**Technical Performance Measures**

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**Abstract.** Technical performance measures (TPMs) are tools that show how well a system is satisfying its requirements or meeting its goals. This paper presents the BAE National Security Solutions TPM process and a TPM template. It gives lessons learned from piloting it on a program.

**The Technical Performance Measures Process**

Technical performance measures (TPMs) are tools that show how well a system is satisfying its requirements or meeting its goals. TPMs provide assessments of the product and the process through design, implementation and test. They assess the product and its associated process, but they are primarily for the product. TPMs are used to (1) forecast values to be achieved through planned technical effort, (2) measure differences between achieved values and those allocated to the product, (3) determine the impact of these differences and (4) trigger optional design reviews. Figure 1 shows a typical TPM chart for an image processing system. In this example, the indicated milestones are Systems Requirements Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR) and Test Readiness Review (TRR).



**Figure 1. A TPM chart for an image processing system.**

TPMs are critical technical parameters that a project monitors to ensure that the technical objectives of a product will be realized. Typically, TPMs have planned values at defined time increments, against which the actual values are plotted. Monitoring TPMs allows trend detection and correction, and helps identify possible performance problems prior to incurring significant cost or schedule overruns.

The purpose of TPMs is to (1) provide visibility of actual versus planned performance, (2) provide early detection or prediction of problems requiring management attention, (3) support assessment of the impact of proposed changes and (4) reduce risk.

The method for measuring the data for the TPM will vary with life-cycle phase. In the beginning, you will use data from legacy systems, blue-sky guesses and approximations. Then you can derive data from models and simulations. Later you will collect data from prototypes. Finally, you will measure data on rudiments of the real system. Even the planned values might not be known at the beginning of the project. The original estimates will be refined by modeling and simulation.

Attributes that could be TPMs for some systems include reliability, maintainability, power required, weight, throughput, human factors, response time, complexity, availability, accuracy, image processing rate, achieved temperature, requirements volatility and speed.

Figure 2 shows the BAE Systems TPM process.

**Figure2. The BAE Systems, National Security Solutions TPM process. Please note that the TPM process is not a serial process. The process has many iterations and feedback loops that are not shown in this figure.**

These are the activities of the TPM process of Figure 2.

* Identify and prioritize key performance requirements. These are the candidate TPMs.
* Prioritize requirements within the requirements management tool (e.g., DOORS). Identify critical technical parameters.
* Perform risk analysis.
* Select TPMs. Fill out a TPM template for each. Add a TPM attribute to the associated requirement in the requirements management database and link the TPM to the risk register.
* Assign responsibility for managing TPMs.
* Conduct expert review of the TPMs. Feedback results and update.
* Incorporate TPMs into appropriate program documents like the Systems Engineering Management Plan (SEMP).
* Schedule, collect, analyze and report TPM measurements. Use the project risk management process to track TPMs. Including the TPMs in the [Risk Register](file:///C:\Mission%20Assurance\IPM\IPM%20(Project%20Work%20Flow)\PD0446.doc) ensures that the planned values and measured values are evaluated monthly. Not all TPMs have to be related to high risks. TPMs are also used to track development of key technical attributes for opportunity identification, etc. However, putting them on the risk register ensures that they get the attention they deserve.
* Perform corrective action and risk mitigation on TPMs that do not meet performance growth values.

**A TPM Template**

**Name of TPM:**

**Purpose of TPM**: How will it be used?

**Source requirement:** A TPM must be tied to a requirement (or a WBS element).

**Risk level:** very high, high, medium, low

**What should be measured?** Include units of measurement

**How should it be measured?** software scripts, inspection, modeling, simulation, analysis, test, demonstration

**How often should it be measured?** This could be time-based or tied to milestones.

**During which project phases should it be measured?** When do you stop collecting data?

**How should it be displayed?** A figure may be best

**To whom should it be presented?** Often this is the Chief Engineer

**Thresholds above or below which action is necessary:** these may be on the figure

**What action should be performed when if thresholds are exceeded?**

**Who should perform this action?**

The Systems Engineering Manager is responsible for collecting, analyzing, reporting and responding to the TPM data. The processed TPMs reports should be presented to the person who can do something about it: often this is the Chief Engineer. The Program Manager has oversight of the program TPMs. The company Measures Analysis Group might use the TPMs for process improvement suggestions.

Program managers traditionally tradeoff cost, schedule and technical performance of a system. Cost and schedule are often tracked with an earned value system. Now TPMs give managers a way to track technical performance. Therefore, managers can adjust cost and schedule according to the forecasts of the TPMs.

## Definitions for Quantitative Measurements

Evaluation criteria, measures and technical performance measures are all used to quantify system performance. These terms are often used interchangeably, but a distinction is useful. Evaluation criteria are used to quantify requirements. Measures are used to help manage a company's processes. TPMs are used to mitigate risk during design and manufacturing.

Performance, schedule and cost **evaluation criteria** show how well the system satisfies its requirements (e.g., in this test the car accelerated from 0 to 60 in 6.2 seconds). Criteria are often called Measures of Performance, Measures of Effectiveness or Figures of Merit. Such measurements are made throughout the evolution of the system: based first on estimates by the design engineers, then on models, simulations, prototypes and finally on the real system. Criteria are used to quantify system requirements; however, they are also used to help select amongst alternative designs. During concept selection, criteria are traded-off, that is, going from one alternative to another increases the value of one criterion while decreasing another.

**Measures** (which are often confused with Metrics) are usually related to the process, not the product. Therefore, they do not always relate to specific system requirements. Rather some measures relate to the company's mission statement and subsequent goals. As an example, a useful measure is the percentage of requirements that change after the System Requirements Review.

**Measure.** A measure indicates the degree to which an entity possesses and exhibits a quality or an attribute. A measure has a specified method, which when executed produces values (or metrics) for the measure.

**Metric.** A measured, calculated or derived value (or number) used by a measure to quantify the degree to which an entity possesses and exhibits a quality or an attribute.

**Measurement.** A value obtained by measuring, which makes it a type of metric.

**Technical performance measures (TPMs)** are tools that show how well a system is satisfying its requirements or meeting its goals. TPMs provide assessments of the product and the process through design, implementation and test. Should they be named Technical Performance Measures or Technical Performance Measurements? The INCOSE Systems Engineering Handbook v2a uses Measurement in the glossary. However, we think that Technical Performance Measure is a better phrase, because a measure is a quantitative attribute used to ascertain or appraise by comparing to a standard [IEEE 1278.3]. Whereas a measurement is the numerical value that is obtained by measuring [IEEE 729]. Measurements are often put into a measure to help the tool accomplish its purpose. The INCOSE Metrics Guidebook for Integrated Systems and Product Development (1995) and The INCOSE Systems Engineering Measurement Primer (1998) use the phrase Technical Performance Measure.

For the rest of this paper we will only discuss Technical Performance Measures.

## Characteristics of TPMs

For which requirements should TPMs be created?

(1) High priority requirements that impact mission accomplishment, customer satisfaction, cost or system usefulness.

(2) High risk requirements that have high probability of failure and great consequences of failure.

(3) Requirements where the desired performance is not currently being met, because the system uses new technology, new constraints have been added (e.g. a drastic increase in the number of users), or the performance target has been increased.

(4) Requirements where the performance is expected to improve with time, where progress toward a goal is expected.

(5) Requirements where the performance can be controlled.

(6) Requirements where the program manager is able to tradeoff cost, schedule and performance. If TPMs exceed their thresholds and indicate imminent cost overruns or failure to meet performance goals, then the associated requirements should be renegotiated with the customer.

TPMs require quantitative data to evaluate how well the system is satisfying its requirements. Gathering such data can be expensive. Because of the expense, not all requirements have TPMs, just the high priority requirements. As a rule of thumb, less than 1% of requirements should have TPMs. Each program might have a half-dozen TPMs.

TPMs

* Should be important
* Should be relevant
* Should be relatively easy to measure, analyze and interpret
* Performance should be expected to improve with time
* If the measure crosses its threshold, corrective action should be known
* The measured parameter should be controllable
* Management should be able to tradeoff cost, schedule and performance
* Should be documented
* Should be tailored for the project

The TPM measures can be displayed with graphs, charts, diagrams, figures or frames, e. g. Statistical Process Control Charts, Run Charts, Flow Charts, Histograms, Pareto Diagrams, Scatter Diagrams, Check Sheets, PERT Charts, Gantt Charts, Line Graphs, Process Capability Charts and Pie Charts.

Figure 3 shows a typical TPM chart for a solar oven design done in a freshman engineering class at the University of Arizona for baking bread.



**Figure 3. A TPM chart for a solar oven design.**

Day-by-day measurement values initially increased because of finding better insulators, finding better glazing materials (e.g., glass and Mylar), more complete sealing the cardboard box and more accurate aiming at the sun. At the time labeled “Design Change-1,” there was a jump in performance caused by adding a second layer of glazing to the window in the top of the oven. This was followed by another period of gradual improvement as we learned to stabilize the two pieces of glazing material. At the time labeled “Design Change-2,” there was another jump in performance caused incorporating reflectors to reflect sunlight onto the window in the oven top. This was followed by another period of gradual improvement as we found better shapes and positions for the reflectors.

At this point, the students and instructor came to realize that they would not reach the goal of 445 °F. So they reevaluated the process and requirements. First, they discussed the consequences of insufficient oven temperature. Enzymes are not deactivated soon enough, and excessive gas expansion causes coarse grain and harsh texture. The crust is too thick, because of drying caused by the longer duration of baking. The bread becomes dry, because prolonged baking causes evaporation of moisture and volatile substances. Low temperatures cannot produce carmelization, and crust color lacks an appealing bloom. If the dough were made richer by adding sugar, eggs, butter and milk, they could get away with temperatures as low as 350°F. But they decided to design our ovens to match the needs of our customers, rather than try to change our customers to match our ovens. After consulting some bakers, the student managers decided that 375°F would be sufficient to avoid the above problems. Therefore, the requirements were changed at the indicated spot and our design was able to meet the goal of the TPM. Of course, this change in requirements forced a review of all other requirements and a change in many other facets of the design. For example, the baking duration versus weight tables had to be recomputed.

We have stated earlier that when it appears that a TPM cannot be met, the program manager must readjust performance requirements, cost and schedule. In this example, we renegotiated the requirements.

If the TPM measurement is being displayed with a graph, then the graph might contain the goal, upper and lower thresholds, planned values and actual values. In Figure 3, the planned values were coincident with the lower limit and were not called out separately.

TPMs can be organized hierarchically. For example, a system might be required to have a certain lifetime. This lifetime would depend upon its mechanical lifetime and its electrical lifetime. In turn, its electrical lifetime would depend on its power consumption and its battery capacity. These could all be TPMs or measures. The lower level measures could be used to derive values of higher level TPMs. The top-level TPMs would be reported to Senior Management. However, it may be difficult to create TPMs, because the key characteristics may come from different branches of the hierarchy tree and the requirements upon which they are based are not necessarily independent.

TPMs are used to identify and track performance requirements that are program critical. TPMs are used to establish the appropriate design emphasis, design criteria and identify levels of technical risk. TPM measurements are collected and tracked against project design objectives in the project’s risk register.

The requirements management module should have an attribute named TPM. The name of each TPM should be entered in the attribute field of the appropriate requirement and this should be linked to the TPM module as shown in Figure 4. Each TPM should also be put in the project’s Risk Register and be evaluated monthly



**Figure 4. Linkages of the TPM module.**

Each TPM must be linked to a requirement (or a work breakdown structure element), have quantitative values, have a risk level and have a priority. Only create TPMs for requirements where you can change something.

TPMs are also used to trigger optional design reviews. For example, at the end of the Concept Evaluation Phase there is an optional design review before the phase review. If everything is progressing smoothly, this optional design review is not performed. But if a TPM exceeds its thresholds, then an optional independent design review will be added to the Engineering Plan. Then the Chief Engineer and the Program Manager meet with the Engineering Project Director to determine the level of each review. These reviews may be (with decreasing level of formality): independent technical reviews, expert reviews, formal inspections or checklist inspections. Cost overruns and schedule slippage can also trigger these optional reviews. Some companies trigger optional reviews if two or more TPMs exceed their thresholds.

TPMs can also be used in tradeoff studies (Daniels, Werner and Bahill, 2001) to choose between alternative concepts. For example, the alternatives that can be used to reduce blood pressure include drugs, exercise, diet and reducing alcohol consumption. If one technique is not working, then you can add or switch to another.

The thing being measured in the TPM may not be the thing you want to improve. For example if you made your blood pressure a personal TPM, you want to reduce your probability of cardio-vascular disease, so you monitor your blood pressure and change your life style. The measurements community would say that blood pressure is an indicator of the probability of cardio-vascular disease.

**Preventing deterioration.** We use TPMs for requirements where the desired performance is expected to improve with time. Another use of TPMs would be to prevent unacceptable degradation of performance. For example, in the design and development process, adding bells and whistles might reduce processing time or increase weight. TPMs could be used to warn of such unwanted behavior.

**Risk Reduction.** Using TPMs is one of the risk reduction methods used at BAE Systems NSS. It helps programs identify critical requirements and it gets these requirements elevated into the project’s risk register to be evaluated monthly. At these monthly evaluations, measures that are not progressing according to plan will be highlighted and discussed to ensure appropriate corrective actions can be taken.

**LESSONS LEARNED**

In 2005, a mature Archive and Dissemination development program piloted this TPM process. This program has been running for seven years. However, the TPM process has only been in use for less than a year on a new spiral development activity. This activity includes requirements analysis, development of the operational concept description, system design, software development, system integration, validation, deployment, interface testing and transition to initial operational capability. TPMs were selected for less than 1% of the overarching program’s 7000+ system requirements. This and previous development activities for the program use the Telelogic DOORS requirements management software to manage all specification, systems and software requirements.

The selected TPMs were related to image processing and data export (dissemination) rates. Due to the compressed schedule, these requirements were identified prior to the Initial Requirements Review (IRR). These requirements were selected after analyzing key performance requirements critical to meeting the user’s needs. Associated risks were identified to address the possibility of not meeting these key requirements and they were entered into the program’s risk register. Specifically, the key requirements and associated risks were related to image processing and dissemination rates. These requirements were deemed at risk of being satisfied as a result of a risk analysis activity. The risk analysis identified the modification of the spiral development’s systems architecture to a slightly more distributed architecture sharing sub-subsystems with a similar system as a risk to performance worthy of monitoring.

After identifying the TPMs for this activity, the processing and dissemination model for this system was modified to reflect the planned architecture. Simulations were run before the Interim Design Review (IDR) using performance volumetrics relevant to the TPMs. The results of the simulations indicated that online dissemination requirements were achievable. However, the simulation results for the dissemination requirements for near-line data (information from tapes in a robot) and off-line data (information from tapes on a shelf) did not support validation of these requirements. As a result, the risks identified for dissemination of data from these locations are still in need of monitoring.

Given the compressed schedule for this activity, and the nature of when the data related to the performance requirements will actually be introduced, the program continues to monitor these TPMs and associated risks. Modifications to the system/hardware design and architecture may be necessary to ensure satisfaction of the near-line and off-line dissemination requirements. Further benchmarking of the as-built system will be necessary to measure the system against its technical objectives.

The project does not yet have any quantifiable data regarding the costs and benefits of using the TPM process to identify, track and resolve technical risks associated with the system’s satisfaction of requirements. However, the TPM process has helped technical leads provide assessments of the product’s performance through design, implementation and test and contributed to better communication of these assessments to Program Management. In summary, a major benefit of using the TPM process has been to formalize the documentation of forecast and measured values required by the system. The technical and management team uses the analysis of differences between these forecasts and measurements to determine potential cost, schedule and/or performance risks/impacts and to spur exploration of approaches to risk mitigation.

**Summary**

TPMs are used to identify and track performance requirements that are program critical. TPMs are used to establish the appropriate design emphasis, design criteria and identify levels of technical risk. TPM measurements are collected and tracked against project design objectives in the project’s risk register. TPMs should be created for high-priority requirements that impact mission accomplishment, customer satisfaction, system usefulness, and where performance improves with time, where performance can be controlled, where management can tradeoff cost, schedule and performance.

**References**

J. Daniels, P. W. Werner and A. T. Bahill, Quantitative Methods for Tradeoff Analyses, *Systems Engineering*, **4**(3), 199-212, 2001.

### Biographies

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**Terry Bahill** is a Professor of Systems Engineering at the University of Arizona in Tucson. While on sabbatical from the University of Arizona, he is doing research with BAE Systems in San Diego. He received his Ph.D. in electrical engineering and computer science from the University of California, Berkeley, in 1975. Bahill has worked with BAE Systems in San Diego, Hughes Missile Systems in Tucson, Sandia Laboratories in Albuquerque, Lockheed Martin Tactical Defense Systems in Eagan MN, Boeing Information, Space and Defense Systems in Kent, WA, Idaho National Engineering and Environmental Laboratory in Idaho Falls and Raytheon Missile Systems in Tucson. For these companies he presented seminars on Systems Engineering, worked on system development teams and helped them describe their Systems Engineering Process. He holds a U.S. patent for the Bat Chooser, a system that computes the Ideal Bat Weight for individual baseball and softball batters. He received the Sandia National Laboratories Gold President's Quality Award. He is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) and of the International Council on Systems Engineering (INCOSE). He is the Founding Chair Emeritus of the INCOSE Fellows Selection Committee.