Methodology for Integration of Evaluation Systems in the Engineering of Large Systems

Dr P H Sydenham

Professor of Systems Test and Evaluation
Systems Engineering and Evaluation Centre
University of South Australia

Honorary Senior Research Fellow
Dept.of Mechanical Engineering
University College London

Fax: +61 8 8365 7643 Sydenham@senet.com.au

Abstract

Test and evaluation is always present in major systems development in some form or other; it is the mechanism for establishing if the final design satisfies the need of the customer. The traditional process is based on a largely unaccountable and non-inheritable procedure in which localised professionalism within the various parts of the design and manufacture organises tests. The principles of a much-improved test and evaluation process are outlined. They provide a sound foundation for setting up a cost-efficient test programs for projects.

1. Introduction: Why Measure When Developing a System?

Measurement systems are used to collect information about the state of systems. That information may be used for two main purposes.

Exploratory use. Here measurement systems are used to generate improved understanding about a real world system; or a virtual representation of it. In this case a hypothesis is first developed about behaviour of a given system that is then tested using sensors and instrumentation to gather the appropriate knowledge with which to evaluate the hypothesis as being true or false.

Control use. By monitoring system state conditions and applying corrective action it is possible to control the operation of a system. In this case the knowledge needed for control has already been established but its variations need to be sensed to see if it operating within the desired limits.

This paper primarily addresses the first use. The same principles, however, can be adapted to generate the high level requirements of a multi-sensor control system.

The number of variables to be measured in large projects can be very large. For example, the development of a modern aircraft, automobile, communication system, air traffic control network or national railway system may well involve in excess of 100,000 monitored parameters.

Ensuring that these large complex systems are maturing according to plan requires numerous tests to be conducted throughout the Systems Engineering life cycle. As it is not economic to measure every possible parameter a sound methodology is needed when designing the measurement systems for large projects. These critical measures are often called system performance ‘metrics’.

The process by which technical performance risk can be monitored, and thus controlled, is generally referred to as 'test and evaluation' (T&E), see Reynolds (1996). It should be used alongside 'project management' (for control of time) and 'financial accounting' (for control of cost).

A scientifically based methodology is needed for setting up the test instrumentation and its sensors that leads, in an efficient and traceable manner, to the most effective tests that should be used in order to obtain satisfactory control of the development of system performance.

This paper sets down the principles and methodology by which large test systems should be created and how the test results should be used to conduct critical evaluations.

2. Efficient Design of Measurement Systems to Monitor Maturity of a Development

2.1 Introduction

As a system design is developed there will be many designers involved. Two different needs for measurement arise as a system is being developed:-

- T&E of the overall system in order to maintain control of the whole system performance
- Localised testing to maintain confidence that subsystems are developing satisfactorily from the standpoint of the localised quality of the engineering design and build process.

Metrics are developed to help ensure that the development work is correctly directed and is resulting in the right performance outcomes. Monitoring of the maturation of these metrics assists develop confidence that the project, as a whole, is maturing to plan.

This paper addresses the holistic T&E requirement for this, which is, more often than not, given too little attention as part of the overall planning process for the engineering of large systems.

2.1 A Suggested Planned T&E Process

Establish the Critical Issues. The top down process begins by deciding those critical issues (CIs) that need to be met for overall satisfaction in achieving the outcomes desired – often called the 'showstoppers'.

These are found in User Needs Statements (variously called mission or vision statements, client requirements documents, statements of objectives or aims). From these are decided the important issues that are critical to success in building a system that performs as needed. These will be found in four different aspects of a project.

- CIPs - Prime purpose of system (issues about the intended purpose that it must satisfy to be regarded as fully successful, for example a motor car needs to move people with sufficient comfort and economy, over given distances, in a defined set of likely circumstances)
- CISs - Suitability of the system to perform its prime need in the stated circumstances of intended use (issues that must be right as it carries out its role, such as reliability, interoperability, maintainability, etc.)
- CIPOs - Policy and political constraints (issues that can limit project progress, such as environmental, political and societal)
- CIPRs – Programmatic development issues (issues in the contractor's process for developing the project)

Setting up this initial set of CIs is key to success in being able to monitor, and thus control by corrective action, the overall development. It is far harder to decide these than it is generally supposed. This activity must commence at the early conceptual stage of a project for it tunes system design thinking. It should not be left to the stages where design is detailed for manufacture for by then is may be too late or costly to make changes. The CIs provide a solid foundation for developing the measurement system needed for overall project performance risk control. CIs should be set up in a database to provide a record and to allow use throughout the project - as will be explained later. Each CI statement should have associated with it a brief explanation of its concept and reasoning for inclusion. The number will vary from tens for small projects, to hundreds for very large undertakings.

The project manager needs some way of knowing that these CIs are all maturing toward their goals at a satisfactory rate. Each CI will most likely be only expressible as a qualitative entity as it will be indirectly obtained from the physical measurements associated with instrument test systems. This requires the concept of the Measures Tree to now be introduced.

Develop Measures Trees. A CI needs some way of determining its value, and uncertainty, at any time during the project. This is done by first deciding the key Measures of Effectiveness (MOE) for each CI. An example is ‘Has the aircraft sufficient range to carry out its main purpose?’

The MOEs are usually indirect measures. They, in turn, also can be broken down into Measures of Performance (MOP). These are more recognisable as measurement values (such as the ‘range’ of an aircraft). Many MOPs are also not directly measurable so must be determined from yet another layer of measures, called the System Performance Parameters (SPP). It will be found that many of these are still not directly measurable, an example being the need to measure the ‘dynamic centre of gravity of an aircraft’, a factor key to in-flight stability. One last reticulation is needed to get to the actually measurable Technical Performance Parameter (TPP) layer.

This traceable hierarchy of descending measurements, from the many CIs, results in a set of Measures Trees, one being shown simplistically in Figure 1.

Needs Statements flow down into Measures Tree for each CI

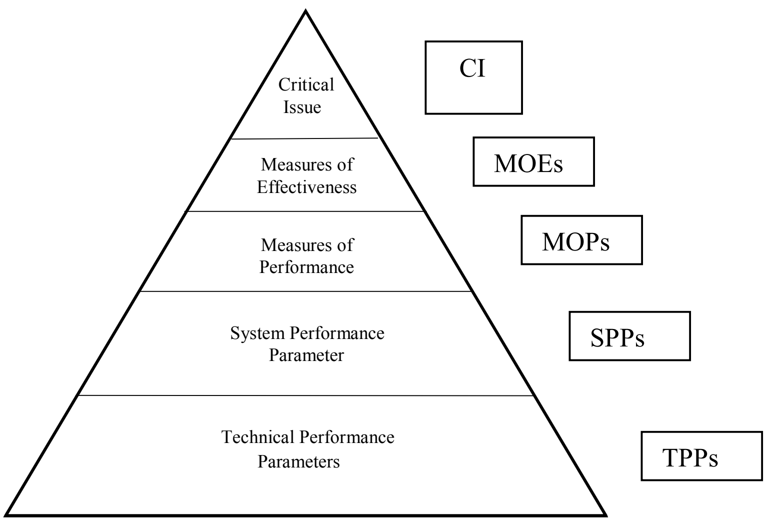

Figure 1. The concept of the Measures Tree - that is created from systematically breaking down the Needs statement for a system development to arrive at actually measurable parameters**.**

Each measure in a Measures Tree must have associated with it the current best estimate of its value, plus the uncertainty estimate of that value. This allows the maturity of a measure to be assessed at any time. A common design review item in System Engineering is reporting on the progressive maturity of what are called Technical Performance Measures (TPMs), see Blanchard and Fabryky (1998). In the methodology given here these exist at appropriate nodes of Measures Trees.

A full set of measures trees for all CIs in large project can contain thousands of measurement values. Many will be used to provide data for more than one tree. If all measures are available at the TPP and SPP levels then the maturity of CI can be calculated by upwardly combining the value and uncertainty for measures trees values to arrive at the respective CI value. Comparison of the desired and actual value shows how well a design parameter is closing on the intended target. The uncertainty value is an indication of the level of confidence that can be ascribed to the value at that time.

Performing this upward, many to one, calculation presents some practical problems because the data may:-

- Have different forms thus making combination complex (single point, statistically different distributions, estimated)
- May be missing (failed tests, tests still to be carried out, etc.)
- Have varying time stamps (carried out at different times)
- Be of a legacy kind (that is, obtained from previous tests to reduce the cost of testing and may not be correct.)

However, this is not an unsurmountable problem. Methods for handling this kind of data processing situation are well developed.

Obtain Data Using Scientifically Based Experiments. Of all these kinds of measures in the various layers of the measures tree the only physically measurable data is that obtained from physical testing with instrument systems using suitably selected sensors - the TPPs.

Obtaining TPP data should be set up with traceable scientific rigour. Recognising that laboratory and range tests are the prime means for establishing new knowledge about the system is central to success. The activity of testing is thus the same as conducting a sound scientific experiment. The similarities between the two processes are shown in Figure 2.

Generalised Scientific Method	Process for Obtaining TPP Data
I. Develop Hypothesis	
1. Identify Question/Problem	1. Develop Test Objectives
2. Formulate Hypothesis	2. Estimate Performance
II. Experiment	
3. Plan Experiment	3. Develop Test Method
4. Conduct the Experiment	4. Collect Test data
5. Analyse Results	5. Place in Measures Trees and combine
III. Use Measurement Data to Verify Hypothesis	
6. Check Hypothesis	6. Compare with Thresholds
7. Refine Understanding	7. Retest or extrapolate

Figure 2. Comparison between the Scientific and Testing Processes

Where complicated sets of TPP and SPP variables exist in a test situation the tests should be carefully designed using sound design of experiment practices, Montgomery (2001), as that allows multi-factorial designs to be applied that can separate the issues whilst making best use of expensive testing resources.

3. Overview of the Whole Process.

The process that integrates all of the above is summarized in Figure 3. More detail is available Sydenham and Kimberley (2000).

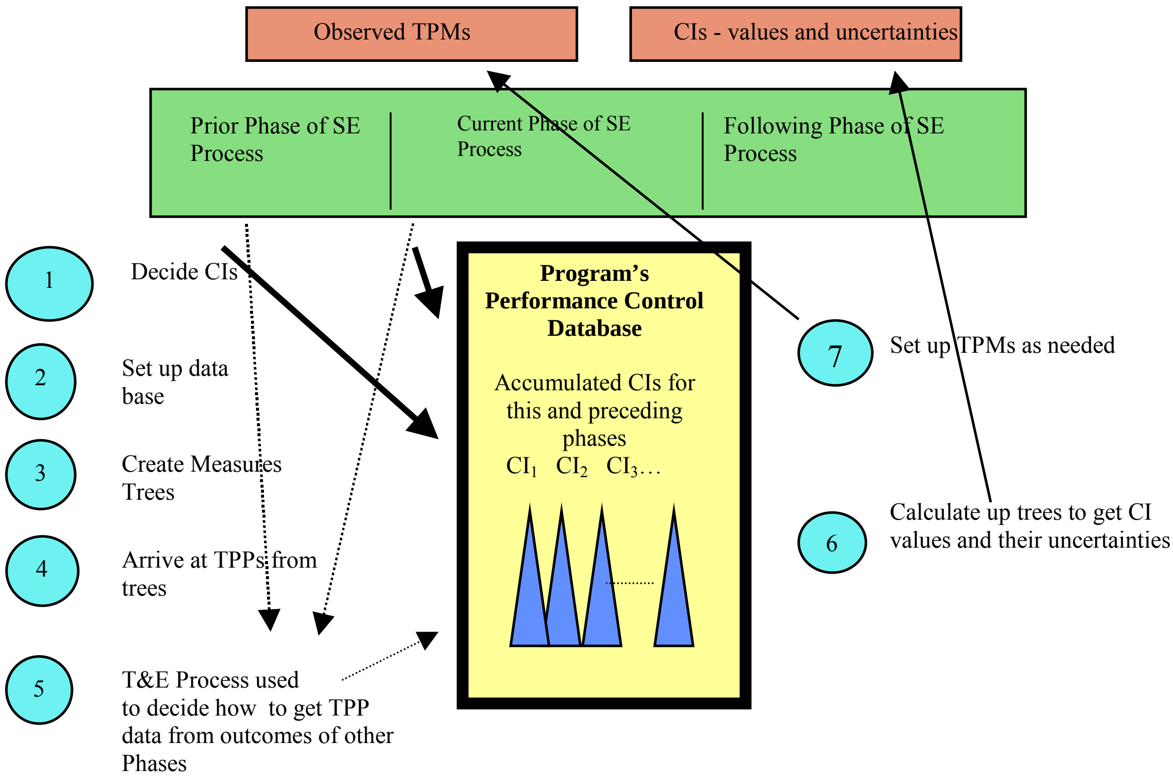

Figure 3. Integrating the various processes into the Systems Engineering life cycle

4. Summary and Conclusions

The cost of testing in the engineering of large systems can easily exceed reasonable budgets. A methodology is needed for ensuring that the right tests are performed, and for creating the necessary multi-sensor systems. The basic features of a scientifically based, rigorous, methodology have been presented that sets up a traceable hierarchy of measurements to monitor the developing maturity of the critical issues associated with a given development. This methodology extends concepts in use today to gain tighter control of system performance as a project passes through it life cycle. It makes past experiences with setting up the various kinds of measures available to other projects allowing their use to mature over time.

References

Blanchard S.B and Fabrycky W.J. 1998, *Systems Engineering and Analysis*, 3rd Ed, Prentice-Hall International Inc, Upper Saddle River, USA.

Montgomery, D C, 2001, *Design & Analysis of Experiments*, 5th Ed, Wiley, New York, USA

Reynolds M, 1996, *Test and Evaluation of Complex Systems,* Wiley, Chichester, UK.

Sydenham P H and Kimberley D, 2000, *Modern Test and Evaluation*, Course Notes, DEGSET, Department of Mechanical Engineering, University College London.