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[1]

Joseph Kasser
Systems Engineering and Evaluation Centre
University of South Australia,
Mawson Lakes Campus, Room F-37
Mawson Lakes, SA, 5095
Australia
Email: Joseph.Kasser@unisa.edu.au

Abstract

Test and Evaluation (T&E) is becoming increasingly important in the current acquisition paradigm as a way to ensure that the military equipment user receives equipment that conforms to its requirements. However, T&E really has several different roles:

- **Testing** – determines the degree of non-conformance to requirements of "as-delivered" equipment.
- **Evaluation** - determines the capability of "as-delivered" or "as-built" equipment.

In recent times, recognizing that the documented requirements do not generally represent the true needs of the user, the T&E role has expanded itself to attempt to ensure that "as-delivered" equipment meets the needs of the user.
This paper discusses the reasons for, the differences between, and how modern quality theory, Information Technology and Knowledge Management, can improve the various roles of T&E.

Introduction

The traditional role of T&E is:

- **Testing** - determines the degree of non-conformance to requirements of "as-delivered" equipment.
- **Evaluation** - determines the capability of "as-delivered" or "as-built" equipment.

The traditional systems development life cycle (SDLC) is characterized by large cost overruns, schedule slips, and dramatic performance deficiencies in weapon, C4I, and automated information systems (DoD 1995). As a consequence, there have been a number of reactions to this situation; including the development of the Capability Maturity Models (CMM) and the requirement for conformance to process standards. A less-publicized, but important reaction has been the expansion of the role of T&E.

The expansion of T&E

Dedicated T&E practitioners, recognizing that the "as-delivered" military equipment does not meet the needs of the users, have expanded the role of T&E to ensure that military equipment fielded in the defence forces (as-delivered) is suitable for use before being placed into service. The drivers for this expansion of T&E include (Dennison 2000):

- Increasing complexity of aircraft and systems.
- Longer development programmes.
- Longer periods of service.
- Changes in policy on airworthiness and liability.
- Funding pressures.

[1] This work was funded from the DSTO SEEC Centre of Expertise Contract.

From the systems engineering perspective, these drivers may be summarized as:

- Equipment is being built to specifications that are poorly written, ill defined, and incomplete.
- The failure to manage changing requirements over the development and operations phases of the SDLC.

T&E in the United States Air Force (USAF) T&E procurement of weapon systems is divided into two roles (Pearson 2000):

- **Developmental test and evaluation** (DT&E): the USAF uses DT&E to learn and confirm, that is, to learn about the system's capabilities, and confirm that it performs according to specifications.
- **Operational test and evaluation** (OT&E): the USAF uses OT&E to answer two fundamental questions. First, given a realistic environment, can the warfighter use the system to accomplish the mission? Second, given the same realistic environment, can the warfighter support and maintain the system?

The USAF makes this clear distinction between DT&E and OT&E to recognize the fact that while a weapons system may meet all the design specifications, it may still fail to accomplish the mission.

Now from the perspective of modern Quality theory, finding defects after production is complete is not very cost-effective. This is because the customer pays for the defects to be produced, then pays for the contractor to effect the repairs (Deming 1986). Thus the USAF T&E approach does not embody modern Quality theory and only mitigates the symptom. It does not remove the root cause of the problem in the system namely the failure to ensure that effort be expended to ensure that the mission requirements are incorporated in the design specifications. This is the function of systems engineering since the goal of the system engineering effort is to provide a system that: Kasser (2000):

- Meets the customer's requirements as stated when the project starts.
- Meets the customer's requirements as they exist when the project is delivered.
- Is flexible enough to allow cost effective modifications as the customer's requirements continue to evolve during the operations and maintenance phase of the system life cycle.

Meeting this goal on large systems developed over a period of years is practically impossible with today's technology. The current acquisition scenario, which takes place within the context of a production paradigm, is characterized by poor requirements and contains poor change management (Kasser and Williams 1998). Now the universe of requirements embodies a number of categories:

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.

The full set of user requirements for a system to be acquired tends to be embodied in the first five of the categories.

Enhancing the traditional role of T&E

The traditional role of T&E is to ensure that the product meets its requirements. In order to perform this role as early as possible in the SDLC, T&E has to ensure that the correct system is built in the first place. It is supposed to do this by determining if the set of user requirements produced by systems engineering are complete, verifiable and understandable. Verifiability and understandability may be achieved by ensuring that the format of the written requirements conforms to the requirements for writing good requirements (Kasser 1995). Completeness, however, has been more difficult to achieve. In any event even verifiable and understandable requirements change over the SDLC and the effects of change needs to be managed over the SDLC.

T&E has not been the only engineering area of activity to recognize the existence of poor requirements engineering management. Requirements engineering itself is evolving from its traditional role as a mere front-end to the SDLC towards a central focus of change management in system-intensive organizations (Jarke 1996). Both systems engineering and T&E can make use of this concept in an interdependent manner by using modern Quality theory, Information Technology and Knowledge Management techniques to expand the traditional Requirements Traceability Matrix into the set of Quality System Elements (QSE). The QSE stored in *a 'Framework for Requirements Engineering in a Digital Integrated Environment* (FREDIE)' tool (Kasser 2000a). The format of the QSE data set is such that each user requirement accepted for the deliverable product by the contractor must be accompanied by both specific measures to determine when compliance has been achieved, and a verification plan. This "forces" customers to think about how they will know that the requirement has been met at the time the requirement is stated.

While systems engineering are developing the requirements and implementation cost and schedule estimates, T&E devise the verification methodology and the cost and schedule estimates for the testing effort.

How T&E can reduce some categories of missing requirements

To maximize the completeness of requirements and reduce the effect of non mission-specific missing requirements, both systems engineering and T&E must also ensure that system to be developed inherits the requirements for the specific type of product. For example, a low earth orbiting (LEO) spacecraft will inherit a set of generic requirements that have been refined from the experience gained in building these vehicles over the last fifty years. These requirements relate to the thermal, vacuum, and electromagnetic environment in space, launch, vibration, and salt spray, etc. Should the LEO spacecraft be a communications satellite, there would then be an additional set of generic requirements to be inherited. As a second example, equipment for use in jungle environments will inherit a set of temperature and humidity requirements while the same or similar equipment destined for use in a desert environment will inherit a different set of temperature and sand-resistance requirements. These generic sets of inherited requirements, stored in knowledge bases, ensure that important but tangential requirements are not forgotten in the design phase, e.g. ensuring that equipment that has to be shipped fits through doors and air cargo containers.

These generic sets of potential inherited requirements currently tend to be based on the experience and education of the practitioners. If the project has the expertise there those requirements are considered. Should the expertise be lacking, they may be missed and have to be incorporated further down the schedule contributing to cost escalations, and schedule delays. These requirements or mission specific knowledge must be available in knowledge bases, which can then provide a set that must be tailored for each specific project. T&E by virtue of being able to build a lessons learned database from the test results on past projects is eminently suitable for providing much of the input to populating the generic knowledge bases for various categories of systems. For any specific new project, the roles of systems engineering and T&E will depend on the project, but the generic functions might be:

- T&E provide the full generic set of requirements based on a whole range of past projects in a knowledge base. This is a corporate activity.
- Systems engineering tailors the generic set for the project by importing them into the project's FREDIE tool. This is a project activity.
- T&E verify that the tailoring performed by systems engineering conformed to the correct pattern for the system. This is a project activity.

Once the initial set of requirements has been accepted, experience has shown that they will change over the SDLC. Efficient through-life systems engineering, change management, and T&E, will require a planned, coordinated and integrated approach as well as data/knowledge warehousing (Dennison 2000). The FREDIE tool can facilitate change management by virtue of its data structure and its ability to use Knowledge Management techniques in the form of smart agents.

It is thus advisable if not incumbent to ensure that a FREDIE tool is used for new projects to avoid much of the costs now incurred in post-production rework and retest, to facilitate managing requirements, design, development, integration, and T&E, in a cost-effective concurrent manner.

Determining the capability of "as-delivered" equipment

Another major role of T&E is to determine the capability of "as-delivered" equipment. This is the where Evaluation determines the:

(1) Extent, by which the requirements have or have not been exceeded.
(2) Unanticipated emergent properties of the system that were not predicted based on the capability of the individual subsystems.
(3) Capabilities of previously owned equipment or equipment built for another customer and made available at a price or schedule that is less than that of custom produced equipment. This is similar to reverse engineering.

Requirements and capability

A requirement can be thought of as consisting of both functionality and Quality criteria. For example, a requirement to ingest sensor data into a system is made up of the input function and the performance parameter for how much data to ingest over a specific period of time. Capability is also made up of functionality and the Quality criteria. "As-delivered" equipment has four states:

- **Capability is exactly equal to the requirements:** the product meets its requirements.
- **Capability exceeds requirements:** either the performance parameters exceed requirements, or unrequired functionality is delivered.
- **Capability does not meet requirements:** either the performance parameters do not meet requirements, and/or required functionality is not delivered.
- **A combination of the previous three:** Some capability exceeds the requirements, some meets them, and some capability does not meet the requirements.

The full set of user requirements and the capability (expressed in terms of functions and Quality criteria) can both be represented in Kiviat Chart format. The Evaluation (1) role can be thought of as determining the capability and then overlaying the capability chart on the requirements chart to identify if the "as-delivered" capability lies within or without the boundary envelope of the requirements. Evaluation (1) can serve two purposes:

- If Evaluation (1) is performed on behalf of the contractor, it may be used to identify places where costs might be cut by reducing unneeded performance. This information is important in a fixed price mass production environment, for example in the automobile construction industry in which a per-item saving of $1 can be significant on a production run of 500,000 units.
- If Evaluation (1) is performed on behalf of the customer it may be used to identify additional capability. For example, supposing an aircraft specified to perform a turn at 2 G's under certain circumstances is found to be capable of a 4-G turn under the same circumstances. This additional performance might allow the pilots to develop a new maneuver. 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.

Software T&E

The last 30 years have seen a transition from hardware based systems to software intensive systems operating on hardware platforms. T&E has to ensure that the hardware-software combination is appropriate. Thus the Evaluation (1) component of T&E needs to incorporate the evaluation of excess capability offered by the Commercial-off-the-Shelf (COTS) components included in the software. The

Evaluation (2) component has been traditionally associated with physical characteristics such as temperature and electromagnetic compatibility issues. In today's software intensive systems the Evaluation (2) component will also need to address issues arising from the interaction of the multiple complex software bases subsystems.

Summary

T&E has several roles in the acquisition process. By:

- Identifying non-conformance to requirements, T&E prevents the delivery of unsuitable equipment to the end user.
- Identifying and reporting the capabilities of "as-delivered" equipment over and above the user requirements, T&E provides a valuable service to the user.
- Collecting generic requirements on types of systems and providing them to systems engineering, T&E helps to minimize more and more categories of missing requirements.

By making use of modern Quality theory, Knowledge Management, and Information Technology, T&E is positioned to work with systems engineering to prevent defects, test for non-conformance to requirements, and evaluate the capability of "as-delivered" equipment in a cost-effective manner over the entire SDLC.

References

Deming, W.E. 1986, *Out of the Crisis*, MIT Center for Advanced Engineering Study.

Dennison, K, 2000, "Integration or Partnership – Trends in UK MoD Air System Test and Evaluation", *Fourth Test and Evaluation International Aerospace Forum*, London.

Department of Defense (DoD), 1995, The Program Manager's Guide to Software Acquisition Best Practices, Version 1.0.

Jarke, M., "Meta Models for Requirements Engineering", *Tenth Knowledge Acquisition for Knowledge-Based Systems Workshop*, Banf, Alberta, Canada, 1996, http://ksi.cpsc.ucalgary.ca/KAW/KAW96/jarke/Jarke.html, last accessed June 22, 2000.

Kasser, J.E., 1995, Applying Total Quality Management to Systems Engineering, Artech House.

Kasser, J.E., Williams, V.R, "What Do You Mean You Can't Tell Me if My Project is in Trouble?" *First European Conference on Software Metrics (FESMA 98),* Antwerp, Belgium, 1998.

Kasser, J.E., 2000, "The WebConference,- A Case Study", *INCOSE Mid-Atlantic Regional Conference,* Reston, VA.

Kasser, J.E., 2000a, "A Framework for Requirements Engineering in a Digital Integrated Environment", *The Systems Engineering, Test and Evaluation Conference*, *(SETE 2000),* Brisbane, Australia.

Pearson Jr., W.D., 2000, "The Role of Test and Evaluation: A United States Air Force Perspective", *Fourth Test and Evaluation International Aerospace Forum*, London.

Author

Dr. Kasser is both a DSTO Associate Research Professor at the University of South Australia (UniSA) and a Distance Education Fellow in the University System of Maryland. He performs research into improving the acquisition process and teaches systems and software engineering subjects. Prior to taking up his position at UniSA, he was a Director of Information and Technical Studies at the Graduate School of Management and Technology (GSMT) at University of Maryland University College (UMUC). There, he was responsible for the Master of Software Engineering (MSWE) degree and the Software Development Management track of the Master of Science in Computer Systems Management (CSMN) degree. He is a recipient of NASA's Manned Space Flight Awareness Award for quality and technical excellence (Silver Snoopy), for performing and directing systems engineering. Dr. Kasser also teaches software engineering via distance education.