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Track 3: Involving Test & Evaluation in Systems Engineering

Interweaving
TEST AND EVALUATION
throughout the
SYSTEMS ENGINEERING PROCESS

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NDIA NATIONAL DEFENSE INDUSTRIAL ASSOCIATION STRENGTH THROUGH INDUSTRY & TECHNOLOGY

ABSTRACT

Legacy acquisition processes bias test and evaluation (T&E) towards final design verification through segmented contractor, developmental, live fire, and operational testing. With increasingly complex systems and greater cost constraints, T&E must transform into a continuum of integrated objectives interwoven throughout the systems engineering process.

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.

This process is carried out in greater complexity throughout the program, and is supported similarly by integrated T&E. 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.

T&E Working Integrated Product Team (WIPT) coordination of these processes can drive early and cost efficient identification of risks and containment of system defects which are easier to correct. By pushing testing "to the left," integrating objectives, and interweaving T&E into all aspects of systems engineering, the required capabilities can be delivered to the warfighter more efficiently and rapidly.

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). T&E can be shown to fulfill a much greater role by study of the various tasks within the overarching systems engineering process and the acquisition life cycle. In fact, defense transformation and evolutionary acquisition tenants demand such an expanded role and level of integration.

Recent changes in defense acquisition policies have been driven by systems complexity and cost constraints. These seek to transform the triad of components of the defense acquisition system. The Joint Capabilities Integration and Development System (JCIDS) shifted requirements generation to a capabilities based, top-down, joint-focused process. Acquisition policy brings spiral development ("evolutionary acquisition") and capabilities delivery into the systems engineering realm, balancing required capabilities with acquisition and life cycle costs and other constraints. The third member of the triad, the planning, programming, budgeting, and execution process (PPBE) has not seen much reform, however. Cost as an independent variable (CAIV) in a highly constrained environment places considerable strain on the system and shapes some of the cultural barriers to overall transformation of this complex acquisition process. Many organizational changes and realignments have occurred or are planned at DoD, joint, and service levels to implement these policy changes.

Within the acquisition leg of triad, there is an ever-increasing focus on disciplined systems engineering and integration of the various types of testing within DoD and service level acquisition policies. Organizations, policies, procedures, and assets must be further aligned to achieve the required level of integration. In particular, T&E must transform into a truly integrated continuum of requirements verification, technology maturation, risk management, capabilities validation, and support assessment. This continuum must itself be interwoven at each iteration of the systems engineering process throughout the acquisition life cycle. The goal of this paper is to indicate areas in T&E methodology and processes where this may occur.

STATE OF SYSTEMS ACQUISITION

Program managers are being tasked to provide capable systems to the user 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 must be undertaken by all members and elements of the greater acquisition community to not merely reform or evolve, but to transform the T&E 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 intelligent risk management. In short, the acquisition system need to transform to deliver the right product on time that works that is affordable and sustainable. The JCIDS, acquisition, and PPBE system form a triad that shapes the overall defense acquisition system. Each of these components must transform to meet the needs of our future military. Challenges within each will be addressed below, however, the focus of this analysis will be on T&E working within systems engineering as part of the acquisition component of this triad.

JCIDS

Transformation to 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 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 (FoS), systems of systems (SoS), and individual systems.[1] JCIDS is a tool used by joint staff and service warfighters and combatant commanders with input in some cases from government acquisition stakeholders, and in limited cases, industry to shape the force capabilities. Maturation of military critical technologies by various national laboratories, service research laboratories, academia, and industry feeds into both JCIDS and acquisition. Systems engineers and testers are less involved at this stage, although can play a key role in defining requirements and ensuring proper context for the flow-down of requirements during later design and testing.

JCIDS is an important step in transformation of the cumbersome acquisition system that results in better articulated capabilities required for systems tied to joint warfighting needs. However, additional work must be done to support the speed, flexibility, and complexity of future systems. Requirements flow-down for concept studies, engineering, testing, and tactics/doctrine development all must link together with engineers and testers playing a vital role at the onset of concepts before they mature into programs of record. Adequate mission context, traceability, and prioritization are needed throughout the acquisition life cycle. Additionally, many systems attempt to “grandfather” themselves, work around this process, or circumvent the intent of the top-down capabilities analysis.

Systems Acquisition

OSD and service level briefings on acquisition and systems engineering indicate a number of critical challenges facing government and industry. 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 system 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 including systems engineering and T&E disciplines must undergo transformation 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]

Systems Engineering Complexity

Figure 1 below, from the Defense Acquisition University curricula, depicts a summary of the systems engineering process, showing input of traditional test and evaluation.

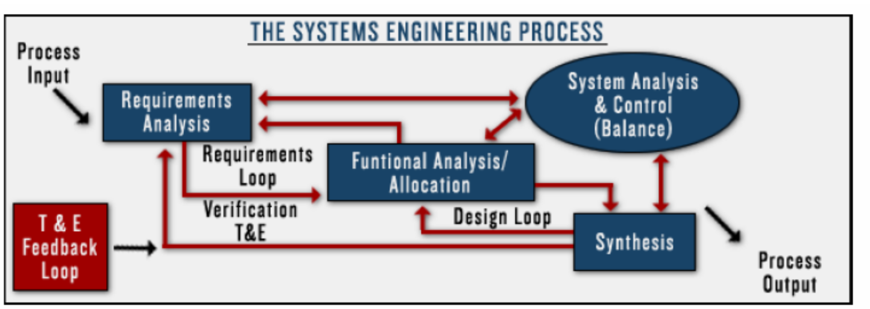


Figure 1: Systems Engineering Process Summary[4]

The ever increasing complexity requires more iterations of this process through multiple iterations during each phase of the acquisition life cycle. This requires additional analysis, testing, and other verification and validation activities due to greater chance of inducing errors and/or misconstrued requirements during the iterations of this engineering process.

Joint Interoperability

The implementation of net-centric operations and net ready key performance parameters highlights this ever-challenging aspect of systems engineering, depicted in figure 2 below.

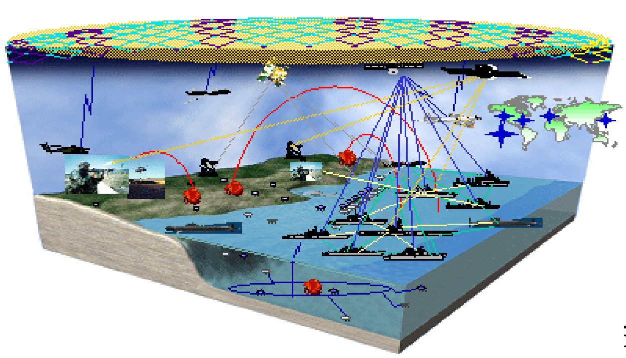


Figure 2: Challenge of Joint Interoperability and Net Centric Operations

Test and Evaluation

Based on these complexities, testers must become more committed to program 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.

DoD Directive 5000.1 states that T&E should be integrated throughout the defense acquisition process and structured to provide accurate and timely information on risks and capabilities to decision makers.[5] 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."[6] Although a variety of organizations play roles in this integration of T&E, the program manager is tasked first and foremost with this daunting responsibility.[7] The Defense Acquisition Guidebook elaborates on the philosophy of integrated T&E in describing how separate industry and government developmental and operational testing can be combined as well as M&S and other activities.[8]

T&E expertise must be included during program conception so that problems are identified and addressed early, rather than exposed in a test report released too late for meaningful and cost-effective changes to be made. T&E must become an integrated continuum of supporting activities for systems engineering verification and operational capabilities exploration in realistic threat and environmental conditions. [9] Systems engineering and test and evaluation master plans (SEP and TEMP) can be aligned with JCIDS documents to describe this integration. 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 warfighter. Whenever feasible, DT&E and OT&E events as well as LFT&E and other activities should be combined to gain optimal use of resources, if that supports technical and operational test objectives. The user community should also be involved early in test planning to ensure the capabilities are delivered as intended.[10]

Analysis of T&E and acquisition processes has shown that there are a number of influential, though seldom analyzed, factors affecting the value of T&E in a given acquisition program. Though changes are being implemented, success is still largely seen as timely entry into the next milestone, culminating in full rate production and fielding.[11] Other influential factors impacting value of T&E including constantly changing requirements, difficulties in testing due to inadequacies in facilities and infrastructure, diminished resources/budgets, changes due to evolutionary acquisition, and acquisition cultural climate (including a "success or perish mentality.[12] Specific drivers include:

- Human decision maker drivers such as risk tolerance, professional experience, personal goals, and effectiveness at decision making
- Business practices and cultural drivers including focus on maintaining viability of the program and of their organization
- Political drivers due to numerous economic, social, popular, legislative, executive, and military culture including impact of perceptions and prejudices

Technical drivers including maturity, risk, focus on exit criteria of passing a test or fielding a system (vice delivery of needed capabilities), and many other engineering factors.[13]

Related to these factors, numerous studies including a COMOPTEVFOR led study to address CNO tasking to reduce T&E costs by 20 % have concluded that: [14]

- T&E must be driven by a single agency, a current challenge for the Navy, and less so for other services, the Army in particular
- lean 6 sigma and other process analysis and improvement techniques must be implemented
- co-located test resources and facilities must be combined as well as greater cross-leverage between government and industry
- increasing visibility of costs as well as the value added nature of T&E to the program and to the warfighters is essential
- closely managing systems upgrades and assessing level of regression testing
- reduction of excessive testing costs due to:
    - redundant testing and certification activities
    - inadequate leverage of T&E disciplines, experimentation, and training exercises
    - use of differing analytical methods to maximize test assets including design of experiments, reduction in pressures to achieve high statistical confidence, and greater use of M&S (particularly for expensive live weapons firings)
    - inadequate risk mitigation in preparation for operational testing
    - poorly written or misunderstood requirements
    - inadequate early software testing and process maturity
- drive to maintain cost and schedule may result in reduction of capabilities and/or reduction in testing to determine those capabilities (although testing, shown below in figure 3 is a small fraction of the budget).

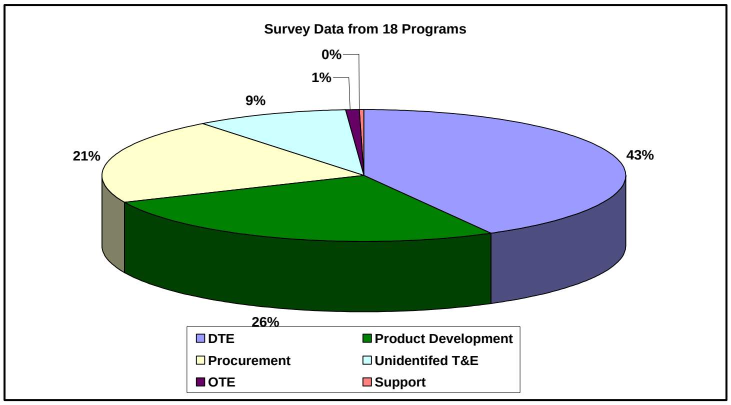


Figure 3: Research, Development, Test, and Evaluation (RDT&E) cost breakdown survey results[15]

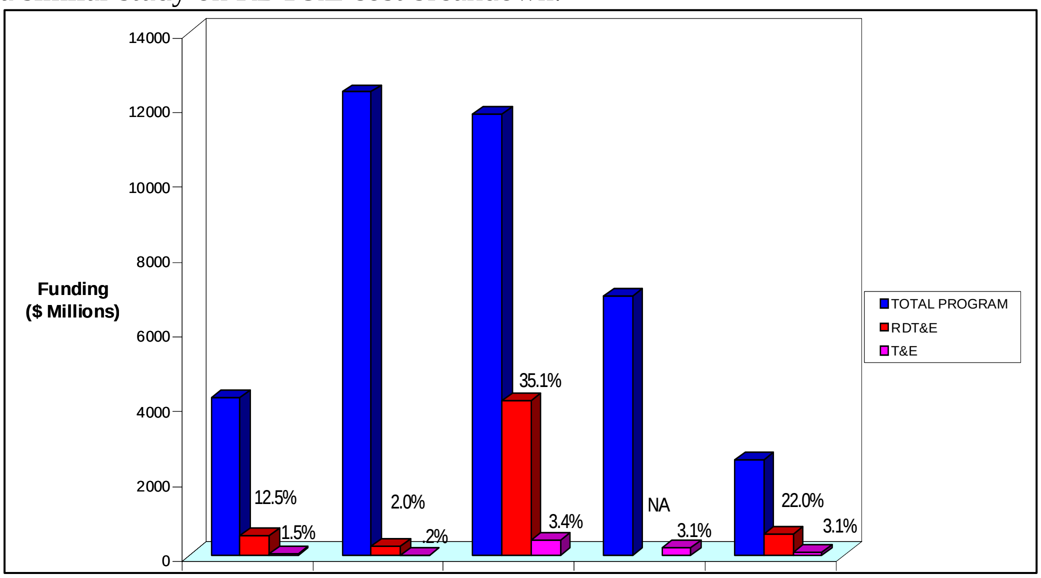
- acquisition, T&E, JCIDS, and other process documents and guidance are not fully aligned particularly at the service levels
- T&E integration within Systems Engineering is gaining more emphasis

"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."[16] The most telling of many of these studies is that volumes of information on acquisition and T&E reforms and best practices are available but many are not implemented, often due to political and business culture drivers.

PPBE

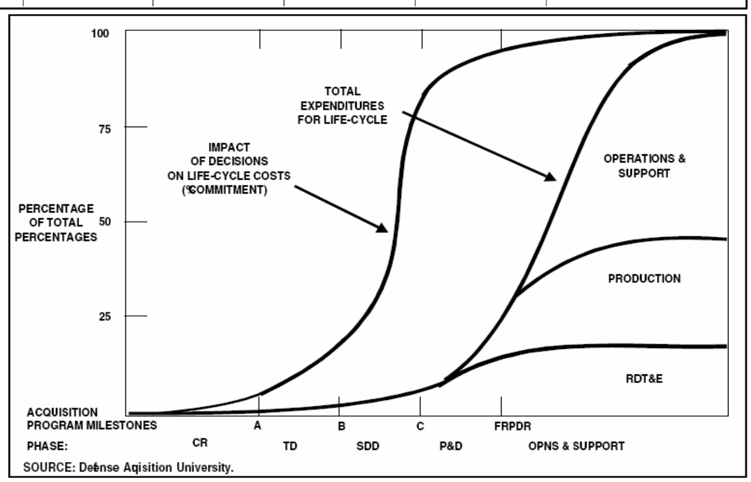
Although mostly beyond the scope of this analysis on T&E, the effect on business culture of CAIV and cost constraints managed under PPBE cannot be ignored. From a Navy perspective, this is highlighted for testers in the CNO's guidance for 2004 that set a goal to "streamline our [T&E] processes through a collaborative effort among Navy, [OSD], and contractor entities, using [M&S] where appropriate, with the goal of reducing the cost of T&E by 20 percent."[17] This goal was laid out as part of the Sea-Trial aspect of the new concept of Sea-Power 21 and other naval transformation strategies. Figure 3 above cited from the COMOPTEVFOR study shows the cost breakdown of T&E, particularly OT&E, as a smaller fraction within RDT&E costs for a sampling a Navy programs. Figure 4 below from various OSD systems engineering briefings shows a similar study on RDT&E cost breakdown.

Figure 4: Selected Army Programs RDT&E Cost Breakdown



Related to these RDT&E cost breakdown graphs is figure 5 below showing relative life-cycle costs for a program.

Figure 5: Relative Life Cycle Cost Breakdown[18]



The cumulative effect of these facts combined with discussion of early and integrated T&E above shows the relative low cost of T&E within the total program compared to its value added. Various other OSD studies indicate a number of systems engineering and T&E driven areas that directly impact cost including the most obvious which is immaturity and instability of requirements along with many other areas.

T&E WITHIN SYSTEMS ENGINEERING PROCESS TASKS

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, design products, and testing of components. As synthesis progresses towards completion, system testing supports interim assessment and final verification of the baseline product.

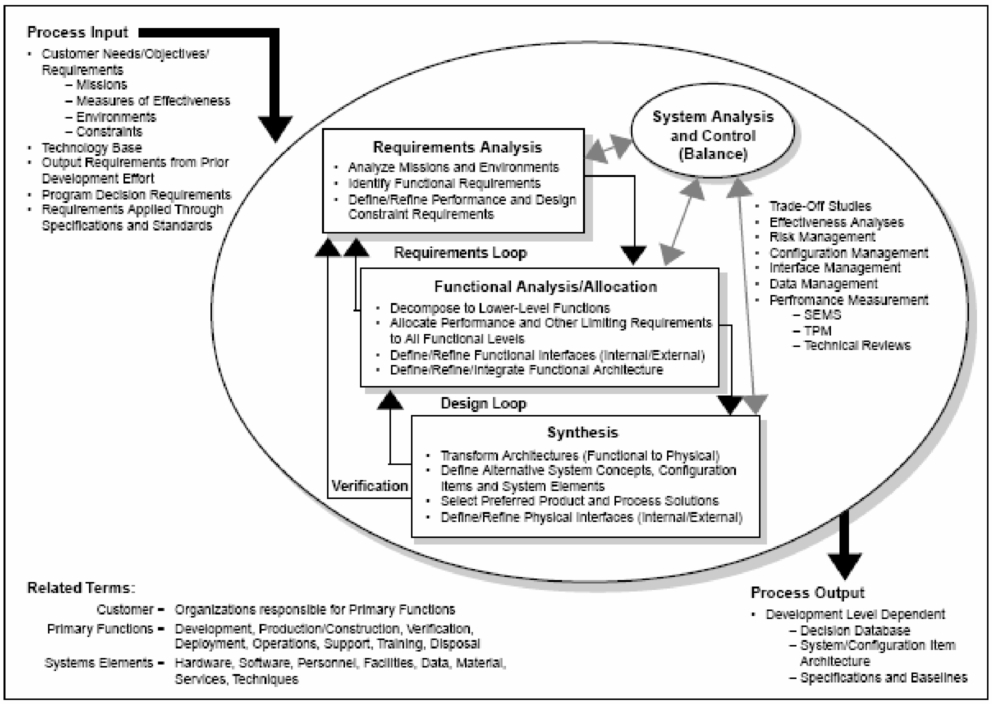


Figure 6: Detailed Systems Engineering Process[19]

This Defense Acquisition University graphic depicts the standard systems engineering process with similar terminology in a number of legacy and emerging standards including the Software Engineering Institute's Capability Maturity Model Integration® (CMMI^SM^), recognized for systems and software engineering process improvement.[20] 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.[21] 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).[22]

A key to this stage is a proper understanding and prioritization of requirements, which can be categorized in the following areas:

1. *Capability that is desired.*
2. *Capability and performance mandated by external constraints liable to change, such as Government regulations, etc.*
3. *Capability and performance mandated by external constraints that are unlikely to change, such as the laws of physics, etc.*
4. *Capability that does not matter to the user one way or the other, and the development contractor is notified of that situation.*
5. *Capability that does not matter to the user one way or the other, and the development contractor is not notified of that situation.*
6. *Capability that is not desired.*
7. *Capability that is desired but the customer does not know that it can be provided.*
8. *Capability that is desired but cannot be provided.*
9. *Capability that is irrelevant to the equipment to be acquired.* [23]

Most requirements fall somewhere in one of the first five of these categories. A proper prioritization of each user requirement/capability is essential along with traceability down to the final design. In many cases, requirements are treated simply as pass/fail and all mandatory, with the only distinction for Key Performance Parameters (KPP), which are used more for acquisition decision making. Priorities and risks must be tied to each of the requirements.

Conversely, T&E activities themselves, later in the acquisition cycle, are supported by early tester involvement. Insight into areas such as customer expectations, project cost and other constraints, life cycle and HSI design, and understanding of the actual context and intentions of requirements can significantly improve test planning (both in allocation of limited resources as well as focusing priority in the most necessary areas). This level of involvement is iterated through the requirements loop between functional allocation and requirements analysis.

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 warfighters 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 Early Operational Assessments (EOAs) prior to Milestone B and Operational Assessments early during the System Development and Demonstration (SD&D) acquisition phase. 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 assist 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).[24] 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."[25] 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."[26]

Evaluation of results in T&E to aid in decision-making must itself transform to express system capability in terms of mission accomplishment, not just failing, meeting, or exceeding requirements.[27] Evaluation itself can be used to identify where requirements are exceeded to the point where capabilities can be trimmed to cut costs (while meeting the requirement). In addition, evaluation can identify added capability that although unplanned, provides significant and cost effective improvement in warfighting performance. "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."[28] Thus T&E serves many roles in development, fielding, and support of the system.

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 SD&D phase where 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 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.

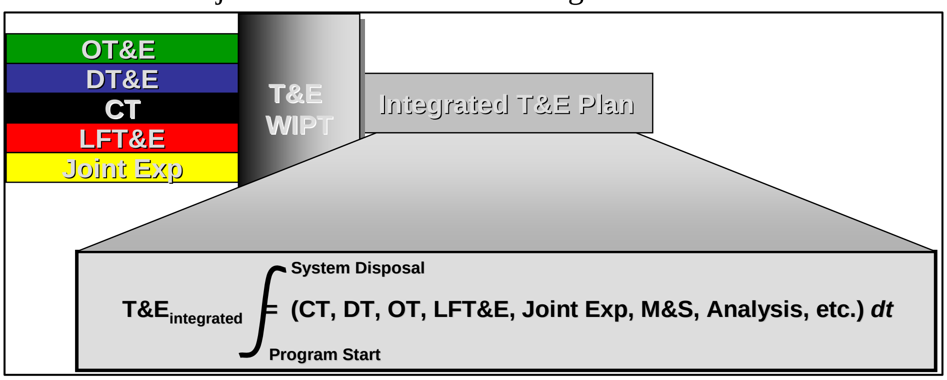


Figure 7: IT&E Concept

Within the Navy's Operational Test Agency, COMOPTEVFOR, the command is implementing an integrated T&E (IT&E) process. This new policy pulls tenants of early involvement, the CNO T&E cost reduction mandate, and the need to pull testing "to the left" together with a dendritic approach to mission area decomposition using standard systems engineering methodology referred to in the Defense Acquisition Guidebook. The focus is early and continuous evaluation of systems, resolving specific OT&E objectives earlier in the acquisition cycle, and reducing redundant testing (to reduce costs). Challenges in implementation include obtaining the necessary buy-in from program managers, adapting joint and service tasks lists for conduct of mission analysis (as well as deriving criteria from the myriad of joint and service doctrine and instructions), implementation of test design methodology including design of experiments, proper breakdown of suitability issues across mission areas, and developing risk based reporting criteria.[29] 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.

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. 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.

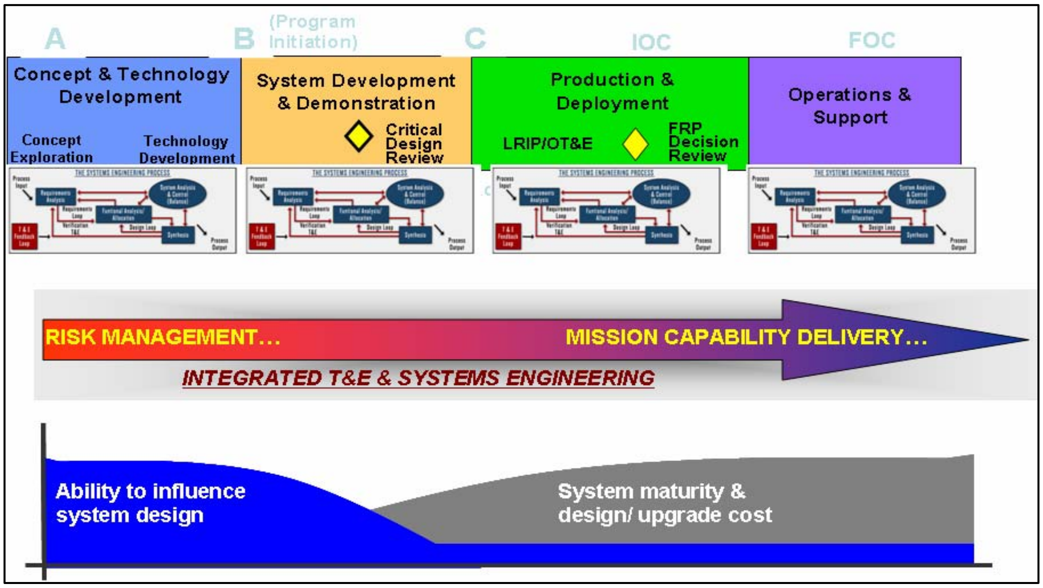


Figure 8: Life-Cycle Integrated T&E and Systems Engineering Summary

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.[30]

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 (EDM), 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 EOAs. The variety and magnitude of new technologies for programs such as DD(X), Future Combat System, and Joint Strike Fighter including platform level computing and software integration incur considerable risks that can be addressed through EOAs and OAs. 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 the following areas:

- Probability of meeting requirements in the Operational Requirements or JCIDS Capabilities documents
- Likelihood of the system being able to counter threats identified in DIA and service intelligence agency threat reports
- Adequacy of requirements and capabilities descriptions
- Level of risk for each critical operational issue/mission area
- Significant trends noted in development efforts, programmatic voids, and test resource shortfalls
- Ability of the program to support adequate OT&E (including adequate test resources) and successfully demonstrate required capabilities for Initial OT&E.

Use of an EOA as a significant tool for risk mitigation in total-ship acquisition programs has been very successful in the recent past. The LPD 17 Program used this tool to identify numerous potential design deficiencies such as obstructions, interferences, traffic choke points, night vision device compatibility, and weapons engagement blind spots. The Strategic Sealift Program EOA identified significant weaknesses in space and deck arrangement, the capability to conduct self-sustained operations, cargo flow paths, and compatibility with ramps and lighterage. CVN-21 EOA surfaced many issues with sortie generation rate KPP assessment, flight deck layout, warfare systems integration and other areas. DD(X) EOA addressed numerous issues in this highly complex program of new technologies, automation/HSI for an optimal size crew, and risks in executing needed transformation of shore support and maintenance.

Of all the phases of a program, this phase and perhaps the beginning of the next phase, SDD, 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 SDD 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 SDD, 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. Integrated T&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.[31]

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 SDD 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 SDD 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 consists of more traditional verification and in particular 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 SDD 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:

- production readiness reviews and in-process reviews
- independent logistics audits
- information assurance certification and accreditation
- spectrum certification
- review of final doctrine and tactics

- implementation of life cycle support plans including maintenance demonstrations
- crew/user training and qualification
- command/fleet/field exercises and training employing the system(s)
- M&S testbed analysis for complex systems integration (such as ship's combat systems)
- final LFT&E including shock qualification/trials and/or lethality evaluation

Periodic feedback on results from IT&E must support early risk reduction. Where possible, these activities must begin in SDD with final validation conducted in this phase. Neither OPEVAL nor TECHEVAL should be the first time that some of these key program areas is addressed.

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 SDD 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.[32] Figure 9 below summarizes the myriad of system characteristics and capabilities that must be monitored and maintained by this integrated continuum of IT&E and systems engineering.

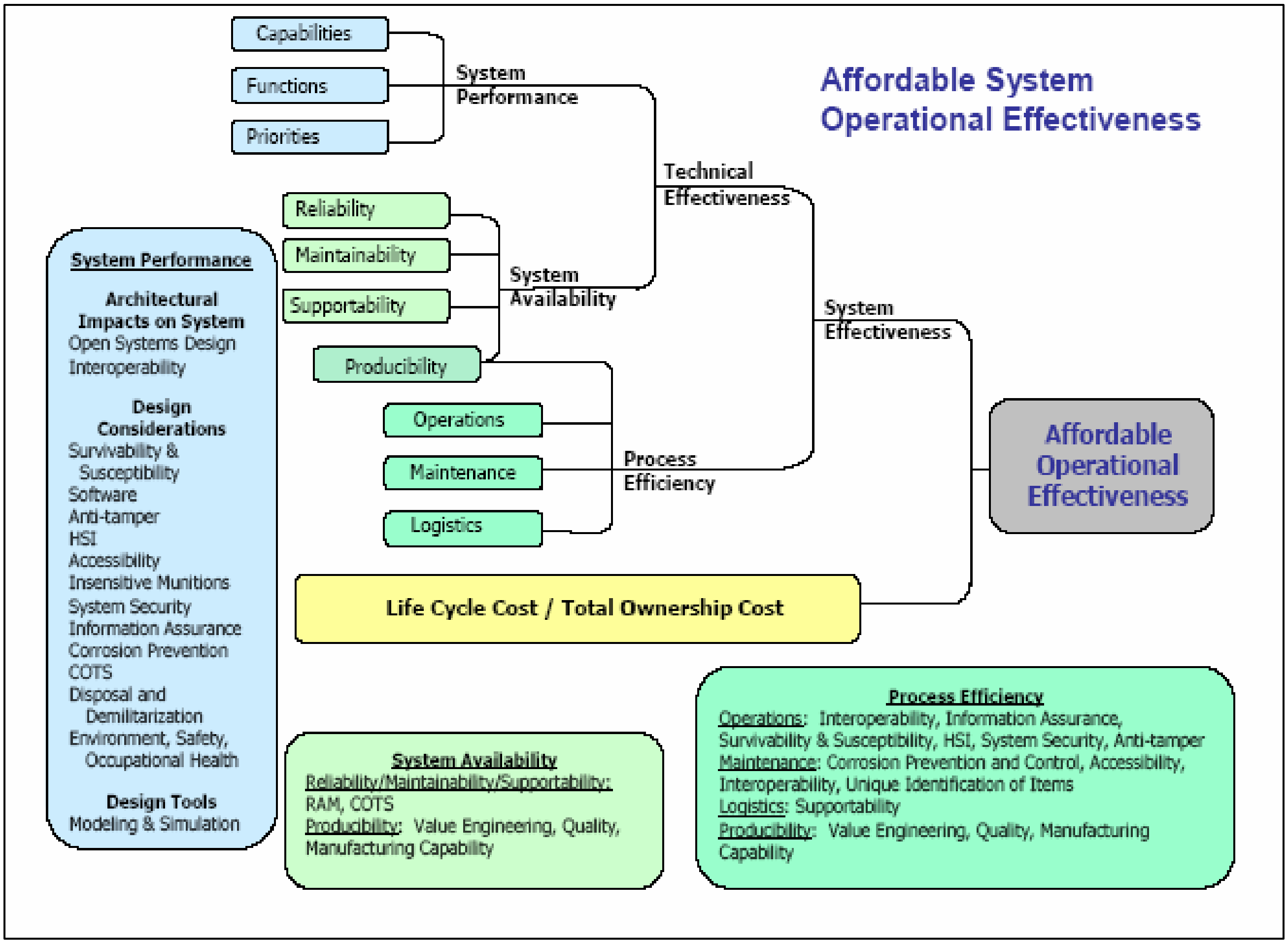


Figure 9: Life Cycle System Characteristics[33]

CONCLUSION

The traditional T&E Working Integrated Product Team 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.

Specific Systems Engineering/T&E Recommendations

Based on the analysis presented, specific recommendations for further transforming systems engineering and T&E to meet these challenges are included below. 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, including many of the recommendations discussed below. [34]

- Fully implement IT&E mandated from the OSD level jointly by OSD/SE-AS and DOT&E as well as by PEOs. Start with review of T&E WIPT processes for major programs, with oversight emphasis on implementing IT&E. Ensure full cooperation between systems engineers and testers during all phases, starting with JCIDS analysis including analysis of material alternatives and development of both the initial capabilities document and the capabilities development document (for each increment, if evolutionary acquisition).
- Pull T&E to the "left," i.e. earlier in acquisition life cycles for systems increments, addressing objectives as early as possible.
- More closely align the T&E Strategy/TEMP, Acquisition Strategy, and Technology Development Strategy/Systems Engineering Plans so each discusses the integration of all types of T&E as IT&E along with systems engineering, risk management, and acquisition.
- Include additional budgetary and other incentives for programs to fully integrate T&E
- Address T&E infrastructure shortfalls and implement database to foster collaborative use of government and industry test resources including M&S
- Restructure TEMP and T&E strategy document formats to better show alignment of all aspects of T&E, incorporating discussion of CT, Experimentation, similar systems T&E as well as DT&E, OT&E, and LFT&E.
- Incorporate additional requirements traceability information in the TEMP to show mission context for each measure of effectiveness and suitability as well as traceability to DT objectives and critical technical parameters. Include annexes for TEMPs to show derivation of test objectives for various areas of T&E.
- Standup a formal Joint T&E organization under JCS with input to TEMPs for all future Acquisition Category (ACAT) I & II programs to address joint T&E requirements.
- Increase collaboration of T&E with fleet/field training and experimentation for leverage of data with incentives for all stakeholders to foster cooperation.

- 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.
- Mission fund independent operational test agencies (OTA) as the new service T&E command to execute testing, some which still require funding from the program offices—this will empower them to implement smart and efficient testing while answering directly and independently to service headquarters staff on effectiveness of IT&E; at the same time, increase visibility and independence of T&E funding from RDTE funding.
- Facilitate smarter testing by realigning OTAs and other T&E organizations for services under a common T&E command reporting to the service chief directly with oversight from DOT&E and a new Joint T&E directorate recommended above. Include in this organization test ranges, facilities, and targets management.
- In support of the previous recommendation, realign PEO and Systems Command T&E organizations with the new service T&E manager for efficient conduct and planning of IT&E.
- Collect management metrics on T&E support from service T&E organizations and PEO and SYSCOM T&E directorates for accuracy in process and reporting as well as support for early program risk reduction.
- Increase visibility of T&E within the defense workforce systems engineering work-field and implement additional or upgraded training to foster IT&E and systems engineering continuum.
- Reduce the number of programs under test by combining and integrating T&E not only within a program but also between related programs or families of systems. Develop, field, and test in parallel/together rather than separately to reduce amount of retesting whenever possible.
- Change the "Pass-Fail" mindset of IOT&E/ OPEVAL 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 more participation of OTAs in CT, DT, and joint experimentation to reduce scope of separate IOT&E events whenever possible.
- While leveraging program and contractor testing and design reviews, require at least one EOA prior to milestone B and one OA prior to milestone C for ACAT I programs or when recommended by DOT&E.
- When possible, link all T&E stakeholders into program design database for complete visibility into requirements analysis and allocation to enable inputs and to aid in rigorous test planning with full traceability.
- Increase education and training within systems engineering and acquisition program management on proper use of M&S for analysis, T&E, and design including proper implementation of verification, validation, and accreditation processes. Increase focus on not just credibility of the M&S tools, but in execution of the analysis and interpretation of the results.
- Increase the use of distributed test tools and networking that enable ease of design, testing, and fixing systems in complex programs.
- Increase CT, DT&E, design engineering, and program management focus on life cycle support, HSI, and other factors above and beyond technical performance and mission effectiveness.

- 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. Incorporate design of experiments where practical and process improvement tools such as six-sigma and CMMI to address program and system performance as well as efficiency of test planning.
- Stabilize T&E and systems engineering within programs to mitigate military billet turnover through adequate documentation.
- Implement certification for T&E processes and organizations including process improvement metrics collection, analysis, and implementation (including quality, utility, and timeliness of information provided to decision makers, users, and other stakeholders).
- "Use Physics of Failure as a tool to predict and analyze system performance and shortfalls."[35]
- Begin inserting operational realism, scenarios, and realistic environments and threat surrogates as early as possible.
- Ensure T&E supports baseline of capabilities with current systems
- Address level of testing, statistical confidence levels, resource cost expenditures on addressing risks in terms of mission consequence to capabilities if projected failures occur and probability of failures occurring during testing and operations. Consider ACAT level and other factors in resourcing for tests. Similarly, address results of testing in the design based on the same standard risk metrics to align all aspects of T&E into program/system risk management. Table 1 presents tailored risk chart for testing management.

Table 1: T&E Planning Risk Matrix[36]

Consequence Probability of Occurrence	1	2	3	4	5
A – Frequent occurrence during tests/operations (probability approaching 1.0)	I	I	II	II	III
B – Probable to occur during tests/operations	I	I	II	II	III
C – Occasional- - likely to occur during tests/operations (probability near 0.5)	II	II	III	III	IV
D – Remote – less likely to occur during tests/operations	II	II	III	IV	IV
E – Improbable – extremely unlikely to occur during tests/operations (probability approaching 0)	III	III	III	IV	IV

Consequence:
- 1 – prevents primary mission or serious safety violation
- 2 – significant primary mission degradation or secondary mission failure/degradation with no work-around
- 3 – significant impact to any mission but work-around is available
- 4 – minor degradation/adverse impact to missions
- 5 – no degradation but operator annoyance or recommended enhancement

Level of testing based on risk or priority of trouble report based on risk:
- I Very High Risk – resolve ASAP
- II High Risk – immediate resolution desirable
- III Manageable Risk – resolution can be delayed
- IV Low Risk – resolution not required

Additional Recommendations to Consider

Beyond the scope of systems engineering and T&E, transformation is necessary in other areas, particularly PPBE. This system drives many of the negative aspects of the acquisition culture that reacts to budget competition and CAIV constraints. PPBE must transform along with acquisition, systems engineering, and T&E disciplines to enable the triad of JCIDS, PPBE, and acquisition to field systems that provide needed warfighting capabilities on time and on budget.

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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.

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