems engineering process. Each and every test must be leveraged by all agencies to gather the most data possible and the expenditure of costly resources must be balanced based on the level or requirement and associated technical risks. To enable such a tightly coupled management of T&E within the iteration of systems engineering activities across the life cycle, engineers, analysts, and program managers need the proper tools and processes to manage the planning, execution, and reporting process for their. The T&E management process must be itself influenced by systems engineering, ensuring a flow down of mission capabilities required down to the lowest level of hardware and software specifications and associated test requirements/objectives. Whether contractor, developmental, live fire, or operational testing, each test must be adequately associated to proper levels of requirements and the mission impact of the test results clearly identified. Rather than a variety of different tests and organizations in conflict, a program's T&E must be an integrated set of activities addressing risks to operational mission performance and subordinate technical parameters. Test resources must be clearly identified early and their costs justified based on the requirements and risks associated.

This process must be managed in a well-thought and structured manner, enabled by software tools such as AVW's Integrated T&E Database. This powerful tool supports a variety of levels of T&E from supporting total ship testing for the Navy's operational test agency to conduct of naval radar systems developmental testing. The tool is designed to connect all levels of test objectives whether they be critical operational issues, critical technical parameters, or lower level technical requirements through to the test event, test resources, results, and associated risk management. This powerful tool allows test engineers to plan the most efficient test to give the decision makers the right level of confidence in technical and operational performance of the system to manage risk and deliver systems to the warfighter. Upon conclusion of a test, the database can provide visibility from the beginning of test planning to test execution to analysis of the results. Lessons learned from the test can feed future events to ensure the overall T&E program is the most efficient and effective.

Transformed T&E must be integrated by organization and by activity through the systems engineering life cycle. T&E must have influence throughout the systems engineering process and in turn use systems engineering principles. Every T&E event must use the right level of resources to address the test objective based on the associated requirements and risk. Finally, T&E must use structured tools to organize a systematic process and document that process and results.

INTRODUCTION

T&E can be seen as a process or series of activities within the greater context of systems engineering. Legacy practices within DoD acquisition and throughout the defense industry still tend to bias testing towards final design verification through segmented contract testing (CT), developmental test and evaluation (DT&E), operational test and evaluation (OT&E), and live fire test and evaluation (LFT&E). Testing can be seen as unnecessary exposure of the program risks to the greater acquisition community while placing programmatic risk on the program's funding. As programs become ever complex, the amount of risk compounded upon risk throughout program and technology increases exponentially. Cost as an independent variable (CAIV) in a highly constrained environment places considerable strain on the system, placing further risks in meeting requirements within the bounds of cost caps.

There is an ever-increasing focus on disciplined systems engineering and integration of the various activities in programs, including T&E. These myriad activities must all provide efficient means of identifying risks as well as assisting in their mitigation and ultimately in determining successful resolution of the risks. T&E organizations, policies, procedures, and assets must be further aligned to achieve the required level of integration needed to provide this level of risk management. T&E can be shown to fulfill a much greater role in risk management as it is becomes an integral part of the overarching systems engineering process and the acquisition life cycle.

The goals of this paper are to:
1) further explore areas in T&E methodology and processes where integration may occur with each other and the overarching systems engineering process (extending a presentation made by this paper's author during the 2005 NDIA Systems Engineering conference);
2) present a toolset that enables efficient integrated test program, the long-term goal being to identify, mitigate, and resolve technical risks in the methodology described above; and
3) propose risk categorization for test planning and associated level of resource costs applied and a similar risk categorization for reporting of test results (flexible to apply to all types of T&E).

Note that although numerous instructions, organizational policies, acquisition study findings, and other references are cited, this paper is not intended to represent any one government or industry position. Information presented is a compilation of the author's research supported by individuals in his organization as well as efforts in his company in tackling some of the challenges presented below.

SYSTEMS ENGINEERING CHALLENGES

Program managers are being tasked to provide capable systems to the fleet faster, with fewer resources, in compliance with more regulatory and statutory requirements, and ever-expanding complexity. As military transformation and evolutionary acquisition reforms continue, a concerted and concurrent effort to not merely reform or evolve, but transform the T&E community must be undertaken by all elements of the greater acquisition community. These efforts must support long-term transformation, with a net effect of reducing total ownership costs while enabling more rapid fielding of needed capabilities through risk management. In short, we

need to transform to deliver the right product on time that works that is affordable and sustainable.

Increasingly Complex Systems and Risks

Transformation in the requirements generation portion of the acquisition triad to the Joint Capabilities Integration and Development System (JCIDS), coupled with more flexible, responsive, and innovative acquisition process is intended to produce better-integrated and more supportable military solutions that address joint capability gaps. This top down driven approach is designed to produce a better-prioritized and logically sequenced delivery of capability to warfighters. JCIDS specifically informs the acquisition process (and in turn systems engineering and T&E) by identifying, assessing, and prioritizing joint military capability needs for families of systems, systems of systems, and individual systems.[1] Even at such an early point in the program, systems engineers and testers in particular can help focus JCIDS so that the operational requirements levied on a program can be decomposed into technical requirements that are measurable and feasible and combine to provide an operationally meaningful capability. A properly functioning Integrated Product Team (IPT) can begin to identify risks and associated mitigations, with T&E enabling proper, objective assessment of technology and concept readiness to transition to system development.

OSD and service level briefings on acquisition and systems engineering indicate a number of critical challenges and risks facing the acquisition community. These include:

- shifting focus from platform requirements to capabilities (for individual or groups of systems) and system solutions
- in turn, a shift to fielding of system of systems and family of systems
- demand for joint interoperability and network centric capability in turn driving much higher levels of integration
- architectures both functional and physical far more complex with many more layers of systems, software, and hardware requirements
- organizational and process changes to align with JCIDS, evolutionary acquisition, and other aspects of military transformation.
- greater reliance on modeling and simulation (M&S) for engineering and T&E.[2]

Systems acquisition and in turn systems engineering and T&E must transform themselves and integrate to deliver what the warfighters need. This includes integrated strategies and plans for engineering and T&E using risk management, M&S, analytical methodology, and other tools to achieve common goals. Engineers, testers, and their processes and insight must be leveraged far earlier in acquisition, from the beginning of JCIDS assessments to traditional design activities until disposal of the system decades into the future. Involvement and interaction must become persistent and continuous.[3]

Based on these complexities, testers must become more committed to program risk mitigation and success regardless of organization. Operational test agencies, government laboratories supporting developmental testing, industry design engineers, program managers, logisticians, and users must all cooperate to achieve cost efficient solutions. Testers must shift their outlook and approach (particularly OT&E), from one of oversight and reporting to early insight into risks and capabilities.

Risk Management enabled by Integrated T&E (IT&E)

DoD Directive 5000.1 states that T&E should be integrated throughout the defense acquisition process and structured better to provide accurate and timely information on risks and capabilities to decision makers.[4] The directive also states, "the conduct of [T&E] integrated with [M&S], shall facilitate learning, assess technology maturity and interoperability, facilitate integration into fielded forces, and confirm performance against documented capability needs and adversary capabilities as described in the system threat assessment."[5] Although a variety of organizations play roles in this integration of T&E, the program manager is tasked first and foremost with this daunting challenge.[6] The Defense Acquisition Guidebook elaborates on the philosophy of IT&E in describing how separate industry and government developmental and operational testing can be combined as well as M&S and other activities.[7] Their end goal is to assist and enable the program manager to lead the acquisition team in managing the risks to ensure the intended capabilities are provided on time and on budget, not the usual, proverbial "two of the three" of those pillars.

T&E must become an integrated continuum of supporting activities for systems engineering verification and operational capabilities exploration in realistic threat and environmental conditions.[8] The focus of individual tests, testing organizations, and recipients of their reports may be different, but the end goals should align towards expeditious introduction of cost effective capabilities to the fleet. Whenever feasible, DT&E and OT&E events as well as LFT&E, contractor testing, joint experimentation, M&S analysis, and other T&E and assessment activities should be combined to gain optimal use of resources, if that supports the myriad objectives. The user community should also be involved early in test planning to ensure the capabilities are delivered as intended.[9]

Critical to understanding of T&E as a whole is the concept of integrating the various aspects and types of T&E while preserving the important and distinct roles. DT&E focuses on specifications, controllable conditions, integration to scripted criteria, and threshold values. DT&E can be conducted across a range of venues from laboratory component tests to system of systems technical interoperability measurements. Capabilities are addressed, however they may not be explored to the extent that OT&E may desire. Operational testers focus more on mission accomplishment, value added to the warfighter, and capabilities and limitations of the system – not necessarily verifying specific requirements and technical specifications. For the final OT&E before fielding, the production system must be evaluated in scenario driven testing in realistic environments as much as possible. With this said, many objectives and resources can be combined between the two, particularly during the System Development and Demonstration (SD&D) phase were prototype or near production systems may be available and can provide both technically and operationally relevant and credible data supporting mutual test objectives. LFT&E objectives must also be melded into the integrated continuum of testing, with significant overlap in survivability requirements and capabilities objectives common with Development and Operational Testing (DT and OT). Additionally, systems analysis including M&S, early joint experimentation, and other events may also provide credible data to support the variety of integrated test objectives. The key is melding the distinct and important viewpoints of T&E and test objectives from the various organizations into a common integrated test program with the minimal expenditure of costly test assets. Figure 1 below depicts this integration process.

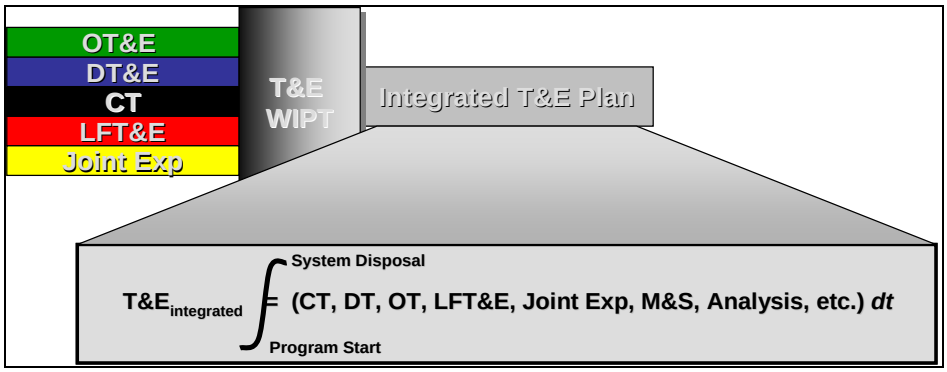

Figure 1: IT&E Concept

For the Navy, COMOPTEVFOR embraced the DoD 5000 directive and further guidance from the CNO to reduce costs in T&E. In their T&E streamlining report, they identified a number of tenants that are essential to IT&E as well as benefits and potential outcomes, including the following:[10]

- fostering greater cross-leverage between government and industry (a key to open and honest dialogue about program technical risks and mitigation strategies),
- increasing visibility of costs as well as value added of T&E to the program and to the warfighters (enabling efficient testing and a greater usage of T&E for it's ultimate purpose in risk management for the program manager and ultimately the user who has to rely on proven capabilities in combat),
- more closely managing systems upgrades and assessing level of regression testing (aligning T&E requirements for resolution of risks/deficiencies and capabilities increments/spirals with risk management processes),
- reduction of excessive testing costs to enable the most efficient use of the program T&E budget targeted to identifying and managing risks through minimizing redundant testing and certification activities; cross leverage of T&E disciplines, experimentation, and training exercises; and use of differing analytical methods to maximize test assets including design of experiments, design for six sigma/lean six sigma, and greater use of M&S when practicable,
- proper risk mitigation from test to test (such that the program manager reduces risks in achieving favorable results from Initial OT&E (IOT&E).
- identifying poorly written or misunderstood requirements even earlier in the process
- ensuring adequate early software testing and process maturity
- ensuring every T&E cost is adequately tied to a technical and/or operational mission requirement with level of testing tied to risks and level of influence on mission accomplishment.

"To lessen the dependence on testing late in development and to foster a more constructive relationship between program managers and testers," GAO recommended in a July 2000 report on best practices that "the Secretary of Defense instruct acquisition managers to structure test plans around the attainment of increasing levels of product maturity, orchestrate the right mix of tools to validate these maturity levels, and build and resource acquisition strategies around this approach."[11] The most telling of many of these acquisition studies is that volumes of information on acquisition and T&E reforms and best practices is available but many are not implemented often due to political and business culture drivers. Without proper management,

IT&E could as well fall by the proverbial wayside no matter how strongly it is mandated and how essential it is to managing risks in today's environment. Challenges in implementation of IT&E type processes within systems engineering and acquisition include:

- obtaining the necessary buy-in from program managers
- adapting various architectural and doctrine oriented mission tasks and functions for systems engineering and test objective breakdowns while maintaining a common taxonomy
- proper implementation of test design methodology including design of experiments
- determining best methodology of decomposing suitability issues across mission areas in order to properly assess and test their impact on each mission area as well as the program as a whole
- developing risk based reporting criteria, a topic addresses here.[12]

Risks in this methodology include acceptance of DT, LFT&E, and CT too early in a program where OT&E objectives may actually not be met and results may not adequately describe mission outcomes in operationally realistic environments. It is imperative to address these risks and challenges and obtain buy-in from all stakeholders to fully implement their vision. In addition to these challenges, a suitable software tool or set of tools including databases must be procured or developed to enable documentation of mission analyses, test objectives, and required test resources as well as tracking accomplishment of those objectives and providing metrics on reduction in separate OT&E costs and time (also addressed in this paper). Further transformation is required across the Navy and throughout DoD in how T&E and systems engineering align.

T&E WITHIN SYSTEMS ENGINEERING PROCESS TASKS

When properly integrated within a program, T&E activities can influence each iteration of this process. Starting with requirements generation, testers can help ensure those requirements are testable, technically feasible, and operationally realistic. During subsequent steps of functional allocation and synthesis, T&E can conduct early test resource budgeting, perform rigorous mission-task oriented test planning with support by systems engineers, and support early risk mitigation through interim evaluation of technologies and testing of components. As synthesis progresses towards completion, system testing supports interim assessment and final verification of the baseline product.

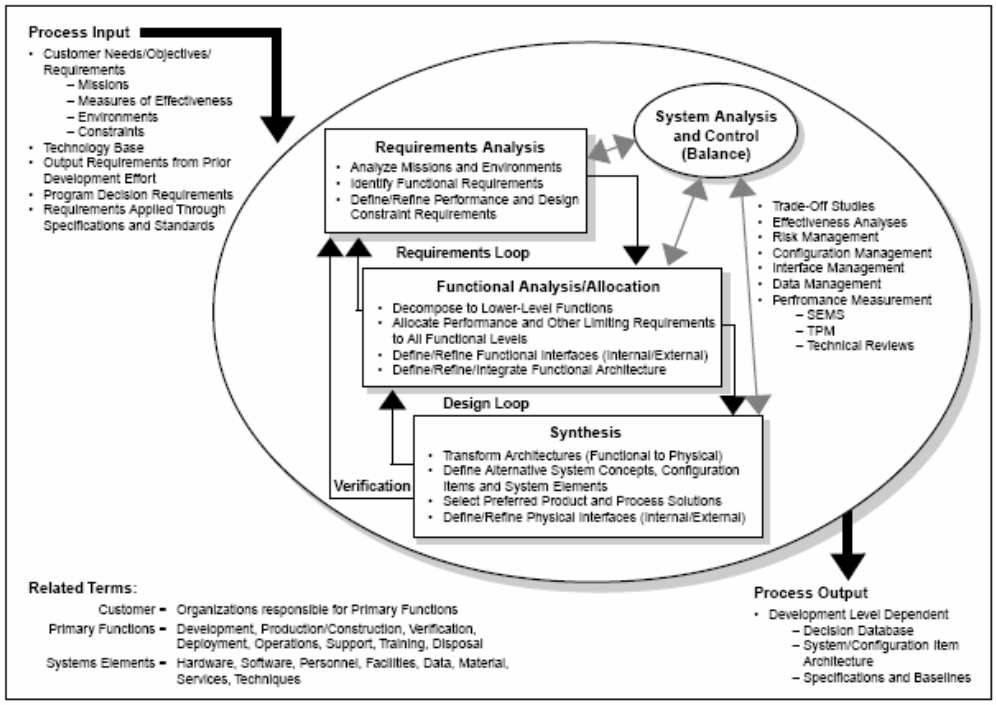

Figure 2: Detailed Systems Engineering Process[13]

The Defense Acquisition University graphic in figure 2 above depicts the standard systems engineering process.[14] Many of these standards delineate use of T&E throughout these various tasks from requirements verification to design validation and the role of the Integrated Product Team in their proper execution.[15] Testers support systems engineering and are aided in their tasking by systems engineers and engineering products in numerous ways described below.

Requirements Analysis

During this beginning phase of systems engineering, testers and T&E early involvement supports a number of critical activities. They can assist in generating meaningful requirements that are measurable, objective, based in an operational mission context, correctly prioritized, and are traceable from JCIDS. Based on understanding of technical and operational functions of the system and/or related systems, testers can assist in analyzing threats and environments, bounding constraints of the system, and aiding in the functional breakdown. Additionally they are suited to selection of technical performance measures, identifying potential technical and operational risks, and influencing human systems integration (HSI).[16]

A key to this stage is a proper understanding and prioritization of requirements in terms of level of importance to the user outright, importance of requirements (including derived ones not explicitly stated by the user) on mission outcome, additional user desires, requirements derived from similar programs that are actually non-essential, and requirements that are beyond the feasibility of budgets and technical maturity.[17] A proper prioritization of each user requirement/capability is essential along with traceability down to lower level technical requirements and specifications to the final design and ultimately to test plans and reports on the components and ultimately the system. T&E involvement supports this traceability as well as

enabling early test planning that meets the technical needs and ultimately the user stated required capabilities that must be demonstrated later in the development cycle. Often, much of a program's development, procurement, and life cycle costs are fixed at this early stage, and it is imperative to start IT&E assessment of the early concepts and requirements.

Functional Allocation and Synthesis

Similar activities are conducted through the more detailed steps of functional analysis/allocation through the design loop with synthesis tasks. Testers support proper breakdown of the system functions and requirements, helping maintain consistency and context with the mission, and definition of interfaces. Greater emphasis can be placed on HSI, life cycle planning, and development of adequate M&S that will support systems analysis, systems design, and T&E verification and validation of requirements and capabilities. T&E may be conducted in the form of early component testing as well as design reviews to assess risks to mission effectiveness and support, particularly with field/fleet users and operational testers involved. This stage can also support early development of tactics and doctrine.

Conversely, the long-term goals of T&E to verify requirements and validate capabilities are supported through involvement in these tasks, even early in the acquisition life cycle. As stated above, there should be adequate data during the design process to being identifying and aiding in program risk identification and management. Long term T&E planning can be made more efficient through tightly coupling planning with design activities so that testing is conducted when components and systems are ready and the proper aspects are tested or evaluated. Additionally, early assessment of life cycle, HSI, software functionality, and other factors can aid in design maturity and provide further insight for T&E to support program success.

Systems Analysis

Systems analysis involves support of the requirements allocation and design through conduct of studies via analysis and M&S. Many of the tools, processes, and results from systems analysis scan directly support early T&E, particularly technology readiness assessments and Early Operational Assessments (EOAs) prior to Milestone B. Similar activities can be conducted as part of systems analysis during SD&D acquisition phase that supports early identification of risks. Development, verification, and validation of M&S tools and analytical results can also directly support filling in gaps in actual testing or supporting limited live test resources. Testing itself can also support systems analysis by providing needed performance data for M&S validation and correction of errors. M&S from analysis can support pre-test and post-test predictions and in design of cost effective live testing. In certain areas such as interoperability, survivability, and lethality, M&S tools are critical in evaluation of requirements. In short, T&E must work in conjunction with systems analysis for adequate early identification of problems and to supplement testing with credible M&S based analytical results.

Verification and Validation

The major role of T&E has always been to determine the capability of "as-delivered" equipment in terms of how well requirements have been met or exceeded (verification), capabilities to conduct warfighting missions have been delivered (validation), as well as additional capabilities, characteristics, and properties of the system (independently or interacting with other systems).[18]

T&E supports verifying that the system requirements are being properly interpreted and allocated during the design processes, verifying that the output of the process meets those requirements, and providing feedback to managers as well as the next iteration of the systems engineering process. "Peer reviews are an important part of verification and are a proven mechanism for effective defect removal... An important corollary is to develop a better understanding of the work products and the processes that produced them so defects can be prevented and process-improvement opportunities can be identified."[19] Besides peer review, verification can take the form of analysis, requirements review, user design reviews, and limited component testing. While verification focuses on correct production per specified requirements, validation, working hand in hand with verification using many of the same processes, products, and personnel, determines that the system "will fulfill its intended use", and "can be applied to all aspects of the product in any of its intended environments."[20] Such activities must be undertaken as early in the program as possible, with T&E processes and organizations providing an independent assessment to the program manager and/or milestone decision authority on the status of the program technically.

The proverbial scorecard used by testers also needs to transform such that T&E express system capability in terms of accomplishing the mission or supporting the technical component necessary for mission accomplishment, not just failing, meeting, or exceeding arbitrary requirements.[21] Evaluation itself can be used to identify where requirements are exceeded to the point where capabilities can be trimmed to cut costs while still meeting the requirement. In addition, evaluation can identify added capability that although unplanned, provides significant and cost effective improvement in warfighting performance otherwise unknown. "The importance of this role of T&E is that it provides the user with information about the additional capability of the equipment which then allows the user to develop additional missions or uses that may not have been present in the original concept of operations for the equipment."[22] Thus, T&E serves many roles in development, fielding, and support of the system.

T&E must involve systems engineers during all verification and validation activities to aid in conduct and analysis of test data/results and categorization of risks and to allow them insight into performance characteristics of the system in operation. These activities are familiar to testers, although these can be conducted far earlier in the acquisition cycle than has been done in the past. This involves T&E early in systems engineering process iterations, not just final Technical Evaluation (TECHEVAL) and Operational Evaluation (OPEVAL) of the system.

IT&E INTERWOVEN THROUGH ACQUISITION LIFE CYCLE

The T&E and systems engineering tasks in the process described above are carried out in increasing complexity throughout the acquisition life cycle as shown in figure 3 on the following page. Concept studies and system definition can involve testers in early design tradeoffs, technical and operational requirements reviews, concept of operations development, user input and interface evaluation, systems analysis, supportability assessments, and prototype component testing. T&E involvement progresses from analysis and assessment to include more comprehensive element and system level technical and operational testing focusing on integration as the baselines mature into preliminary and final design. T&E culminates in mission verification of the final product baseline after low-rate production articles are completed.

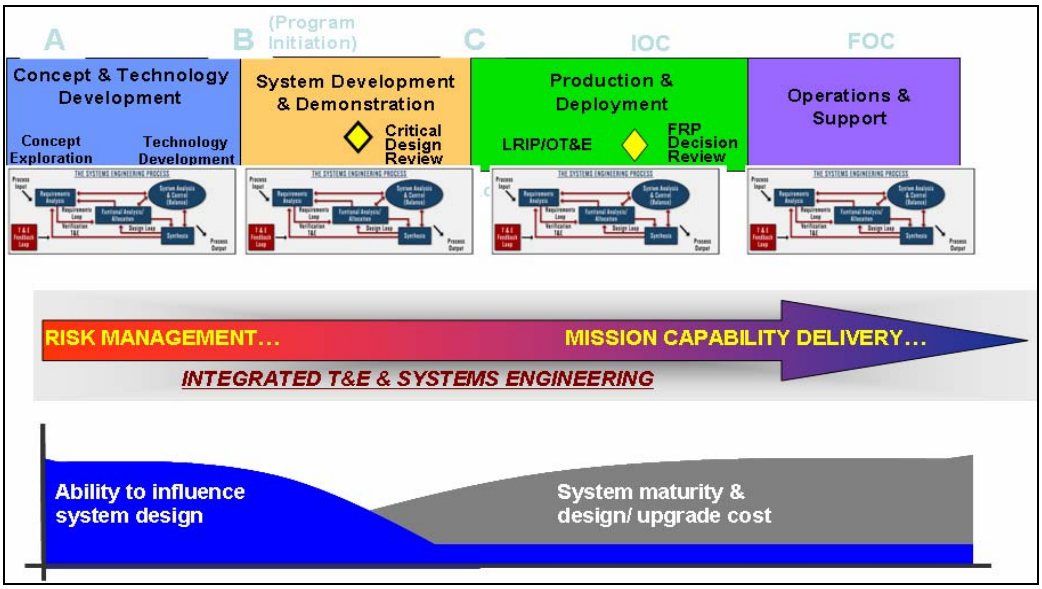

Figure 3: Life Cycle IT&E and Systems Engineering Summary

Concept and Technology Development

During these activities (prior to milestone B), laboratory testing and M&S are conducted by the contractors and the development agency to demonstrate and assess the capabilities of key subsystems and components based on JCIDS documents. Along with technology maturity assessment, the program develops T&E Strategy, Technology Development Strategy, and many key documents driving the program through the life cycle.[23]

Many of the tasks described in the previous discussion of the systems engineering process, specifically under requirements analysis, are appropriate to this phase; however, all of the tasks are conducted to some degree at this early stage prior to establishment of the actual program of record. Testers and engineers can participate in the JCIDS analysis itself, provide feedback on testability of requirements, aid in concept of operations (CONOPS) development, and collect data from advanced technology demonstrations and joint experimentation. T&E activities supporting this phase include technology feasibility studies, DT&E conducted on engineering development models, design reviews with user/warfighter representatives including EOAs, and analysis (with or without M&S). Involvement by testers and engineers as early as possible in this phase, including during the JCIDS capability assessment, is essential for long-term program success.

Evaluation of technologies undergoing maturation in this phase is critical to long-term success and can be provided in particular by focused testing with prototype models and by engaging the user and operational test community with an independent review of the concepts of operation and design in the form of EOAs. The variety and magnitude of new technologies for programs such as DDG 1000, Future Combat System, and Joint Strike Fighter including platform level computing and software integration incur considerable risks that can be addressed through EOAs and Operational Assessments (OA). Their value particularly for ship acquisition programs is often understated since the costs for correcting major issues in ship design increase exponentially once past milestone B into detailed design and ship construction. Typical EOAs provide an

overall assessment of risks for the program in adequacy of requirements flowdown, assessment of how threats are being addressed, risks in technology and development of the program, life cycle issues, and other concerns.

Of all the phases of a program, this phase and perhaps the beginning of the next phase, SD&D, have the most profound impact on long-term viability of the program and military success. However, testers and engineers usually have the least input and involvement, while, as shown above they can have the most impact with the least cost. Ensuring proper requirements, CONOPS, and planning for system development is far superior to waiting till a system is fully matured, tested, and a number of critical issues are raised far too late to correct without serious cost overruns.

System Development and Demonstration

During the SD&D Phase, concepts approved for prototyping form the baseline used for detailed test planning of the full system that is matured through the design process. DT&E is conducted to aid engineering design, system development, risk identification, and to evaluation of the growth of technical maturity and performance to reach intended level supporting desired capabilities for fielding. DT and CT may be conducted in laboratory tests of components, software qualification tests, and prototype system engineering tests. At the exit from SD&D, engineering is primarily complete including survivability/vulnerability, compatibility, transportability, interoperability, reliability, maintainability, safety, human factors, and logistics supportability factors. Multiple OAs conducted similar to the EOA and/or integrated with DT and CT support identification and mitigation of risks in support of the overall program risk mitigation strategy. The early T&E program is accomplished in an environment containing limited operational realism that may affect viability of OT&E results; however, this information is essential as early in the program as possible. Some of the most important products are user assessments of system maintainability, supportability, human factors, and safety issues. IT&E should address each of those areas along with growing data for estimation of long-term reliability, availability, and maintainability (RAM). IT&E must support decision to proceed into low-rate-initial production.[24]

The continuum of design and analysis support from T&E personnel include review of detailed designs, user evaluations as discussed above, assessment of CONOPS viability, liaison with military doctrine commands for development of tactics and doctrine, assisting with trade studies, and conduct of EOAs and OAs. Products of the SD&D phase are verified and validated through a range of IT&E activities including lab, testbed, and field/flight/at-sea testing on prototypes and surrogate platforms. Survivability (including shock qualification) and/or lethality evaluation may be conducted in this phase, although the may not be completed until early in the next phase just prior to fielding. User commands and certification agencies can help address various life cycle support and other issues including information assurance and spectrum management. Each of these activities brings a certain lens with which to view the program, and if properly integrated within the systems engineering process, can aid in delivery of a final product ready for production, qualification, and introduction into military use.

Adequate requirements generation and flow-down and subsequent risk reduction conducted in the first phase, concept and technology development, is most critical to program success.

However, program success hinges on continued focus in SD&D on risk mitigation and completing requirements traceability (with correct intent and mission context) and verification to support entry into production, IOT&E, and delivery with a system of adequate maturity.

Production and Deployment

Production and IOT&E mark the key points in the first portion of this phase. T&E during this phase consists of more traditional verification and (more so) validation events. TECHEVAL and IOT&E/OPEVAL are conducted to resolve critical technical parameters and operational issues and determine mission capability. However, this cannot be the primary source of information on a system. A majority of issues should be surfaced during SD&D with testing in this phase conducted primarily to confirm mission capabilities in a production representative system prior to fielding. In addition to traditional final TECHEVAL and OPEVAL/IOT&E, IT&E can still pull in other activities from this phase including design reviews, independent logistics audits, certifications (including information assurance certification and accreditation), life cycle planning, user training, fleet/field exercises, and shock qualification and LFT&E. Periodic feedback on results from IT&E must support early risk reduction so there are no surprises in the TECHEVAL and OPEVAL reports. Our systems are too complex to allow any significant changes after the initial units are tested and prepared for initial operational capability. As successive upgrades are developed and fielded as well as deficiencies and issues from previous ones are corrected and tested, the various test and systems engineering communities must be present to help the program manager map out the clear path to achieve the intended capability for that increment/spiral on time. Where possible, these activities must begin in SD&D with final validation conducted in this phase for each increment/spiral with no major surprises in the outcomes of testing. Neither OPEVAL nor TECHEVAL should be the first time that some of these key program areas are addressed; however given the complex nature of systems, statutory requirements, and good engineering practice, these tests by necessity will remain. However, as stated previously, they cannot be the first time that a system is challenged with realistic threats and environments or when the user if allowed to fully explore the system.

After the Full Rate Production Decision Review, T&E activities continue to provide important insights into performance of the program. T&E coupled with systems engineering can support Production Acceptance T&E and monitoring long-term RAM characteristics. As the systems are fielded, the program transitions into operations and support where upgrades are fielded and tested among many other activities.

Operations and Support

As adequate numbers of systems are fielded to full operational capability, the program must transition to this phase. When necessary, T&E can confirm need to improve support or upgrade systems to maintain RAM and mission effectiveness. T&E is used in similar processes during SD&D and Production and Deployment phases prior to introduction on pre-planned improvements and new spirals. Where appropriate JCIDS documents are updated with similar involvement by testers in requirements analysis as discussed in the concept and technology demonstration phase above. With the advent of spiral development and evolutionary acquisition, there may be multiple iterations of the acquisition life-cycle, each with multiple iterations of systems engineering and T&E as previously described. IT&E must continue to support needs of

follow on OT&E, DT&E, LFT&E, certifications, and life-cycle support and maintenance. As capabilities are increased or added, new and/or improved doctrine and tactics must be developed and tested, bringing doctrine commands into play once again. Also, as threat and operating environments change due to internal and external factors, JCIDS and requirements documents must be iterated and system upgrades implemented through the appropriate level of engineering changes, software upgrades, system overhauls/upgrades, service life extensions, development of follow-on variants, retrofit of new capabilities, or some combination. Each of these will require the same focus from T&E as previous configurations of the system throughout the life cycle.[25]

RECOMMENDATIONS FOR IMPLEMENTING RISK-DRIVEN IT&E

First and foremost, the program must obtain agreement on level of integration of T&E and systems engineering among all stakeholders and associated organizations, processes, and governing documents. The traditional T&E Working IPT (WIPT) must take a greater role in the program coordinating with risk management, systems engineering, and other entities. All aspects of T&E, analysis, M&S, design verification and validation, concept experimentation, and certification evaluations must be integrated and then interwoven with the appropriate systems engineering tasks through the life cycle of each increment of a program/system. All aspects of T&E must be pulled left to provide early risk mitigation and ensure proper requirements flow-down. The T&E WIPT and other key organization in the program must efficiently coordinate these processes to ensure success. If these are implemented with complete buy-in and resources provided from all stakeholders and participants, the program will be able to efficiently identify risks, contain and correct system defects prior to delivery, and provide cost effective capabilities to the warfighters when they are needed.

Once IT&E is successfully implemented, the level of involvement should address each T&E and systems engineering task and activity throughout the life cycle as detailed in the previous section. The following paragraphs discuss specific ways how IT&E can be implemented in a program and specifically alignment to program risk mitigation strategies.

Risk Basked Test Planning and Reporting

All T&E organizations must address planning from a risk driven approach. The level of testing, degree of independence (e.g. of OT from DT and in turn from CT), statistical confidence levels, resource cost expenditures, and other aspects of test planning can be tied to risks in terms of mission accomplishment or technical support of the appropriate aspects of a mission. Upon completion of testing and analysis, failures, anomalies, and deficiencies can be categorized and prioritized with clear traceability to the mission impact and probability of occurrence. Subsequent development efforts can then be guided by the risk driven prioritization for both additional development resources as well as prioritization of re-testing resources and timing. In addition, by reporting tests in a risk-based format, this supports closer alignment with the program risk registry and risk management program. Table 1 presents tailored risk chart for testing management, both planning and reporting.

Table 1: T&E Planning and Reporting Risk Matrix
(derived from Army T&E guidance and other references)[26]

Probability of Expected or Actual Issue/Failure Occurrence **Consequence of risk/measure failing**	**5**	**4**	**3**	**2**	**1**
A – Frequently occurs during tests/operations (probability near 1.0)	**II**	**II**	**I**	**I**	**I**
B – Probably will occur during tests/operations	**II**	**II**	**II**	**I**	**I**
C – Occasionally may occur during tests/operations (probability near 0.5)	**III**	**II**	**II**	**II**	**I**
D – Remote chance to occur during tests/operations	**III**	**III**	**II**	**II**	**II**
E – Not likely to occur during tests/operations (probability near 0)	**III**	**III**	**III**	**II**	**II**

Consequence Levels:
1: prevents accomplishment of primary mission or presents a serious safety hazard
2: significant primary mission degradation without a work-around, secondary mission failure, or moderate safety hazard
3: major secondary mission degradation w/o work-around; primary mission degradation w/ work-around
4: minor degradation/impact to primary and secondary missions
5: no impact to mission but operator annoyance or recommended enhancement
(Note that lower level testing and technical measurements do not directly tie to these consequence levels; however, adequate requirements traceability conducted early in the program should support tracing of technical risks and failures to overarching operational/mission based capabilities).

Risk Levels:
For Test Planning, priority of test resource allocation and level of test integration:
I: High Risk – The specific technical specification, operational requirement/capability/mission area requires significant CT, some degree of separate DT to verify technical performance, and a significant amount of independent OT (and LFT&E as appropriate) to verify mission capabilities; highest priority for resource allocation; more test runs/ conditions permutations than other tests; most scrutiny required before integrating tests
II: Moderate Risk – The specific technical specification, operational requirement/capability/mission area requires some dedicated DT and OT with a medium resource priority and less scrutiny before integrated tests completely
III: Low/Manageable Risk – The specific technical specification or operational requirement requires little to no independence between CT, DT, OT, and LFT&E; strong candidate for fully leveraging a small set of integrated tests for all data; lowest priority for resource allocation

For Test Reporting, priority of trouble report & urgency of resolution based on operational risk:
I: High Risk – resolve prior to fielding & conduct major re-test of mission area prior to fielding with the most resources applied
II: Moderate Risk – resolve prior to fielding and re-test the specific requirement as soon as possible (depending on the requirement, re-test may be allowed to be conducted during follow-on T&E after fielding); apply moderate amount of resources to re-test
III: Low/Manageable Risk – resolve when possible but does not impact fielding; re-test at next available previously planned test event; lowest prioritization for test resources

The matrix above can be adapted to unique aspects of a program's risk management strategy; however, the basic philosophy should remain valid. The importance is use of a more objective, standard framework for assignment of precious testing resources and reporting of results that is easily aligned with and traceable to risk management processes. If all T&E organizations are focused in aligning and transforming their processes to enable efficient risk mitigation while maintaining their unique focus (especially OT&E and LFT&E under Title X statutes), the program manager will have more data to define and mitigate those risks early. Additionally, a common risk based planning and reporting framework will enable the other aspects of IT&E across systems engineering process and life cycle and result in more cost efficient testing.

The IT&E Database Toolset

Risk based IT&E so closely woven into the systems engineering process must be managed in a well thought and structured manner, enabled by software tools such as AVW's IT&E Database. This powerful tool supports a variety of levels of T&E from supporting total ship testing for the Navy's operational test agency to conduct of various warfare systems developmental testing. The tool is designed to connect all levels of test objectives whether they be critical operational issues, critical technical parameters, or lower level technical requirements through to the test event, test resources, tests results, lessons learned, and associated risk management.

The AVW IT&E database toolset as depicted below in figure 4 is essential for managing and documenting total life-cycle T&E efforts for complex platforms and system-of-systems acquisition programs. This toolset supports the test designer in planning, resourcing, cost-estimation, data management, data analysis, and lessons learned generation for all aspects of T&E (engineering demonstrations experimentation, systems analysis including M&S requirements and intended usage definition, HSI usability testing, CT, DT, LFT&E, OT, as well as risk management support).

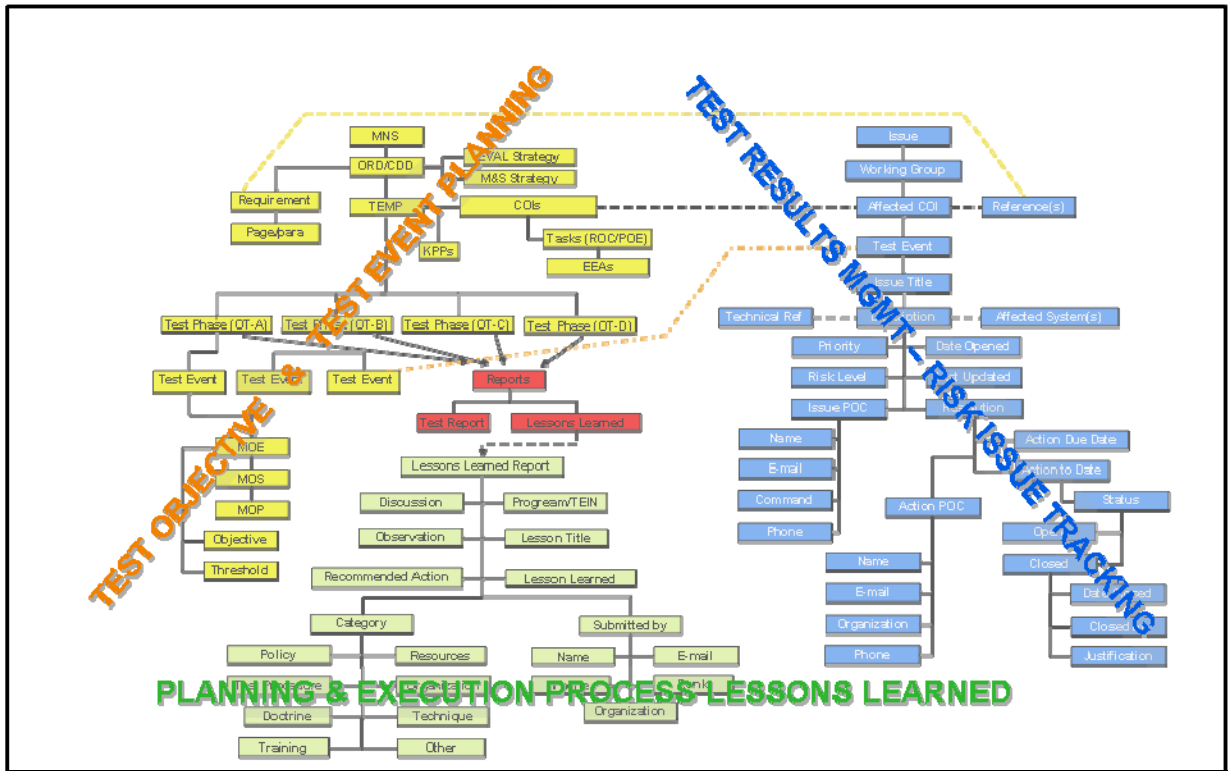

Figure 4: AVW IT&E Database Toolset Architecture

The IT&E toolset supports rigorous, systems engineering methodology for review of requirements, capabilities, operational/mission tasks, and functional tasks. It can then be used to carry forward JCIDS analysis to development of critical operational issues for operational testers, live fire critical survivability and/or lethality issues, measures of effectiveness, suitability, and performance, critical technical parameters, and technical performance measures.

The traceability allows testers and engineers to view the specific requirements or specifications to be tested within the context of the larger framework of technical and operational requirements that lead to the intended mission capabilities. Moving forward from requirements traceability, a test designer can then create specific test objectives whether technical measurements or measures of performance that describe operational tasks. Test matrices are created using statistical methods and other processes based on varying conditions to be controlled or presented during the test. Roll-up of test resource requirements for events allows development of realistic figures for TEMP Part V estimates as well as budget programming and test readiness reviews. Use of tailored reports of test objectives aids test directors in producing data collection/management plans, detailed test plans, and test conductor checksheets. AVW testers prototyped use of personal digital assistants for subjective data collection with electronic checksheets derived from the program IT&E database tools.

The historical tracking and archiving of verified specific test objectives and higher-level critical issues maintains the requirements traceability through to verified results as well as issues and risks flowing from those test results. Output of risks supports rapid reporting of issue to the program manager even as the test is still ongoing and ultimately rapid creation of formal test reports based on risks identified during the test. This ongoing risk tracking drives further integration of T&E for the program and helps to transform it into the continuous involvement and risk mitigation that is needed by the programs.

Not only does the toolset drive engineers and analysts in a systems engineering influenced test process, it tracks and archives results and individual issues from each test event, traceability from requirement to test events, and risk management and mitigation efforts for the program manager and other acquisition stakeholders. The toolset also provides customizable outputs of necessary issue data; rapid drafting and release of informal and formal test reports and automated informal observation reports, and other reporting activities; and trace-back to test events, resources, objectives, and associated requirements. The lessons learned module additionally provides a means of storing lessons from test planning and execution in the standard Joint/Service Lessons Learned Formats. In addition, the long-term continuity of knowledge of program issues and testing to date for new program personnel is an invaluable benefit.

In summary, the AVW IT&E toolset enables efficient, effective, and responsive T&E management for the most challenging of test programs. It provides the necessary traceability, planning, management, and reporting capabilities necessary to adequately implement IT&E and address the ever-complex risks for the current programs. IT&E is essential to mitigate those risks, and it can only be implemented with a toolset and processes such as these.

Other Recommendations

Numerous other areas through programs T&E and other processes can be transformed to enable more efficient T&E including IT&E implementation. Numerous studies have provided lessons learned, best practices, and recommendations for process improvement for T&E and acquisition in general, but most have not been implemented substantially in programs.[27] The following is a partial list of recommendations developed during this research as well as derived from numerous studies (a more comprehensive treatment was included in the 2005 edition of this paper):

- Fully implement IT&E with mandate/enculturation from OSD level down to institutionalization within PEO and Program Management Organizations.
- More closely align T&E Strategy/TEMP, Systems Engineering Management Plan, and Acquisition Strategy to drive this transformation.
- Maximize test data and usage of that data across test programs and fully align results to the program's risk registry while conducting assessment and testing as early and as often as possible with all organizations to support continuous risk identification and mitigation.
- Incorporate additional test objectives and requirements traceability information in the TEMP to show some degree of mission context as well as underlying technical framework supporting each critical operational issue, measure of effectiveness/suitability/performance, critical technical parameter, lower technical specification, and test objectives with traceability across this spectrum.
- Align service T&E organizations around a common core of trained T&E professionals under the Enterprise business model with linkage to Joint T&E organization and DOT&E
- Implement more rigorous systems engineering methodology in all aspects of test planning and develop or procure adequate tools to allow management of IT&E for the program and various organizations.
- Collect management metrics on T&E support from service, PEO, program management office, service systems/material command, and other T&E organizations/directorates for accuracy in process and reporting as well as support for early program risk reduction.
- Reduce the number of programs undergoing unique tests by combining and integrating T&E not only within a program but also between related programs or families of systems (such as with PEO-IWS led Enterprise Air Warfare Ship Self Defense Testing). Develop, field, and test in parallel/together rather than separately to reduce amount of retesting whenever possible as well as supporting rigorous systems/family of systems testing in challenging multi-unit joint warfare level testing/exercises.
- Begin inserting operational realism, scenarios, and realistic environments and threat surrogates as early as possible while not affecting the ability to test technical parameters.
- Change the "Pass-Fail" mindset of IOT&E to an evaluation and exploration of operational capabilities and limitations; require OTAs to provide feedback on testing in progress, while allowing them to maintain independence. Foster early collaboration of CT, DT, OT, LFT&E as well as training exercises and experimentation. Also, ensure T&E supports baselining of new capabilities with current systems capabilities.
- Increase program management focus on life cycle support, HSI, and other factors beyond technical performance and mission effectiveness earlier in the process.
- Coordinate use of standard statistical methodology for T&E and analysis of probabilistic measures of effectiveness, suitability, performance, and technical parameters to ensure common results, incorporating design of experiments and lead six sigma practices where practicable.

CONCLUSION

T&E is an essential tool for the PM for managing risk. Transformed T&E must be integrated by organization and by activity through the systems engineering life cycle to provide cost efficient but continuous feedback on risks, both technical and operational. T&E must have influence throughout the systems engineering process and in turn use systems engineering principles to

make this effective. Every T&E event must use the right level of resources to address the test objective based on the associated requirements and risk. Test results must be adequately tied to risk based results that enable correlation to program risks and can help drive development and re-testing resource allocation and prioritization. To adequately implement this level of integrated testing, adequate software tools such as AVW's IT&E Database Toolset must be used to adequately define and integrate tests, manage resources, track test objective traceability to the requirements, allocate resources, and report findings on a risk basis. These and other process transformations will better align T&E within systems engineering to enable to program manager to define and control risks and ultimately deliver the required capability within budget and on schedule.

ABOUT THE AUTHOR

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AVW Technologies, Inc. is a small, veteran owned business that provides professional engineering services to naval acquisition programs, T&E support to COMOPTEVFOR and naval acquisition programs, and engineering management consulting services to ship builders. Corporate efforts to date have primarily been focused on surface ship acquisition, from design through production and Test and Lifecycle Management; however, we are branching into other areas of naval and joint acquisition and T&E. AVW is a recognized leader in the use of integrated data environments and digital product models to support ship acquisition, as well as the use of M&S technologies to support design, production, and T&E. AVW staff includes former COMOPTEVFOR Operational Test Directors who are well versed in distributed land based test beds and their use in design integration testing, the T&E WIPT, requirements document and TEMP development and approval process, and managing developmental and operational assessments and testing. Staff acquisition expertise and naval experience have made AVW a key member of Seabasing concept development, capabilities assessment, and acquisition planning.

NOTES

This paper derived from author's original presentation briefed during T&E track concurrent session of NDIA Systems Engineering Conference 2005 (see http://www.dtic.mil/ndia/2005systems/tuesday/tribble.pdf and http://www.dtic.mil/ndia/2005systems/tuesday/tribble2.pdf for paper and presentation).

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[1] Defense Acquisition Guidebook (DAG) Version 4.5, para. 1.3.
[2] "The Role of T&E in the Systems Engineering Process", Glenn Lamartin (OSD/AT&L, Director Defense Systems), 17 Aug 2004.
[3] Ibid.
[4] DoDD 5000.1, 12 May 2003, para. E1.1.11.
[5] Ibid.
[6] DoDINST 5000.2, 12 May 2003, para. E.5.1.1.
[7] DAG, para. 9.1.5.
[8] Ibid, para. 9.3.1.
[9] Ibid, para. 9.3.3.
[10] COMOPTEVFOR letter 1000, ser 00/409, "T&E Streamline and Cost Reduction Task Final Report, Volume I," 6 Jul 2005.
[11] GAO Report NSIAD-00-199, "Best Practices: A More Constructive Test Approach is Key to Better Weapon System Outcomes," July 2000.
[12] COMOPTEVFOR letter, 3980 ser 00/391, "Policy and Information Notice 05-1, OT&E Framework and the IT Methodology," of 28 Jul 2005.
[13] Systems Engineering Fundamentals, Defense Acquisition University, Jan 01, pg. 31.
[14] Capability Maturity Model Integration® (CMMI^{SM}), Version 1.1, Carnegie Mellon University Software Engineering Institute, Mar 2002, pg. 67.
[15] CMMI^{SM}, pg. 68.
[16] Systems Engineering Fundamentals, Defense Acquisition University, Jan 01, pg. 41.
[17] Enhancing the Role of Test and Evaluation in the Acquisition Process to Increase the Probability of the Delivery of Equipment that Meets the Needs of the Users, Joseph Kasser, SETE2000 Conference paper, pg. 2.
[18] Ibid., pg. 4.
[19] CMMI^{SM,} pg. 462-463.
[20] CMMI^{SM,} pg. 481-482.
[21] Enhancing the Role of T&E..., pg. 4.
[22] Ibid.
[23] T&E Management Guide, Defense Acquisition University, Jan 05, pg. 1-4 – 1-8.
[24] Ibid. pg. 1-4 – 1-8.
[25] Ibid. Jan 05, pg. 1-4 – 1-8.
[26] Department of the Army Pamphlet 73-1, "T&E in Support of Systems Acquisition", 30 May 03, tables 6-6, 6-7, and 6-8.
[27] DAG, para. 9.8.1.