Technical Performance Measurement, Earned Value, and Risk Management: An Integrated Diagnostic Tool for Program Management

◆

Commander N. D. Pisano, SC, USN
Program Executive Office for Air ASW, Assault, and Special Mission Programs (PEO(A))

Abstract

This research effort, sponsored by the Program Executive Office for Air ASW, Assault, and Special Mission Programs (PEO(A)), is known as the Navy PEO(A) Technical Performance Measurement (TPM) System. A retrospective analysis was conducted on the T45TS Cockpit-21 program and real-time test implementations are being conducted on the Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS) program, the Navy's H-1 helicopter upgrade program, and is currently under consideration for other test implementations across the Department of Defense (DoD) and in private industry.

Currently-reported earned value data contains invaluable planning and budget information with proven techniques for program management, however, shortcomings of the system are its emphasis on retrospection and lack of integration with technical achievement. The TPM approach, using the techniques of risk analysis and probability, offers a promising method to incorporate technical assessments resulting *systematically* from technical parameter measurements to derive more discrete management data sufficiently early to allow for cost avoidance. Results obtained from TPM pilot programs, particularly the Cockpit-21 program, support this premise.

Several preliminary issues of interest and conclusions are delineated in this paper that demonstrate that the TPM methodology is a powerful integrated diagnostic tool in support of the new paradigm advocating a multidisciplinary approach to program management. It also promises to provide a powerful new tool in proactive risk management.

Introduction.

In recent years the Department of Defense (DoD) and all segments of the American economy have been under increasing pressure to change the way in which business is conducted. This condition is the result of a number of converging trends and discrete events--the end of the Cold War, a political environment skeptical of defense expenditures and active international involvement, a reduced industrial base, growing international competition, evolving quality-focused management methodologies, a rapidly expanding and innovating Information Technology (IT) community, pressures on governments to reduce operations and balance budgets--that have created an environment of constant, rapid, and unpredictable change requiring new management approaches and techniques.

For the government systems program managers and their teams, this environment creates pressures that are translated into the need to deliver products using best value analysis with cost as the overriding determinant. As a result, information is needed to allow the manager to make informed trade-off decisions as early in program execution as possible.

…the cost avoidance window of opportunity is before the fifteen percent mark in contract completion.

In addition, any condition threatening the health of program development must be identified sufficiently early to allow managers to mitigate those areas of technical, cost, and schedule risk. The oft-repeated rule-of-thumb within the DoD and private industry is that the cost avoidance window of opportunity is before the fifteen percent mark in contract completion.[1] After this point, the opportunity for the avoidance of additional resource consumption is greatly diminished and mitigation focuses upon the recovery from lost effort and remaining cost and schedule risk. This and other research argues for concurrent risk identification and reduction beginning in the concept phase of programs and carrying through engineering and manufacturing development.[2]

Current acquisition reform initiatives are rapidly moving program management teams to adoption of a holistic approach to complex systems acquisition. Implementation of **Integrated Product**

and Process Development (IPPD) technique, with its focus on integration of program management activities through multidisciplinary Integrated Product Teams (IPTs), has established the cultural and structural framework for systems thinking. However, few tools exist to support this new paradigm.

While traditional cost and schedule analysis, systems engineering, and risk management provide the program management team with a broad range of tools, many of these techniques are derived from separate systems that are viewed in isolation from one another. Like viewing television, each separate image flashed before the program manager takes on an importance and reality of its own, providing little context relative to other factors. In addition, the signals from each of these disciplines are being broadcast over separate channels, and often deliver contradictory messages.

The perspective of many of these traditional management control systems is also retrospective in nature, documenting history rather than providing the program team with the essential information needed for day-to-day management. In many Earned Value Management Systems (EVMS), information is normally thirty to sixty days old and identify cost and schedule variances well beyond the window of opportunity for cost and schedule risk avoidance.

These systems measure work accomplishment as opposed to technical achievement.[3] As a parent I provide my son with a separate two week allowance for his school expenses. Under systems that measure work accomplishment based on time-phased budgeting, his successful taking of an exam and the expenditure of all of his money within the allotted time would earn 100% value regardless of the grade he achieved. The underlying weakness in this approach is apparent.

> *… the basic tenets of the process are the need for "seamless management tools" that support an integrated approach … and "proactive identification and management of risk" for critical cost, schedule, and technical parameters …* (former Secretary Perry's memo of May 1995)

As it relates to program management, IPPD guidance implicitly acknowledges these deficiencies. In former Secretary of Defense Perry's memo of May 1995, in which he directs the use of IPPD throughout the DoD, two of the basic tenets of the process are the need for "seamless management tools" that support an integrated approach to program management with the goal of enhancing team decision-making, and "proactive identification and management of risk" for critical cost, schedule, and technical parameters compared against best-in-class industry benchmarks that provide verification of actual achievement of technical and business-based parameters.[4]

In support of IPPD, and as of this writing, DoD 5000.2-R is being updated to require Integrated Baseline Reviews (IBRs) within six months after contract award to ensure reliability in planning and performance measurement.[5] For those program offices that have conducted an IBR, important insight has been gained by members of the IPT into the interrelationships between various management control systems and processes.

Both the commercial systems engineering and cost/schedule analysis communities are undergoing similar change. The proposed revision to EIA/IS-632, an industry systems engineering standard, recently reviewed at the annual meeting of the International Council on Systems Engineering (INCOSE), includes Technical Performance Measurement (TPM) as a critical product metric.[6] In addition, within the industry standard EVMS, technical performance goals are listed as necessary indicators to be used in order to measure programmatic progress among its 32 criteria.[7]

The tools required to support the demands of this new environment must be those that:

(a) provide an integrated view across programmatic elements;
(b) support the process of distributed empowerment implicit in the IPT approach;
(c) logically organize data resulting from systems engineering, risk management, and earned value processes;
(d) provide a "real time" indication of contract performance and future cost and schedule risk;
(e) support the development of systems thinking within an integrated program model.

The Program Executive Office for Air Anti-Submarine Warfare, Assault and Special Mission Programs PEO(A) TPM system is a promising methodology that addresses these goals and fits well within the basic tenets of IPPD and acquisition reform by integrating technical performance with earned value based upon programmatic risk assessments and probability. This methodology provides a flexible framework, based on effective business practices, that provides government-contractor program management teams with the information they need to make informed management decisions at critical milestones.

Background.

The TPM project was undertaken in 1991 by the PEO(A) within the Naval Aviation Systems Team (NAST). From its earliest inception, the PEO recognized the need for an integrated approach to monitor program performance based upon the simple principle that the solution be of practical utility to the program office. Consequently, in early 1991, a team consisting of representatives from each PEO(A) program office was organized to identify and validate a process for the integration of cost, schedule, and technical performance metrics. After several meetings and off-site planning conferences, this group generated a requirements specification that became the basis for the project.

This document identified the need for a standard process for baseline planning, tracking, and reporting of technical performance measurements in a manner similar to, and concurrent with, cost and schedule metrics. In addition, the document specified the need for a means of determining cost and schedule impacts based upon technical performance. In 1993, the TPM Working Group selected both a proof-of-concept and commercial-off-the-shelf (COTS) implementation strategy to achieve the goals of the requirements specification.

The proper identification of technical performance parameters (TPPs) and the validity of technical baseline establishment were seen early in the project as a key to the proof of concept.

The proper identification of technical performance parameters (TPPs) and the validity of technical baseline establishment were seen early in the project as a key to the proof of concept. The **Air Deployable Active Receiver (ADAR)**, a sonobuoy program, was the first pilot project selected to test the basic premise that a systematic TPM planning and tracking function would provide an early warning, significantly before legacy performance measurement systems, to be of practical benefit. Insights gained from this pilot:

- First, cost and schedule impact assessments could not always be clearly determined because there was not clear linkage between technical parameters and budgeted work packages via the Work Breakdown Structure (WBS).
- Second, where cost and schedule impact assessments could be made, the linkage could be made at a fairly high level within the WBS (level 4) and all work packages could be associated directly with the parameter.
- Third, a statistical association of technical accomplishment inserted into cost and schedule could produce calculated impacts amazingly close to what was eventually experienced.
- Fourth, the identification and tracking of technical performance metrics in a disciplined and systematic fashion provides significant early warning of potential problems and their nature.

With the promising results from the ADAR program, the TPM Project Team selected the **Light Airborne Multipurpose System (LAMPS) Block II Upgrade**, another helicopter program, for its next pilot. The Block II program was selected based upon its complexity, its high dollar value, and the high technical risk inherent in the effort. The TPM team also decided, concurrent with this pilot, to apply economic utility theory as the means for determining the technical metric that would be used for calculating cost and schedule impacts.

The results from LAMPS Block II were not as encouraging as in the ADAR pilot but, in hindsight, of greater value:

- First, the technical parameters collected were of too high a level and did not derive from disaggregated lower level parameters.
- Second, the practical application of the utility curve assessment approach proved both impractical and theoretically unsound.
- Third, the overall framework of estimating cost and schedule impacts using the “value” of technical progress as a foundation was not flexible enough to exploit the full range of existing cost estimating techniques. The framework relied solely upon expert opinion--the most subjective method in the cost estimating arsenal--eschewing through the approach both parametric and industrial engineering measurement.

While pursuing its proof-of-concept effort, the TPM Project Team formally surveyed both the commercial sector and other government program offices to determine if other methodologies or products existed that would meet the goals of the requirements specification. After extensive research, only one untested commercial product seemed to show promise. This product, TCS Integra by Quantitech Inc. of Huntsville, Alabama, was selected for test implementation and the results from its retrospective pilot implementation on a PEO(A) program are presently undergoing review.

By the fall of 1995, with a record of one win and one loss, and an apparent wrong turn in selecting economic utility theory as its framework, the TPM Project Team conducted a thorough reevaluation of its mission and methodology. It was clear that if the original goal of the requirement specification was to be met, an 80% solution that was well-grounded in each of the disciplines of systems engineering, risk management, and cost/schedule analysis would have to be found.[8]

The Key: Systems Thinking and Probability.

In all systems where optimum performance is necessary or desired, it is useful to establish what engineers call a negative feedback system. Negative feedback is the basis for automatic control and regulation. It can best be understood by a description of its opposite, which is positive feedback. In chemistry, positive feedback usually takes the form of an explosion. In program management, positive feedback will take the form of a program requiring greater and greater commitment of resources for achievement of requirements specifications well beyond what was originally anticipated.[9]

Most U.S. Navy ships still use steam as their main source of propulsion. In the 18th century one of the roadblocks to the effective use of steam technology was the inability to control steam pressure. This inability persisted until James Watt (1736-1819) and the Watt steam governor came along. The principle of the governor was to create an automatic valve that would regulate the flow of steam to the piston. The trick was to link the valve to the rotary motion of the engine. The faster the engine moves, the more the valve shuts down. The slower the engine moves, the more the valve opens up. The means used was just as simple and elegant. A pair of balls on hinged arms spin around using the principle of centrifugal force. When the balls spin fast, they rise up on their hinges; when spinning slowly they hang down. The hinged arms are linked to the steam throttle.

Our feedback systems must be robust enough to give us a discrete indication of variability in progress to allow for adjustments to be made.

With effective tuning, the Watt governor keeps the engine turning at a constant rate despite fluctuations from the source of heat. The Watt steam governor was responsible for the effective use of steam in industrial production, giving rise to the industrial revolution, and to the creation of great navies that could navigate the oceans independent of the wind.

What the program manager needs is the equivalent of a Watt steam governor. If we view a program as a system, what we see are resources as our inputs (in terms of money, time, and expertise) with the end item (e.g., a ship, aircraft, or satellite) as our output. Our feedback systems must be robust enough to give us a discrete indication of variability in progress to allow for adjustments to be made. Preferably, our feedback systems will be negative ones, but, as we all should know, social systems, of which a program is one, are more complicated than our analogy to a relatively simple steam plant.

A program, as an organization, is a type of complex adaptive system. A complex adaptive system is one that acquires information about its environment and its interactions within the environment, identifies information of importance, places that information within the context of a contextual framework, model, or "schema," and then acts on the basis of that schema.[10] The individual members of the program office--people--act as complex adaptive systems themselves and exert a powerful influence on the selection of both schema and those adaptive pressures that are used in making decisions. The extent to which their learning brings about adaptive or maladaptive behavior will determine the survival or failure of the organization.[11]

In constructing a negative feedback system for a complex adaptive system, an understanding of the schema and context in which the system functions is necessary. Also, the model should be as simple as possible and only contain those elements absolutely necessary for approximating reality.

The IPPD technique provides the necessary schema around which to construct our tools, with its emphasis on:

- decentralized authority through the IPTs,
- the renewed importance of cost as the independent variable,
- the use of performance specifications in acquisitions, and
- the emphasis on advance planning and quality as a by-product of the work performed.

That these business practices are becoming universal in both government and private industry also lends us valuable insight.

Stephen Jay Gould, the noted Harvard polymath, in his book Full House, in using the disappearance of the .400 hitter from baseball as his subject to demonstrate increasing excellence of play, illustrates that complex systems tend to organize themselves as a set of probable outcomes, often within a normal distribution. Variation in this distribution changes over time as members become familiar with their environment. Gould concludes that (a) complex systems improve when the best performers play by the same rules for extended periods of time, and (b) as play improves and bell curves march toward the right wall, variation must shrink.[12] Implicit in these conclusions is the effective ability of members of the complex system to learn and adapt.[13]

Foundation … With the adoption of earned value management and critical path scheduling as industry standards, the foundation was laid in the fall of 1995 for the TPM Project Team to use the principles of systems thinking and apply them to the existing disciplines of cost/schedule control, risk management, and systems engineering to create an integrated diagnostic tool. Also, the rapid advances in desktop computing power, even within the short life of the project, brought with it the ability to cost-effectively integrate these concepts.

First choice … The first choice was to ensure that the methodology was integral to existing processes involved in planning and tracking program performance, and supported the cultural and structural processes established under IPPD. It was decided that both a TPM process and a practical, interactive tool would be developed to facilitate an understanding of technical, cost, and schedule risk issues.[14]

Second choice … The second choice to make was to select the way in which technical performance impacts would be expressed. The team decided that, with the emphasis on cost, the industry EVMS would be used as the user interface. This approach had worked well on ADAR. This meant that the Budgeted Cost for Work Performed (BCWP), or "earned value," would need to be informed by technical achievement, but in a way that would lend credence to the projected impact.

Approaches … Within the risk management discipline, there are basically two general approaches for estimating cost impacts--probabilistic and deterministic. A probabilistic approach is top-down, based upon the probability of outcomes. The Monte Carlo analysis model is a good example of a probabilistic approach. A deterministic approach is bottom-up, based upon a sequence of causes. Learning curve estimation is a deterministic method, though it still possesses a large element of probability. Probabilistic models are by nature inexpensive to apply but sometimes lack credibility. Deterministic models are more expensive to apply but credibility is also an issue if the work is not disaggregated properly. Also, as noted above, no model is ever completely deterministic--the proper mix between the two approaches must be selected.[15]

This last point goes to the heart of the approach eventually selected. Risk determination is, by nature, probabilistic. As we noted above, complex systems tend to organize themselves in a normal distribution of likely outcomes. As procedures and practices become standard, the best performers tend to follow the general trend toward excellence and variation around the mean shrinks. Other distributions apply in less mature environments, but a statistical tool using the assumption outlined above as its basis should meet the requirement of providing sufficient early warning of technical perturbations in program development as long as the technical metrics are derived systematically, a planning baseline is established, and technical performance parameters are disaggregated and properly tied to the WBS.[16]

Earned Value calculation … With the assistance of Naval Reserve Unit NAVAIRSYS 1187 under the command of CAPT A. R. Pagnotta, USNR-R (now retired), a unit consisting of information technology and systems engineering professionals, statisticians, and mathematicians, the TPM Project Team reengineered the TPM method of calculating technical earned value. Technical earned value would be the key metric used in recalculating BCWP and also used in the algorithm to calculate schedule impacts.

Gantt charts are the standard tracking tool linking program activities with time. Each TPP normally has a progress plan assigned to it based on how the development activities will be performed.

It is a common commercial practice to segment work into key product development paths, or technical progress plans, assignable to specialties within a function or functions. Gantt charts are the standard tracking tool linking program activities with time. Each TPP normally has a progress plan assigned to it based on how the development activities will be performed.[17]

With this in mind, the team selected as its method for calculating technical earned value:

- A 90-50-10 <u>risk profile</u>, that is equivalent to the probability of successfully achieving the next TPM milestone [Pr(S)].
- The profile is then applied at each assessment date, which could be monthly, or some other period.[18]

This approach isolates technical performance, in terms of technical achievement and deviation, from cost and schedule.

The means of establishing the 90-50-10 probability distribution exploits standard risk management estimation techniques based on analogy, parametrics, and industrial estimation, and is constructed concurrent with, and integral to, the establishment of the Systems Engineering Management Plan (SEMP). The methodology of using technical progress plans and applying a risk profile against each assessment date is similar to the establishment of a formal baseline for WBS work package budgets and schedules. The baselining issues raised through this process are then of service during the IBR.

Once again, the application of systems thinking is instructive in understanding the application of the probability distribution. A popular analogy concerns placing a monkey in front of a typewriter. According to this story, given enough time, the monkey would eventually produce the collected works of Shakespeare. Unfortunately for the analogist, systems, even live ones, do not work this way. Rare is the sudden act of creation from whole cloth. Richard Dawkins, the Charles Simonyi Chair of Public Understanding of Science at Oxford, limited his simulated computer monkey to producing, in a single random step, the sentence uttered by Polonius in the play Hamlet: "Methinks it is like a weasel." The odds of getting it in a single step is about 1 in 10,000 million million million million million million--requiring a longer time to achieve than all of the time that has expired since the beginning of the universe. When, however, the monkey used cumulative progress, built from previous steps in achievement, the computer built the target phrase in generation 43 on the first run and in generation 64 on the second run.[19]

This example demonstrates that establishing the probability of successfully achieving the next technical performance milestone is the proper approach in deriving a technical earned value. The probability of successfully achieving an end goal in a single step is vanishingly small and, if applied in a methodology, will give us an overstated negative impact. In our approach, however, each Pr(S) represents a discrete event along our progress plan that, when combined with previous scores, gives us an assessment of the cumulative achievement along the development path. Breaking down the path into these discrete probability assessments also has the effect of isolating and reducing subjectivity. Development is, after all, an evolutionary process built on the cumulative effort expended toward the achievement of eventual program goals.

An Integrated Diagnostic Tool.

Having resolved the major issues of its bottom-up review, in November 1995 the TPM Project Team concurrently pursued the development of both a methodology and software application to achieve the integration of cost, schedule, and technical performance. Several additional meetings resulted in the development of a general framework that would use the existing internal management methodologies of prime contractors, as much as practicable, and to reorganize existing data in a way to achieve the desired integration.

The final result of these meetings was a methodology consisting of three phases. Figure 1 provides an overview of the entire methodology.

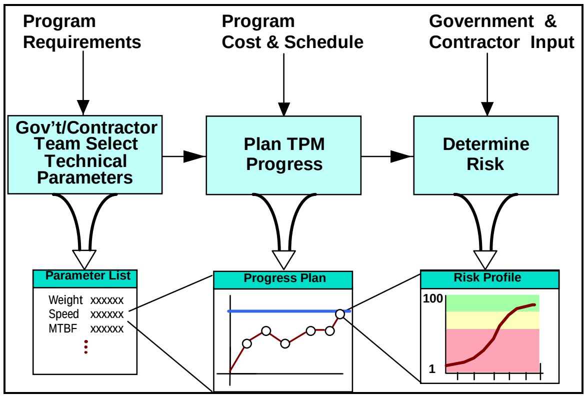

Figure 1: TPM Methodology Overview

1. **Select Technical Parameters.** Concurrent with the formulation of the SEMP, the following criteria are used to assist in the selection of critical TPPs:

- Those that are program cost drivers, reside on the critical path schedule, or that represent, based on formal assessment, high risk to the program.
- Once selected, TPPs are organized in a weighted hierarchy to establish relative importance and interrelationships.
- Linkage is made to the contract WBS. This last activity is accomplished in order to obtain a "technical budget baseline," or the budget associated with the work packages that are responsible for a particular parameter's developmental success, and that would ultimately be placed at risk should performance not meet expectations.

2. **Plan TPM Progress.** The second phase is to baseline technical performance measurement through the establishment of a technical progress plan for each TPP. The approach to planning and baselining TPM is virtually the same as that used in baselining cost and schedule measures with the common goal of establishing a framework from which to assess actual progress and measure relative performance. A disaggregate approach is used to reduce subjectivity by developing progress plans for lower level TPPs and applying the cumulative scores from these lower level plans to higher, summary level, TPPs. Figure 2

shows a typical progress plan for the weight of a key component.

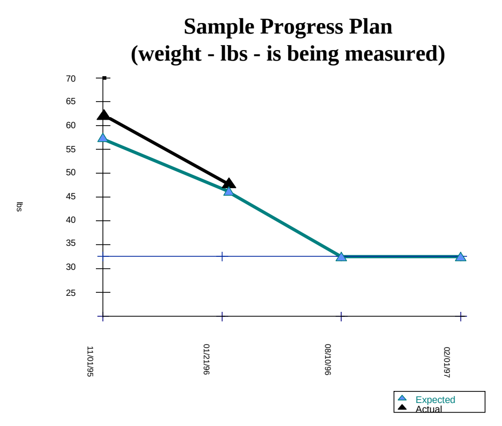

Figure 2: Sample Progress Plan

In the Gantt chart used as our example, the technical assessment activity dates are displayed along the horizontal axis and the units of measure are on the vertical axis. The straight line at the 32.5 pound mark represents the end goal. The lower downward sloping line marked by open triangles is the technical progress plan while the bolder upper sloping line marked by filled triangles traces the actual achievement. This component was considered to be critical to the end item design and a bellwether of overall aircraft weight.

> *A TPP may be any function, physical characteristic, design goal, or other aspect of a project that has been defined by the requirements of the program.*

Looking at our example in isolation from other factors and other technical parameters points out the weakness of a reductionist approach to program management in which TPMs are collected apart from other activities. The importance of the technical variance, that is, the space between the open and closed triangles is unknown and can easily be dismissed. Presently, an assessment of this variance relies too heavily on expert opinion. Consequently, this process is highly subjective and leaves open the possibility of a "rubber" technical baseline--one in which the significance of any variance can be misinterpreted. This is the importance of establishing a TPP hierarchy and weighting activities relative to each other in an IPT environment.

The weight example provided is, of course, highly simplified and given only as an analogue for development metrics that may be used to track technical progress. A TPP may be any function, physical characteristic, design goal, or other aspect of a project that has been defined by the requirements of the program. Both process and product metrics are candidates that may be selected as TPPs. In software development, our experience indicates that qualitative process metrics, such as staffing and error reporting, are more reliable indicators of poor technical achievement than more traditional product metrics such as source lines of code.

3. **Determine Risk.** The third and last phase is to apply the 90-50-10 risk profile to each planned value within the technical progress plan to serve as a benchmark against actual achievement. Insertion into earned value is accomplished by applying the confidence factor as the technical performance score to calculate a technically informed BCWP. Critical path schedule impacts are calculated similarly by applying the confidence factor as the achievement metric against the portion of the schedule placed at risk by the technical parameter(s).

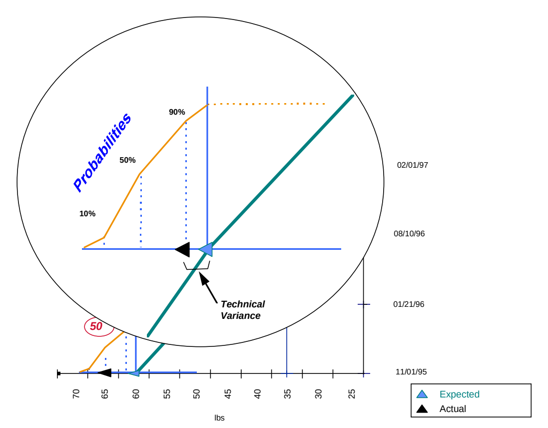

Figure 3: Progress Plan with Risk Profile

Figure 3 above illustrates the technical variance for our component weight example. A probability distribution is applied to every assessment date on the progress plan, which has been rotated so that the original y-axis is horizontal. In this example, the second assessment date is magnified to show in detail the relationship established between the actual measures and the assessed probabilities of success [Pr(S)]. The actual measure is above the expected value, a potentially unfavorable condition when measuring weight reduction. In this case the actual measure falls at the 90 percent confidence level. Interpolation is used to calculate values that fall on intermediate points along the slope of the distribution.

In this particular example, a single-sided probability distribution is applied since our area of interest is only in the area above the technical progress plan. In cases where a variance significantly above or below the expected value is an indicator of poor technical achievement, such as in the case of software problem reports or staffing, a double-sided distribution is applied to determine the earned technical value.

Distributions may be customized based upon any standard analogous, parametric, or industrial engineering technique. In some cases, a tolerance band is wider at the beginning of the technical activity and becomes tighter over time. Should customization not be applicable in every case, a default normal distribution is applied that establishes the 90 percent confidence factor to actuals at 5 percent deviation from expectation, 50 percent confidence at 10 percent deviation from expectation, and 10 percent confidence at 20 percent deviation from expectation.

The **technical earned value** is inserted into EVMS by multiplying the confidence level by the BCWS for the WBS elements associated with the TPP. For example, if the cumulative BCWS for a WBS element is $50,000, and the cumulative technical earned value is 50 percent, then the calculated BCWP is $25,000. Once BCWP is calculated, performance indices, variances, and estimates at complete can be calculated.[20]

Critical path schedule impacts are also calculated by using the confidence level metric. This is accomplished by taking the baseline schedule for the associated activity and multiplying the portion of the activity placed at risk by the confidence level subtracted from 100 percent confidence. For example, a scheduled activity is 90 days duration. If the cumulative confidence level is 90 percent and all 90 days of the activity is placed at risk by the associated technical performance activity, then a 10 percent lost effort is calculated to project a possible slip of nine days for the activity. Using standard COTS critical path scheduling tools, impacts for associated activities can be calculated automatically.

The Cockpit-21 program provided an excellent analysis environment with several years of Cost Performance Reports (CPRs) and technical performance data that included comprehensive planning and reported actuals.

Proving the Methodology: The T45TS Cockpit 21 Retrospective Analysis

Once settling on a methodology, questions arose for the TPM Project Team concerning interfacing the TPM software tool with EVMS software packages. Performance Analyzer (PA), the standard government software tool, proved not to be Windows capable and did not offer all of the features desired for calculating earned value impacts. As a result, the team settled on a Windows-compliant COTS EVMS tool known as wInsight with which to establish compatibility. The plan was to fit the TPM tool later to PA once it became Windows capable. For the moment, however, wInsight would be the product used to calculate EVMS impacts.

To prove out the methodology, the TPM Project Team decided that a retrospective analysis conducted against actual outcomes on a mature contact would be the best approach. The exit criteria for a successful test would be (a) early warning of technical perturbations in the program before the 15 percent mark in the contract, (b) early warning significantly before indications from traditional performance measures, and (c) calculated cost projections that were statistically significant when compared against actuals.

At the end of November 1995, the Program Executive Officer (PEO) gave his approval to the TPM Project Team to use the T45TS Cockpit 21 project as its proof-of-concept test bed and the project began in earnest. The Cockpit 21 program was managed by the Jet Flight Training Program Office (PMA 273) under PEO(A). The program involved the development and installation of a digital cockpit into the T-45A aircraft. Previously, this aircraft was procured using analog cockpit instrumentation. The new cockpit has improved training effectiveness by enhancing the cockpit with a digital data bus and multi-function displays that will more closely resemble features on an increasing number of newer fleet aircraft.

A three-year letter contract was awarded on 29 May 1992 to McDonnell-Douglas (MDA) as the prime contractor, however, this contract was not definitized until March 1994. The delay in definitization was attributable solely to pricing issues. The system requirements were very well defined and had no impact on contract definitization.

Smith's Industries of the United Kingdom was the subcontractor awarded a major portion of the software development work for the digital cockpit. The contract between MDA and Smith's was Firm Fixed Price (FFP). After some time for ramp-up, work on Cockpit 21 development commenced in full in July 1992.

The Cockpit-21 program provided an excellent analysis environment with several years of Cost Performance Reports (CPRs) and technical performance data that included comprehensive planning and reported actuals. The program's reported cost and schedule information showed good performance even in the Defense Acquisition

Executive Summary (DAES) system, but the products being developed were clearly not meeting the schedule. Technical perturbations were being experienced that were not being reflected in the cost reports.

To ensure that the TPM Project Team could conduct the study in an objective fashion, certain information was withheld by the program office. Specifically, this included the renegotiated contract ceiling that had recently been settled, and additional cost risk identified by the prime in negotiations. Also, only one interview was conducted with the program technical representative to determine the risk items under the TPP selection criteria. That person was asked specifically to express his judgment and concerns as he recalled them at contract award. This condition would at least bound the analysis to a single-blind approach. Otherwise, only those formally reported metrics were used to load into the software tool developed to support the methodology.

The Display Generation WBS element was the largest single budgeted item reported. Since this directly related to the software development of the Cockpit 21 digital displays, known as the Display Electronics Unit (DEU), the Software Development Plan (SDP) was reviewed for documentation on software metrics. A good set of metrics was reported and these were used in the test set. The SEMP also contained metrics on Flight Test Problem Reporting and these were also included. Other metrics were also found for Reliability, Cooling Requirements, and Electrical Power. These elements, however, did not meet the criteria for selection of TPPs and were not included in the test. In any event, since technical achievement in these areas exceeded the technical progress plans, they would not have affected the results of the study.

Test results … At the end of January 1996, the test results on the Cockpit 21 program were formally reported to the PEO. The analysis showed that:

(a) Technical perturbations in software development containing significant cost risk are first identified in November 1992 before the 15 percent point in contract performance.

(b) These results are consistent from November 1992 and throughout 1993, providing an eighteen month early warning before other performance measurement techniques began reporting mitigating activities.

(c) The methodology was discrete enough to identify the specific activities contributing to technical cost risk.

(d) Calculated estimates-at-complete using the wInsight tool were within one standard deviation of the negotiated contract ceiling of $68 million and the additional cost risk identified by the MDA--mitigation instituted by the prime on the FFP subcontract impacted total program cost. All elements of the study's exit criteria had been met.[21]

As a result of the positive results of the TPM study, an internal **Peer Review** of the Cockpit 21 study results was conducted from February to April 1996. Members for the Peer Review Committee were assembled from the Naval Aviation Systems Command (NAVAIR) cost analysis and systems engineering competencies, PEO(A) program offices, Defense Systems Management College (DSMC), the Institute for Defense Analyses (IDA), and private industry. The TPM Project Team authored a white paper and submitted their data and results to intense scrutiny by the group. On 24 April 1996, the peer review group endorsed TPM as a promising approach, ratified the plausibility of the TPM mathematical concepts, and recommended prospective implementation of the methodology on future contracts.[22]

A False Start and A Good Start.

As a result of the positive results from Cockpit 21, and the recommendation for prospective implementation by the peer review group, the Navy's **Stand-Off Land Attack Missile-Expanded Response (SLAM-ER)** program sought to implement the TPM methodology to identify and mitigate existing cost and schedule perturbations and to avoid future ones. The program, being 41 percent complete, was thought to provide a unique opportunity for applying the methodology both retrospectively and prospectively. In hindsight, however, this factor was the main barrier to implementation.

The retrospective application of a process improvement tends to be costly and requires changes to existing procedures. The process also becomes external to the system and excludes stakeholders from critical decision-making in the application of the process--it documents history and nothing more. As a result, rather than enhancing existing processes, application of TPM on SLAM-ER would have been prescriptive on both the program office and the prime contractor. In addition, requirements for technical performance data were eliminated from the contract deliverable items under the aegis of "streamlining" and the program office was not willing to invest additional resources in implementing the process.

Lessons learned … The lessons learned from SLAM-ER were instructive and led to adjustments in the manner in which the TPM methodology would be applied in future. Only new contracts would be selected for implementation. In addition, a feasibility study would be conducted prior to commitment of project resources and costs for implementation would be identified up-front to the program office. The project would also use standard risk management return-on-investment criteria to determine if an implementation was feasible, and develop other metrics to determine the methodology's utility.

In July 1996 the TPM Project Team accepted a request from the **Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS)** program office to apply TPM as a joint pilot implementation. The WAAS program is developing an enhanced Global Positioning System (GPS) to provide accurate aircraft reporting anywhere on or near the surface of the earth. The system will ultimately satisfy the requirements of all phases of flight, including precision approach and landings.[23]

The prime contractor is Hughes Information Systems Company of Fullerton, California. The contract value, negotiated in October 1996, is approximately $500 million. The TPM database for this effort has been populated and implementation continues with the first reported cost reports. The initial results are encouraging.

Before contract award the program office committed itself to ensure that a comprehensive TPM approach that included the PEO(A) methodology would be properly implemented and funded. The TPM planning, which included Hughes personnel through the construction and verification of TPPs, progress plans, and probability distributions was exhaustive and required contractually-defined deliverables (CDRLs). The approach, because it involved the substitution of electronic for more labor-intensive paper-based SEMP deliverables, has had the effect of reducing effort involved in CDRL delivery. The WAAS program office also included TPM-informed information in the Performance Evaluation Plan (PEP) as a determining factor in the contract award fee arrangement.

Preliminary conclusions … Some preliminary conclusions can be drawn from the WAAS experience. First, the contractor-government program team have gained insights into the relationship between cost, schedule, and technical achievement issues that would not have otherwise been available. Second, the TPM approach is compatible with and complementary to existing TPM and risk assessment methods used by the prime contractor. Third, the initial results from the first cost reports indicate that technical perturbations revealed by TPM reinforce an interactive environment supportive of the IPT structure. Fourth, costs and efforts associated solely with the implementation, while requiring significant advance planning, are marginal.

Conclusion.

The PEO(A) TPM methodology provides a promising first step in the integration of cost, schedule, and technical performance. It achieves this goal through a flexible and robust methodology that is of practical use to both government and commercial program managers and their teams. This methodology has evolved over time and will continue to do so as current and future implementations provide additional insight into proactive technical risk management.

As an interactive and integrated diagnostic tool, TPM promises to provide necessary insight into those issues of importance to IPT members, thereby supporting the concept of distributed empowerment, and to provide sufficient early warning of technical cost risk to allow for early mitigation and cost avoidance. It also promises to provide an integrated tool to the business of program management that will support the new management paradigm of functional integration and systems thinking.

References

Christensen, David D. “Cost Overrun Optimism: Fact or Fiction?” Acquisition Review Quarterly 1 (Winter 1994).

Coleman, Charles; Kathryn Kulick, and CDR Nick Pisano. “NAVAIR PEO(A) Technical Performance Measurement (TPM) Retrospective Implementation and Concept Validation on the T45TS Cockpit-21 Program.” (Unpublished white paper) Washington, DC: April 24, 1996.

Dawkins, Richard. The Blind Watchmaker. New York: W.W. Norton, 1996.

Department of Defense. Acquisition Management Policies and Procedures. (Draft DoD Directive 5000.1 and Draft DoD Instruction 5000.2). Washington, DC: October 1995.

Department of Defense. (Draft DoD Regulation 5000.2-R). Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs. Washington, DC: December 1996.

Engineering Industrial Association, EIA 632 Version 0.8. “Processes for Engineering a System.” (January 1997).

Federal Aviation Administration. WAAS Program Evaluation Plan. (Draft) Washington, DC: 1996.

Ferris, Timothy. The Mind’s Sky: Human Intelligence in a Cosmic Context. London: Bantam Press, 1992.

Gell-Mann, Murray. The Quark and the Jaguar. New York: W.H.Freeman and Company, 1995.
Gould, Stephen Jay. Full House. New York: Harmony Books, 1996.

Michaels, Jack V. Technical Risk Management. Upper Saddle River, NJ: Prentice Hall PTR, 1996.

Naval Aviation Systems Command. Peer Review Group Recommendation. April 24, 1996

NSIA Management Systems Subcommittee, EVMS Work Team. Industry Standard Guidelines for Earned Value Management Systems. August 8, 1996.

Secretary of Defense Perry, W. J. “Use of Integrated Product and Process Development and Integrated Product Teams in DoD Acquisition.” Washington, DC: Office of the Secretary of Defense, May 1995.

Simons, Robert. “Control in an Age of Empowerment.” Harvard Business Review (March-April 1995).

Under Secretary of Defense (Acquisition & Technology) Kaminski, P.G. Reengineering the Oversight and Review Process. Washington, DC: 1995.

Under Secretary of Defense (Acquisition & Technology) and Assistant Secretary of Defense for C3I. Rules of the Road: A Guide for Leading Successful Integrated Product Teams. Washington, DC: November 1995.

Endnotes

---

[1] David D. Christensen, “Cost Overrun Optimism: Fact or Fiction?” Acquisition Review Quarterly 1 (Winter 1994): 29.

[2] Jack V. Michaels, Technical Risk Management (Upper Saddle River, NJ: Prentice Hall PTR, 1996): 9.

[3] NSIA Management Systems Subcommittee, EVMS Work Team, Industry Standard Guidelines for Earned Value Management Systems (August 8, 1996): 3-10.

[4] Secretary of Defense W. J. Perry, “Use of Integrated Product and Process Development and Integrated Product Teams in DoD Acquisition” (Washington, DC: Office of the Secretary of Defense, May 1995): Attachment 2.

[5] Department of Defense Regulation 5000.2-R (Draft), Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs (December 1996): Section 3.3.4.6.

[6] Engineering Industrial Association, EIA 632 Version 0.8. “Processes for Engineering a System” (January 1997): 33-34.

[7] NSIA Management Systems Subcommittee, Industry Standard Guidelines for Earned Value Management Systems, 2-1.

[8] All of the information for this section was summarized from Charles Coleman, Kathryn Kulick, and CDR Nick Pisano, “NAVAIR PEO(A) Technical Performance Measurement (TPM) Retrospective Implementation and Concept Validation on the T45TS Cockpit-21 Program,” (Unpublished white paper), April 24, 1996.

[9] Richard Dawkins, The Blind Watchmaker (New York: W.W. Norton, 1996): 196-198.

[10] Murray Gell-Mann, The Quark and the Jaguar (New York: W.H.Freeman and Company, 1995): 17.

[11] Ibid., 298-301.

[12] Stephen Jay Gould, Full House (New York: Harmony Books, 1996): 111-128.

[13] Using an athletic activity as a model of organization for complex social systems is not as restricted as some may argue. Sufficient evidence in the field of neuroscience indicates that certain athletic functioning, such as hitting and throwing, resides in the premotor cortex of the brain--the same location used for discriminating patterns, logical thinking, and abstract thought. See Timothy Ferris, The Mind’s Sky: Human Intelligence in a Cosmic Context (London: Bantam Press, 1992): 108-112.

[14] For an effective discussion of Interactive Control Systems see Robert Simons, “Control in an Age of Empowerment,” Harvard Business Review (March-April 1995): 80-88.

[15] Michaels, 75-78.

[16] A complete discussion of aggregation vs. disaggregation can be found in Michaels, 76.

[17] Commanding Officer, NR NAVAIRSYS 1187 memo Ser 075 dated 19 Nov 95.

[18] Ibid.

[19] Dawkins, 46-49.

[20] Coleman, Kulick, and Pisano, 8-15.

[21] Ibid., 15-56.

[22] Peer Review Group Recommendation dated 24 April 1996.

[23] Taken from the Introduction to the WAAS Program Evaluation Plan draft, undated, 1996.